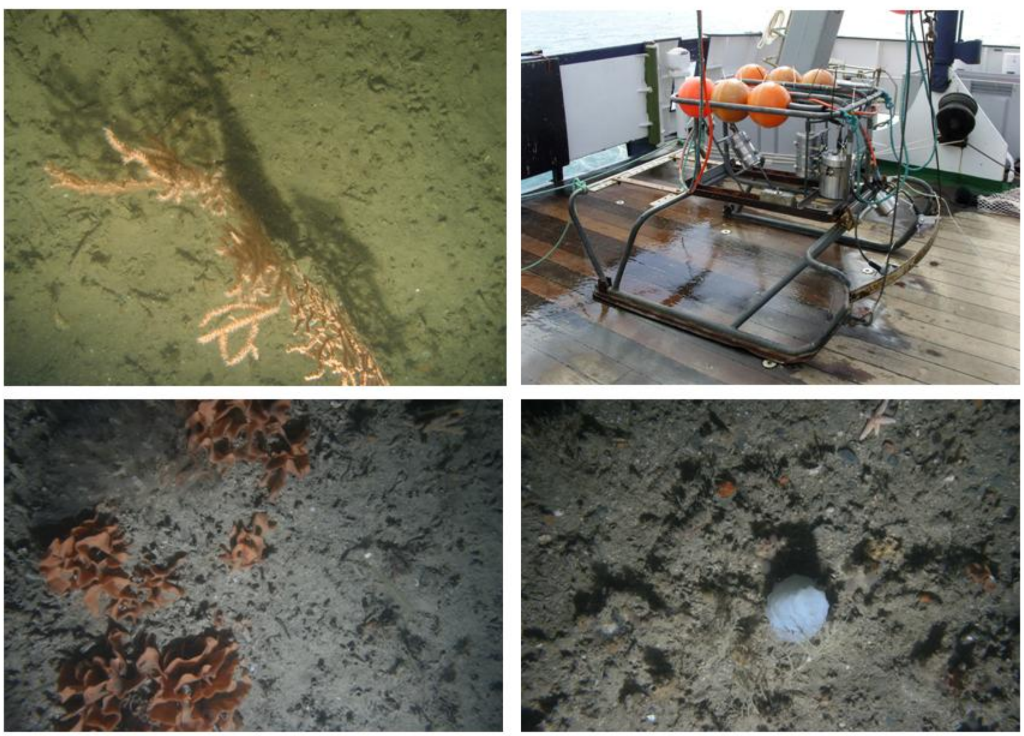
Quantification of epibenthic fauna in areas subjected to different regimes of scallop dredging activity in Lyme Bay, Devon



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Abstract

The aim of the study was to establish baseline conditions for the abundance and mean size of four species of interest (Pink seafans *Eunicella verrucosa*, dead men's fingers *Alcyonium digitatum*, ross coral *Pentapora fascialis* and king scallop *Pecten maximus*) across Lyme Bay shortly after the implementation of four voluntary Marine Protected Areas (MPAs) inside which scallop dredging stopped in September 2006. The research undertaken was the initial stage of a proposed longer-term project to quantify the effectiveness of the reserves in the protection of the reef communities, to examine potential recovery rates in areas that had been exposed to scallop dredging, and to determine if there were fishery spill-over effects arising from increases in scallops within the areas protected from fishing.

Observations of the four species of interest were made in areas that were either inside or outside each of the four MPAs. Both within and outside the MPAs we examined areas that had been fished previously by scallop dredging and areas that had not been subjected to fishing. This information was ascertained by overlaying scallop fishermens' track plots onto a map of Lyme Bay.

At all sites, images of the seabed were obtained using replicated video tows (10 minutes in duration) in March-April 2007. From each tow, 85 metre transects were randomly selected and the abundance and size of each of the four species of interest within the field of view of the camera were recorded.

Significant differences were found between areas inside and outside reserves for the abundance and size of *E. verrucosa* (higher abundance in areas closed to fishing, and greater size in areas closed to fishing but that previously were not fished). For *A. digitatum* there was a higher abundance in areas closed to fishing and there were more in areas that were not fished (regardless of whether they were inside or outside the closed areas). They were also larger in areas that were closed to fishing and that previously had not been fished. There was a strong effect of site associated with the abundance of *P. maximus,* the highest abundance occurred at Lanes ground. There was not significant difference between areas that were closed or open to fishing. No significant differences were found for *P. fascialis* when comparing areas closed or open to fishing, or areas that were previously fished or those that were unfished.

Quantile regression analysis identified that the abundances of *E. verrucosa*, *A. digitatum* and *P. fascialis* were limited by fishing activity but that the absence of fishing activity did not mean that a species would be present at any particular location. In other words, there was no evidence that a lack of fishing activity was associated with the presence of these species.

Substratum type had a significant effect on the presence of species such that *E. verrucosa*, *A. digitatum* and *P. fascialis* were found more commonly over rock and *P. maximus* over sand. There were more dense populations of sea fans and dead men's fingers inside the reserves than outside, indicating that the reserves had been placed over the most dense populations of these species. Strong relationships were identified between abundance and substratum type.

If funded, a currently submitted research proposal would enable continued monitoring of abundances in combination with oceanographic and genetics studies to gather information on the rate of recovery of the reef communities from trawling activity, possible spillover effects for the exploited scallop population, the displacement of trawling activity and interconnectivity between temperate marine reserves.

Purpose

In 2006, following a request by English Nature (subsequently Natural England) for the Fisheries Minister to impose a stop order on towed bottom fishing in Lyme Bay, DEFRA undertook consultation with the relevant key stakeholders. The eventual outcome extended the existing voluntary closures in Lyme Bay and implemented two new areas of the seabed closed to fishing on a voluntary basis. The fishing industry began to observe this voluntary agreement in September 2007 which excludes all towed scallop dredging gears from the four specified areas in Lyme Bay.

The simultaneous exclusion of towed scallop dredging activity from four areas of the seabed provided a unique and important opportunity to understand the rate and mechanisms of recolonisation of areas of the seabed that previously have been exposed to different amounts of disturbance by towed fishing gear. This also provided a unique opportunity to examine in a robust manner the ecological consequences of using spatial closures as tools that would contribute to the goal of sustainable fisheries. The four areas closed to scallop dredging in Lyme Bay can be treated as replicates in an experiment. The great majority of relevant studies of the ecological studies of the effects of implementing marine protected areas are pseudo-replicated and as such the conclusions from such studies should be viewed with caution as they do not enable the effects of 'fishing' to be discerned from other environmental gradients or habitat differences that might account for the reported differences between the 'closed' area and an adjacent location used as a comparator ('control' area).

Subsequently, scientists at Bangor University applied to the Natural Environmental Research Council (NERC) for funding through their Urgency scheme to collect baseline information that would provide the scientific basis to study in the longer-term the rate and mechanisms of recovery and potential fishery spillover effects associated with the Lyme Bay voluntary closures. This resulted in the award of a NERC research grant (NE/E011268/1 – Principal Investigator JG Hiddink, value £281 000) for a period of 12 months commencing after the award of contract in January 2007. Sampling in Lyme Bay commenced in February 2007 with an initial multibeam survey of the seabed within the originally requested 60 nm² area proposed for closure. This, in conjunction with the track plots of fishing tows supplied by the South West Inshore Fishermen's Association enabled the designation of sample sites assigned to four different 'treatments' based on their status (closed to towed bottom fishing gears/ open to towed bottom fishing gear) and fishing history (fished / not fished). In this report, we present the data for observations made with towed video camera. Analysis of still camera images will be available in May 2008.

1. Introduction

1.1. Background information and aim of the proposed study

Lyme Bay is situated in the English Channel off the Devon and Dorset coastline (Figure 1.1.) at depths of between 15-30 m (chart datum). Some of the reef associated species within Lyme Bay are included in the United Kingdom Biodiversity Action Plan (UK BAP), i.e. the pink sea fan *Eunicella verrucosa* and sunset cup coral *Leptopsammia pruvoti*. Other epifaunal species of ecological significance within this reef community are the bryozoan, *Pentapora fascialis* [ross coral], and the soft coral *Alcyonium digitatum* [dead men's fingers]. The area has been subjected to fishing pressure, in particular from scallop dredging, which is conducted throughout the bay to harvest the economically valuable king scallop *Pecten maximus*. Scallop dredging and other towed bottom fishing gears are detrimental to reef communities (e.g. Kaiser *et al.*, 2006). On 24th August 2006 the then Fisheries Minister Ben Bradshaw MP declared that a voluntary ban on commercial fishing activity within four areas of the seabed in Lyme Bay would come into effect. This effectively resulted in the establishment of four voluntary MPAs (Figure 1.1.). The primary purpose of the voluntary closures is to protect pink sea fans. However, additional benefits may result from the voluntary closures, e.g. they may enhance scallop numbers in regions outside the reserve as a result of accumulated reproductive biomass within the closed areas.

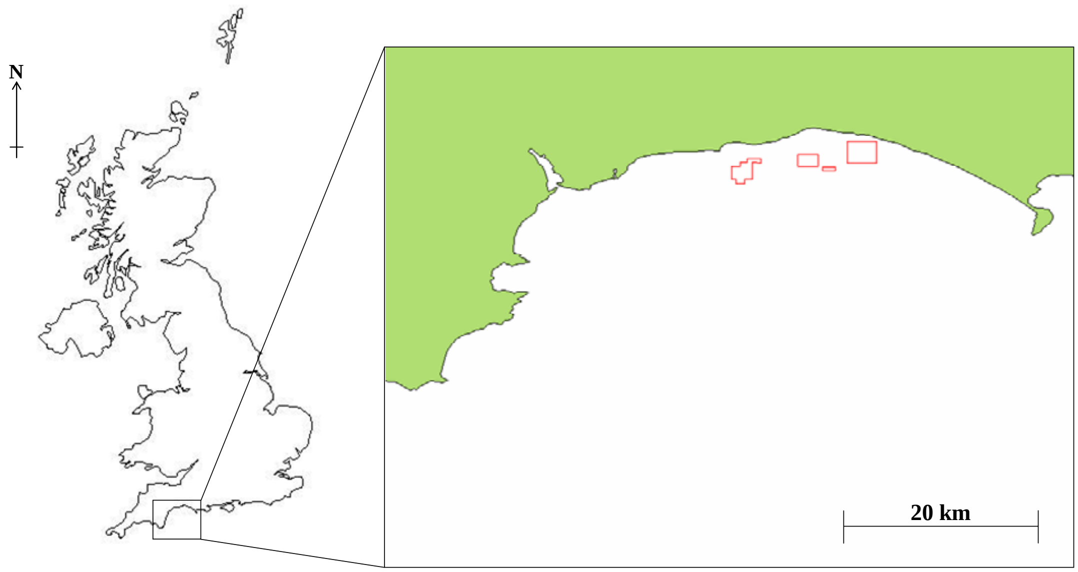


Figure 1.1. The location of Lyme Bay and the four Marine Protected Areas (highlighted by the red outlines).

The present study reports preliminary findings sufficient to provide a scientific basis for the establishment of a longer-term four year study designed to investigate recovery of sea fans and other species, in addition to the potential for fishery spill-over effects. At present, no funds have been allocated to enable a longer-term study to occur.

The present study established the baseline conditions for the abundance and relative size of key emergent species within the biogenic community in March-April 2007, a short while after the implementation of the reserves. We have focussed on four key species, namely *Eunicella verrucosa*, *Pentapora fascialis*, *Alcyonium digitatum* and *Pecten maximus*. Comparisons were made between areas that have been subject to fishing pressure and those that have not, both inside and outside the voluntary closed areas, and these ‘treatments’ were replicated across the four areas.

1.2. The impacts of scallop dredging on biogenic habitats

In the UK, scallops are caught using gangs of Newhaven dredges fished either side of a vessel, and are typically towed at a speed of 2.5 knots. The precise number of dredges will vary according to local legislation and the power of the vessel. Newhaven dredges are fitted with spring-loaded tooth bars with teeth typically 12 – 15 cm long. Each dredge is fitted with a bag with a chain belly made of steel rings (Watson *et al.*, 2006). The weight of the gear and the tooth bar and chain belly in combination mean that scallop dredges create substantial physical disturbance to the seabed and its biota. The severity of the impact of scallop dredging varies according to the substratum, the fishing history and degree of natural disturbance that occurs in a habitat (Kaiser *et al.*, 2006). As with other towed bottom fishing gears, biogenic and reef habitat are more sensitive to scallop dredging than unconsolidated sediments and studies undertaken to date indicate biological recovery to occur on a scale of several to > 5 years (Kaiser *et al.*, 2002, 2006).

1.3. Marine Protected Areas

Marine Protected Areas (MPAs) restrict to varying degrees anthropogenic activity within specified regions of the sea and are implemented either for the protection of a particular habitat or species of ecological importance or for the protection and enhancement of a commercial fisheries resource (Roberts *et al.*, 2001). When reviewing published studies on the effects of MPA implementation it is important to recognise that the conservation effects of reserve protection on vulnerable species are likely to be greatest for slow-growing, late maturing species. The reason for this is that these are often the species most heavily impacted by anthropogenic activities, hence their recovery trajectories occur over longer time periods. This highlights the importance of consideration of the life history of the protected species in both reserve designation and subsequent monitoring activity.

The implementation of MPAs to increase fisheries yields might be achieved through realised ‘spillover’ effects that occur outside the reserve either through emigration of adults or larvae (Gell and Roberts, 2003). However, while such spillover effects have been demonstrated in tropical systems (Roberts *et al.*, 2001), empirical evidence that this occurs in temperate systems is lacking (Hilborn *et al.*, 2004; Kaiser, 2005). The major problem with the scientific evaluation of the introduction of MPAs is a lack of replication and habitat confounding effects associated with the use of inappropriate comparator areas adjacent to the MPA. Typically individual reserves have been established over small regions deemed important for aesthetic reasons with little or no consideration given to scientific objectives (Jennings, 2000). The development of MPAs in this way makes it difficult to separate the effect of the protection from the effect created as a result of location. In the present study the creation of four MPAs within the same locality offered a unique opportunity to include replication in the study design and thus produce a dataset with appropriate statistical power to test the effects associated with the implementation of the voluntary closed areas (MPAs).

In their review of the published literature on the response and recovery within benthic communities to the alleviation of fishing pressure Kaiser *et al.* (2006) found mean abundance data between control and treatment sites to be the most commonly used factor in the determination of the level and speed of recovery. Whilst this is an important parameter for consideration, and possibly adequate for identification of recovery trajectories of smaller infaunal organisms, taken alone it is not a representative measure for the health of larger biota such as sea fans. For these species an estimation of biomass is vital in determining ecosystem health, as many small structures may be able to persist in the presence of sustained fishing pressure, but there would be an absence of the larger, older specimens indicative of an undisturbed community. Additionally these larger-bodied, slow-growing species are often colonial precluding the identification of individual organisms. This is directly relevant to the present study where three of the four species of interest (*Eunicella verrucosa*, *Pentapora fascialis* and *Alcyonium digitatum*) are large and slow-growing. Therefore both abundance and a measure of the size of individuals are important community parameters in the assessment of the changes associated with the Lyme Bay MPAs. Hereafter, we refer to the voluntary closed areas in Lyme Bay as MPAs for simplicity.

1.4. Hypothesis and specific objectives

The study was conducted shortly after the implementation of the MPAs. We collected video and still camera observations that would enable us to test whether differences occurred in species' abundance or relative size across the different 'treatments'. We tested the null hypothesis that 1) there was no difference among the four MPAs, 2) no difference inside and outside MPAs and 3) no difference between areas that had been fished and areas that were not fished (presently or in the past).

2. Methodology

2.1. Experimental design

The experiment was designed to be implemented across the four Marine Protected Areas (MPAs) (Beer Home Ground, East Tennants, Lanes Ground and Sawtooth Ledges) with two factors investigated:

1. *Protection*: stations inside MPAs (Closed) and outside MPAs (Open);

2. *Fishing Activity*: stations that had been fished prior to implementation of the MPAs (Fished) and stations that had not been fished prior to implementation of the MPAs (Not Fished).

This provided four possible treatment combinations with each replicate belonging to one of the following groups – Closed Fished (CF), Closed Not Fished (CNF), Open Fished (OF) or Open Not Fished (ONF).

Fishing activity was calculated from differential global positioning system (DGPS) data obtained from the scallop fishermen operating within the Lyme Bay area. This provided information on the precise location of fishing activity in the years between 2000 and 2006 in the form of tracking lines. To calculate a measure of trawl intensity the surveyed region was divided into 500 metre by 500 metre raster squares and the total length of tracking lines within each cell quantified. It was assumed that each scallop dredge had an eight metre wide impact (four dredges on each side of the boat) and the trawl intensity was calculated by dividing the total area impacted (total line length multiplied by eight metre width of impact) by the total area of the raster cell. This provided a relative measure of the number of times a particular area of the seafloor had been impacted by towed gear in the preceding six years.

For each of the four marine reserves, four stations were sampled for each combination of protection and fishing activity (closed fished, closed not fished, open fished and open not fished). All stations were situated on substrates that seemed suitable for *E. verrucosa* (reefs and other rough grounds), as identified from a multi-beam survey that was undertaken in March 2007. Four stations were situated on haphazard locations within areas that fulfilled these criteria. An exception to this was the East Tennants closed area, where no areas existed that were both closed to fishing and previously fished and therefore no stations could be selected in this treatment combination. Therefore 60 stations were sampled in total (as outlined in Table 2.1).

Table 2.1. Block experimental design indicating the number of replicate samples taken from each treatment at each site.

Site	Protection	Fishing Activity	Replicates
Beer Home Ground (BR)	Closed (C)	Fished (F)	4
		Not Fished (NF)	4
	Open (O)	Fished	4
		Not Fished	4
East Tennants (ET)	Closed	Fished	0
		Not Fished	4
	Open	Fished	4
		Not Fished	4
Lanes Ground (LN)	Closed	Fished	4
		Not Fished	4
	Open	Fished	4
		Not Fished	4
Sawtooth Ledges (ST)	Closed	Fished	4
		Not Fished	4
	Open	Fished	4
		Not Fished	4
TOTAL			**60**

2.2. Sampling procedure

Videographic sampling was conducted across the 60 stations throughout Lyme Bay aboard the *RV Prince Madog* from 29th March to 6th April 2007 (Figure 2.1; Figure 2.2). A RovTech Underwater Video System was used in the data collection. The video camera was attached to a metal sled which was lowered to the seafloor. At each station the camera was towed along the seabed for 10 minutes in as straight a line a possible. The location and depth were recorded at the start and end of each tow from which the total distance of the tow in metres was calculated. The videos were recorded on to DVD and saved as .VOB files.

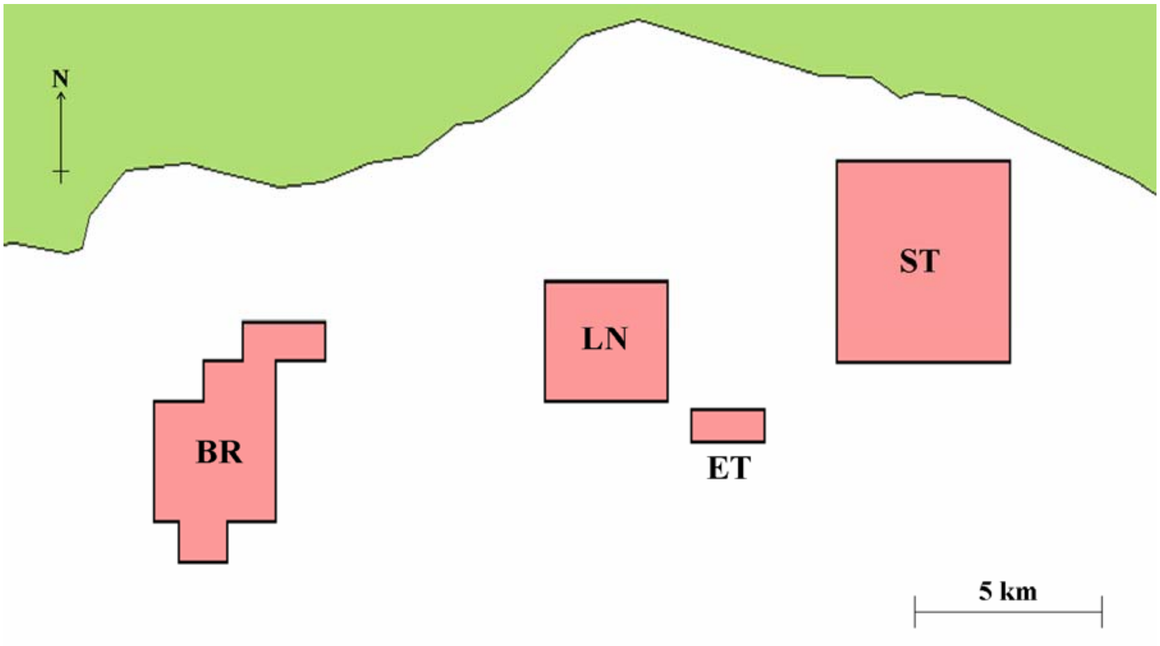


Figure 2.1. Location of the four MPAs. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges.

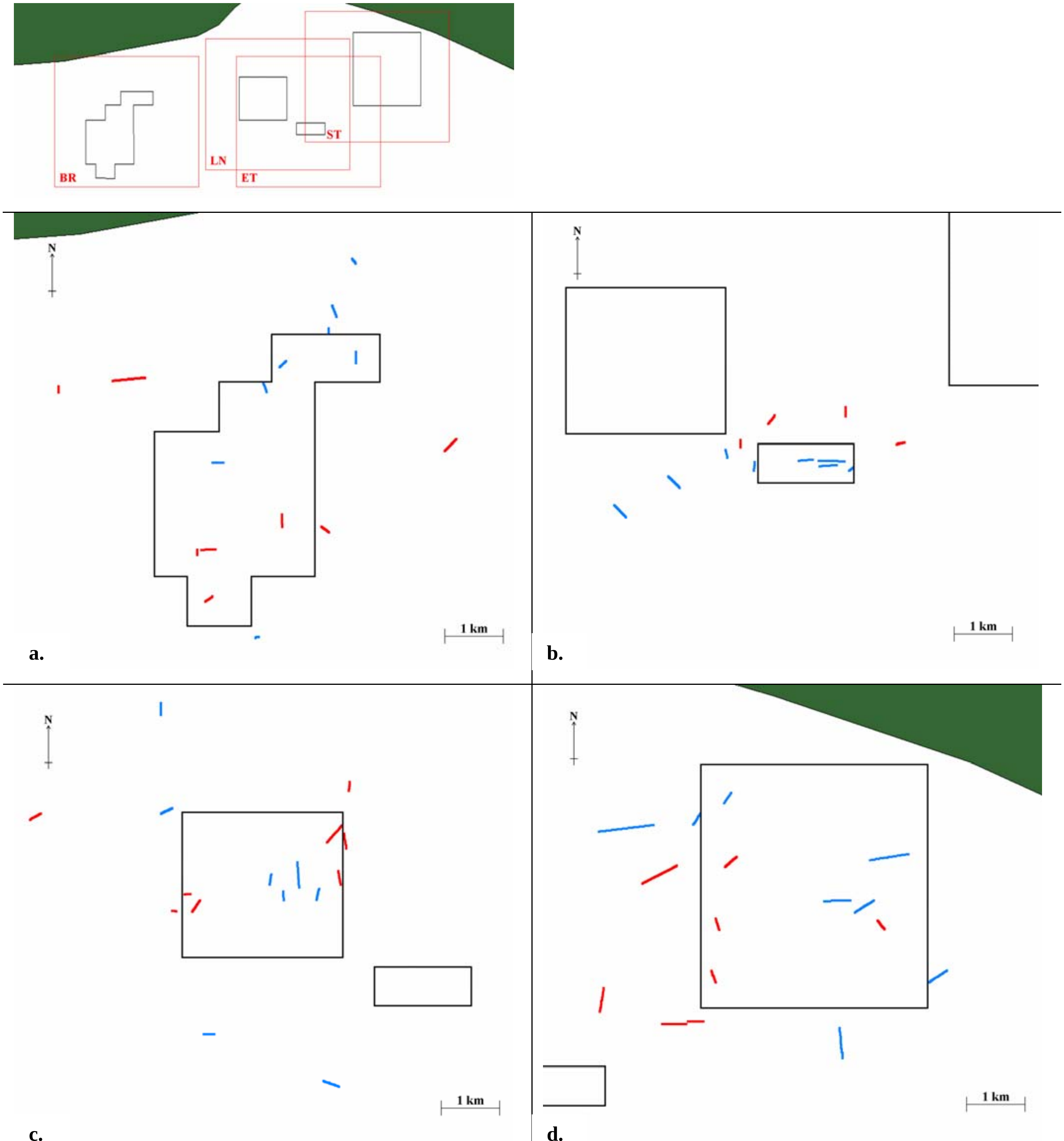


Figure 2.2. Location of the tows associated with each MPA. Red = fished, blue = unfished. **a.** Beer Home Ground. **b.** East Tennants. **c.** Lanes Ground. **d.** Sawtooth Ledges. Start and end co-ordinates for each tow are given in Appendix I.

2.3. Video analysis

Each video was split into frames saved as bitmap images using *FFmpeg* run on a *Microsoft Windows XP* operating system through *Cygwin*. The videos were split at a rate of 25 frames per second and each image was numbered chronologically. The start frame for the tow was taken to be that where the camera first reached the seafloor and the end frame that where the camera lifted away from the seafloor. The total number of frames between the start and end frame was used to calculate a precise duration for each tow.

Within each tow every encounter with an individual from the four species of interest (*Eunicella verrucosa*, *Alcyonium digitatum*, *Pentapora fascialis*, *Pecten maximus*) was recorded. The frame with the individual most centrally positioned within it was saved and the frame number recorded from which the time and distance of the individual through the tow were calculated. If the individual was in an appropriate position within the frame measurements were made of height and width within the frame (Figure 2.3) using the measuring tool in *Adobe Photoshop*. For the measurements the widest points in each direction were taken to enhance uniformity between measurements in different frames. A relative measurement for size was calculated by multiplying the height and width measurements. Video imagery of a tape measure underwater taken using the same system was used to convert this relative measurement into an approximate two-dimensional area coverage of the actual size of each individual organism within the frame. Whilst these measurements will only be approximate and only give a two-dimensional area representation of each individual, the relative difference between the size of individuals remains the same and was therefore considered adequate for analysis in the present investigation.

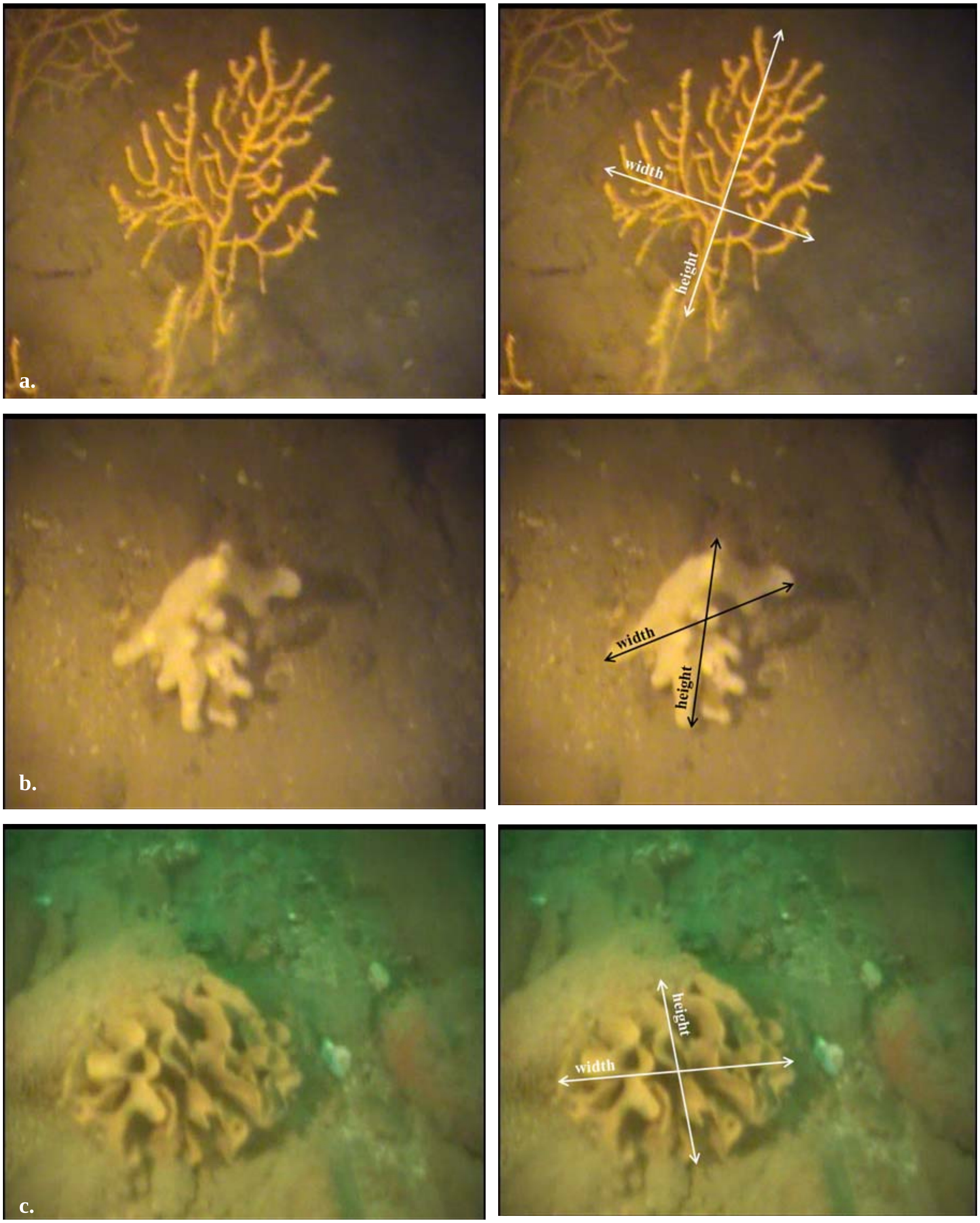


Figure 2.3. Examples of frames that were chosen for size measurements for each of the four species of interest and examples to show how the height and width measurements were taken **a.** *Eunicella verrucosa*. **b.** *Alcyonium digitatum*. **c.** *Pentapora fascialis*.

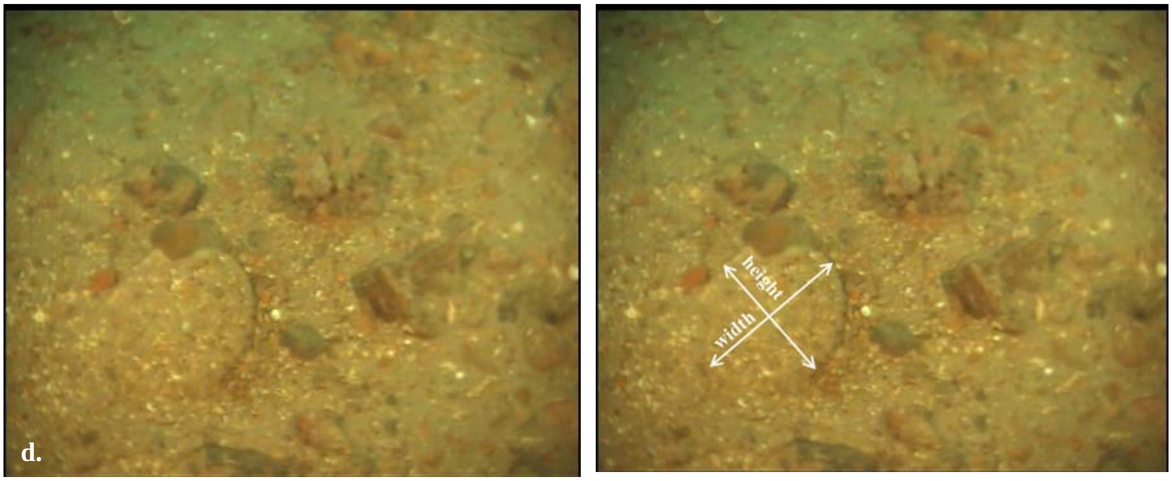


Figure 2.3. Examples of frames that were chosen for size measurements for each of the four species of interest and examples to show how the height and width measurements were taken **d.** *Pecten maximus*.

Substrate type was assessed visually using 11 discrete categories as outlined in Figure 2.4. The frame number for a change in substrate type was recorded and from this the percentage coverage across tows was calculated and each individual could be assigned a substrate group.

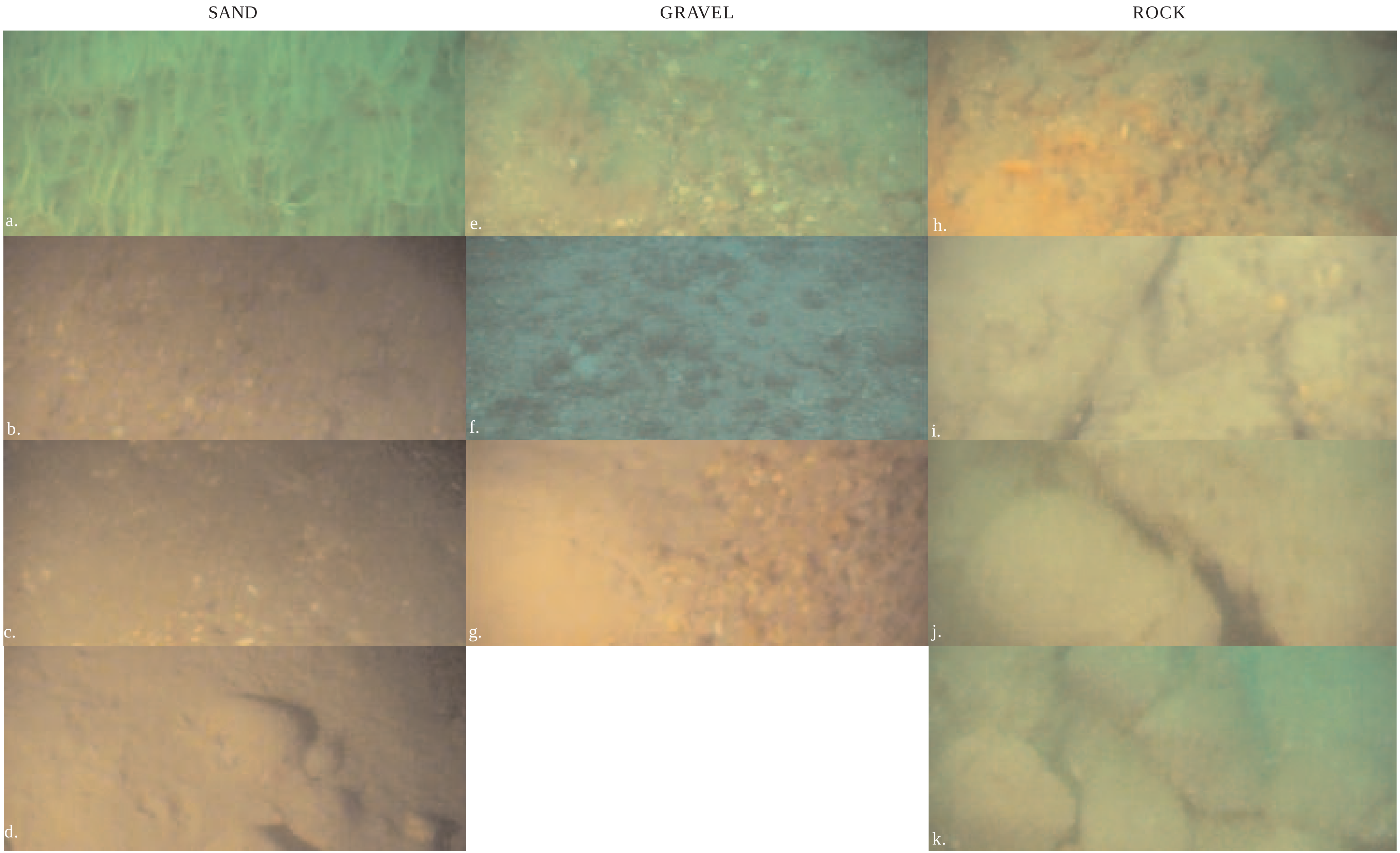


Figure 2.4. Example images for each of the 11 identified sediment sub-categories within the three broad groupings of sand, gravel and rock. a. Brittlestar beds over sand. b. Coarse sand, some small rocks. c. Fine sand. d. Fine silt covering small rocks. e. Gravel. f. Gravel and rubble. g. Gravel and sand bars. h. Exposed bedrock. i. Large boulders. j. Large boulders and slabs of bedrock. k. Small rocks.

2.4. Statistical analysis

All of the tows differed in length and so it was necessary to standardise to the length of the shortest tow. Therefore an 85 metre transect from each tow was used in the analysis. The start point for the section was randomly selected (Appendix I).

The datasets for the four species were analysed independently. Following transformation, the abundance datasets were analysed using a three factor ANOVA with site (BR, ET, LN, ST), protection (C, O) and fishing activity (F, NF) as the factors. This was conducted both including and excluding the East Tennants' transects for which there were no closed fished replicates. In the ANOVA excluding the East Tennants' transects two way interaction terms between factors were included. Where significant differences were found Tukey's pairwise comparison was conducted to determine where the differences lay. In addition, a quantile regression was conducted between the abundance datasets and the trawl intensity as, whilst sites were assigned to either a 'fished' or 'not fished' category, the level of fishing activity was a continuous scale and therefore the regression analysis might identify patterns that could not be detected in categorical ANOVA analysis .

The calculated area (mm^2) was used as a measure of size. For the size datasets the information was grouped across site as it was considered that the greater differences would lie between treatment. Following transformation an ANOVA was conducted for each species with treatment (CF, CNF, OF, ONF) as the factor.

The differences between substrate coverage of the 11 predefined sub-categories across the tows and in association with the different species of interest were analysed using Chi-squared goodness-of-fit tests. Following findings from the initial analysis, correlation and further Chi-squared analysis were conducted on the three broader substrate descriptions – sand, gravel and rock as outlined in Figure 2.4. The abundance of the three sessile species (*E. verrucosa*, *A. digitatum* and *P. fascialis*) per 100 metres of rock substrate was calculated and further three factor ANOVA analysis conducted on this data.

3. Results

3.1. Pink sea fans (*Eunicella verrucosa*)

3.1.1. E. verrucosa abundance

The abundance of *E. verrucosa* across the transects ranged from 0 to 99 individuals. For all reserves except Lanes Ground the highest abundance occurred within the closed and not fished sites (Table 3.1.).

Table 3.1. The total number of *Eunicella verrucosa* across the four transects (a distance of 340 m) at each site within each treatment. BR Beer Home Ground, ET East Tennants', LN Lanes Ground, ST Sawtooth Ledges. CF closed fished, CNF closed not fished, OF open fished, ONF open not fished.

	CF	**CNF**	**OF**	**ONF**
BR	2	19	3	8
ET	-	143	32	6
LN	11	8	29	0
ST	26	40	18	11

Following a square root transformation the full dataset including East Tennants' was checked for normality and heterogeneity of residual variance and a three factor ANOVA was conducted to test for significant differences between site, protection and fishing activity.

Table 3.2. The abundance of *Eunicella verrucosa* across all four sites, protection and fishing activity (square root transformed data). BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	O
BR	1.052 ± 0.466	0.672 ± 0.363
ET	4.150 ± 2.490	2.538 ± 0.381
LN	1.142 ± 0.391	0.673 ± 0.673
ST	2.279 ± 0.661	1.132 ± 0.579
	F	**NF**
BR	0.467 ± 0.241	1.257 ± 0.506
ET	2.366 ± 0.895	2.380 ± 1.360
LN	1.259 ± 0.699	0.556 ± 0.314
ST	1.744 ± 0.593	1.668 ± 0.717
	C	**O**
F	1.241 ± 0.394	1.395 ± 0.460
NF	2.342 ± 0.714	0.588 ± 0.285

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
Site	3	21.409	25.392	8.464	2.27	0.091
Protection	1	15.475	15.558	15.588	4.19	0.046
Fishing activity	1	0.114	0.114	0.114	0.03	0.862
Residual	54	201.118	201.118	3.724		
Total	59	238.116				

The abundance of *E. verrucosa* was significantly higher in closed than in open areas (Table 3.2.b and Figure 3.1.b.). There were no significant differences between the sites (Figure 3.1.a.) and fishing activity also had no effect on abundances of sea fans (Figure 3.1.c.).

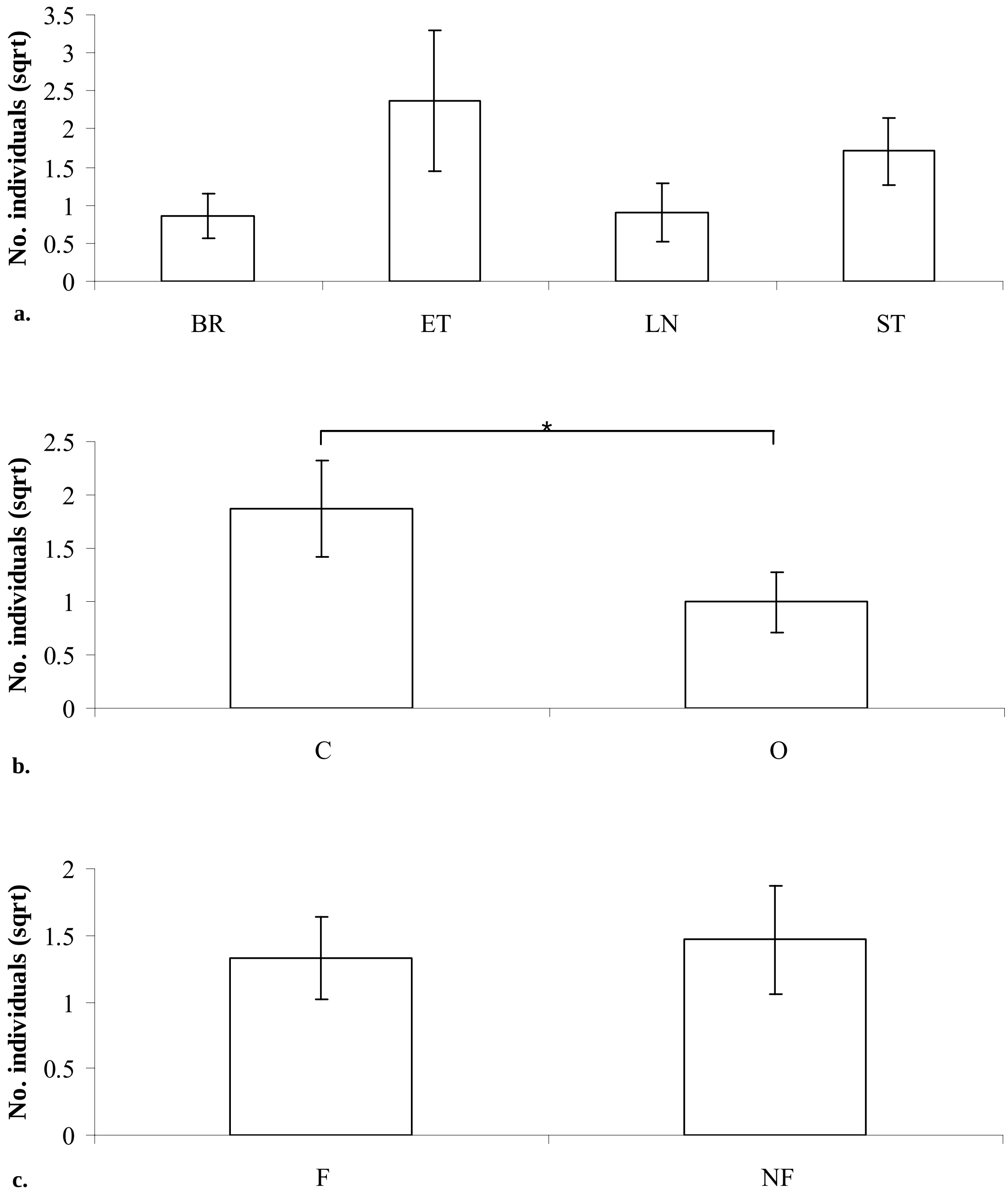


Figure 3.1. Mean ± standard error of *Eunicella verrucosa* abundance per standardised 85 metre transect. * = significant difference. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished. The data has been subjected to a square root transformation.

The East Tennants' transects were removed from the dataset due to the lack of closed and fished sites within this reserve and following tests for normality and heterogeneity of variance of the residuals the three factor ANOVA was repeated with two way interaction terms between factors.

Table 3.3. The abundance of *Eunicella verrucosa* across three sites, protection and fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.
(a) Means (± standard error) of abundance.

	C	**O**
BR	2.630 ± 1.930	1.375 ± 0.885
LN	2.375 ± 0.981	3.630 ± 3.630
ST	8.250 ± 3.500	3.630 ± 2.020
	F	**NF**
BR	0.625 ± 0.375	3.380 ± 1.980
LN	5.000 ± 3.540	1.000 ± 0.732
ST	5.500 ± 2.420	6.380 ± 3.460
	C	**O**
F	3.250 ± 1.490	4.170 ± 2.540
NF	5.580 ± 2.460	1.580 ± 1.030

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj MS**	***F***	***P***
Site	2	134.04	67.02	1.35	0.271
Protection	1	28.52	28.52	0.58	0.453
Fishing activity	1	0.19	0.19	0.00	0.951
Site*Protection	2	69.54	34.77	0.70	0.502
Site*Fishing activity	2	97.13	48.56	0.98	0.384
Protection*Fishing activity	1	72.52	72.52	1.47	0.234
Residual	36	1780.75	49.47		
Total	47	2188.98			

There was no significant interaction between any of the factors (Table 3.3.b.). With all of the East Tennants' transects removed from the analysis there was also no significant difference between site, protection or fishing activity (Table 3.3.b. and Figure 3.2.).

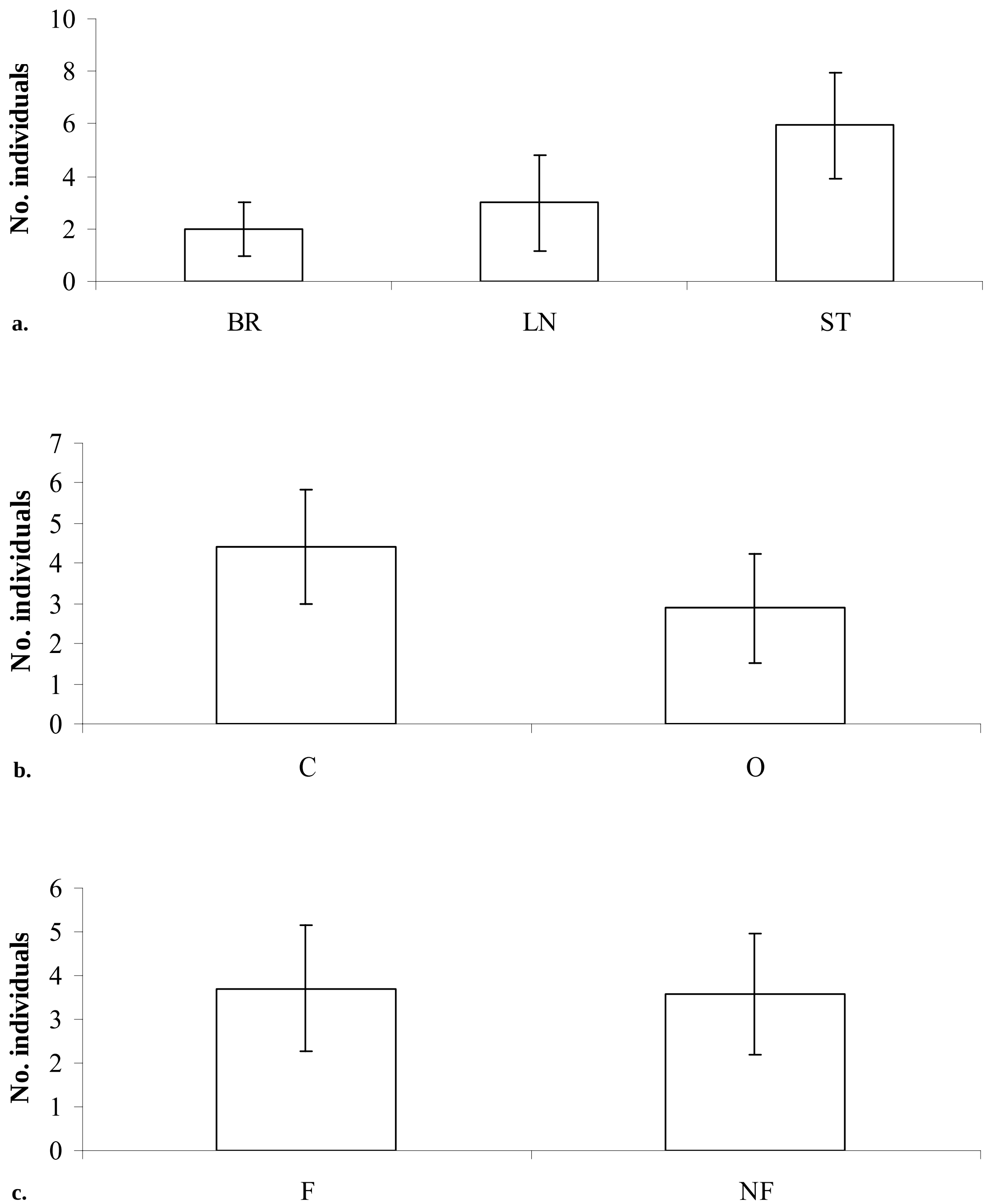


Figure 3.2. Mean ± standard error of *Eunicella verrucosa* abundance per standardised 85 metre transect with the East Tennants' transects excluded. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

These analyses show that there was no significant effect of fishing activity on the abundance of *E. verrucosa* either including or excluding the East Tennants' transects, when fishing activity was classified as a categorical variable (fishing or no fishing). One limitation to the ANOVA analysis was the division of the transects into distinct fished and not fished groups when the level of trawl effort is a continuous scale. It is possible that this, combined with other factors on limiting the abundance of *E. verrucosa*, such as the availability of suitable substrate type and the movement of water currents within Lyme Bay, are obscuring a link between fishing activity and *E. verrucosa* abundance. Therefore a quantile regression between the level of fishing activity for all the transects including East Tennants (calculated as outlined in Methodology, Section 2.1) and *E. verrucosa* abundance was conducted using the 99% quantile after $\log_{10}$ transformation of the abundance data.

Table 3.4. The analysis of *Eunicella verrucosa* abundance (log scale) across all transects against the fishing effort expressed as the number of times trawled from 2000 to 2006. The slope and intercept from quantile regression analysis using the 99% quantile.

		Value ± SE	***t***	***P***
Quantile regression	Slope	-0.599 ± 0.334	-1.791	0.079
	Intercept	4.605 ± 0.552	8.348	<0.001

The slope identified by the quantile regression was almost significantly different from 0 (Table 3.4.). This suggests that the presence of *E. verrucosa* is limited by the occurrence of trawling activity in the area as can be seen by the negative slope of the regression line. Absence of or low level trawling activity within any specific region of the seafloor however does not mean that *E. verrucosa* individuals will be present within that region. There were many sites where there was a low level of trawling activity and no, or few, *E. verrucosa* individuals present (Figure 3.3.). This may be due to other factors limiting *E. verrucosa* abundance in these regions.

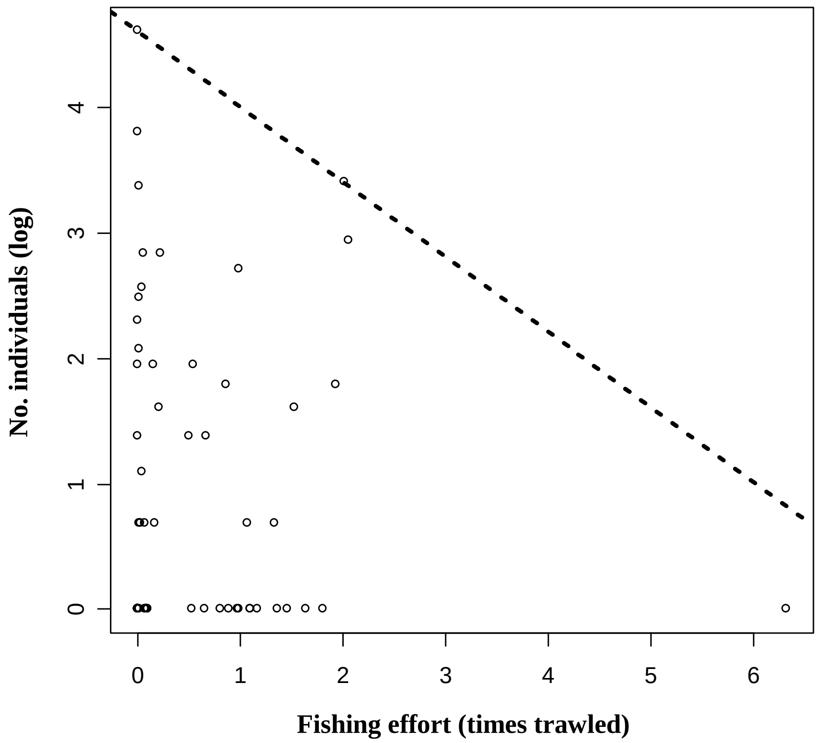


Figure 3.3. The relationship between the level of fishing activity (times trawled) and the abundance of *Eunicella verrucosa* (log scale) per standardised 85 metre transect as identified by quantile regression (τ = 0.99).

3.1.2. E. verrucosa size

The mean size of *E. verrucosa* across treatment was highest in closed not fished areas at 19638 ± 2195 mm^2 and lowest in open not fished areas at 5784 ± 2018 mm^2. Following log_{10} transformation the residuals for the size (mm^2) were tested for normality and equal variance. An ANOVA routine was conducted across the factor of treatment (CF, CNF, OF, ONF).

Table 3.5. The results of the analysis of variance for size (mm^2) of *Eunicella verrucosa* across treatment (log scale).

(a) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj MS**	***F***	***P***
Treatment	3	11.517	3.389	9.08	<0.001
Residual	221	93.390	0.423		
Total	224	104.907			

(b) Multiple comparison between mean abundance with treatment as the factor using Tukey's method. Minimum difference required for significance at 5% level = 0.267 (95% CI of the differences). * = significant. Column means are subtracted from row means.

Treatment	**CF**	**CNF**	**OF**
CNF	0.443*		
OF	0.676	-0.376*	
ONF	-0.158	-0.601*	-0.225

E. verrucosa was significantly larger in closed and not fished areas than in all other treatments (Table 3.5.a, Table 3.5.b., Figure 3.4.).

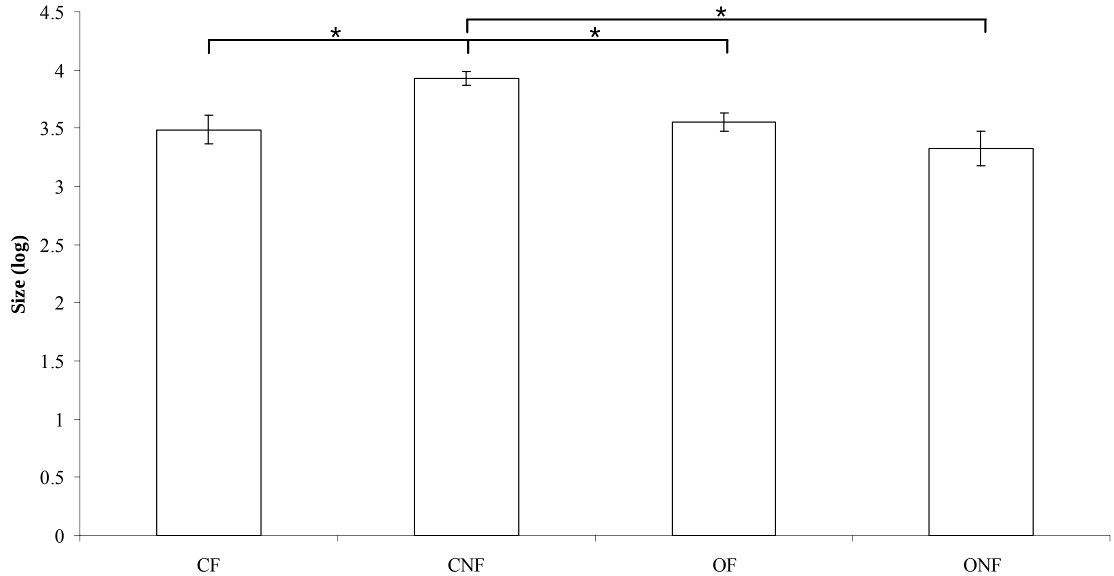


Figure 3.4. Mean ± standard error for the size (mm^2) of *Eunicella verrucosa* across treatments (log scale) per standardised 85 metre transect. CF closed fished, CNF closed not fished, OF open fished, ONF open not fished. * = significant difference.

3.2. Dead man's fingers (*Alcyonium digitatum*)

3.2.1. A. digitatum abundance

The abundance of *A. digitatum* ranged from 0 to 325 individuals across the transects. Following a fourth root transformation of the full dataset, including the East Tennants' transects, the residuals were tested for normality and heterogeneity of variance indicating that an ANOVA could be performed.

Table 3.6. The abundance of *Alcyonium digitatum* across all four sites, protection and fishing activity (square root transformed data). BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	1.512 ± 0.156	0.490 ± 0.240
ET	1.840 ± 1.090	0.367 ± 0.256
LN	0.808 ± 0.255	0.250 ± 0.164
ST	0.594 ± 0.233	0.359 ± 0.240
	F	**NF**
BR	0.854 ± 0.261	1.148 ± 0.287
ET	0.000 ± 0.000	1.288 ± 0.586
LN	0.274 ± 0.180	0.784 ± 0.251
ST	0.196 ± 0.196	0.758 ± 0.234
	C	**O**
F	0.783 ± 0.209	0.074 ± 0.074
NF	1.331 ± 0.294	0.658 ± 0.180

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	***F***	***P***
Site	3	3.016	3.111	1.037	1.72	0.173
Protection	1	7.419	7.419	7.419	12.33	0.001
Fishing activity	1	5.404	4.275	4.275	7.10	0.010
Residual	54	32.496	32.496	0.602		
Total	59					

The abundance of *A. digitatum* was significantly higher in closed areas than open areas (Table 3.6.b. and Figure 3.5.b.) and there were significantly more *A. digitatum* in not fished than in fished regions (Table 3.6.b. and Figure 3.5.c.). There was no significant difference in the abundance of *A. digitatum* between the sites (Table 3.6.b.).

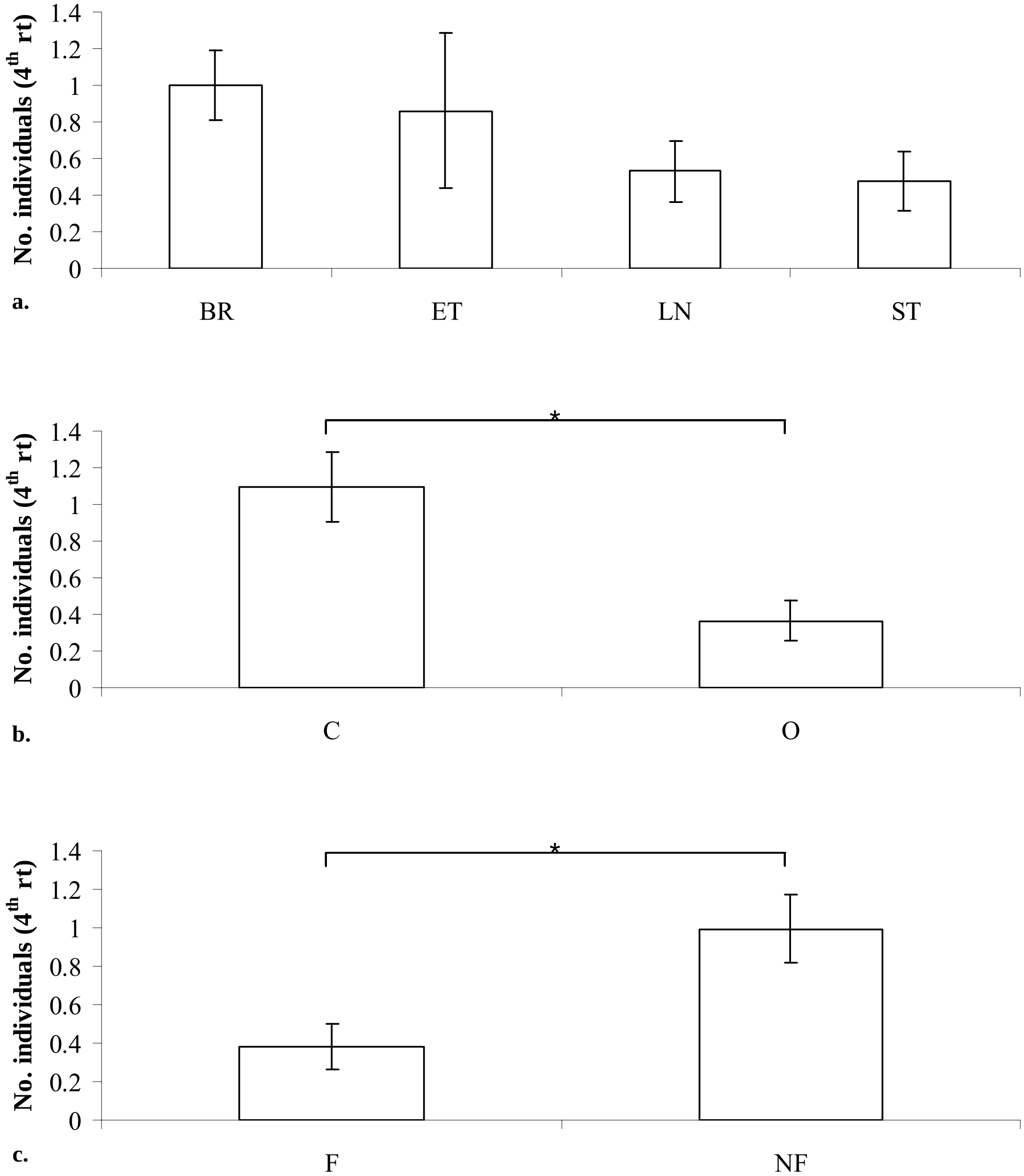


Figure 3.5. Mean ± standard error of *Alcyonium digitatum* abundance per standardised 85 metre transect. * = significant difference. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished. The data has been subjected to a fourth root transformation.

Following removal of the East Tennants' transects from the dataset, the residuals were tested for normality and equal variance and the three factor ANOVA was repeated with two way interaction terms included between the factors.

Table 3.7. The abundance of *Alcyonium digitatum* across three sites, protection and fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.
(a) Means (± standard error) of abundance.

	C	O
BR	8.000 ± 3.690	1.125 ± 0.581
LN	2.500 ± 1.440	0.250 ± 0.164
ST	1.250 ± 0.726	1.250 ± 0.996
	F	**NF**
BR	2.630 ± 1.130	6.500 ± 3.870
LN	0.375 ± 0.263	2.380 ± 1.450
ST	0.750 ± 0.750	1.750 ± 0.940
	C	**O**
F	2.333 ± 0.865	0.167 ± 0.167
NF	5.500 ± 2.590	1.583 ± 0.701

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj MS**	***F***	***P***
Site	2	112.79	56.40	2.37	0.108
Protection	1	111.02	111.02	4.66	0.038
Fishing activity	1	63.02	63.02	2.65	0.113
Site*Protection	2	98.29	49.15	2.06	0.142
Site*Fishing activity	2	17.04	8.52	0.36	0.702
Protection*Fishing activity	1	9.19	9.19	0.39	0.539
Residual	36	857.75	23.83		
Total	47	1305.48			

There were no significant interactions across any of the three factors (Table 3.7.b.). In the absence of East Tennants there remained a significantly higher abundance of *A. digitatum* in closed than in open areas (Table 3.7.b. and Figure 3.6.b.). There was no significant difference in the abundance of *A. digitatum* between the sites (Table 3.7.b.). Whilst the abundance of *A. digitatum* remained higher in not fished areas than fished areas in the absence of the East Tennants' transects (Figure 3.6.c.) this difference was no longer significant (Table 3.7.b.).

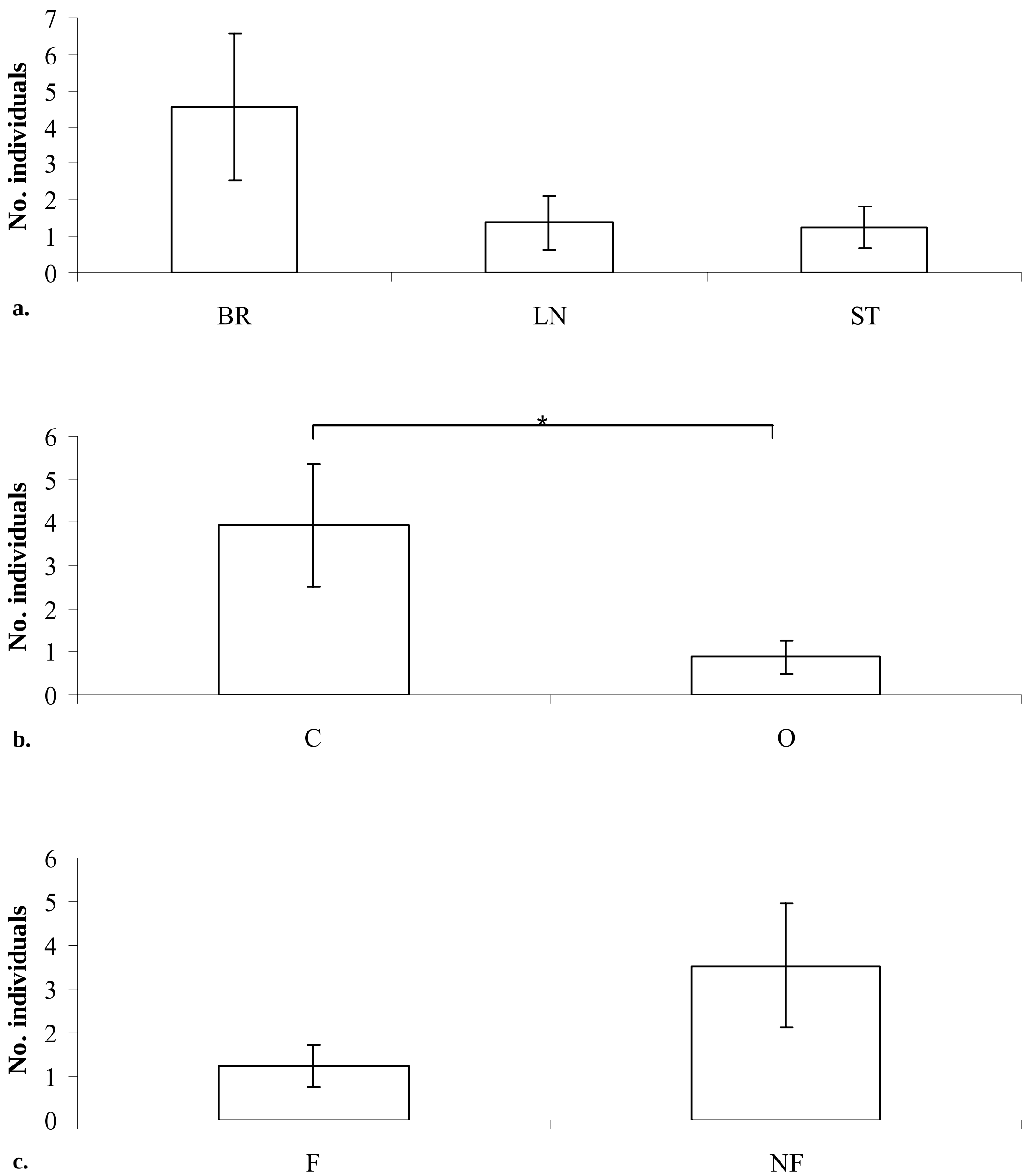


Figure 3.6. Mean ± standard error of *Alcyonium digitatum* abundance per standardised 85 metre transect with the East Tennants transects excluded. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

A quantile regression between the level of fishing activity across all transects including East Tennants and the abundance of *A. digitatum* was conducted using the 99% quantile following $\log_{10}$ transformation of the abundance data.

Table 3.8. The analysis of *A. digitatum* abundance (log scale) across all transects against the fishing effort expressed as the number of times trawled from 2000 to 2006. The slope and intercept from quantile regression analysis using the 99% quantile.

		Value ± SE	***t***	***P***
Quantile regression	Slope	-0.9157 ± 0.557	-1.643	0.105
	Intercept	5.787 ± 0.840	6.891	<0.001

The slope of the quantile regression was not significantly different from 0 (Table 3.8.). However the negative slope highlighted that the presence of *A. digitatum* was limited by the occurrence of trawling activity in the area (Table 3.8.). As with *E. verrucosa*, a low level of trawl disturbance within a region does not predict a high abundance of *A. digitatum* as can be seen by the cluster of points in Figure 3.7 about the origin.

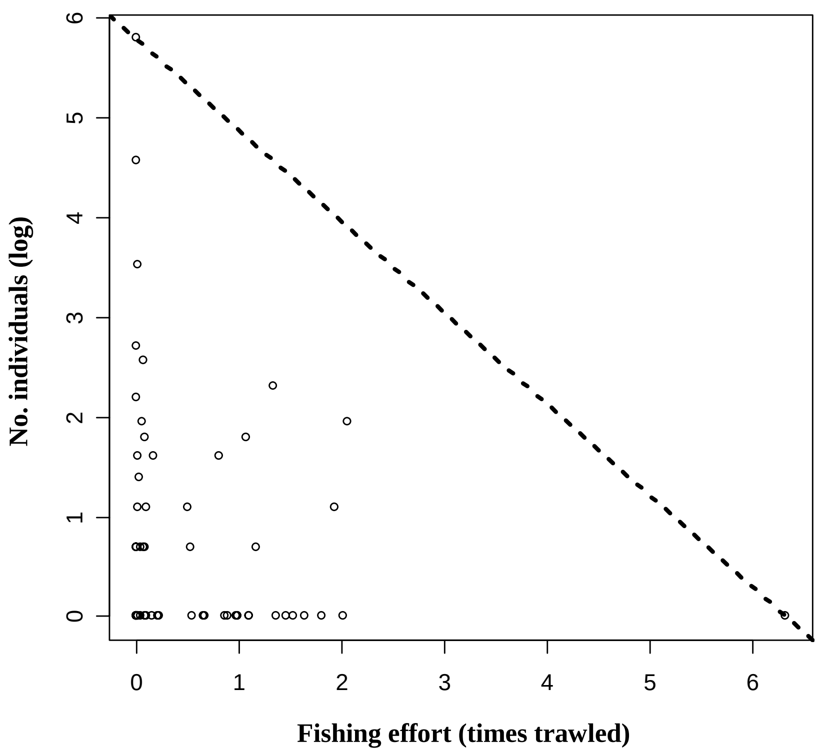


Figure 3.7. The relationship between the level of fishing activity (times trawled) and the abundance of *Alcyonium digitatum* (log scale) per standardised 85 metre transect as identified by quantile regression (τ = 0.99).

3.2.2. A. digitatum size

The mean size of the *A. digitatum* individuals across the treatments ranged from 1069 ± 240 mm^2 in closed and fished areas to 3710 ± 408 mm^2 in closed not fished areas. There were no *A. digitatum* individuals present for measurement across any of the open fished transects and therefore the analysis was conducted for only three of the four treatments (CF, CNF, ONF). The residuals were tested for normality and equal variance and ANOVA techniques applied in the analysis.

Table 3.9. The results of the analysis of variance for size (mm^2) of *Alcyonium digitatum* across treatment.

(a) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	DF	Seq SS	Adj MS	*F*	*P*
Treatment	2	103952692	51976346	3.08	0.049
Residual	137	2314042866	16890824		
Total	139	2417995558			

(b) Multiple comparison between mean abundance with treatment as the factor using Tukey's method. Minimum difference required for significance at 5% level = 1966 (95% CI of the differences). * = significant. Column means are subtracted from row means.

Treatment	CF	CNF
CNF	2641*	
ONF	731	-1909

A. digitatum was significantly larger in closed not fished regions than in closed fished regions (Table 3.9. and Figure 3.8.).

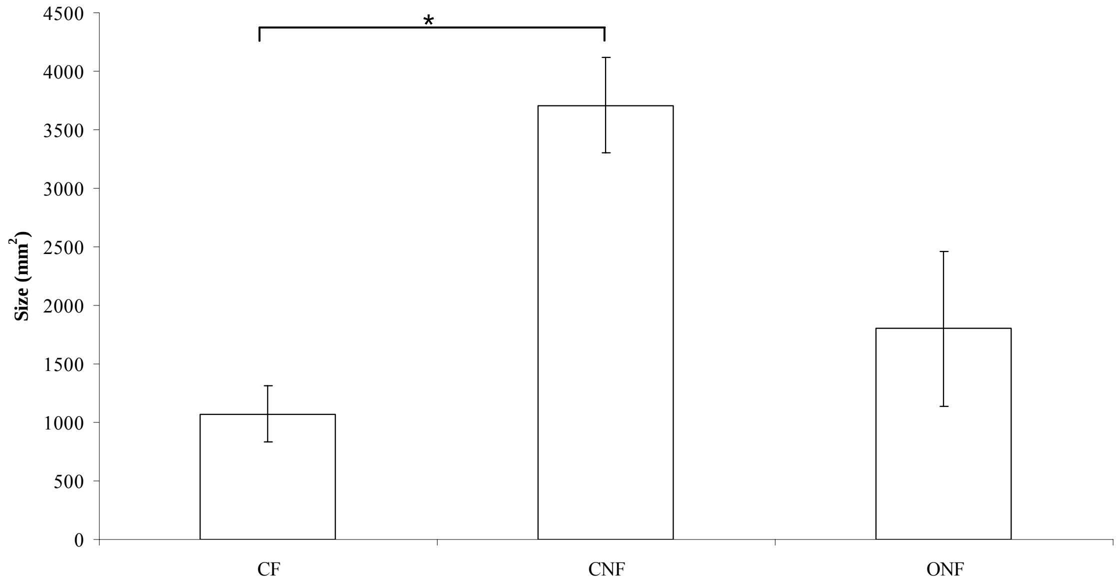


Figure 3.8. Mean ± standard error for the size (mm^2) of *Alyconium digitatum* per standardised 85 metre transect across treatments. CF closed fished, CNF closed not fished, ONF open not fished.

3.3. Ross coral (*Pentapora fascialis*)

3.3.1. P. fascialis abundance

P. fascialis was the least abundant of the four target species and only 36 individuals were observed across 12 of the 60 transects (Table 3.10.). They ranged in abundance across the transects from 0 to 16 individuals.

Table 3.10. The total number of *Pentapora fascialis* across the four transects (a distance of 340 m) at each site within each treatment. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. CF closed fished, CNF closed not fished, OF open fished, ONF open not fished.

	CF	CNF	OF	ONF
BR	0	0	1	1
ET	-	3	1	0
LN	1	16	1	0
ST	1	0	4	8

The residuals of the full dataset including the East Tennants' transects was tested for normality and heterogeneity of variance and a three factor ANOVA conducted across the factors of site, protection and fishing activity.

Table 3.11. The abundance of *Pentapora fascialis* across all four sites, protection and fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	0.000 ± 0.000	0.250 ± 0.164
ET	0.750 ± 0.479	0.125 ± 0.125
LN	2.130 ± 1.990	0.125 ± 0.125
ST	1.500 ± 0.681	0.000 ± 0.000
	F	**NF**
BR	0.125 ± 0.125	0.125 ± 0.125
ET	0.250 ± 0.250	0.375 ± 0.263
LN	0.250 ± 0.164	2.000 ± 2.000
ST	0.500 ± 0.378	1.000 ± 0.681
	C	**O**
F	0.471 ± 0.260	0.188 ± 0.101
NF	1.690 ± 1.020	0.063 ± 0.063

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	***F***	***P***
Site	3	9.233	8.823	2.941	0.61	0.611
Protection	1	13.127	13.127	13.127	2.73	0.105
Fishing activity	1	5.939	4.400	4.400	0.91	0.343
Residual	54	260.100	260.100	4.817		
Total	59	288.400				

There was no significant difference in the abundance of *P. fascialis* across any of the three factors (Table 3.11.b.). However, whilst not significant differences, it can be seen from Figure 3.9 that the abundance of *P. fascialis* was higher in closed areas than open areas and higher in not fished areas than fished areas. The absence of *P. fascialis* across the majority of transects has created a high standard error about the mean values and therefore these differences are not significant.

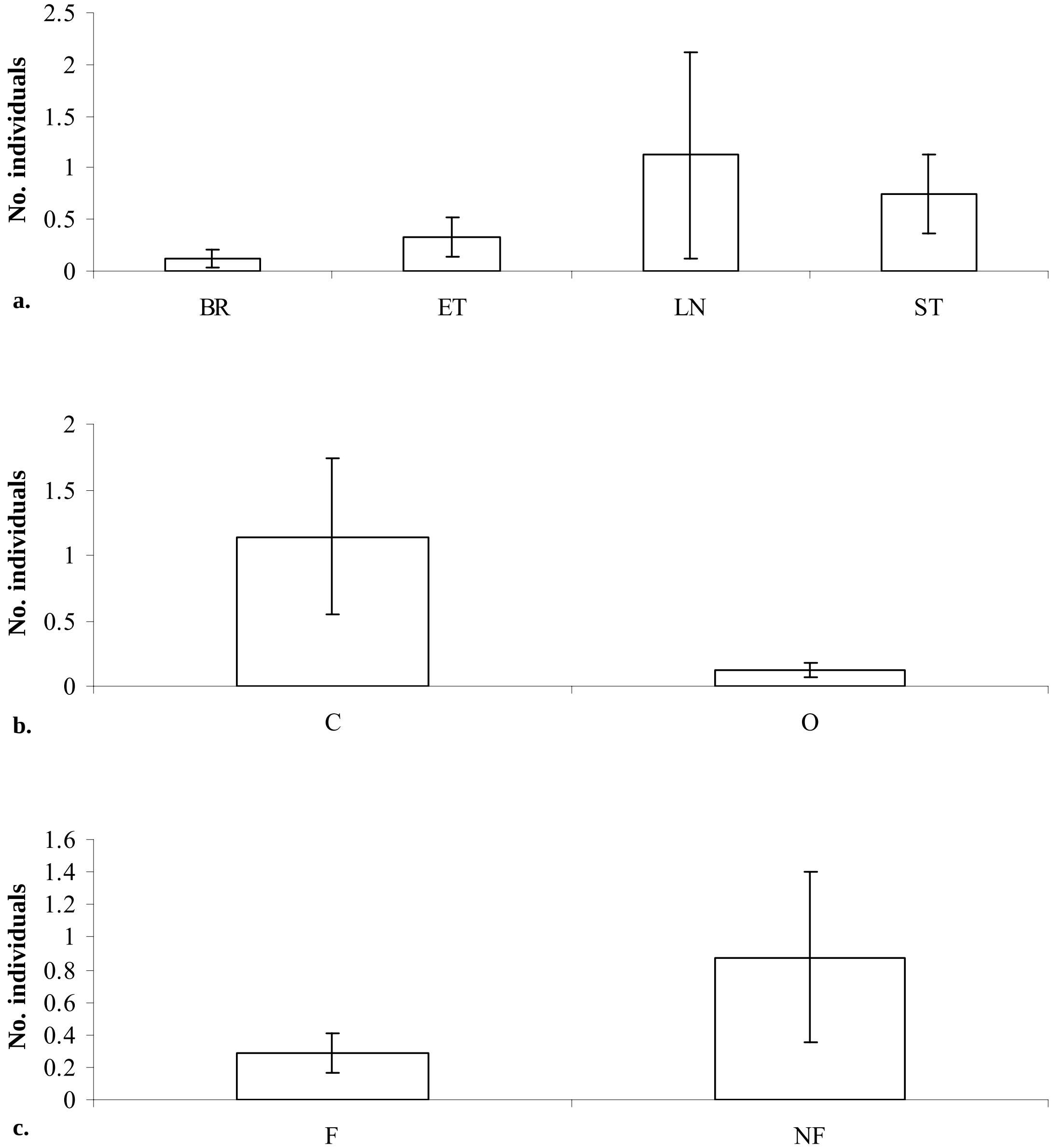


Figure 3.9. Mean ± standard error of *Pentapora fascialis* abundance per standardised 85 metre transect. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

After the removal of the East Tennants' transects the *P. fascialis* abundance data was tested for normality and heterogeneity of variance of the residuals and a three factor ANOVA conducted with two way interaction terms between factors.

Table 3.12. The abundance of *Pentapora fascialis* across three sites, protection and fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	0.000 ± 0.000	0.250 ± 0.164
LN	2.130 ± 1.990	0.125 ± 0.125
ST	1.500 ± 0.681	0.000 ± 0.000
	F	**NF**
BR	0.125 ± 0.125	0.125 ± 0.125
LN	0.250 ± 0.164	2.000 ± 2.000
ST	0.500 ± 0.378	1.000 ± 0.681
	C	**O**
F	0.417 ± 0.260	0.167 ± 0.112
NF	2.000 ± 1.350	0.083 ± 0.083

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj MS**	***F***	***P***
Site	2	8.167	4.083	0.67	0.517
Protection	1	14.083	14.083	2.32	0.137
Fishing activity	1	6.750	6.750	1.11	0.299
Site*Protection	2	11.167	5.583	0.92	0.409
Site*Fishing activity	2	6.500	3.250	0.53	0.591
Protection*Fishing activity	1	8.333	8.333	1.37	0.250
Residual	36	219.000	6.083		
Total	47	282.667			

There were no significant interactions between the three factors (Table 3.12.b.) and there was no significant difference in the abundance of *P. fascialis* across the factors of site, protection or fishing activity (Table 3.12.b.). After the removal of the East Tennants' transects there remained a higher mean abundance of *P. fascialis* in closed than open areas and in not fished than fished areas despite these differences not being significant (Figure 3.10.).

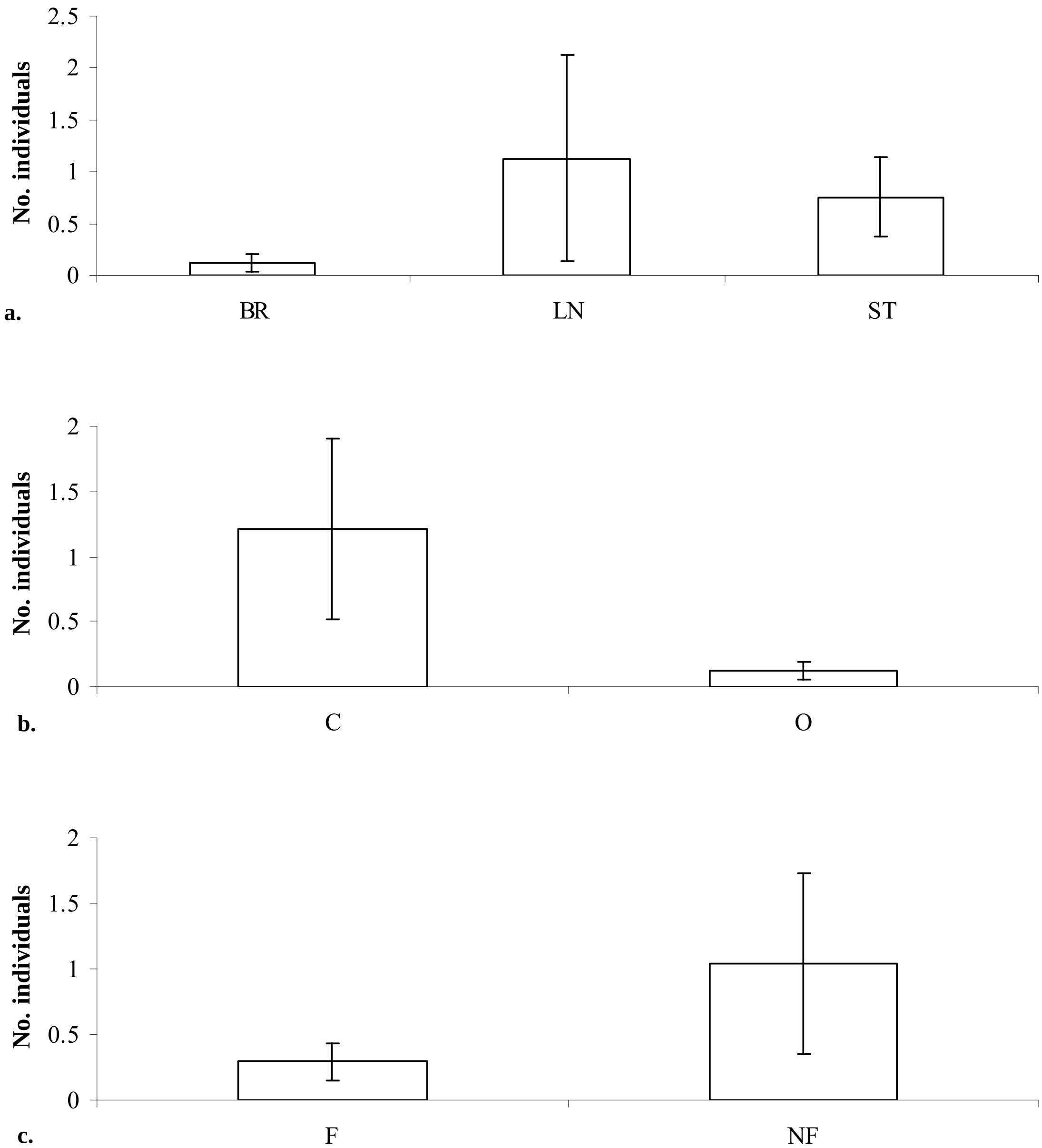


Figure 3.10. Mean ± standard error of *Pentapora fascialis* abundance per standardised 85 metre transect with the East Tennants' transects excluded. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

Quantile regression analysis was conducted between the $\log_{10}$ transformed *P. fascialis* abundance dataset and the level of trawl activity for all of the transects including East Tennants using the 99% quantile.

Table 3.13. The analysis of *Pentapora fascialis* abundance (log scale) across all transects against the fishing effort expressed as the number of times trawled from 2000 to 2006. The slope and intercept from quantile regression analysis using the 99% quantile.

		Value ± SE	***t***	***P***
Quantile regression	Slope	-0.461 ± 0.422	-1.093	0.279
	Intercept	2.912 ± 0.677	4.303	<0.001

The slope of the quantile regression was not significantly different from 0 (Table 3.13.). However, a large number of the transects with high *P. fascialis* abundance had a level of fishing activity of 0 or just over 0 times trawled (Figure 3.11.).

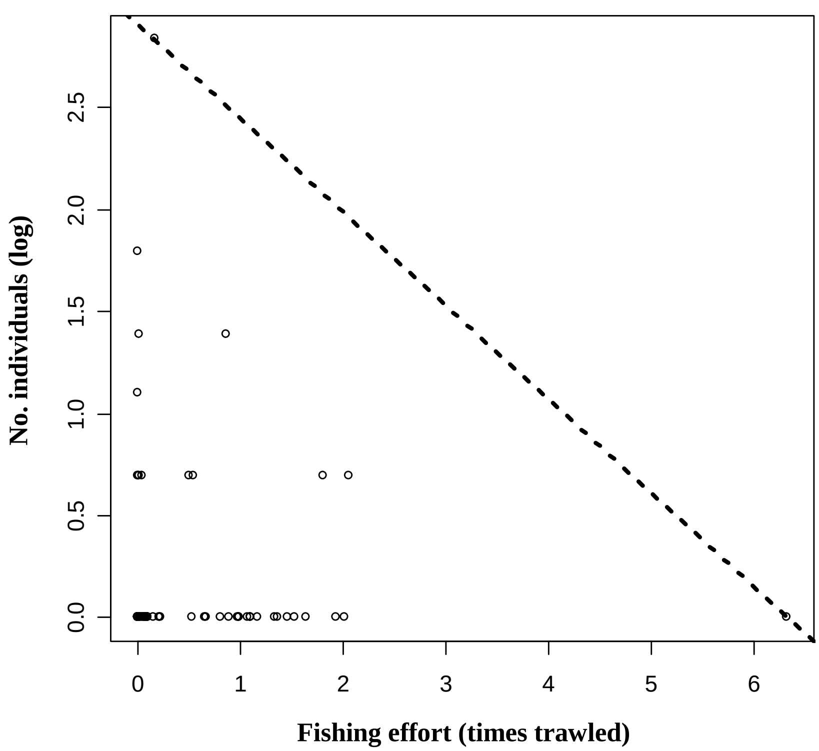


Figure 3.11. The relationship between the level of fishing activity (times trawled) and the abundance of *Pentapora fascialis* (log scale) per standardised 85 metre transect as identified by quantile regression (τ = 0.99).

3.3.2. P. fascialis size

There were no measurements for the size of *P. fascialis* individuals occurring within open not fished areas and therefore only three treatments were included in the analysis. The residuals of the size measurements (mm^2) were tested for normality and heterogeneity of variance and ANOVA analysis was performed across the factor of treatment.

Table 3.14. The results of the analysis of variance for size (mm^2) of *Pentapora fascialis* across treatment, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj MS**	***F***	***P***
Treatment	2	143220346	71610173	0.97	0.401
Residual	15	1105860902	73724060		
Total	17	1249081248			

There was no significant difference in the size (mm^2) of *P. fascialis* individuals across the three tested treatments (Table 3.14 and Figure 3.12.).

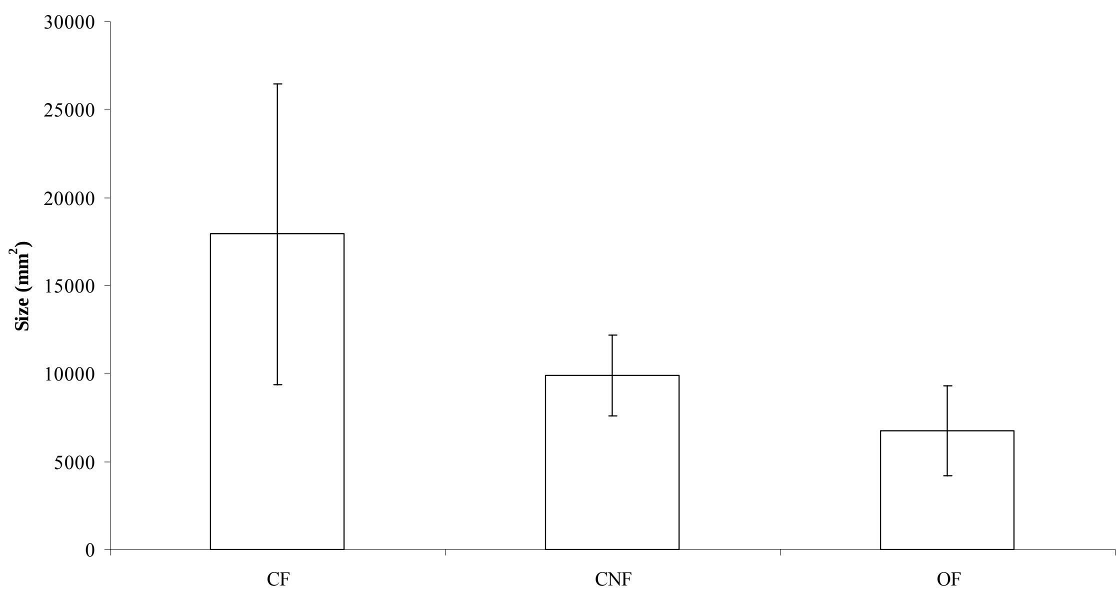


Figure 3.12. Mean ± standard error for the size (mm^2) of *Pentapora fascialis* per standardised 85 metre transect across treatments. CF closed fished, CNF closed not fished, OF open fished.

3.4. King scallops (*Pecten maximus*)

3.4.1. P. maximus abundance

The number of *P. maximus* present across the transects varied from 0 to 20 individuals per transect. The residuals for the abundance of *P. maximus* across all four sites were tested for normality and equal variance and a three factor ANOVA conducted across site, protection and fishing activity.

Table 3.15. The abundance of *Pecten maximus* across all four sites, protection and fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	3.250 ± 0.861	3.250 ± 1.050
ET	4.750 ± 2.430	8.880 ± 2.060
LN	10.000 ± 1.450	9.130 ± 2.200
ST	3.125 ± 0.934	5.630 ± 2.090
	F	**NF**
BR	2.875 ± 0.789	3.630 ± 1.080
ET	12.750 ± 2.560	4.880 ± 1.390
LN	8.380 ± 1.680	10.750 ± 1.940
ST	4.630 ± 1.750	4.130 ± 1.610
	C	**O**
F	5.250 ± 0.986	7.190 ± 1.590
NF	5.440 ± 1.290	6.250 ± 1.270

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	***F***	***P***
Site	3	392.90	388.95	129.65	6.14	0.001
Protection	1	18.82	18.82	18.82	0.89	0.613
Fishing activity	1	7.52	5.46	5.46	0.26	0.349
Residual	54	1139.35	1139.35	21.10		
Total	59	1558.58				

(c) Multiple comparison between mean abundance with site as the factor using Tukey's method. Minimum difference required for significance at 5% level = 3.921 (95% CI of the differences). * = significant. Column means are subtracted from row means.

Treatment	**BR**	**ET**	**LN**
ET	4.163*		
LN	6.312*	2.150	
ST	1.125	-3.038	-5.187*

There was no significant effect of protection or fishing activity (Table 3.15.b.) observed on the abundance of *P. maximus*. There were, however, significantly more *P. maximus* present in Lanes Ground than in Beer Home Ground or Sawtooth Ledges and significantly more in East Tennants than in Beer Home Ground (Table 3.15.b., Table 3.15.c., Figure 3.13.a.).

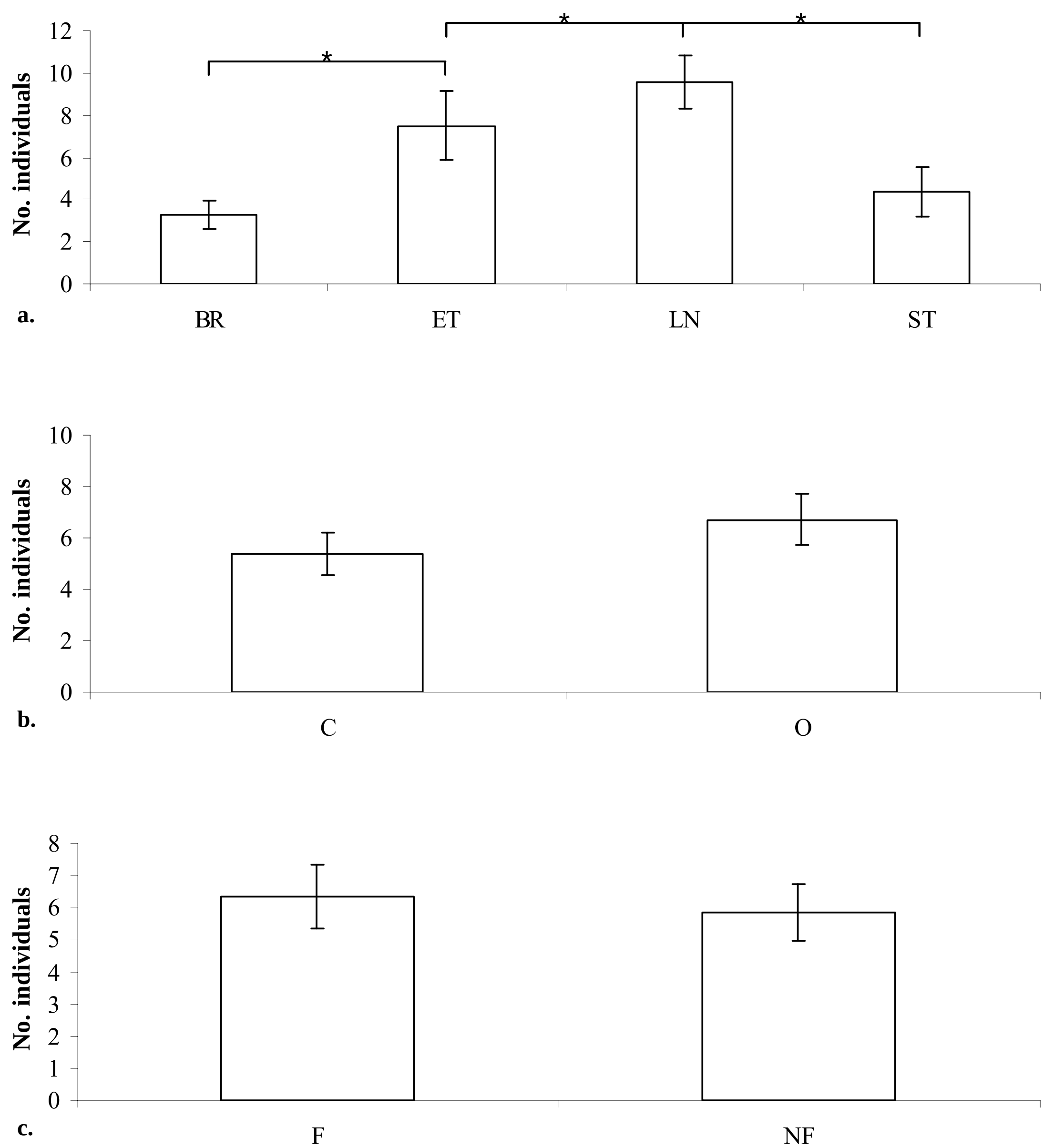


Figure 3.13. Mean ± standard error of *Pecten maximus* abundance per standardised 85 metre transect. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

The East Tennants' transects were removed from the dataset and following tests for normality and equality of residual variance a three factor ANOVA with two way interaction between the factors was conducted.

Table 3.16. The abundance of *Pecten maximus* across three sites, protection and fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	3.250 ± 0.861	3.250 ± 1.050
LN	10.000 ± 1.450	9.130 ± 2.200
ST	3.125 ± 0.934	5.630 ± 2.090
	F	**NF**
BR	2.875 ± 0.789	3.630 ± 1.080
LN	8.380 ± 1.680	10.750 ± 1.940
ST	4.630 ± 1.750	4.130 ± 1.610
	C	**O**
F	5.250 ± 0.986	5.330 ± 1.660
NF	5.670 ± 1.570	6.670 ± 1.610

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj MS**	***F***	***P***
Site	2	362.79	181.40	8.72	0.001
Protection	1	3.52	3.52	0.17	0.683
Fishing activity	1	9.19	9.19	0.44	0.511
Site*Protection	2	24.54	12.27	0.59	0.560
Site*Fishing activity	2	16.63	8.31	0.40	0.673
Protection*Fishing activity	1	2.52	2.52	0.12	0.730
Residual	36	748.75	20.80		
Total	47	1175.48			

(c) Multiple comparison between mean abundance with site as the factor using Tukey's method. Minimum difference required for significance at 5% level = 4.274 (95% CI of the differences). * = significant. Column means are subtracted from row means.

Treatment	**BR**	**LN**
LN	6.312*	
ST	1.125	-5.187*

There were no significant interactions between the three treatments (Table 3.16.b.) and there was no significant effect of protection or fishing activity (Table 3.16.b.). There was a significantly higher abundance of *P. maximus* in Lanes Ground than in Beer Home Ground or Sawtooth Ledges (Table 3.16.b., Table 3.16.c., Figure 3.14.a.).

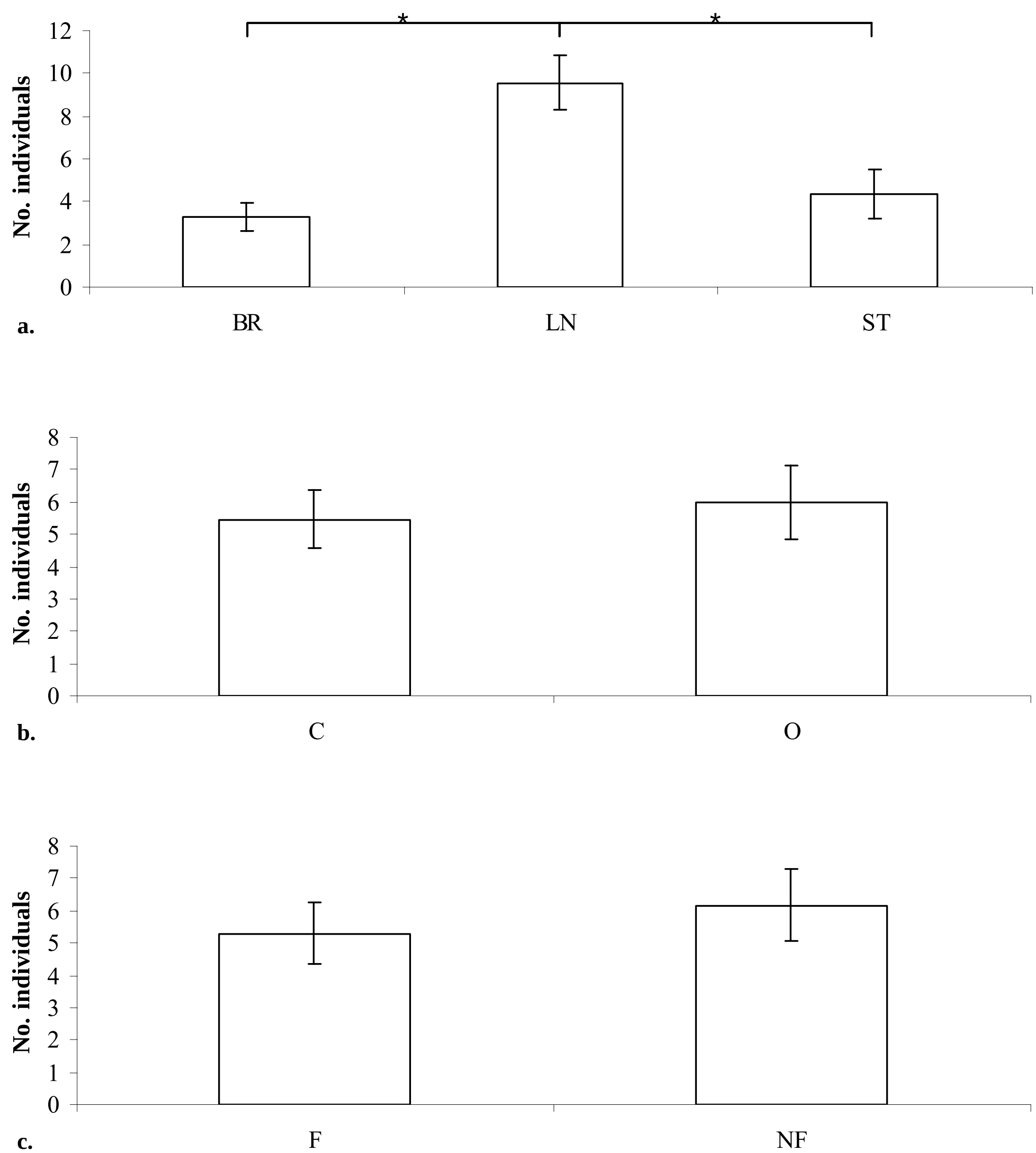


Figure 3.14. Mean ± standard error of *Pecten maximus* abundance per standardised 85 metre transect with the East Tennants transects excluded. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

Quantile regression analysis was conducted between the $\log_{10}$ transformed *P. maximus* abundance dataset and the level of trawl activity using the 95% quantile to further investigate any relationship.

Table 3.17. The analysis of *Pecten maximus* abundance (log scale) across all transects against the fishing effort as the number of times trawled from 2000 to 2006. The slope and intercept from quantile regression analysis using the 95% quantile.

		Value ± SE	***t***	***P***
Quantile regression	Slope	-0.030 ± 0.192	-0.156	0.877
	Intercept	2.944 ± 0.196	15.047	<0.001

There was little relationship between the number of times trawled and the abundance of *P. maximus* present and the slope of the regression line was not significantly different from 0 (Table 3.17.). Some of the transects with the highest abundance of *P. maximus* individuals were found at locations where there were high levels of fishing activity (Figure 3.17.).

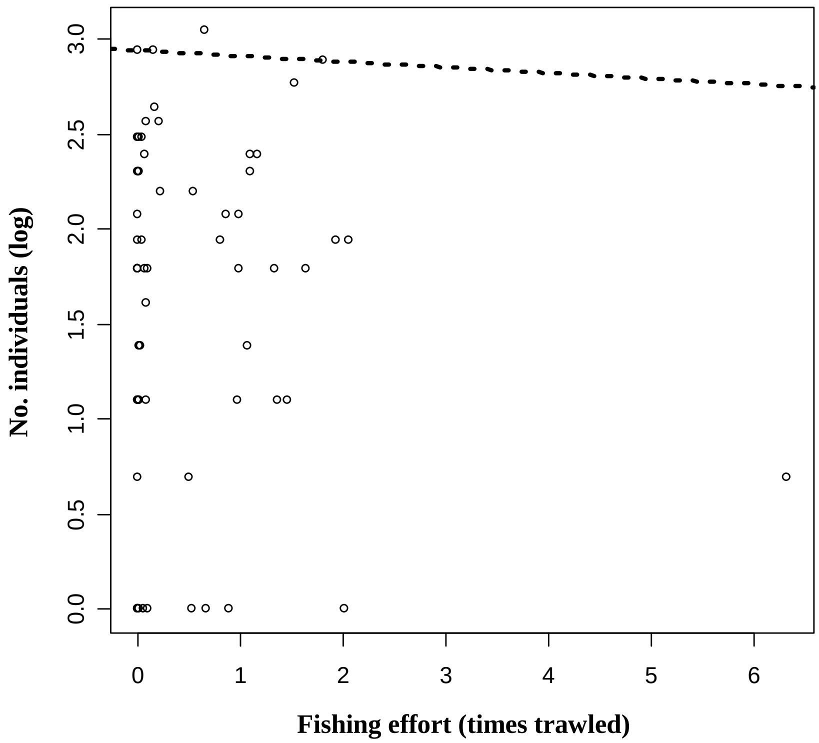


Figure 3.15. The relationship between the level of fishing activity (times trawled) and the abundance of *Pecten maximus* (log scale) per standardised 85 metre transect as identified by quantile regression (τ = 0.95).

3.4.2. P. maximus size

The residuals for the size (mm^2) of the *P. maximus* individuals were tested for normality and equal variance and an ANOVA routine was conducted across the factor of treatment (CF, CNF, OF, ONF).

Table 3.18. The results of the analysis of variance for size (mm^2) of *Pecten maximus* across treatment, Seq = sequential, Adj = adjusted for entry order.

Source	DF	Seq SS	Adj MS	*F*	*P*
Treatment	3	143308499	47769500	1.18	0.318
Residual	162	6543035677	40389109		
Total	165	6686344176			

There was no significant difference in the size of *P. maximus* across treatment (Table 3.18. and Figure 3.16.).

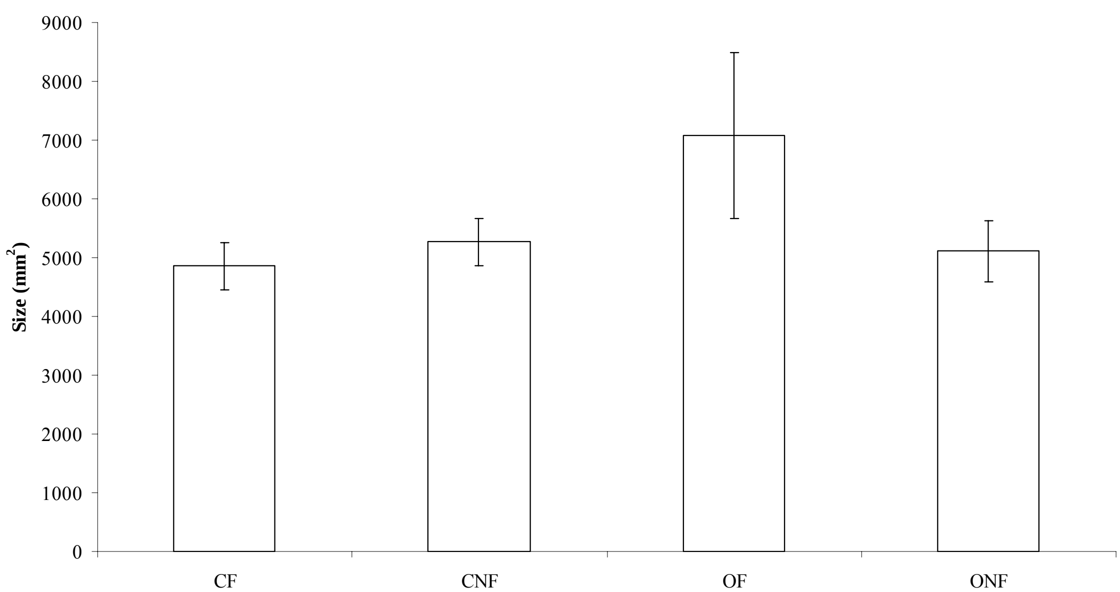


Figure 3.16. Mean ± standard error for the size (mm^2) of *Pecten maximus* per standardised 85 metre transect across treatments. CF closed fished, CNF closed not fished, OF open fished, ONF open not fished.

3.5. Substrate analysis

3.5.1. Substrate distribution across transects and species

The substrate was not constant across the transects and varied considerably from regions of fine silt to large boulders and exposed bedrock. The two most common substrate types across all transects were 'coarse sand, some small rocks', which accounted for 59% of substrate coverage, and 'large boulders and slabs of bedrock' accounting for 12% of substrate coverage (Figure 3.17.).

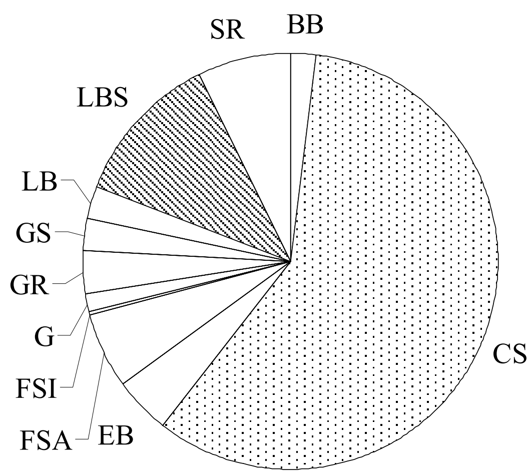


Figure 3.17. Substrate coverage of the total analysed area. BB brittlestar beds over sand, CS coarse sand some small rocks, EB exposed bedrock, FSA fine sand, FSI fine silt covering small rocks, G gravel, GR gravel and rubble, GS gravel and sand bars, LB large boulders, LBS large boulders and slabs of bedrock, SR small rocks.

The species were not uniformly distributed across the substrate types. Chi-squared goodness-of-fit tests were conducted for each species to determine whether species were more strongly associated with some substrate types. *E. verrucosa*, *A. digitatum* and *P. fascialis* were all more strongly associated with rock-based substrates whilst the scallop species, *P. maximus*, was more commonly associated with sand-dominated substrates (Figure 3.18.). *E. verrucosa* was not evenly distributed across the substrate types (χ^2 = 1097.92, df = 10, P < 0.001). It was most common on 'large boulders and slabs of bedrock' where 54% of all individuals were found. *A. digitatum* did not show an even distribution across substrate types (χ^2 = 2118.64, df = 10, P < 0.001) with 'large boulders and slabs of bedrock' being the most common substrate type associated with 63% of all recorded individuals. There was also an uneven distribution of *P. fascialis* (χ^2 = 86.22, df = 10, P < 0.001) with 'primarily small rocks' and 'large boulders and slabs of bedrock' accounting for 75% of all individuals. *P. maximus* was unevenly distributed (χ^2 = 1878.31, df = 10, P < 0.001) with 74% of all recorded individuals being over 'coarse sand, some small rocks'.

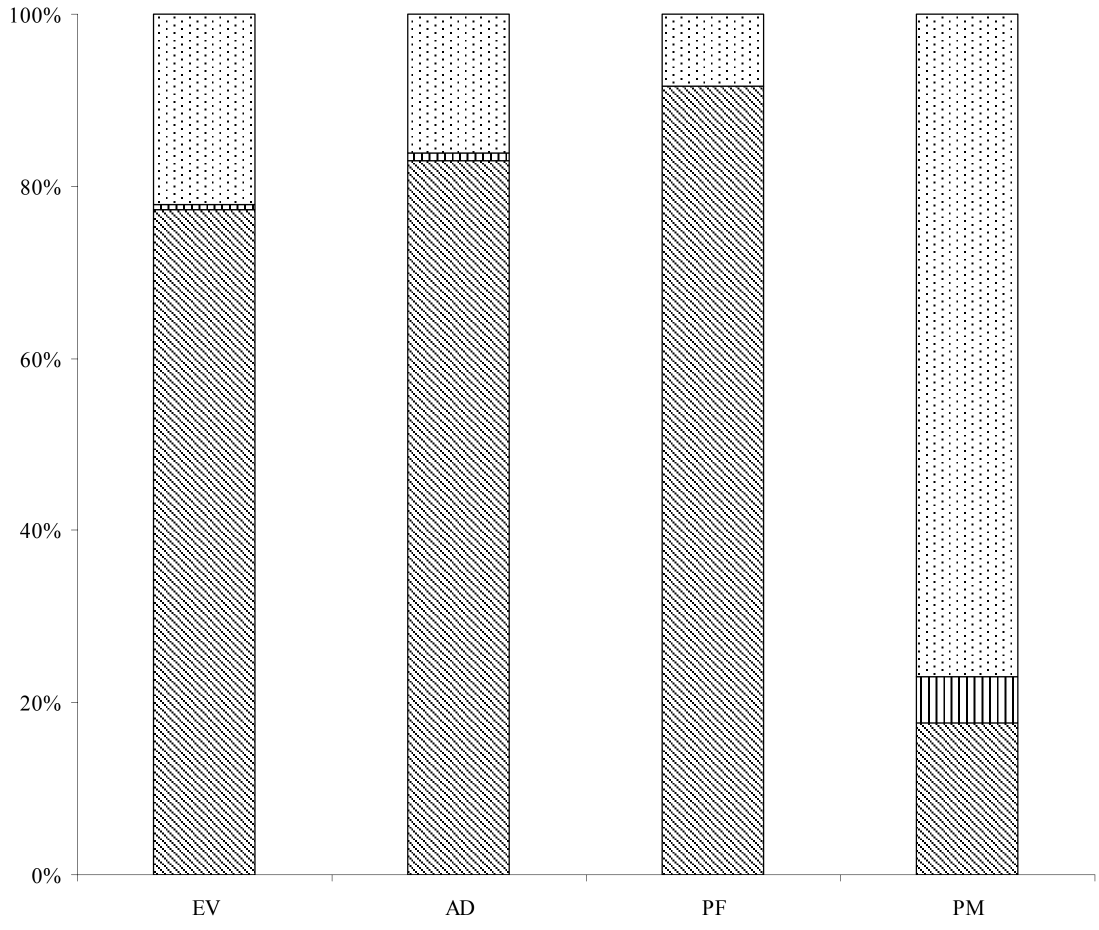
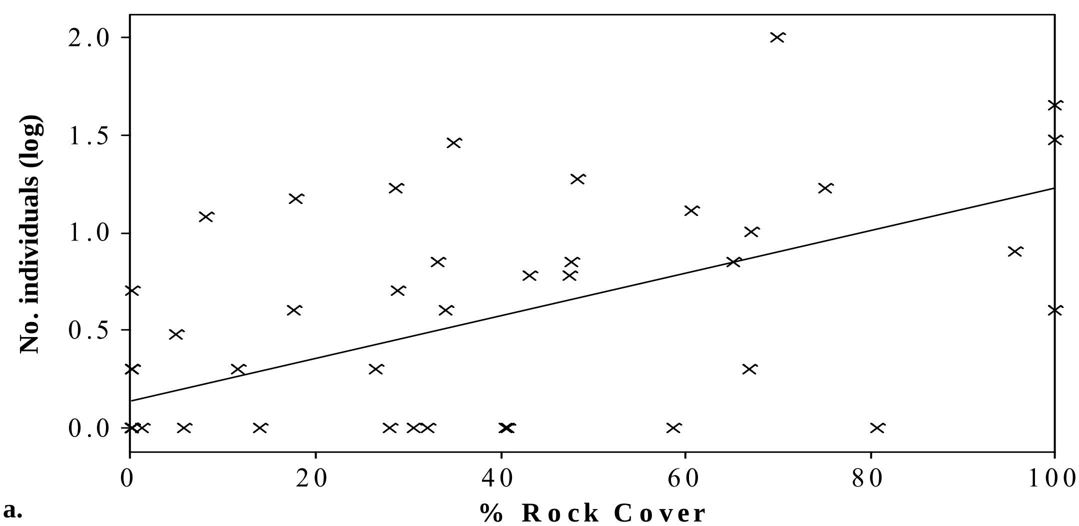


Figure 3.18. Seabed substrate associated with each species calculated as a percentage of the total number of individuals present. EV *Eunicella verrucosa*, AD *Alcyonium digitatum*, PF *Pentapora fascialis*, PM *Pecten maximus*. Sand (dotted shading), Gravel (vertical lined shading), Rock (diagonal lined shading).

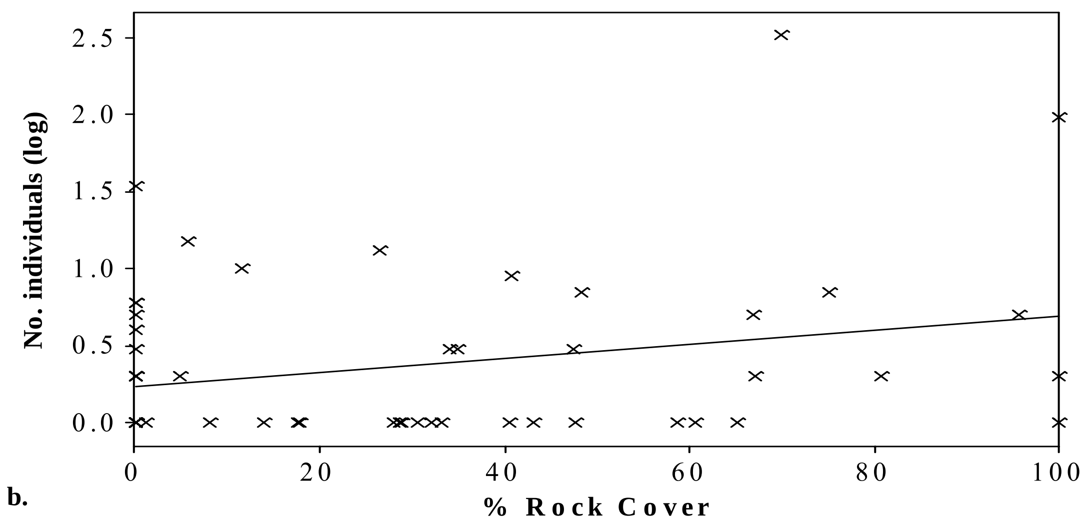
3.5.2. Further analysis of species abundance on rock based substrates

The substrates were grouped more generally into the categories of sand, gravel and rock for further analysis (as outlined in Methodology, Figure 2.4). Due to the high abundance of *E. verrucosa*, *A. digitatum* and *P. fascialis* observed over rock substratum correlations between abundance and the percentage rock cover over each transect were conducted. Following a $\log_{10}$ transformation of the abundance data there was a significant positive correlation between the percentage of rock cover across an individual transect and the abundance of *E. verrucosa* (Figure 3.19.a. Pearson's $r = 0.635$, df = 59, $P < 0.001$), the abundance of *A. digitatum* (Figure 3.19.b. Pearson's $r = 0.278$, df = 59, $P = 0.032$) and the abundance of *P. fascialis* (Figure 3.19.c. Pearson's $r = 0.413$, df = 59, $P = 0.001$).



a.

Figure 3.19. The relationship between the percentage rock cover of each transect and the abundance of **a.** *Eunicella verrucosa.*



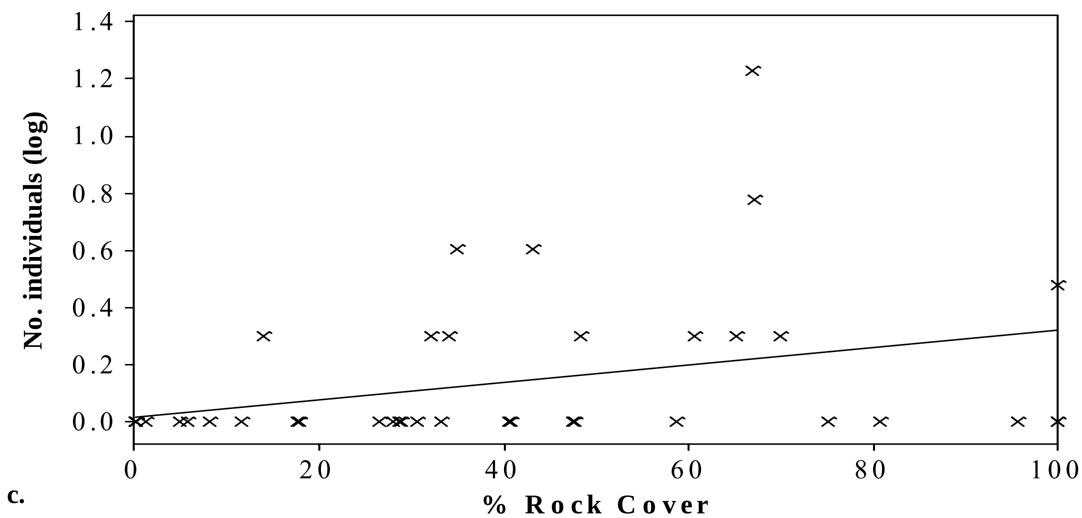


Figure 3.19. The relationship between the percentage rock cover of each transect and the abundance of **b.** *Alcyonium digitatum.* **c.** *Pentapora fascialis*.

The distribution of rock across site was uniform (Figure 3.20.a. $\chi^2 = 7.097$, df = 3, $P = 0.069$) with rock coverage inside all reserves ranging from 16.6% in Beer Home Ground to 34.5% in East Tennants. However, the composition of this rock substrate from the four sub-categories was markedly different across the four reserves with East Tennants and Sawtooth Ledges being dominated by large boulder substrates (accounting for 77.0% and 75.9% respectively at each site), whilst Beer Home Ground was dominated by 'exposed bedrock' (52.5%) and Lanes Ground by 'small rocks' (64.7%) (Table 3.19.).

Table 3.19. Percentage contribution of the four rock sub-categories to the overall composition of the rock substratum at the four different sites. EB exposed bedrock, LB large boulders, LBS large boulders and slabs of bedrock, SR small rocks.

Substrate Type	**BR**	**ET**	**LN**	**ST**
EB	52.5	11.6	14.1	2.5
LB	20.3	11.3	10.7	10.6
LBS	17.1	77.0	10.5	75.9
SR	10.1	0.0	64.7	11.1

There was no significant difference of the percentage rock cover between the closed and open areas (Figure 3.20.b. χ^2 = 2.648, df = 1, P = 0.104) or the fished and not fished treatments (Figure 3.20.c. χ^2 = 2.358, df = 1, P = 0.125). However when the percentage rock cover was tested across the four treatment groups (CF, CNF, OF, ONF) there was found to be a significant difference with a higher percentage rock cover in the closed not fished treatment than any of the other treatments (χ^2 = 14.010, df = 3, P = 0.003). Uneven distribution of substrate across treatment may have interfered with detection of the effect of the treatment itself.

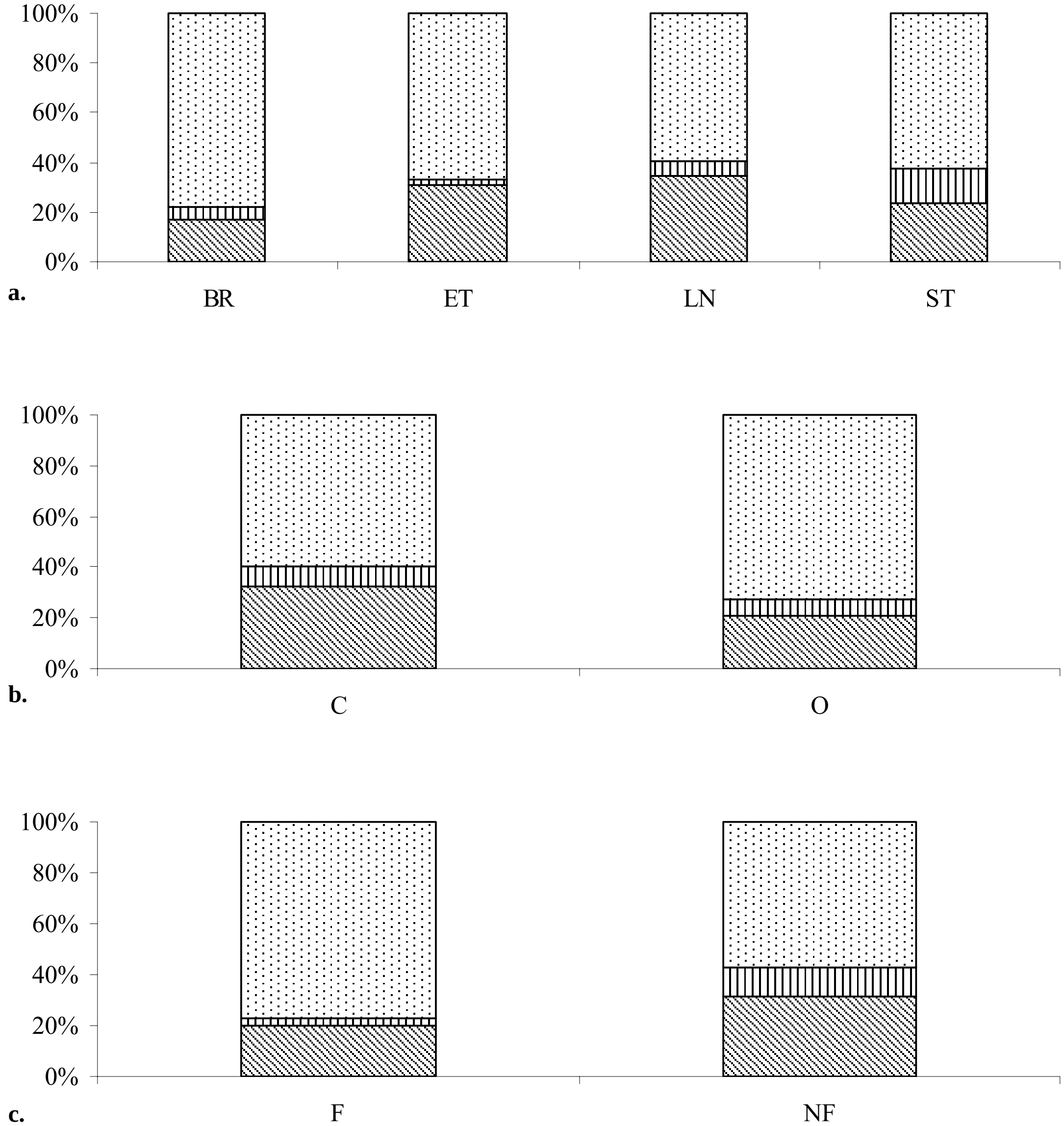


Figure 3.20. Percentage contribution of substrate grouped into three broad categories sand (dotted shading), gravel (vertical lined shading) and rock (diagonal lined shading). **a.** Substrate distribution across site, BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. **b.** Substrate distribution across protection, C closed, O open. **c.** Substrate distribution across fishing activity, F fished, NF not fished.

Due to the uneven distribution of rock cover across treatment further analysis was conducted by extracting the information from the sections of transect over rock based substrate with the aim of determining whether the differences between protection and fishing activity were larger when analysing only the areas amenable to the development of a reef community. This removed some transects from further analysis entirely, leaving 35 of the 60 transects remaining within the analysis. The remaining transects were evenly distributed across site (eight transects each in Beer Home Ground and East Tennants, nine transects in Sawtooth Ledges and ten transects in Lanes Ground) and protection (17 transects in closed areas and 18 transects in open areas) but they were not evenly distributed across fishing activity (14 transects in fished grounds and 21 transects in not fished grounds). From the 35 transects remaining the number of *E. verrucosa*, *A. digitatum* and *P. fascialis* per 100 metres of rock were calculated.

Following square root transformation the residuals of the *E. verrucosa* abundance dataset was tested for normality and heterogeneity of variance and the three factor analysis of variance routine was repeated.

Table 3.20. The abundance of *Eunicella verrucosa* present per 100 metres of rock substratum across all four sites, protection and fishing activity (square root transformed data). BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	3.200 ± 1.600	1.113 ± 0.683
ET	9.500 ± 2.310	3.000 ± 1.120
LN	1.439 ± 0.525	1.460 ± 1.460
ST	4.558 ± 0.926	3.300 ± 1.670
	F	**NF**
BR	0.877 ± 0.877	2.510 ± 1.080
ET	4.910 ± 1.200	4.450 ± 2.270
LN	2.610 ± 1.240	0.675 ± 0.464
ST	4.564 ± 0.398	3.800 ± 1.460
	C	**O**
F	3.063 ± 0.828	3.456 ± 0.909
NF	4.200 ± 1.120	1.163 ± 0.626

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	***F***	***P***
Site	3	66.547	77.684	25.895	4.03	0.016
Protection	1	33.518	35.965	35.965	5.60	0.025
Fishing activity	1	4.483	4.483	4.483	0.70	0.410
Residual	29	186.240	186.240	6.422		
Total	34	290.788				

(c) Multiple comparison between mean abundance with site as the factor using Tukey's method. Minimum difference required for significance at 5% level = 2.938 (95% CI of the differences). * = significant. Column means are subtracted from row means.

Treatment	**BR**	**ET**	**LN**
ET	2.998*		
LN	-0.954	-3.952*	
ST	1.559	-1.440	2.513

The abundance of *E. verrucosa* was significantly higher at East Tennants than at Beer Home Ground or Lanes Ground (Table 3.20.b., Table 3.20.c., Figure 3.21.a.). There were also significantly more *E. verrucosa* in closed areas than in open areas (Table 3.20.b. and (Figure 3.21.b.). There was no significant effect of fishing activity on the abundance of *E. verrucosa* (Table 3.20.b.).

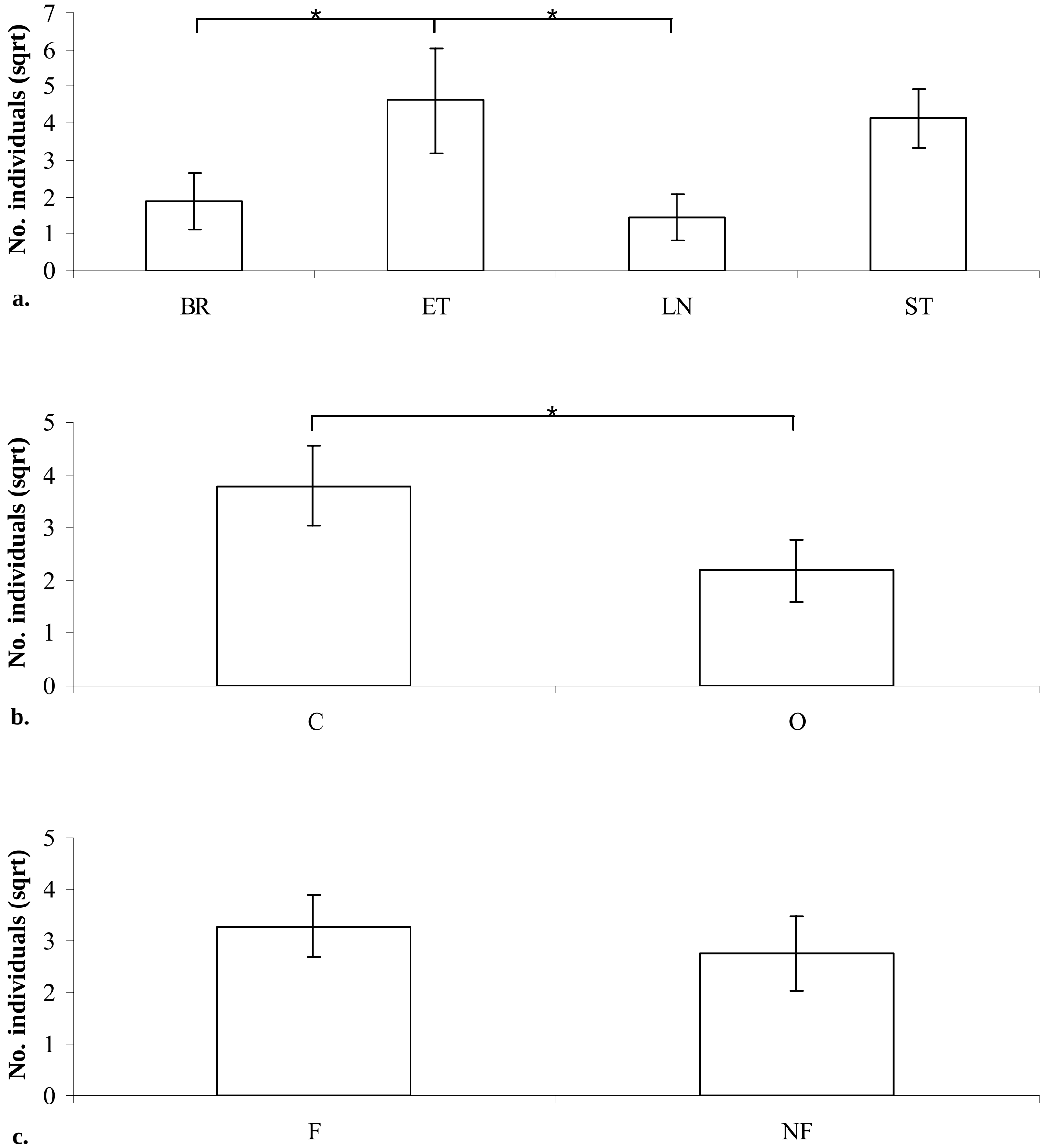


Figure 3.21. Mean ± standard error of *Eunicella verrucosa* per 100 metres of rock based substrate. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished. The data has been subjected to a square root transformation.

The *A. digitatum* abundance dataset was subjected to a square root transformation and the residuals tested for normality and heterogeneity of variance indicating the suitability of the ANOVA routine for analysis.

Table 3.21. The abundance of *Alcyonium digitatum* present per 100 metres of rock substratum across all four sites, protection and fishing activity (square root transformed data). BR Beer Home Ground, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

(a) Means (± standard error) of abundance.

	C	**O**
BR	2.090 ± 1.050	0.970 ± 0.598
ET	16.660 ± 6.090	2.750 ± 2.750
LN	2.060 ± 1.110	0.000 ± 0.000
ST	0.968 ± 0.323	1.390 ± 1.390
	F	**NF**
BR	1.949 ± 0.989	1.057 ± 0.661
ET	0.000 ± 0.000	9.970 ± 4.500
LN	0.394 ± 0.394	1.800 ± 1.160
ST	0.390 ± 0.390	1.683 ± 0.690
	C	**O**
F	1.058 ± 0.533	0.329 ± 0.329
NF	4.680 ± 2.060	2.290 ± 1.640

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	***F***	***P***
Site	3	153.91	200.07	66.69	3.67	0.024
Protection	1	94.35	78.06	78.06	4.29	0.047
Fishing activity	1	48.38	48.38	48.38	2.66	0.114
Residual	29	527.25	527.25	18.18		
Total	34	823.89				

(c) Multiple comparison between mean abundance with site as the factor using Tukey's method. Minimum difference required for significance at 5% level = 4.947 (95% CI of the differences). * = significant. Column means are subtracted from row means.

Treatment	**BR**	**ET**	**LN**
ET	5.236*		
LN	-0.810	-6.046*	
ST	-1.045	-6.282*	-0.2353

The abundance of *A. digitatum* per 100 metres of rock substrate was significantly higher at East Tennants than at any of the other three sites (Table 3.21.b., Table 3.21.c., Figure 3.22.a.). The abundance of *A. digitatum* per 100 metres of rock substrate was significantly higher in closed than in open areas (Figure 3.22.b.). The ANOVA identified no significant effect of fishing activity on the abundance of *A. digitatum* (Table 3.21.b.). This difference was not highlighted as significant by the three factor ANOVA as at Beer Home Ground the abundance of *A. digitatum* was higher at fished locations than at not fished locations and therefore there is interaction occurring between factors (Table 3.21.a.).

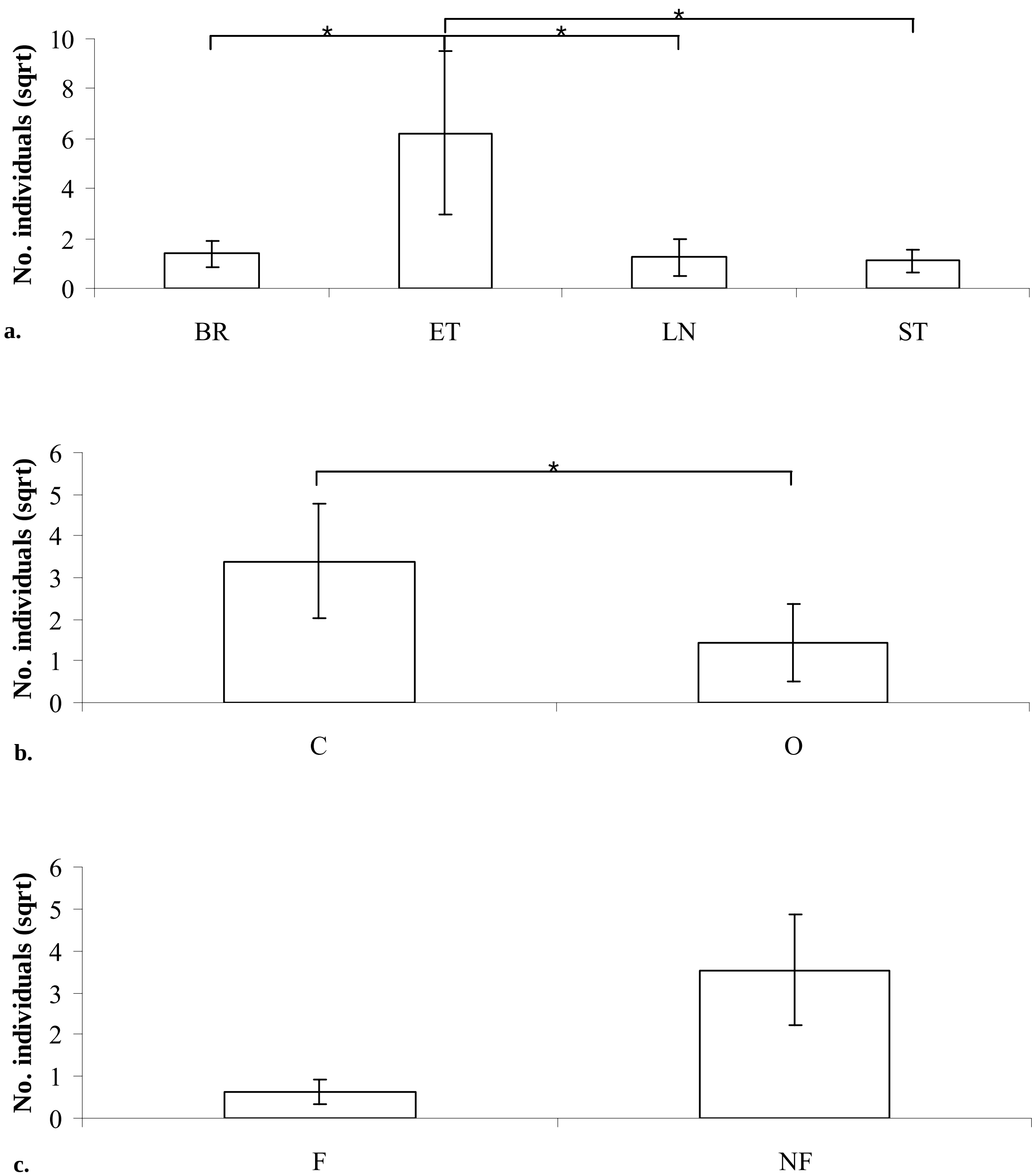


Figure 3.22. Mean ± standard error of *Alcyonium digitatum* per 100 metres of rock based substrate. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished. The data has been subjected to a square root transformation.

The residuals of the *P. fascialis* dataset were tested for normality and equal variance and a three factor ANOVA conducted across the factors of site, protection and fishing activity.

Table 3.22. The abundance of *Pentapora fascialis* present per 100 metres of rock substratum across all four sites, protection and fishing activity.

(a) Means (± standard error) of abundance.

	C	**O**
BR	0.000 ± 0.000	2.400 ± 1.670
ET	2.017 ± 0.336	0.323 ± 0.323
LN	4.700 ± 4.350	0.919 ± 0.919
ST	3.800 ± 1.580	0.000 ± 0.000
	F	**NF**
BR	1.150 ± 1.150	1.700 ± 1.700
ET	0.646 ± 0.646	0.807 ± 0.505
LN	1.372 ± 0.879	4.400 ± 4.400
ST	2.660 ± 1.930	2.430 ± 1.720
	C	**O**
F	2.070 ± 1.300	1.135 ± 0.582
NF	3.870 ± 2.390	0.852 ± 0.852

(b) Analysis of variance table, Seq = sequential, Adj = adjusted for entry order.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	***F***	***P***
Site	3	31.03	15.17	5.06	0.19	0.900
Protection	1	27.84	24.84	24.84	0.95	0.337
Fishing activity	1	4.83	4.83	4.83	0.18	0.670
Residual	29	756.91	756.91	756.91		
Total	34	820.61				

There was no significant effect of site, protection or fishing activity on the abundance of *P. fascialis* (Table 3.22.b. and Figure 3.23.).

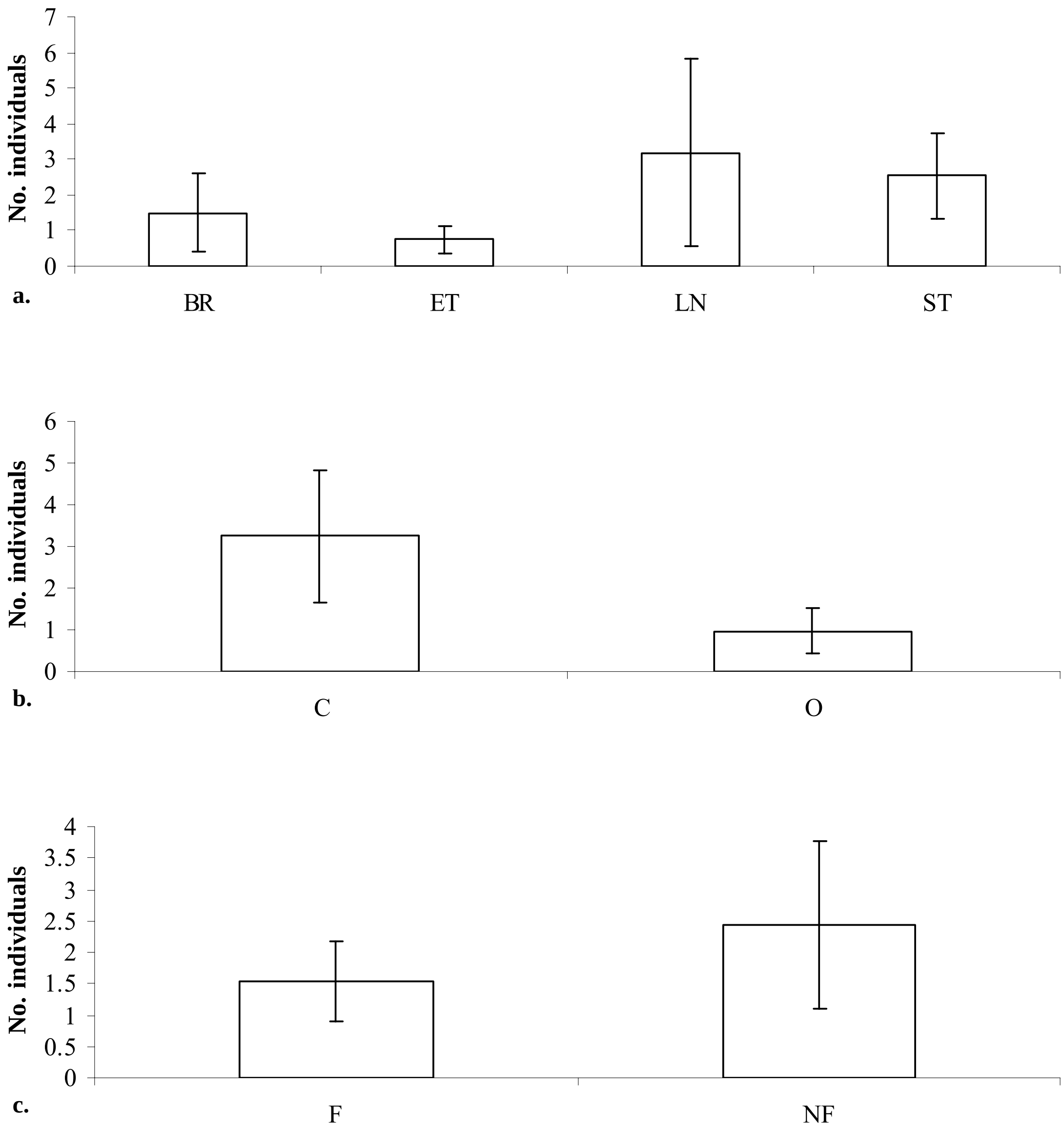


Figure 3.23. Mean ± standard error of *Pentapora fascialis* per 100 metres of rock based substrate. **a.** across sites, **b.** across protection, **c.** across fishing activity. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. C closed, O open. F fished, NF not fished.

4. Discussion

4.1. Trends in the abundance and size of the species of interest

Eunicella verrucosa, *Alcyonium digitatum* and *Pentapora fascialis* are sessile species and require a solid surface to which they can adhere (Manuel, 1988). The relationship between species abundance and substrate type was found to be strong and the abundance of these three species was shown to increase as the percentage of rock cover increased (Figure 3.19.). All three species showed a higher abundance within areas closed to fishing compared with areas open to fishing, although for *P. fascialis* this difference was not significant (Table 3.11.b.). The mean size of both *E. verrucosa* and *A. digitatum* was also found to be significantly higher inside the closed-unfished areas than across the other three treatments. In addition, there were no significant differences between the abundances of these three latter species between sites. These preliminary findings suggest that the four MPAs have been placed in locations whereby they protect the most dense populations of the sessile species of interest, in particular the pink sea fan *E. verrucosa*. However, even within the areas closed to fishing, the sessile species were highly aggregated in their distribution despite the wide availability of apparently suitable habitat. This suggests that the demography of existing aggregations of sessile species and local hydrodynamics have an important influence on the distribution of these biota.

The physical shape of *E. verrucosa* individuals makes them particularly susceptible to damage via direct impact with towed fishing gears due to their fragile structure and the considerable size of the oldest specimens. Therefore it was interesting to note that there was a higher (though not significant) abundance of *E. verrucosa* in East Tennants and Sawtooth Ledges than there was in Beer Home Ground or Lanes Ground. This is likely to be related to substrate type as whilst these two MPAs did not have a significantly larger percentage of rock cover than the other two (Figure 3.20.a.), the rock cover within them was dominated by large steep boulders that offer protection from towed fishing gear. An alternative explanation is that boulder areas retain the larvae of seafans much better than more open areas of seabed. In contrast at Beer Home Ground and Lanes Ground the majority of the rock substratum was comprised of the sub-categories ‘exposed bedrock’ and ‘small rocks’ respectively, both of which are habitats more amenable to bottom trawling and affording less protection to large epifaunal organisms. This was supported by our dataset as 57.9% of all *E. verrucosa* individuals were found within the boulder-dominated regions whilst only 16.2% and 3.0% were found over ‘exposed bedrock’ and ‘small rocks’ respectively.

The abundance of *A. digitatum* was found to be significantly higher in unfished regions than in fished regions (Figure 3.5.c.). The abundance of *P. fascialis* was also higher in unfished regions but this difference was not significant (Table 3.11.b.). There was found to be no significant difference in the abundance of *E. verrucosa* between fished and unfished regions. The higher abundance of individuals in unfished locations combined with the larger specimen size of both *E. verrucosa* and *A. digitatum* found within the closed unfished sites suggests that unfished locations that have a suitable substrate and hydrographic regime support dense communities of these epifaunal species.

The closed unfished sites have remained undisturbed by bottom trawling and scallop dredging and should be associated with individuals of the largest body-size. This expectation was supported by the findings of the present study.

We were able to identify areas that are currently open to fishing, but that have remained unfished. However, the abundance of sea fans was lowest in these areas and might have occurred as a result of the displacement of a greater amount of fishing activity into these areas (Dinmore *et al.*, 2003). When the sea fan abundance data was grouped within treatment groups (CF, CNF, OF, ONF) the highest abundance was found in closed unfished locations (13.13 ± 6.35 individuals) and the lowest abundance in open unfished locations (1.56 ± 0.84 individuals). The consequences of the displacement of fishing activity into previously unfished areas is an issue that should be considered carefully before the implementation of areas closed to fishing.

4.2. The impact on scallop populations

The sediment distributions recorded by the present study show that the areas inside the MPAs consist of approximately 65% sand and gravel substrate and 35% rock substrate

(Figure 3.20a). Whilst, as outlined above, protection of the rock substrate is essential in the preservation of the large sessile biota that comprise the biogenic reef community, the alleviation of fishing pressure in soft sediment regions could be important in the enhancement of exploited scallop populations; another potential outcome of reserve creation. The *Pecten maximus* population was not evenly distributed across the four sites in Lyme Bay. There was a significantly higher abundance of *P. maximus* in Lanes Ground than at either Beer Home Ground or Sawtooth Ledges. This could be as a result of sediment type. There was a large coverage in Lanes Ground of small rocks over sand and gravel substrates that may provide the scallops with enhanced shelter against the dredges. Collie *et al.* (1997) noted an apparent correlation between scallop distribution and larger sediment fractions such as coarse gravel which they attributed to an inability of juvenile scallops to colonise areas where shifting sediments may result in burial or clogged feeding apparatus. The sediment analysis in the present study was only conducted from a visual assessment of the video footage. There was no relationship between the abundance of *P. maximus* and levels of fishing activity. Accordingly, given that scallop dredging removes scallops from the seabed, it would appear that scallops are likely to become more abundant in those areas that previously were fished but that are now closed to fishing.

4.3. Limitations of the present study

One limitation of the study was the delay between the instigation of the voluntary closed areas and the time it took to submit the urgency grant to NERC, for NERC to referee, agree, and fund the project. Such a delay is an inevitable result of due process in obtaining such research funding. Nevertheless, it is possible that in the intervening period, displaced fishing activity may have corrupted the ‘open-unfished’ areas. It should be possible to retrospectively examine this possibility through examination of more recent track plots from fishing vessels.

As with experimental layout, the ability (statistical power) to detect the effects of limiting factors such as fishing, habitat effects or environmental forcing, would be increased with greater replication. Although we were able to analyse an additional replicate per treatment with the input of DEFRA funding, further video tows could be analysed with additional resources. However, the outcome of this report is based on the analysis of the greatest possible sample size given the time constraints of the public consultation period.

The distribution of reef communities in Lyme Bay is highly aggregated with concentrations of biomass associated with small areas of the seafloor. For example, over 40% of all *E. verrucosa* individuals found were present within two of the closed-unfished replicates in East Tennants whilst the other two replicates in that treatment contained no *E. verrucosa* individuals. Therefore whilst in certain specific regions of the bay there were high abundances of the species of interest, the generation of average values across regions decreases the influence of such values in the identification of differences across the levels of protection or fishing activity.

The fishing effort data used in the present study is unlikely to account for all fishing activity that has occurred in the region. Data was provided by scallop fishermen operating in Lyme Bay and whilst the DGPS information provides a detailed account of areas that have been dredged there is no guarantee that the information supplied was exhaustive. Additionally dredging effort information was only available from 2000-2006 and therefore fishing activity prior to this time (from which impacted benthic substrates are still likely to be recovering even in the absence of subsequent trawl disturbance), and in the early months of 2007 just before the survey was conducted, were not included. Nevertheless, the behavioural tendency of fishermen to utilise the same tows repeatedly provides a measure of confidence that this information is highly indicative of the history of fishing on the seabed in Lyme Bay.

Acknowledgements

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References

Collie, J.S., Escanero, G.A. and Valentine, P.C., 1997, Effects of bottom trawling on the benthic megafauna of Georges Bank. Marine Ecology Progress Series, **155**, 159-172.

Dinmore, T.A., Duplisea, D.E., Rackham, B.D., Maxwell, D.L. and Jennings, S., 2003, Impact of a large-scale area closure on patterns of fishing disturbance and the consequence for benthic communities. ICES Journal of Marine Science, **60**, 371-380.

Gell, F.R. and Roberts, C.M., 2003, Benefits beyond boundaries: the fishery effects of marine reserves. Trends in Ecology and Evolution, **18**, 448-455.

Hilborn, R., Stokes, K., Maguire, J., Smith, T., Botsford, L.W., Mangel, M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cochrane, K.L., Garcia, S., Hall, S.J., Kirkwood, G.P., Sainsbury, K., Stefansson, G. and Walters, C., 2004, When can marine reserves improve fisheries management? Ocean and Coastal Management, **47**, 197-205.

Jennings, S., 2000, Patterns and prediction of population recovery in marine reserves. Reviews in Fish Biology and Fisheries, **10**, 209-231.

Kaiser, M.J., 2005, Are marine protected areas a red herring or fisheries panacea? Canadian Journal of Fisheries and Aquatic Sciences, **62**, 1194-1199.

Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J. and Karakassis, I., 2006, Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series, **311**, 1-14.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S. and Poiner, I.R., 2002, Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries, **3**, 114-136.

Manuel, R.L., 1988, *British Anthozoa* (eds E.J. Brill & W. Backhuys). The Linnean Society of London and the Estuarine and Brackish-Water Sciences Association.

Roberts, C.M., Bohnsack, J.A., Gell, F., Hawkins, J.P. and Goodridge, R., 2001, Effects of Marine Reserves on Adjacent Fisheries. Science, **294**, 1920-1923.

Watson, R., Revenga, C. and Kura, Y., 2006, Fishing gear associated with global marine catches II. Trends in trawling and dredging. Fisheries Research, **79**, 103-111.

APPENDIX I

Table I.i. Start and end locations for all tows and the position along them of the 85 metre transect. BR Beer Home Ground, ET East Tennants, LN Lanes Ground, ST Sawtooth Ledges. CF closed fished, CNF closed not fished, OF open fished, ONF open not fished.

MPA	Treatment	Start Latitude (d.m)	Start Longitude (d.m)	End Latitiude (d.m)	End Longitude (d.m)	Total Distance (m)	Start of Transect (m)	End of Transect (m)
BR	CF	50º 38.199	03º 03.865	50º 38.262	03º 03.833	122.581	18	103
BR	CF	50º 37.745	03º 03.701	50º 37.822	03º 03.623	219.344	80	165
BR	CF	50º 38.298	03º 03.784	50º 38.266	03º 03.547	169.506	64	149
BR	CF	50º 38.665	03º 02.548	50º 38.548	03º 02.519	284.612	31	116
BR	CNF	50º 39.928	03º 02.786	50º 40.043	03º 02.847	196.635	6	91
BR	CNF	50º 40.191	03º 02.513	50º 40.260	03º 02.398	224.695	5	90
BR	CNF	50º 40.265	03º 01.563	50º 40.152	03º 01.594	212.416	21	106
BR	CNF	50º 39.169	03º 03.608	50º 39.155	03º 03.442	185.876	30	115
BR	OF	50º 40.022	03º 05.184	50º 40.054	03º 04.643	637.806	274	359
BR	OF	50º 38.510	03º 01.919	50º 38.480	03º 01.803	145.581	20	105
BR	OF	50º 39.988	03º 05.973	50º 39.915	03º 06.019	147.133	44	129
BR	OF	50º 39.329	03º 00.021	50º 39.407	02º 59.847	250.209	24	109
BR	ONF	50º 37.397	03º 02.864	50º 37.356	03º 02.969	309.455	176	261
BR	ONF	50º 40.450	03º 01.806	50º 40.562	03º 01.775	126.082	23	108
BR	ONF	50º 40.778	03º 01.804	50º 40.615	03º 01.862	144.864	42	127
BR	ONF	50º 41.352	03º 01.650	50º 41.308	03º 01.568	210.591	52	137
ET	CNF	50º 39.221	02º 52.555	50º 39.217	02º 52.145	272.800	95	180
ET	CNF	50º 39.225	02º 52.867	50º 39.233	02º 52.635	159.967	15	100
ET	CNF	50º 39.174	02º 51.980	50º 39.114	02º 52.078	481.471	243	328
ET	CNF	50º 39.151	02º 52.276	50º 39.163	02º 52.542	313.129	9	94
ET	OF	50º 39.390	02º 51.335	50º 39.409	02º 51.206	209.106	100	185
ET	OF	50º 39.671	02º 52.128	50º 39.766	02º 52.131	155.493	59	144
ET	OF	50º 39.594	02º 53.339	50º 39.687	02º 53.238	175.975	23	108
ET	OF	50º 39.384	02º 53.713	50º 39.462	02º 53.746	149.562	18	103
ET	ONF	50º 38.734	02º 55.722	50º 38.652	02º 55.567	288.072	82	167
ET	ONF	50º 39.057	02º 54.887	50º 38.932	02º 54.741	160.134	70	155
ET	ONF	50º 39.121	02º 53.570	50º 39.206	02º 53.545	150.218	20	105
ET	ONF	50º 39.256	02º 53.979	50º 39.335	02º 54.008	237.062	53	138
LN	CF	50º 40.150	02º 56.347	50º 40.145	02º 56.461	255.428	37	122
LN	CF	50º 40.678	02º 54.213	50º 40.844	02º 54.023	195.901	83	168
LN	CF	50º 39.959	02º 56.336	50º 40.078	02º 56.226	134.132	49	134
LN	CF	50º 40.352	02º 54.062	50º 40.249	02º 54.024	379.778	12	97
LN	CNF	50º 40.249	02º 55.133	50º 40.345	02º 55.107	183.529	63	148
LN	CNF	50º 40.221	02º 54.675	50º 40.477	02º 54.701	180.392	81	166
LN	CNF	50º 40.091	02º 54.909	50º 40.175	02º 54.916	475.093	116	201
LN	CNF	50º 40.175	02º 54.376	50º 40.078	02º 54.408	155.785	36	121
LN	OF	50º 39.968	02º 56.579	50º 39.975	02º 56.657	168.850	61	146
LN	OF	50º 41.215	02º 53.904	50º 41.305	02º 53.881	253.247	118	203
LN	OF	50º 40.639	02º 53.945	50º 40.773	02º 53.988	203.669	102	187
LN	OF	50º 40.971	02º 58.707	50º 40.906	02º 58.847	92.475	1	86
LN	ONF	50º 38.689	02º 56.175	50º 38.696	02º 56.008	196.553	107	192
LN	ONF	50º 38.239	02º 54.287	50º 38.155	02º 54.064	304.651	23	108
LN	ONF	50º 41.042	02º 56.657	50º 40.966	02º 56.816	233.713	95	180
LN	ONF	50º 42.019	02º 56.848	50º 42.113	02º 56.792	186.069	20	105
ST	CF	50º 40.246	02º 50.259	50º 40.398	02º 50.330	146.790	42	127
ST	CF	50º 40.828	02º 50.226	50º 40.909	02º 50.285	165.219	21	106
ST	CF	50º 41.443	02º 50.139	50º 41.548	02º 49.966	281.089	0	85

MPA	**Treatment**	**Start Latitude (d.m)**	**Start Longitude (d.m)**	**End Latitiude (d.m)**	**End Longitude (d.m)**	**Total Distance (m)**	**Start of Transect (m)**	**End of Transect (m)**
ST	CF	50º 40.808	02º 47.660	50º 40.902	02º 47.763	211.935	50	135
ST	CNF	50º 41.589	02º 47.281	50º 41.536	02º 47.857	341.428	182	267
ST	CNF	50º 41.006	02º 48.118	50º 41.099	02º 47.793	209.225	23	108
ST	CNF	50º 41.077	02º 48.583	50º 41.071	02º 48.203	226.017	4	89
ST	CNF	50º 42.068	02º 50.270	50º 42.143	02º 50.138	208.006	11	96
ST	OF	50º 39.966	02º 52.061	50º 40.172	02º 52.001	193.979	15	100
ST	OF	50º 39.846	02º 51.111	50º 39.855	02º 50.821	170.442	20	105
ST	OF	50º 39.812	02º 50.828	50º 39.859	02º 50.488	204.257	106	191
ST	OF	50º 41.436	02º 50.870	50º 41.282	02º 51.404	344.199	34	119
ST	ONF	50º 39.507	02º 48.297	50º 39.758	02º 48.330	233.232	26	111
ST	ONF	50º 40.275	02º 46.989	50º 40.398	02º 46.669	219.635	47	132
ST	ONF	50º 42.069	02º 50.466	50º 41.902	02º 50.660	191.992	22	107
ST	ONF	50º 41.867	02º 51.211	50º 41.794	02º 52.109	531.039	150	235