Lyme Bay - A case study: measuring recovery of benthic species, assessing potential spill-over effects and socio-economic changes

Lyme Bay Closed Area - Measuring Recovery of Benthic Species in cobble reef habitats

Analysis of data collected by SCUBA divers

September 2008, August 2009 and July 2010

A Report to Natural England and DEFRA

by

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Executive Summary

As a consequence of growing concern about the impacts of mobile bottom fishing methods on the sessile (attached) epifauna living on subtidal reefs within Lyme Bay, southwest U.K., the Government closed a 60 nm^2 area to all bottom fishing towed gear (essentially bottom trawls and scallop dredges) in July 2008. This closure was designed to include all known vulnerable reefs and reefs known to support rich epifaunal assemblages within Lyme Bay, especially those supporting assemblages considered to be of high conservation importance and particularly vulnerable to bottom fishing towed gear, e.g. assemblages rich in erect sponge species and gorgonian (seafan) beds. It incorporated four pre-existing voluntary closures. These smaller areas had already been closed, with limited success, to towed bottom fishing gear on a voluntary agreement basis for between two and seven years.

The aim of the study was to monitor change in the sessile species assemblages occurring on boulder reefs in Lyme Bay following the exclusion of towed bottom fishing gear. In particular, to monitor change in species assemblages at sites within the new statutory closure (but outside the pre-existing voluntary closures) relative to change occurring at:
      a) sites within the pre-existing voluntary closure and
      b) nearby sites outside the closed area where fishing by towed bottom gear was still permitted.

The hypothesis the study was required to test was that, over time, species assemblages within sites in the new statutory closure but outside the pre-existing voluntary closures would change to more closely resemble those in the pre-existing voluntary closures and become less similar to sites where fishing by towed bottom gear was still permitted. However, the three treatment areas were found to be different, in terms of total species numbers and taxonomic groups considered particularly sensitive to bottom fishing mobile gear.

Methods
Data were collected by SCUBA divers at 10 fixed sites across Lyme Bay in September 2008, August 2009 and July 2010. These sites represented the three treatments considered: three sites were located within the new closure but outside the established voluntary closures (termed New Closure); four within one of the pre-existing voluntary closures (termed Closed Controls) and three outside the closed area where fishing by towed bottom gear was still permitted (termed Open Controls). Closed Control sites were confined to only one of the four pre-existing voluntary closures (Lane's Ground reef) as the habitats and associated species assemblages were different in all four voluntary closures; Lane's Ground was the only one that comprised boulder and cobble reef. Two permanent markers (8 metres apart) were haphazardly deployed at each site within an area of boulder and cobble reef.   Between the two markers at each site, a line was laid and 8 x 1metre was surveyed either side of this line. fixed transects were laid and surveyed annually; eight 0.25m2 quadrats were dropped haphazardly (up to 5m either side of the transect centre line)and surveyed annually to record the conspicuous species present.

The habitat selected for study comprised a high proportion of cobbles and small boulders with mixed, fine sediment between them in a water depth of 20-22m below chart datum. Areas of bedrock reef and extensive patches of sand and gravel seabed were avoided as far as possible, except for one station (New Closure Site 5) which was located on level bedrock with a thin silt veneer.

Change in benthic assemblages in Lyme Bay was investigated using multivariate statistical methods (PERMANOVA in PRIMER) which depended on the initial construction of a similarity matrix using the Bray-Curtis coefficient of similarity on variously transformed data. Univariate data were investigated employing matrices derived using the Euclidean distance measure. PERMANOVA analysis was undertaken using 9999 permutations, all analyses returned more than 9910 unique permutations.

Results and interpretation
The total number of taxa recorded over the three years in the quadrat survey was 163, not all taxa being present in all years. The range of the mean number of taxa in the three treatments was 35-41 at the start of the study in 2008 increasing slightly to 27-43 in 2010. The most

diverse assemblages were found at the Closed Control sites (41-45 taxa per site) contrasting with 27-35 taxa per site recorded at the Open Controls.

The univariate PERMANOVA tests on the total number of taxa and overall abundance in quadrats showed that there were statistically significant differences between treatments ($P<0.05$) but not years. There was no treatment by year effect, thus the differences between treatments remained more or less constant during the three years of the study.

PERMANOVA pair-wise test of assemblage composition for quadrat data for treatments showed that the three treatments were all statistically significantly different.

Distinct differences in species assemblage composition were noted between Open Control sites east and west of the statutory closure, reflecting the differences in the benthic conditions and strong environmental gradients across Lyme Bay from east to west. Markedly lower numbers of erect and encrusting sponges, soft coral *Alcyionium digitatum* and *Phallusia mammillata* tunicates were recorded in all Open Control sites in all years compared to Closed and New Closure, again reflecting the differences in environmental conditions across Lyme Bay, east or west of the statutory closure.

The mean total number of taxa recorded from all replicates over the three year period for each treatment showed the Open Controls (three sites) supporting fewer taxa in total than either the Closed Controls (four sites) or the New Closure (three sites). The higher count at the Closed Control sites was likely to be partly due to a sample area effect with four sites in the treatment and three sites in the New Closure. The total number of taxa appeared to decline within the Open Control sites, possibly reflecting continued fishing impacts (and possibly increased effort through displaced fishing activity).

The multidimensional scaling (MDS) plots for both key taxa and total taxa in quadrats within the New Closure (in 2010) showed the samples for New Closure sites to be more widely dispersed (i.e. more dissimilar to each other) than Closed Controls and comparable to the dissimilarity of the Open Controls. This may reflect changes in stress within the New Closure following cessation of towed bottom fishing; it has been proposed that a change in the multivariate dispersion of assemblage data provides a measure of pressures (stresses) impacting on marine benthic communities (Warwick & Clarke, 1993)

Differences recorded between treatments, in terms of species richness, reflect the sensitivity to disturbance of the various taxa. This was particularly noticeable for sponges, a group considered particularly sensitive to disturbance by bottom fishing mobile gear. The Closed Control sites showed a greater cover by encrusting sponges than either of the other two treatments and were statistically significantly different from Open Controls. Branching sponges were present in very low numbers at the Open Control sites while quadrat estimates showed highly variable numbers at Closed Control and New Closure sites. All types of sponges were more abundant in Closed Control and New Closure sites compared with the Open Controls (Figure 16) over all three years.

Possible early signs of recovery
The fixed transect data, though again highly variable, indicate a possible slight recovery of this group over the study period within both the New Closure and Closed Controls. Sponge assemblages are considered the single most important feature of the boulder and cobble reefs within Lyme Bay, and regionally appear unique to the central nearshore benthos of Lyme Bay, the sponge diversity having been previously described as possibly unsurpassed Southwest Britain (Devon Wildlife Trust, 1995). Sponge species, in particular, have been identified (through qualitative comparison of video data from the same site within Lane's Ground reef shot in 1996 and 2008) as appearing to have declined markedly in the twelve years prior to establishment of the statutory closure (Munro, pers. obs), whilst Kefalas *et al.* (2003) identified erect branching sponges as particularly sensitive to damage from scallop dredges. Thus a possible slight recovery in sponges is considered a welcome sign and, if confirmed by subsequent monitoring, would provide a strong endorsement of the statutory closure. It has been shown that recovery of sponge assemblages after cessation of disturbance is very slow, with one study showing little or no improvement after four years (Hiscock, 1994). It therefore seems likely that, if recovery of sponge assemblages is indeed occurring as initial data indicates, it will take require several more years monitoring to confirm this.

Study hypothesis findings
No evidence was found to support the study hypothesis. Open Control sites appeared significantly different, in terms of total number of species and assemblage composition from both New Closure and Closed Control sites in year one of the study (2008) and remained so 2009 and 2010. Key taxonomic groups branching and encrusting sponges were much lower in the Open Controls than either New Closures or Closed Controls in all years, as were the soft coral *Alcyonium digitatum* and the large solitary ascidian *Phallusia mammillata*. The most likely explanation is that this reflects the differences across Lyme Bay, specifically the differences in benthic conditions (environmental gradients) east and west of the closed area. Consequently direct comparison of changes in assemblage composition and taxon abundances between treatments inside and outside the statutory closure are more likely to reflect environmental differences in habitat and environmental conditions than differences in exposure to towed bottom fishing. This does not mean there is no fishing impact outside the closure, simply that they cannot be differentiated from the differences due to environmental conditions.

Recommendations

Closed Controls and New Closure
It is recommended that monitoring is continued in order to assess whether the signs of recovery noted prove statistically significant over time and whether they are sustained. A minimum of four years further monitoring is considered essential to determine this.

Open Controls
It appears that the Open Controls (outside the statutory closure) do not provide good comparisons with boulder and cobble reef species assemblages inside the statutory closure simply because environmental conditions are too different. It is unlikely that reef species assemblages directly comparable with those inside the New and Closed Controls exist within Lyme bay outside the statutory closure. Thus further monitoring of Open Controls (for this purpose) would seem of little benefit. Re-allocating effort to additional sites within the Closed and New Controls should therefore be considered.

1   INTRODUCTION

1.1   Background

Concerns about the effects of bottom towed fishing gear on the rocky and boulder and cobble reefs within Lyme Bay, and their associated fauna, have been expressed since the late 1980s. Of particular concern was the increase in scallop dredging, due to the robust nature of the steel, spring-loaded dredges employed and their ability to work across rocky areas that would damage trawl nets.   This practice was believed to be causing significant degradation of habitat and loss of epifaunal species within subtidal reef habitats. In response to these concerns and several studies indicating damage (e.g. Munro,1992; 1993; Devon Wildlife Trust, 1998) a voluntary agreement was negotiated between the Devon Wildlife Trust and local fishermen whereby bottom towed fishing gear would not operate within two vulnerable reef areas, known as Lane's Ground and Saw-tooth Ledges. This agreement came in to effect in 2001.   Two other reef areas, known as Beer Home Ground and the East Tennants Reef, were subsequently added in 2006. The agreement was considered a partial success, with many fishermen abiding by it. However, it appeared not all fishermen were abiding by the agreement and damage continued to be recorded. As a consequence of growing concern, the U.K. Government closed a 60 nm^2 area to bottom towed fishing gear in July 2008. This closure was implemented under Statutory Instrument (S.I.) legislation and was designed to include all known vulnerable reefs and reefs known to support rich epifaunal communities within Lyme Bay, including the four existing voluntary closures.

The study described in this report was designed to monitor the changes that occurred in boulder and cobble reef assemblages within the closure following cessation of impacts from bottom towed fishing gear. It was conducted as part of a larger study, commissioned by DEFRA and led by the University of Plymouth Marine Institute (project partners the Marine Biological Association of the United Kingdom (MBA), Plymouth Marine Laboratory Limited (PML) and Marine Bio-images) with the aim of assessing both the ecological and socio-economic impacts of the closure.

1.2   Study aims

The aim of this study was to monitor change in the sessile species assemblages occurring on boulder and cobble reefs in Lyme Bay following the exclusion of towed bottom fishing gear (principally scallop dredges and bottom trawls) in July 2008 from the statutory closure. In particular, to monitor change in species assemblages at sites within the new statutory closure (New Closure) but outside the pre-existing voluntary closures relative to change occurring at a) sites within the pre-existing voluntary closures (Closed Control sites) and b) nearby sites outside the closed area where fishing by towed bottom gear was still permitted (Open Control sites).

The hypothesis being tested is that, over time, assemblages within stations in the New Closure would change to more closely resemble those in the older Closed Control sites and less similar to Open Control sites that continue to be fished.

Boulder and cobble reef habitats are a conspicuous feature within the statutory closure. They are known to support epifaunal assemblages rich in sponge, tunicate and bryozoan species (Devon Wildlife Trust, 1995, Eno *et al.*2001) (Figure 1). They also appear to be one of the habitats suffering greatest damage from towed bottom fishing gear (C. Munro, pers. obs. and communication from local fishermen, recreational divers and conservation NGOs) (Figure 2). This is due to: a) their low profile which presents little barrier to dredges or trawls (compared to the ledges and pinnacles of rocky reefs), b) the boulders and cobbles that form the reef are displaced and rolled by passing fishing gear, destroying soft-tissued attached species (C. Munro, pers. obs.), and c) large amounts of sediment lying between the boulders is mobilized, smothering filter feeding organisms which are a major component of the epifaunal assemblage (C. Munro, L. Baldock, pers. obs.). Boulder and cobble reefs are a well studied feature within the statutory closure. In particular, Lane's Ground reef, the boulder and cobble reef that forms one of the pre-existing voluntary closures, has been the subject of numerous studies since 1991 (e.g. Devon Wildlife Trust 1995, 1998, 2007; Munro, 1992, 1993; Eno *et al 2001).* Thus a significant amount was already known about the range and distribution of life forms occurring on these reefs and about the impacts of mobile fishing gear on these boulder and cobble reefs, greatly aiding study design.   Casual observation over time, and comparison

of video footage from the same location on Lane's Ground Reef (C. Munro, 1996, Devon Wildlife Trust, 2008 unpublished data) suggest a marked decline in both sponge diversity and abundance. Changes in the epifaunal assemblages on boulder and cobble reefs following the cessation of bottom towed fishing gear therefore seemed an appropriate feature for a detailed study by divers to focus on.

2 LYME BAY

2.1 Lyme bay general description

In order to understand the design and site selection of this study it is necessary to understand the distribution of habitats, species assemblages and environmental conditions within Lyme Bay. The strong gradients in environmental conditions, benthic habitats and associated species assemblages across the bay prohibit widely spaced control sites (Figure 3) Lyme Bay is a wide, south-facing bay that straddles the Devon-Dorset border, Southwest England.

Most of the central part of the bay, within 5 nautical miles (nm) of the shore is less than 30 metres depth below chart datum (CD). Tidal streams are relatively weak, rarely exceeding 1.5 knot in the centre of the bay. These currents vary across the bay, being very weak in the west becoming progressively stronger to the east. The seabed is predominantly a mixture of muddy sand, sand, gravel and small stones, with rock outcrops scattered across the inner part of the bay, particularly in the east. A number of rivers flow in to the bay; these are (from west to east) the Teign, the Exe, the Otter, the Sid, the Coly, the Axe and the Char. Of these, only the Teign and the Exe (both west of the closed area) contribute significant outflows; the flows from these significantly alter conditions in the western part of Lyme Bay, creating muddier and more turbid conditions.
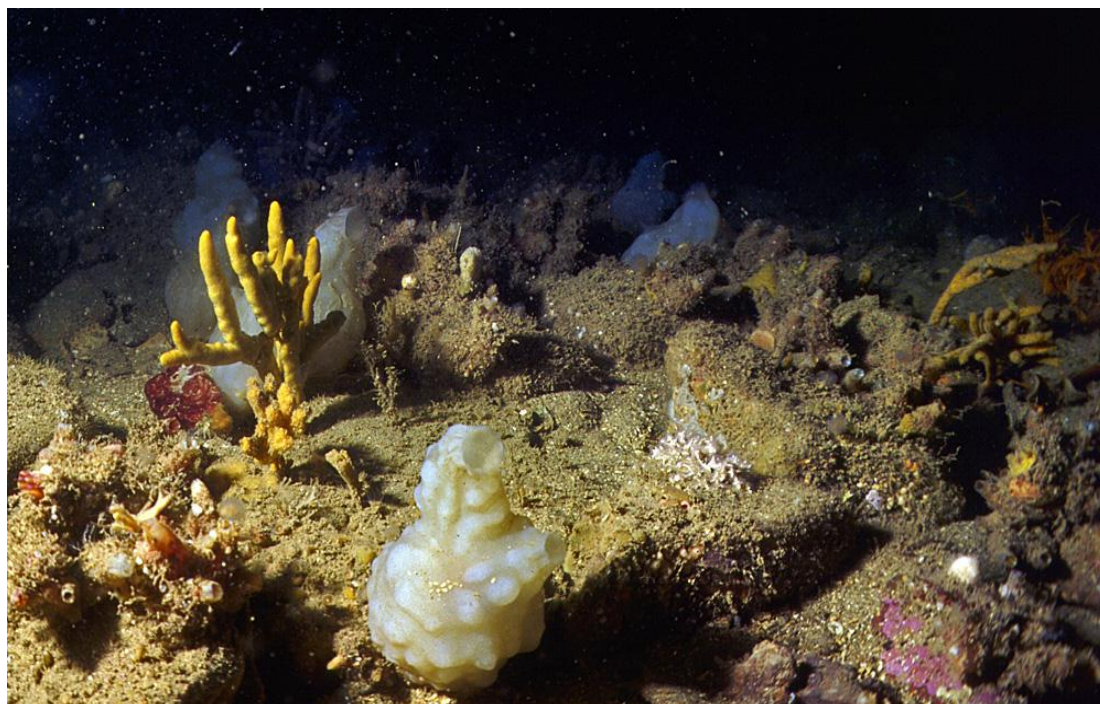
Figure 1 A photograph of Lane's Ground boulder and cobble reef taken in the early 1990s, showing the abundance of erect sponges such as Axinella dissimilis, (centre left) Stelligera and Raspailia species (centre, far right) and the abundance of Phallusia mammillata (centre, foreground and distance) that characterised this habitat then. Anecdotal reports, comparison of video footage and photographs, and personal observations by the authors suggest a marked decline in erect and branching sponge species, in particular slow growing Axinellid species, since the mid-1990s, with impacts from towed bottom fishing gear considered the probable cause. © C. Munro.
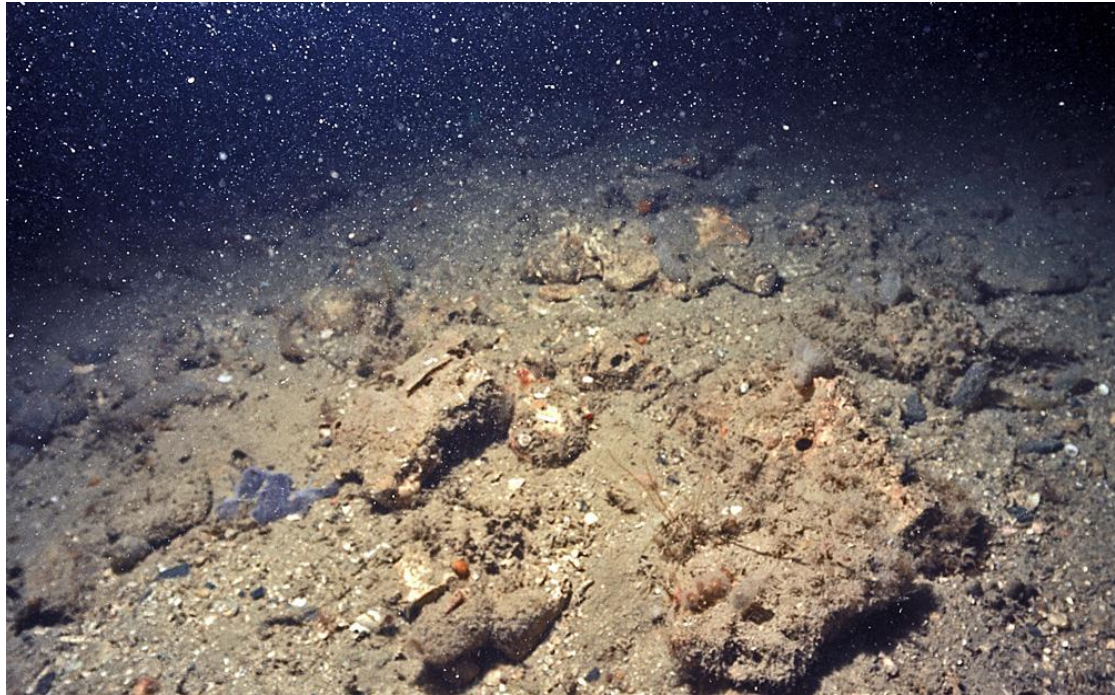
Figure 2: An area of boulder and cobble reef within the central nearshore part of Lyme Bay, photographed within 24 hours of scallop dredgers having been observed working in the vicinity (C. Munro, pers. obs.). The 'backscatter' in the water column is due to the high levels of suspended sediment. This photograph was taken in the late 1990s. © C. Munro.
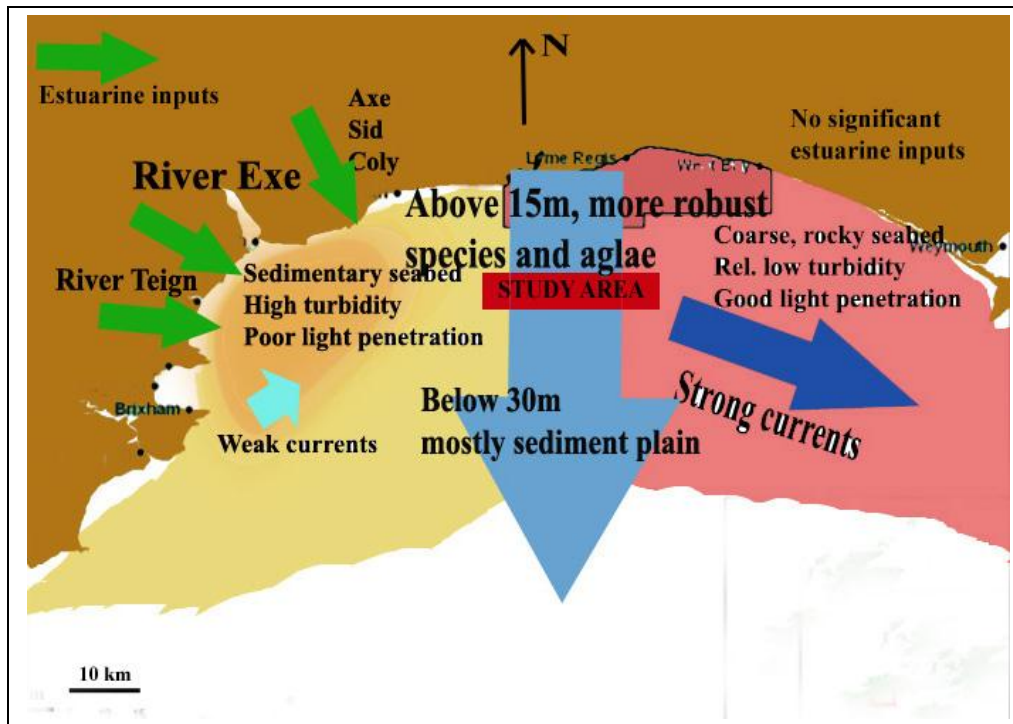
Figure 3: Diagram of Lyme Bay showing the gradients in environmental conditions and habitat types occurring in Lyme Bay. This illustrates some of the factors contributing to the uniqueness of the reef habitats within the central, nearshore part of the Lyme Bay and also the constraints on study design and control site placement.

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2.2 Lyme Bay reefs

2.2.1 Reef structure
Lyme Bay extends from Berry Head in the west to Portland Bill in the east. It is an area of complex geology; the seabed consists of predominantly sedimentary subtidal reefs composed of limestone, sandstone and mudstone (blue lias clay) outcrops across the inner, central part of the bay. Almost all of the reef outcrops lie within the 30 metre depth contour. In the west of the bay the reefs are mostly low-lying sandstone and mudstone; in the east they are mostly composed of harder limestone outcrops. Reef structure falls into three broad categories:
- stepped reefs, with level 'plateaus' (Figure 4) dropping away vertically or sometimes undercut;
- slab or large boulder reefs composed of mounds of large limestone slabs, 1-2 metres across (Figure 5);
- small boulder and cobble reefs, level plains of limestone cobbles and small boulders (up to circa 70cm across) (Figures 1, 10, 11 and 12).

2.2.2 Abiotic influences on reef assemblages
River outflows and weaker tides in the west (Figure 3) result in seabed conditions predominantly fine sediment and such reefs as are present tending to have a sediment veneer. Due to the stronger tidal streams reefs in the eastern this part of the bay tends to support richer epifaunal turfs; in particular larger attached filter feeding organisms tend to flourish in the eastern region, less so in the west (Devon Wildlife Trust, 1995; Munro, Baldock, pers. obs.). The above factors also mean that a greater percentage of the eastern part of the bay consists of reef habitat. There is obviously a gradation between these zones; however in general terms the western boundary of the closed area approximates to the division between western, fine sediment seabeds and eastern, reef and mixed sediment seabeds.

2.2.3 Structural influences on reef assemblages
The assemblages supported also vary with the physical structure of the reef. Long-lived filter feeding organisms dominate the tide-swept crests of rocky ledges; boulder and cobble reefs, inherently less stable, are generally dominated by smaller organisms such as sponges and tunicates. Shallower reefs do not support large, slow growing organisms such as large *Eunicella verrucosa* seafans (presumably due to their vulnerability to wave surge). Some assemblages appear very habitat specific; dense clusters of the sunset coral, *Leptopsammia provoti*, occur at the base of tideswept rock faces in the eastern part of the bay, but no-where else in the bay; pink seafans (*E. verrucosa*) occur in dense stands in narrow bands along the tops of rock crests (Figure 4) but may be completely absent a few metres back, where currents are weaker (Munro, Baldock, pers. obs.). Thus different species assemblages flourish on the different reefs within the bay. The area and profile of reefs are also strong influences on species assemblages. The central areas of larger reefs suffer less from sediment scour and thus tend to support assemblages richer in fragile filter feeding species, particularly longer lived species such as Axinellid sponges. For similar reasons this also applies to higher profile reefs. Conversely, smaller and lower profile areas of reef are prone to sediment scour and periodic burial under shifting sediment (e.g. following winter storms) thus generally support less diverse assemblages comprising more robust and opportunistic species. These factors were required to be considered to ensure that study sites across all three treatments were comparable.

Figure 4: Level bedrock 'plateau' at the top of a tideswept rock outcrop in the eastern part of Lyme Bay, with numerous large Eunicella verrucosa seafans the most conspicuous feature.© C. Munro.
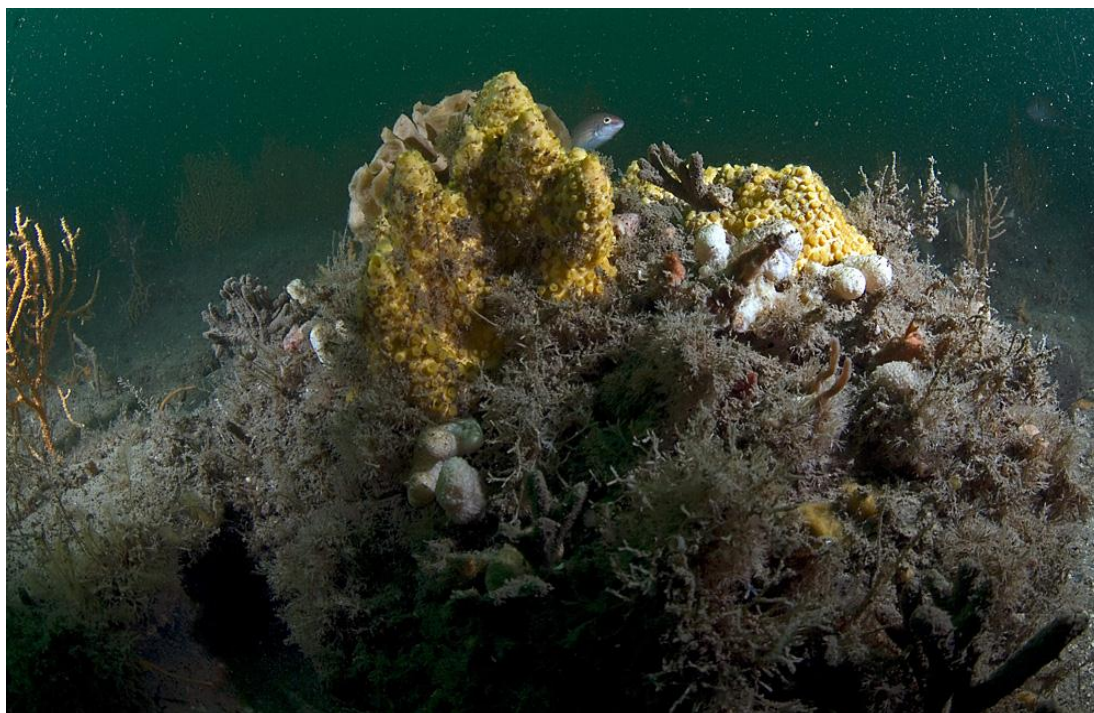
Figure 5: Reef composed of large limestone slabs, with large yellow Cliona celata sponges, Alcyonium digitatum soft corals (dead men's fingers) and large Eunicella verrucosa seafans prominent within the epifaunal assemblage.© C. Munro.

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2.2.4   Reef distribution with Lyme Bay

West of the statutory closed area the seabed is mostly muddy or fine sand with areas of maerl gravel; hard substrate is rare and the few offshore reefs are low-lying and mostly dominated by rapidly growing, opportunistic, species such as the sea squirt *Ascidia aspersa* although some bedrock reefs support richer sponge and hydroid communities (Devon Wildlife Trust, 1995, 2007, Holme, N.A. 1961, C. Munro, pers. obs., P. Smith, Aquatonics ltd. and R. Nunny, Ambios Environmental, pers. comm.). The greatest concentration of harder seabed (cobble, stepped and boulder reefs) lies in the area from just west of Beer Head to just east of West Bay (Devon Wildlife Trust, 1995, 1998, Munro, 1993). These are the reefs contained within the current Statutory Instrument closure. Additional reef areas lie further east, in particular off Abbotsbury and Chesil Cove, interspersed with areas of coarse sand and mixed sediment.

These reefs do not occur as large homogeneous blocks but mostly consist of mosaics of bedrock, boulder or cobble outcrops interspersed with patches of sand or gravel. The scale of these mosaics will vary from rock covering tens of hundreds of metres on some slab boulder reefs to patchworks of sand and rock each no more than a few tens of metres across (C. Munro; L. Baldock, *pers. obs.*). This spatial variation in habitat needed be factored in to the study design in order to ensure comparisons are valid.

Given that these, and other abiotic factors described earlier, will influence the mix of species on any given reef and how individual species will flourish, it was attempted to standardise the habitat type as much as possible, employing a stratified sampling strategy; sampling stations being haphazardly located within the selected habitat.

It was decided that boulder and cobble reef habitat best suited the study for the following reasons:
* it is known to be a widespread habitat within the central nearshore part of Lyme Bay
* it is known to support broadly similar faunal assemblages;
* it is a reef habitat where towed bottom gear is known to have been worked regularly in the past as the low profile associated with it, compared to other reef habitats, makes it less likely that gear will be lost or damaged;
* it is considered particularly susceptible to damage from mobile fishing gear as smaller boulders and cobbles are easily dislodged and rolled whilst the low relief results in attached fauna being buried under sediment mobilised by passing gear;
* it does not have the physical heterogeneity of bedrock reefs (pinnacles, horizontal plateaus, vertical faces and overhangs) that creates a high diversity of environmental conditions and habitats and associated discrete suits of species that makes comparisons between sites more complex;
* it is a habitat known to occur in all three (Closed, New and Open) treatment categories. In particular, it exists along a discontinuous band running east-west that roughly follows the 18-20 metre depth contour, allowing all study sites to be located in the same depth band.
* previous studies of epibenthic faunal diversity in Lyme Bay had identified this boulder habitat type as being structurally complex and species rich;
* cobble reef habitat was also selected for purely practical reasons; being relatively level with few environmental gradients over short distances it is highly amenable to random sampling and quantitative data collection using quadrats and line transects; also the depth zone (18-21 metres) did not impose significant time constraints on the divers. Typical, undisturbed, cobble reef habitat can be seen in figure 10; degraded cobbled habitat (station 9, 2009 monitoring period) can be seen in figure 11;
* it is suspected that recovery might be noted quicker in the faunal communities occurring on boulder and cobble reefs than on the inherently more stable bedrock reef communities which tend to support greater abundances of slow growing longer lived species (e.g. *Eunicella verrucosa*); cobble reefs within Lyme Bay have been found to support a mix of slow growing and rapidly growing species (C. Munro, L. Baldock, pers obs), believed due to their intermediate level of stability.

Circalittoral boulder and cobble reef selected comprises a high proportion of cobbles and small boulders (MNCR definition Hiscock, 1996) with mixed, fine sediment between them in a water depth of 18-22m below chart datum. The boulder and cobble reefs studied here often classify in the following biotope:

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Bryozoan turf and erect sponges on tide-swept circalittoral rock (CR.HCR.XFa.ByErSp)
(Connor *et al.*, 2004).

3   METHODOLOGY

3.1   Location of monitoring stations

 It was intended that benthic communities at stations located within the pre-existing closed areas should be representative of assemblages relatively unaffected by mobile fishing gear, given that the hypothesis being tested is that, over time, communities within stations in the New Closure would change to more closely resemble those in the older (Closed) voluntary closures. The authors and the survey vessel skipper's personal experience of the distribution of habitat types across Lyme Bay and reference to habitat distribution maps allowed coarse selection of potentially suitable boulder and cobble reef habitats in all three treatments. Suitability of habitat was then confirmed using drop down video; this was necessary given the patchy nature of boulder and cobble reefs.

A reef area, know as Lane's Ground (one of the previously established voluntary areas was well known to the team from numerous earlier studies, e.g. Munro, 1992, 1993, Eno *et a*l. 2001) was chosen as the general location for Closed Control monitoring stations as it represented the only area of boulder and cobble reef habitat within the pre-existing voluntary closures. The three other voluntary closures each supported very different reef habitats and assemblages not replicated elsewhere within the bay. Typical, relatively undamaged, Lane's Ground boulder and cobble reef can be seen in Figure 10. It is a narrow reef (approximately 2-300 metres wide and several kilometres long) running parallel to the shore, 20-22m below chart datum. Similar boulder and cobble reef extends, discontinuously, along the same depth contour east and west of the of Lane's Ground voluntary closure to just beyond the boundaries of the New Closure. Open Control Stations were located close to the boundaries of the (NC) statutory closure. Whilst this is not ideal, more distant comparative stations were not possible due to lack of suitable reef habitat and markedly different environmental further east or west.

3.2   Selection of key taxa and survey methodology

Emphasis was placed on practical considerations. Using the teams' long involvement and extensive knowledge of the area, species were selected on the following criteria:

> 1. They had to be widespread and relatively common throughout the study area, present in densities that were likely to yield statistically usable data;

> 2. All identification would be done *in situ*, thus they must be visually distinguishable from similar species. Where this could not be done but species were still considered important enough to be counted then similar species would be recorded as a single entity (e.g. the Axinellid sponges *Raspailia hispida* and *Stelligera stuposa* or the calcareous tube worms *Salmacina dysteri* and *Filograna implexa*). Where certain groups, representing many species, were considered functionally important and occupied significant amounts of space but were often difficult to identify to species level *in situ* these were recorded as aggregated groups (e.g. encrusting sponges, colonial tunicates).

> 3. Representative examples of most of the sessile, epilithic macrofaunal phyla found in the area should be included; particular weighting was given to species considered highly likely to be damaged by mobile fishing gear, visually prominent and present in numbers that could be quantified during the course of a dive (e.g. the parchment tubeworm *Chaetopterus variopedatus* is large, fragile and generally present in densities of 0-20 per 0.25m^2 quadrat and so was viewed as important for inclusion whereas *Pomatoceros* sp. calcareous worms are small, robust and often present in densities of several hundred per 0.25m^2 so were not included).

In total 46 key taxa categories (species or species groups of two or more similar species, including size class divisions) were counted in each quadrat (Table 1). The growth form of each species was taken into account when determining how best to record it, for example, the

scallop *Pecten maximus* occurs as discrete individuals so counts of absolute number were made, similarly erect axinellid sponges occur as discrete, upright colonies and so were also counted as absolute number; encrusting sponges (e.g. *Hemimycale columella*) occur as a spreading clonal sheets and so were recorded as total percentage cover, similarly low bryozoan turf. Some organisms are suited to either method, depending on their size and density, e.g. the colonial anthozoan *Alcyonium digitatum* (dead men's fingers) forms discrete lobes interconnected by creeping stolons; these lobes may vary greatly in size and may also occur in high densities forming a carpet . For this, and some other species, there was merit in recording both discrete counts and percentage cover. This was done with a view to determining the most appropriate form for analysis once all data were available.

A key consideration of recovery is not only the numbers of individuals per unit area or total space occupied by all individuals but also the survivorship, and thus growth, of individuals or individual colonies. For larger, longer lived species it was recognised that simple counts would not provide any measure of survivorship. A good example of this is the bryozoan *Pentapora fascialis*. This is a rapid coloniser of moderately disturbed ground (C Munro, pers. obs.) but highly susceptible to physical disturbance. Consequently numerous small colonies (1-5cm diameter) may occur on recently disturbed ground but larger colonies (up to 0.75m or more diameter) only exist on stable habitats free from disturbance for many years. Thus for relevant species counts were subdivided into size classes. For example, the axinellid sponge group *Stelligera stuposa/Raspailia hispida* was recorded in height classes <3cm; 3-10cm and 10+cm. This resulted in a total of 46 categories recorded in key taxa (taxa and sub-dividing size classes).

It was also considered important to obtain a measure of overall diversity as previous observations had suggested this appeared to decline in damaged areas (C. Munro, L. Baldock, pers. obs.). Thus in addition to enumerating all key species all other species, including vagile species, were recorded (presence only) within quadrats. Due to inherent variability between divers it was decided, after comparing data to use only diver D1's records for all other species in each quadrat. Diver1 was selected as diver D2 was taking all photographs in addition to conducting quadrat counts for key taxa as so was under greater time pressure.

Less time was available for the belt transect surveys as this task was completed by the first dive pair after they had ensured correct location of the station markers (first year) and had successfully relocated the station markers (second and third year). Five larger species and species groups were counted:
- the seafan *Eunicella verrucosa*;
- the soft coral *Alcyonium digitatum*;
- the bryozoan *Pentapora fascialis*;
- the sponge *Cliona celata* (raphus form only);
- the large solitary tunicate *Phallusia mammillata*
- all erect branching sponges taller than 3cm high.

Divers also recorded all additional species (presence only) but this was not always completed due to time constraints.

The densities of key species, and overall diversity, varied dramatically between stations thus the emphasis was placed on ensuring complete data collection. The maximum no decompression stop time was similar at each station given that one criterion for station selection was similar depth (tidal state varying this slightly); an effective working time of approximately 35 minutes was available at each station.

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Table 1: Key taxa – Quadrat Data (with measure used: counts #, % cover)

Sponges	Bryozoa
Stelligera/Raspailia <3cm	*Pentapora fascialis* <3cm
Stelligera/Raspailia 3-10cm	*Pentapora fascialis* 3-10cm
Stelligera/Raspailia >10cm	*Pentapora fascialis* >10<20cm
Stelligera/Raspailia %	*Pentapora fascialis* >20cm
Axinella dissimilis/damicornis 3-10cm	*Pentapora fascialis* %
Axinella dissimilis/damicornis % cover	*Alcyonidium cf diaphanum* #
Tethya citrina #	*Alcyonidium cf diaphanum* %
Tethya citrina % cover	Encrusting bryozoa (*Cellipora* etc.) %
Cliona (raphus form) 3-10cm	Bryozoan turf - Crisiidae et %
Cliona (raphus form) %	
Iophon/Iophonopsis %	**Tunicata**
Hemimycale columella %	*Phallusia mammillata* #
Encrusting sponges indet. %	*Phallusia mammillata* %
	Pyura microcomsmus/Polycarpa pomaria #
Cnidaria	*Pyura microcomsmus/Polycarpa pomaria* %
Hydrallmania falcata %	*Polycarpa scuba /Dendrodoa* %
Nemertesia spp %	Colonial Tunicates %
Eunicella verrucosa <3cm	
Eunicella verrucosa 3-10cm	
Eunicella verrucosa >10cm	
Alcyonium digitatum lobes	
Alcyonium digitatum %	
Aiptaisia mutabilis #	
Hydroid turf %	
Hydroid turf <3cm	
Hydroid turf 3-10cm	
Hydroid turf >10cmcm	
Epizoanthus couchi %	
Annelids	
Myxicola infundibulum #	
Filograna implexa/Salmacina dysteri %	
Protula/Serpula #	

Table 2: Key taxa counted in fixed transects (area: 8mx2m, two replicates)

Erect branching sponges	*Eunicella verrucosa*
Cliona celata	*Pentapora foliacea*
Alcyonium digitatum	*Phallusia mammillata*

3.3 Data collection

Data were collected by SCUBA divers at 10 fixed stations across all three treatments in September 2008, August 2009 and July 2010. Three stations were located within the new closure but outside the established voluntary closures (New Closures (NCs)), four within Lane's Ground pre-existing voluntary closures (Closed Controls (CCs)) and three outside the closed area where fishing by towed bottom gear was still permitted (Open Controls (OCs)) (Figure 6).

3.3.1 <u>Sampling regime</u>

At each of these fixed stations the following samples were collected:
Quadrats
- Replication: x8 quadrats (area 0.25m^2) Figures 9, 13 and 14
- Surveyors: Diver 1 (D1) & Diver 2 (D2)
- Quadrats were haphazardly selected, by dropping from greater than one metre above the seabed (they descend in an unpredictable manner) within an area up to 5m either side of the centre line of the 8m fixed transect. Only areas of suitable habitat were included; if a quadrat landed on a patch of sand (an unsuitable habitat) it was discounted and the quadrat dropped again.
- Surveyors: two divers (D1 x5 replicates, D2 x3 replicates)
- Measures: % cover of selected taxa (Table1) divers D1 and D2 presence/absence of additional taxa identified *in situ* (Table 2) diver D1 only.

Fixed Transects:
- Scale: 8m x 1m (area 16m^2) established between the end markers for each transect.
- Replication: x2
- Surveyors: two divers, not always the same personnel (D3, D4, D5, D6)
- Measures: counts of key taxa (Table 3) within the transect; presence/absence of visually prominent taxa (Table 4) identified *in situ* by the divers.
- These transects are fixed locations, the same transect returned to each year.
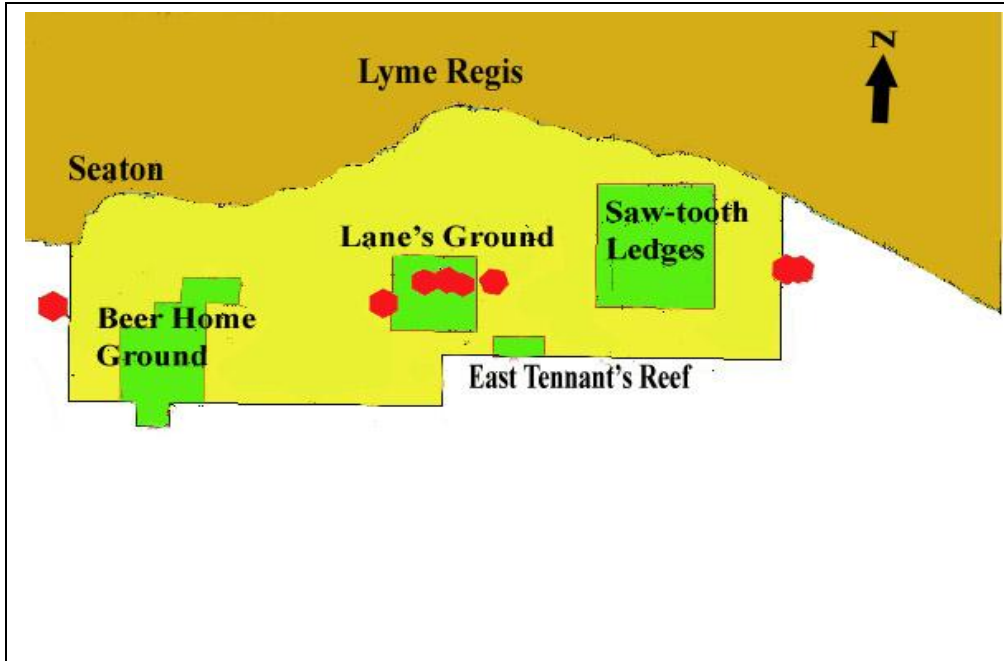
Figure 6. Map of Lyme Bay showing existing voluntary protected areas (green boxes), new statutory closed area (yellow box) and location of dive monitoring stations (red hexagons).
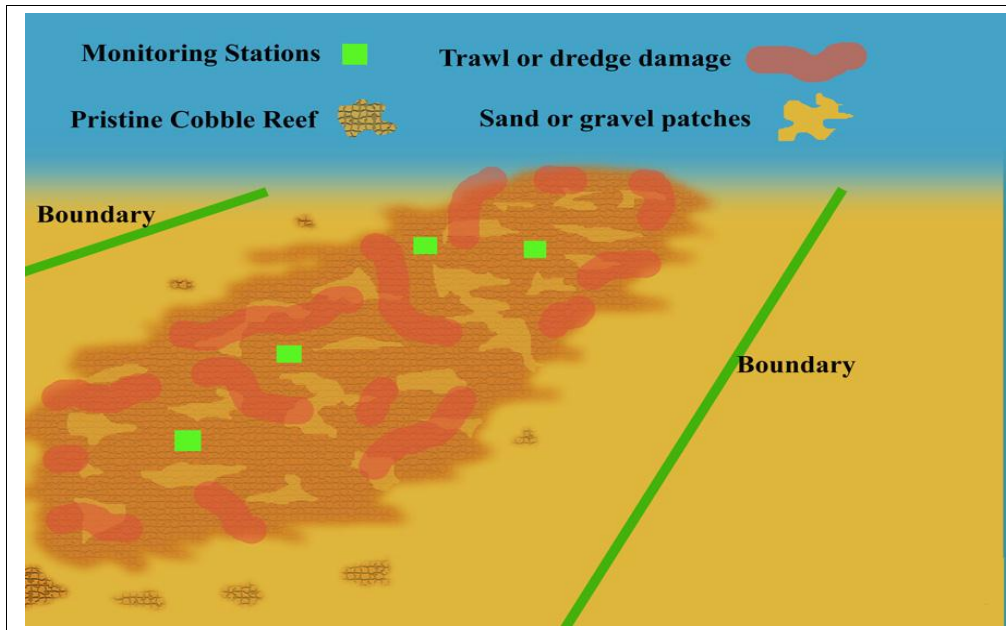
Figure 7: Illustration of Lane's Ground pre-exisiting voluntary closure, showing the arrangement of CC stations and the matrix or cobble reef and sand ribbons, plus tracks of clearly degraded reef (through trawl or dredge damage) necessitating careful selection of suitable, relatively pristine areas in which stations were haphazardly located.
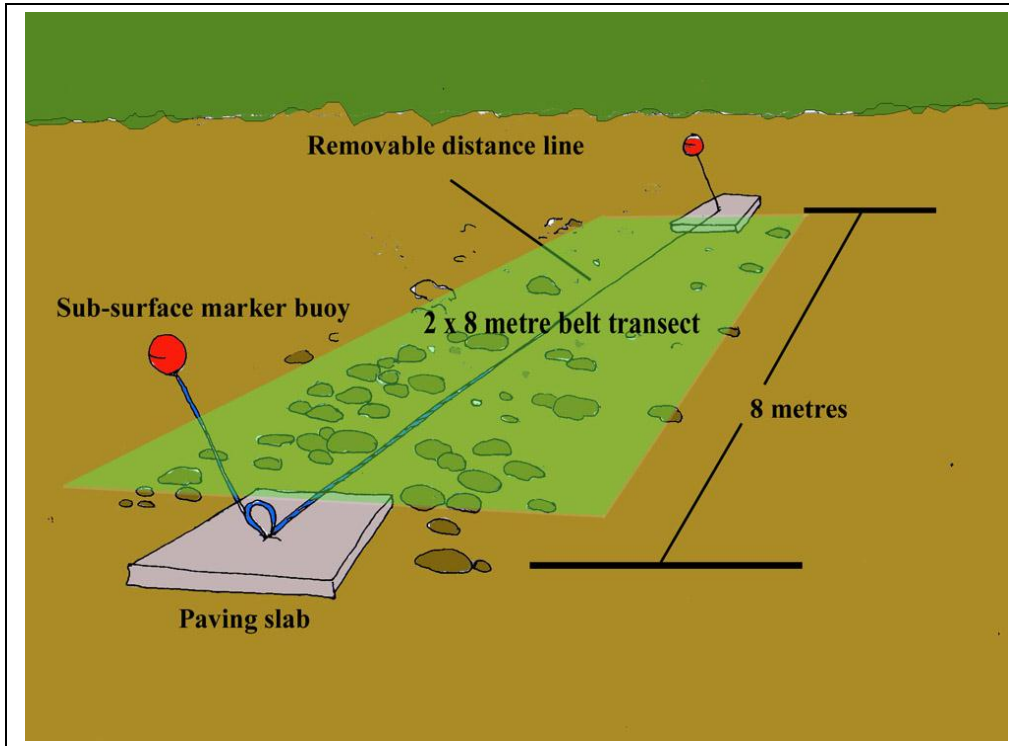
Figure 8: Layout of monitoring stations showing two concrete slabs with attached sub-surface marker buoys (left permanently in place). Also illustrated is the 8 metre transect line between each marker (re-laid each survey event) defining the belt transect.
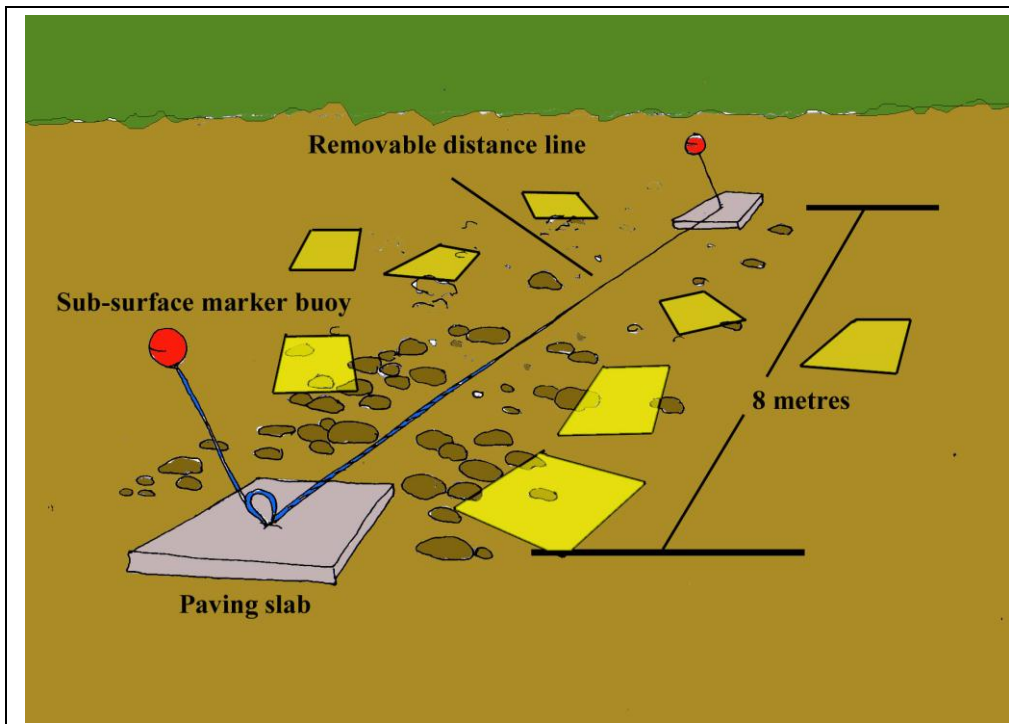
Figure 9: Layout of monitoring stations illustrating the haphazard distribution of 0.5 x 0.5m quadrats between the two marker concrete slabs.
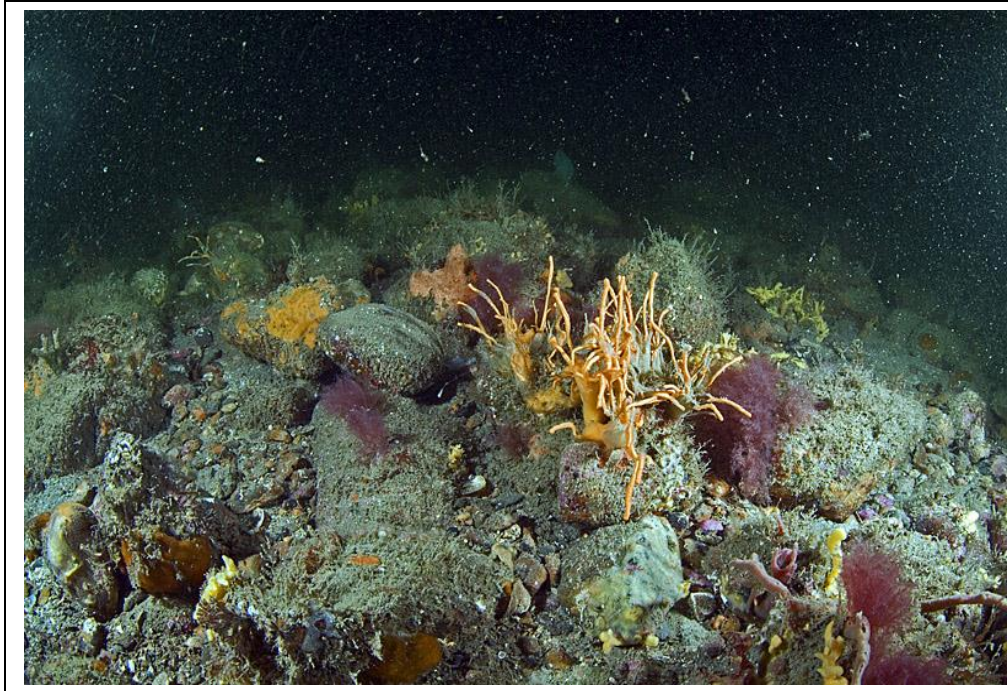
Figure 10. Typical undisturbed cobble reef habitat and species assemblage from Lyme bay in the 20-22m CD depth range, showing the rich assemblage of encrusting and branching sponges, red algae and hydroid turf species.

Figure 11. Disturbed cobble reef habitat (Station 9, Open Control site)
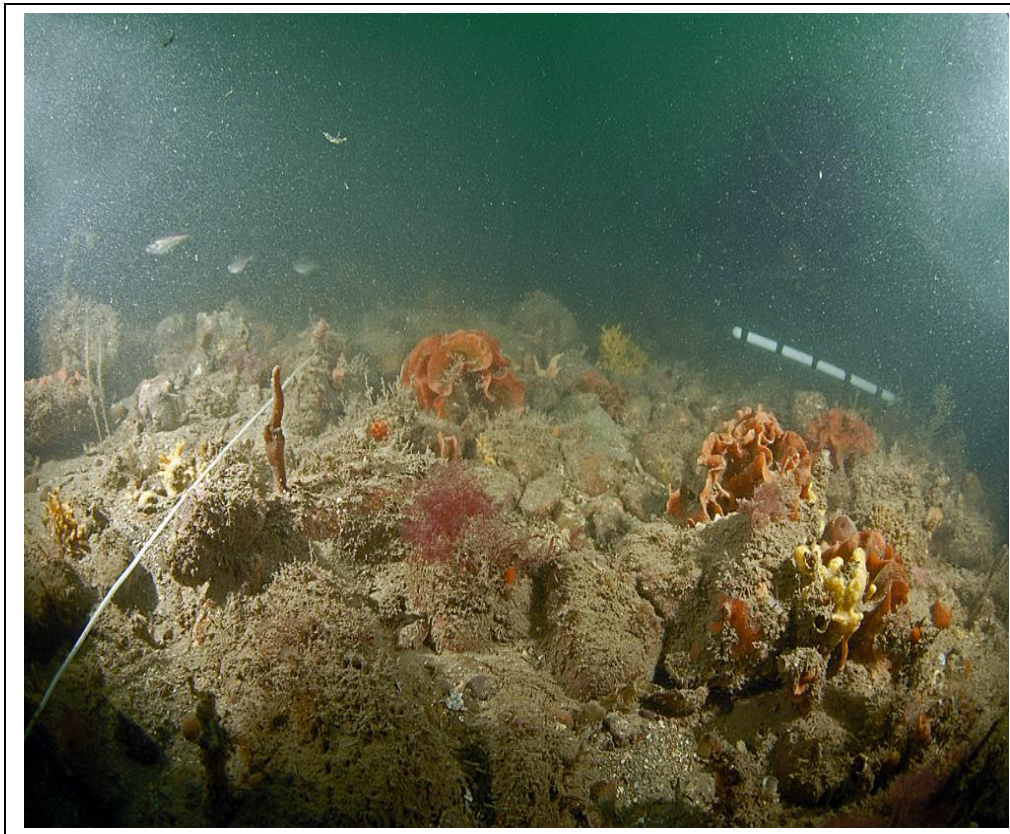
Figure 12: Relatively pristine station with filamentous red algae, Nemertesia antennina hydroids, several Pentapora fascialis colonies, Alcyonidium diaphanum colony, encrusting and massive sponges (Iophon/Iophonopsis sp.)and tunicates (Pyura/Polycarpa sp.) visible; the laid transect line can be seen in the left hand side of the image, a surveyor (L. Baldock) conducting quadrat counts can just be made out in the top right hand side of the image. Typical fine sediment with shell gravel can be seen between the boulders. The image also illustrates typical underwater visibility in central Lyme Bay.
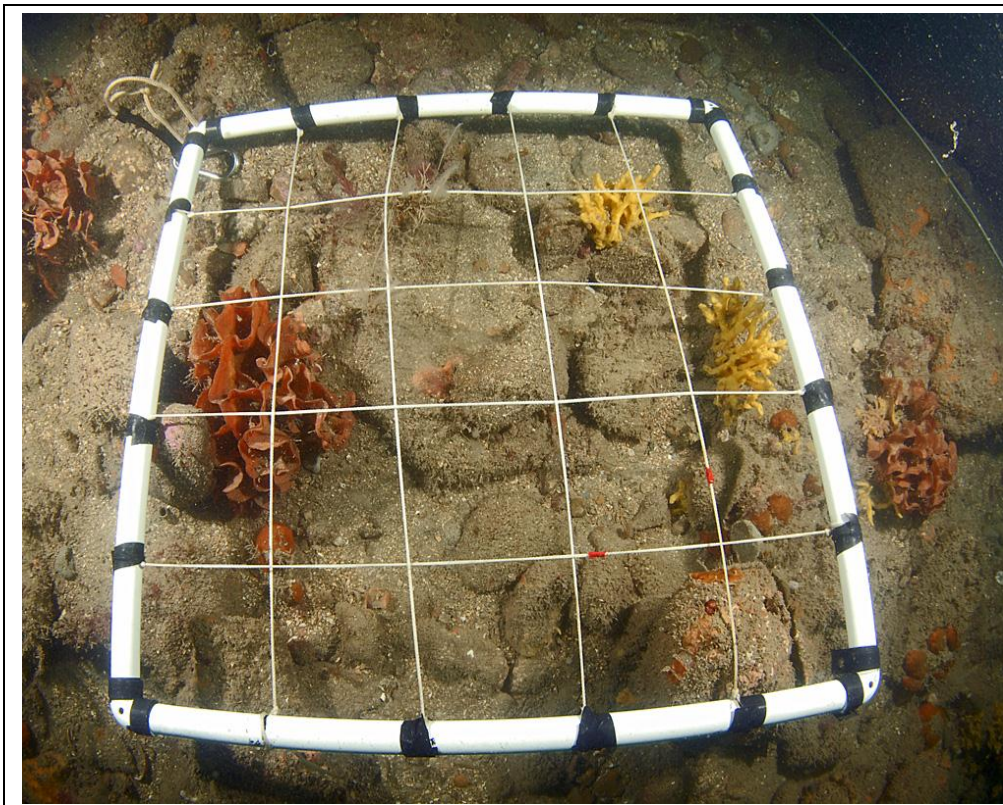
Figure 13 Strung 0.25m² quadrat used in this study. The station transect line can be seen in the top right hand corner of the image.

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3.4 Data Analysis

The statistical packages PRIMER and PERMANOVA+ (Clarke & Warwick, 2001; Anderson *et al.*, 2008) was used to compare response metrics between treatments and years.

Typically a species will be absent from many of the samples but when present counts are often highly variable with an abundance probability distribution strongly right-skewed. Species are not distributed at random in space, but are often highly clustered. This leads to counts which are, compared to a standard Poisson model, over-dispersed, and when combined with a high prevalence of zeros in the data set causes problems in attempting parametric modelling (Anderson *et al.*, 2008).   The multivariate non-parametric statistical approach to analysis developed in PRIMER and PERMANOVA+ makes no assumptions regarding the distribution of variables (in this case species) which are necessarily forced on the data by parametric methods. Community data are multivariate (large numbers of species subject to high statistical noise) and these data need to be analysed *en masse* (Anderson *et al.*, 2008). A wide variety of studies of benthic marine communities has demonstrated that species-dependant multivariate methods are more sensitive than species-independent methods in discriminating between sites and times (Clarke & Warwick, 2001).

Change in taxon assemblages was investigated using methods which depended on the initial construction of a similarity matrix using Bray-Curtis dissimilarities (Bray and Curtis 1957). The suitability of this coefficient for use in a wide range of ecological studies has been thoroughly discussed by Clarke *et al.* (2006). Univariate data were investigated employing matrices derived using the Euclidean distance measure (Anderson *et al.*, 2008). Throughout this analysis the term species richness is defined as the total number of taxa. PERMANOVA analyses were undertaken using 9999 permutations, all analyses returned more than 9910 unique permutations.

Two-dimensional (2D) representations of similarities between assemblages are presented using plots derived from the ordination of samples by non-metric multi-dimensional scaling (MDS).   These provide a "map" of the similarities between samples in two dimensions; samples closer together are more similar than those located further apart. The value for stress shown for each MDS plot provides a measure of how good a fit the 2D representation

is to the distribution of the samples within multivariate space. Clarke & Warwick (2001) have argued that stress values <0.2 provide a potentially useful 2D interpretation of the relationships between assemblages.

The following data sets for the summers of 2008. 2009 and 2010 were used in further analysis:

1. quadrat data – key taxa (see Table 1) (average of eight spatially correlated replicates for each site);
2. quadrat data – total taxa (total number of taxa derived from the average of five spatially correlated replicates for each site).

Since the fixed transect surveys constituted non-independent, repeated-measures results from these are presented as summary plots only.

3. Transect data – counts of key taxa (2008-2010)
4. Transect data – total species (2009-2010)

These data were collected to provide additional information about each site but, given the constraints of diver safety, were not replicated nor were the measures independent.
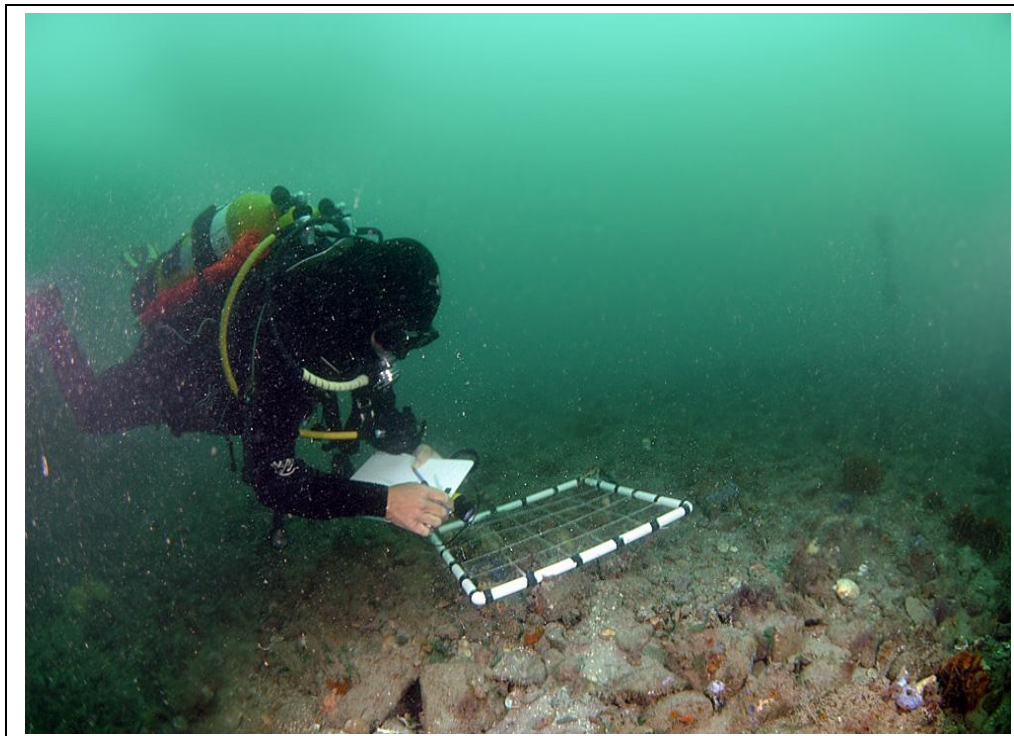
Figure 14. Diver surveying haphazardly dropped strung quadrat. One sub-surface marker buoy is just visible on the right hand side of the image.

4   RESULTS

4.1   Quadrat Data - Species Richness and Abundance

The total number of taxa recorded over the three years in the quadrat survey was 163, not all taxa being present in all years. The range of the mean number of taxa in the three treatments was 35-41 at the start of the study in 2008 increasing slightly to 27-43 in 2010. The most diverse assemblages were found at the Closed Control sites (41-45 taxa per site) contrasting with 27-35 taxa per site recorded at the Open Controls (Figure 15). The total number of taxa in the Closed Controls changed little over the three years. The total number in the New Closure was similar to that in the Closed Controls in 2008 and 2009 but appeared to decline slightly in 2010. The total number of taxa in the Open Controls was lower than Closed and Open Controls in all three years and appeared to decline slightly over the three year period.
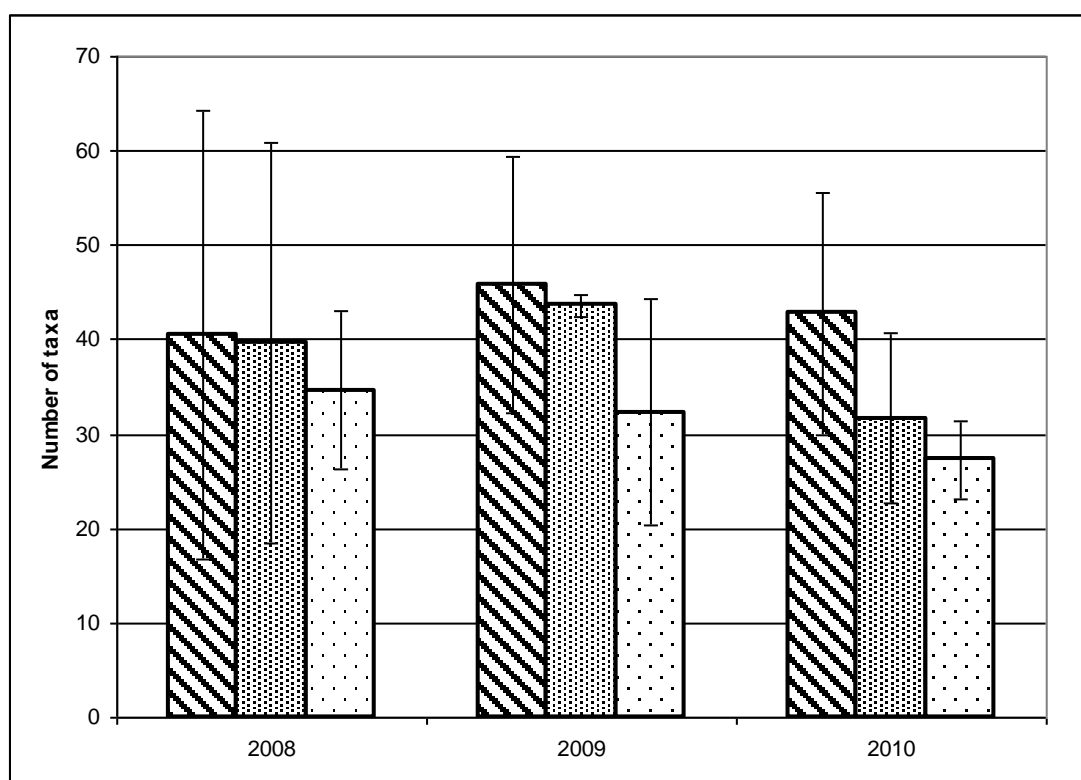
Figure 15: Quadrats - total number of taxa recorded (area 1.25m2) (Mean ⬚ 2x SE - by treatment. Key: cross hatched - Closed Controls, dark stippling - New Closure, light stippling - Open Controls).

The univariate PERMANOVA test on the total number of taxa in quadrats showed that there were statistically significant differences between treatments (P=0.007) but not years (P=0.13). There was no treatment by year effect (Table 5).

Source	df	SS	MS	Pseudo-F	P by permutation
Treatment	2	687.24	343.62	6.7535	**0.0065****
Year	2	225.1	112.55	2.212	0.1325
TrxYe	4	163.26	40.814	0.80214	0.5321
Residual	21	1068.5	50.881		
Total	29	2119.5			

Table 3: PERMANOVA table of results – Quadrats - Total Number of Taxa

The univariate pair-wise PERMANOVA test for the total number of taxa recorded for each treatment over the three years showed:

- ⊀ no statistically significant difference between Closed Controls and New Closure sites (P=0.20),
- ⊀ a statistically significant difference between Closed and Open Control sites (P=0.003),
- ⊀ a statistically significant difference between New Closure and Open Control sites (P=0.02).

The mean total number of taxa recorded from all replicates over the three year period for each treatment showed the Open Controls (three sites) supporting fewer taxa in total than either the Closed Controls (four sites) of the New Closure (three sites) (Table 6).

Treatment	Mean number of taxa	2x SE
Closed Controls	85	4.16
New Closure	76	15.14
Open Controls	59	12.70

Table 4: Quadrats - mean total number of taxa from all replicates recorded over a three year period in the three treatments.

The mean abundances within quadrats of each of four taxonomic groups (from within the key taxa recorded) are shown in Figure16. These were selected as dominant cover-forming groups (hydroid and bryozoan turf) or already noted as highly vulnerable to physical disturbance (sponges). The numbers of branching sponges and the cover of sponge crusts were statistically significantly different between treatments (P=0.003 and P=0.0005 respectively). All types of sponges were more abundant in Closed Control and New Closure sites compared with the Open Controls (Figure 16) over all three years. No statistically significant differences were detected between treatments for percent cover of either hydroid (P=0.97) or bryozoan turf (P=0.41) (Table 3). Cover of hydroid turf showed a decline at all sites over the study from a mean of 13.7% in 2008 to 3.2% in 2010, differences in cover between years were statistically significant (P=0.002). By contrast turf forming bryozoa showed little change between treatments and years with a mean cover over treatments and years of 2.4%. All taxa were highly variable in abundance. The results of the Permanova main test for selected key taxa in quadrats is given in Table 7.
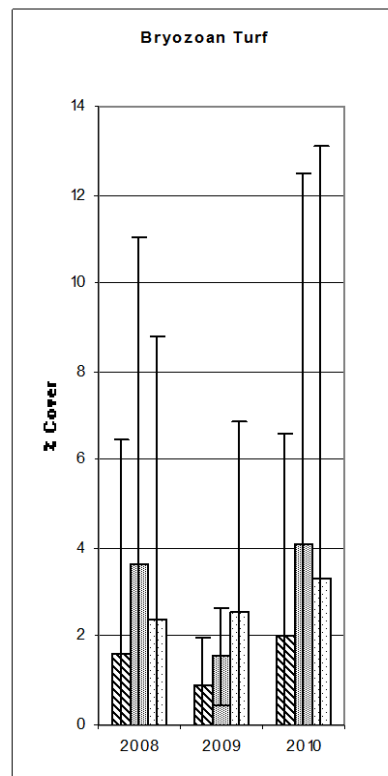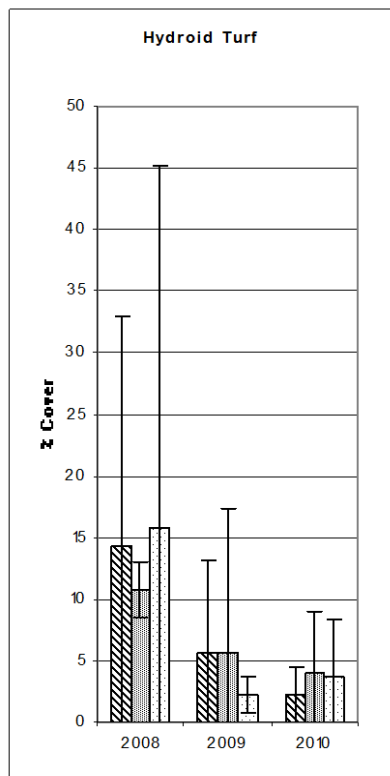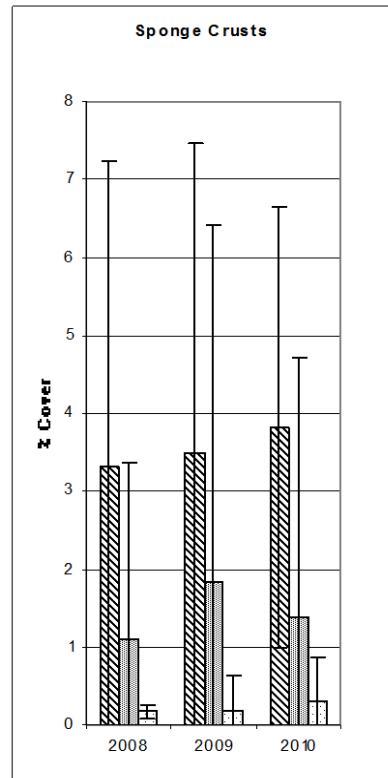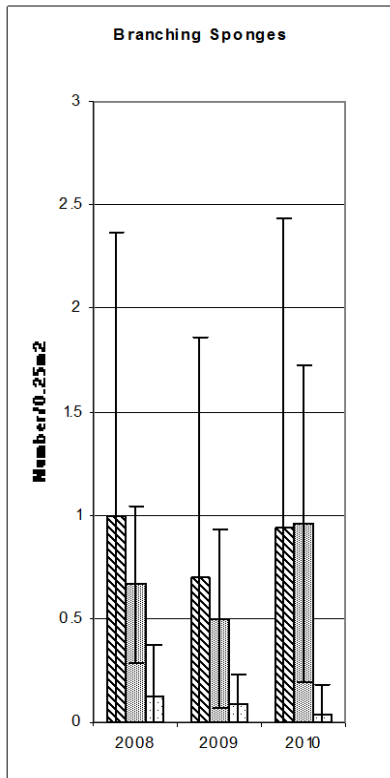
Figure 15: Quadrats - abundance by treatment of branching sponges, sponge crusts, hydroid turf and bryozoan turf (area: 0.25m2).(Mean □ 2x SE, Key: dark grey (diagonal stripes) - Closed Controls, light grey (stipple) - New Closure, white - Open Controls).

Branching sponges					
Source	df	SS	MS	Pseudo-F	P by permutation
Year	2	0.26034	0.13017	0.59359	0.5607
Treatment	2	3.4315	1.7158	7.8241	**0.0025****
YexTr	4	0.25801	6.45E-02	0.29415	0.8743
Residual	21	4.6051	0.21929		
Total	29	8.5756			
Sponge crusts					
Source	df	SS	MS	Pseudo-F	P by permutation
Year	2	0.64411	0.32205	0.13977	0.8657
Treatment	2	59.877	29.939	12.993	**0.0005*****
YexTr	4	0.74267	0.18567	8.06E-02	0.9884
Residual	21	48.389	2.3042		
Total	29	109.69			
Hydroid turf					
Source	df	SS	MS	Pseudo-F	P by permutation
Year	2	624.33	312.17	7.8485	**0.002****
Treatment	2	2.3646	1.1823	2.97E-02	0.9723
YexTr	4	67.866	16.967	0.42658	0.813
Residual	21	835.25	39.774		
Total	29	1553.1			
Bryozoan turf					
Source	df	SS	MS	Pseudo-F	P by permutation
Year	2	11.001	5.5007	0.65864	0.5276
Treatment	2	15.125	7.5627	0.90553	0.4183
YexTr	4	4.4394	1.1098	0.13289	0.9698
Residual	21	175.38	8.3516		
Total	29	205.65			

Table 5: Quadrats - PERMANOVA main test for selected key taxa

4.2   Quadrat Data - Assemblage Composition

Assemblage composition was statistically significantly different between treatments (P=0.0002) but not between years (P=0.095). Results of the main test are shown in Table 8.

Source	df	SS	MS	Pseudo-F	P by permutation
Year	2	2554	1277	1.6	0.0948
Treatment	2	7534.2	3767.1	4.6	0.0002***
YexTr	4	1799.3	449.82	0.6	0.9684
Residual	21	17093	813.97		
Total	29	28918			

Table 6: PERMANOVA main test – Quadrats - Key Taxa Assemblages

The results of the PERMANOVA pair-wise test for treatments showed that the three treatments were all statistically significantly different from each other (Table 6).

Groups	t	P by permutation
Closed Controls, New Closure	1.7914	**0.0164***
Closed Controls, Open Controls	2.8323	**0.0001****
New Closure, Open Controls	1.6668	**0.0105***

Table 7: PERMANOVA Pair-wise Test for Treatment – Quadrats – Key Taxa Assemblages

Figure 17 shows a 2D MDS plot for the assemblage data for quadrat key taxa. In this case stress for the 2D plot is relatively high (0.19) but the 2D plot is a more convenient representation of the multi-dimensional space than the three dimensional one where the stress is acceptably low at 0.12 providing a reasonable description of the assemblage relationships.
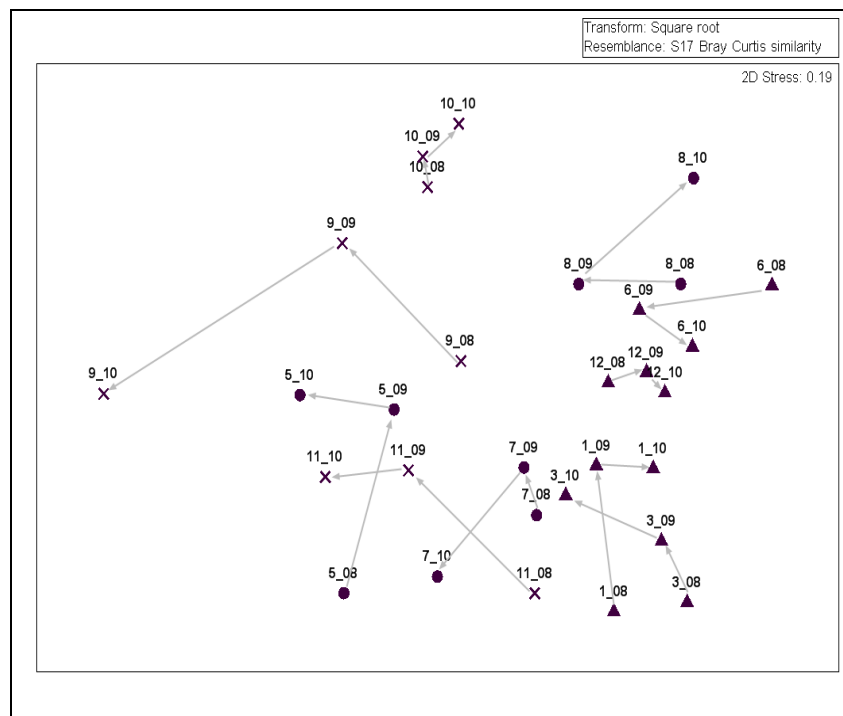
Figure 16: Quadrat key taxa assemblages - MDS plot showing assemblage similarity for treatments and years with trajectories superimposed.(Key: solid triangles - Closed Controls, solid circles - New Closure, crosses - Open Controls. Labels: Site by Year).

Trajectories for each site over the three years are superimposed. This highlights how similarities between assemblages at each site changed over the three year study period. Assemblages at the Closed Control sites were more similar to each other than to either the New Closure or the Open Control assemblages and showed least change over the three years.

A measure of the homogeneity of distances between samples in a treatment in multivariate space (PERMDISP, Anderson *et al.*, 2008) showed a statistically significant difference between centroids (P=0.04). This measure calculates the mean distance of each point in multivariate space from its group centroid (the centre of the group), the groups being treatments in this case. Closed Control assemblages showed a decrease in dispersion over the three years (mean=23.4 ± 2x SE 2.2) and were more similar to each other compared with either the New Closure assemblages (mean=27.7 ± 2x SE 2.6) or the Open Controls (mean=28.6 ± 2x SE 4.0). These two treatments showed a similar degree of dispersion between samples with the New Closure sites increasing in 2010 compared with 2009 (Figure 18).
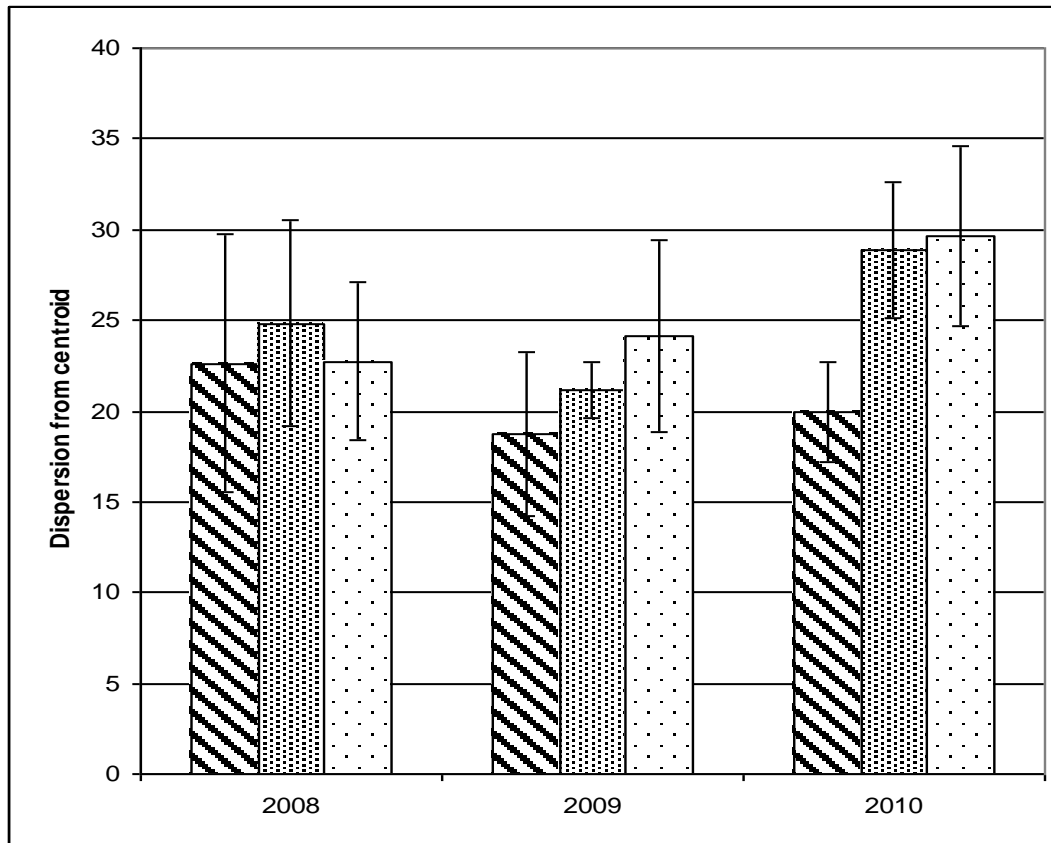
Figure 178: Quadrats key taxa assemblages – multivariate dispersion from centroids by treatment and year(Mean ⬚ 2x SE, Key: diagonal hash - Closed Controls, dense stipple - New Closure, sparse stipple - Open Controls).

Figure 19. MDS plot for averaged data for the factor treatment & year for quadrat key taxa (mean ±SE). This clearly demonstrates the relatively smaller change in similarity occurring in the assemblages at the Closed Control sites (especially between 2009 and 2010) by comparison with those under the other two treatments. Furthermore, the assemblages at the Open Control sites are very clearly separated from those at both the Closed Control and the New Closure sites.
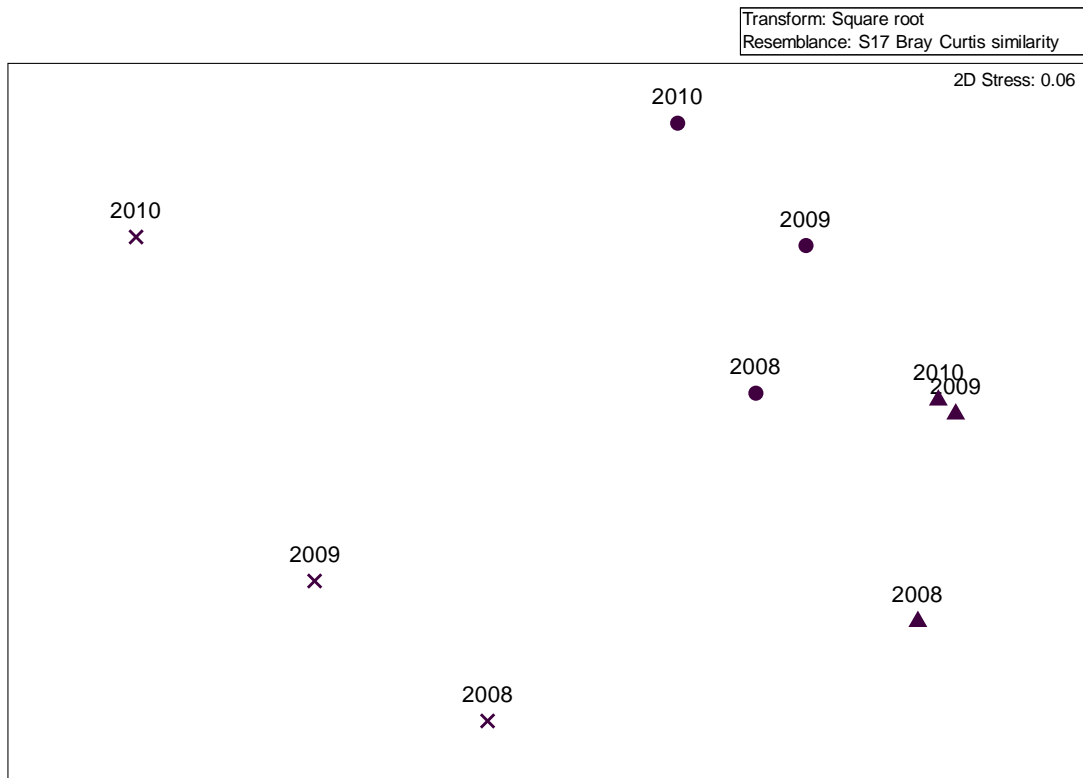
Figure 18: Quadrat key taxa assemblages - MDS plot showing averaged data for factor treatment & year(Key: solid triangles - Closed Controls, solid circles - New Closure, crosses - Open Controls. Labels: by Year).

Assemblages defined by the presence of all taxa showed a distinction between Open Control sites and Closed Control and New Closure sites summarised using the ordination of samples by MDS (Figure 20). Between year differences in similarity of assemblages at each site were least among the Closed Controls which group together in the upper left of the diagram along with site 7 in the New Closure.
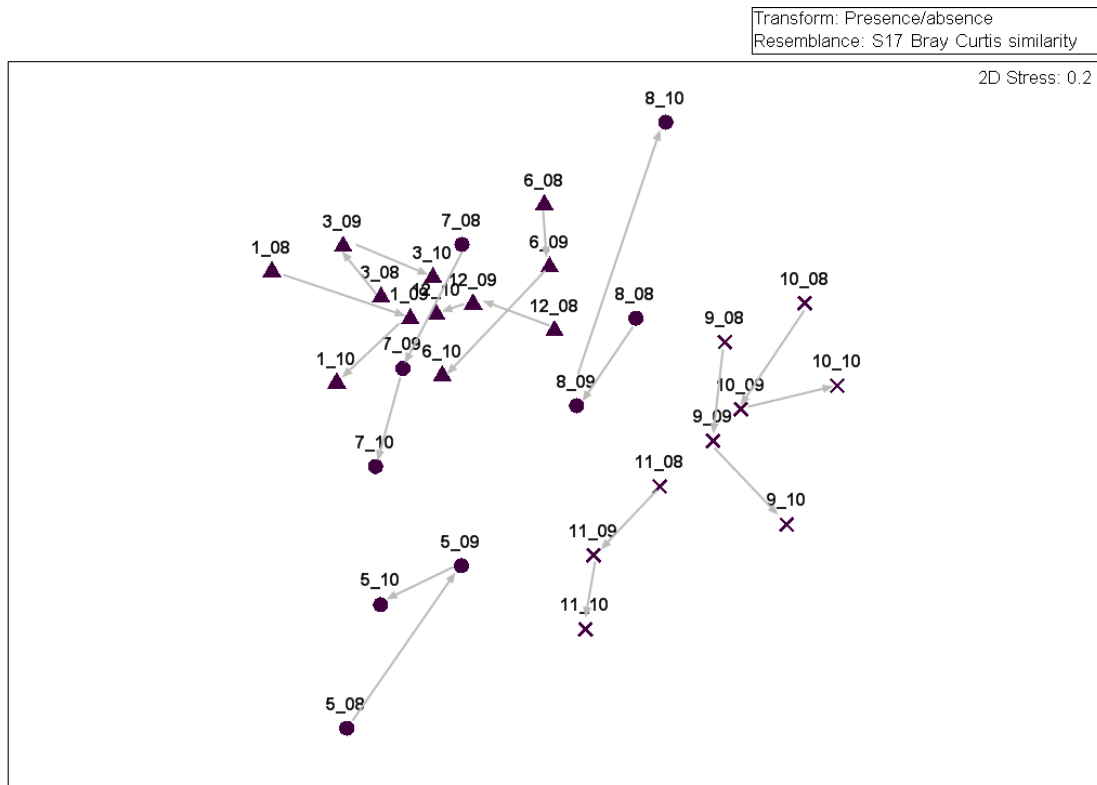
Figure 19: Quadrats all taxa - MDS plot with annual trajectories superimposed(Key: solid triangles - Closed Controls, solid circles - New Closure, crosses - Open Controls. Labels: Site by Year).

The PERMANOVA main test (Table 10) showed statistically significant differences between assemblages of all taxa between all treatments (P=0.0001) and all years (P=0.0001) (Table 6).

Source	df	SS	MS	Pseudo-F	P by permutation
Year	2	7877	3938.5	3.0641	**0.0001***
Treatment	2	12720	6360	4.948	**0.0001***
TrxYe	4	4151.2	1037.8	0.8074	0.8141
Residual	21	26993	1285.4		
Total	29	51733			

Table 8: PERMANOVA main test – Quadrats – All Taxa

4.3   Quadrat Data – Taxa contributing to treatment differences

An analysis of the contributions of variables (taxa) to the similarity between samples (SIMPER routine) showed the following taxa distinguished between treatments.

4.3.1   Closed Controls

Sponge taxa were an important component of the assemblages at these sites. Sponges included branching species such as *Haliclona oculata, Raspailia* and *Stelligera*; massive-lobose species such as *Hemimycale columella*, *Dysidea fragilis*, an entity tentatively identified as *Iophon* sp and a number of encrusting species. Other distinguishing taxa were the tubicolous polychaete *Chaetopterus variopodetus*, solitary tunicates *Phallusia mammillata* and *Pyura/Polycarpa* species and foliose red algae such as *Rhodymenia ardissonei* and *Hypoglossum hypoglossoides* together with filamentous forms.

4.3.2   New Closure

Assemblages at these locations included the octocoral *Alcyonium digitatum*, small colonies of the hydroid *Nemertesia*, colonial tunicates such as *Didemnum maculatum*, *Sidnyum elegans,*

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Lissoclinum perforatum and *Morchelium/Aplidium.* Bryozoan turf was also a feature of these sites.

4.3.3   Open Controls

The assemblages at these sites were less diverse than those in the other two treatments and were characterised by the presence of the hydroids *Hydrallmania falcata* and *Sertularia argentea*, terebellid polychaetes, barnacles (*Balanus* sp), hermit crabs (Paguridae) and the bryozoan *Alcyoniudium* cf *diaphanum.* Again turf forming bryozoa such as *Cellaria* sp and Crisiidae were a feature of these sites.

4.4   Transect Data - Species Richness and Abundance

Total taxa were recorded in fixed transects in 2009 and 2010 with 185 conspicuous taxa reported overall. The range between treatments being 34-41 taxa in 2009. The mean number of taxa at the Closed Control and New Closure sites increased from 38 to 68 and 34 to 58 respectively in 2010 (Figure 21) while the mean number of taxa decreased slightly at the Open Control sites (41 to 34 taxa).
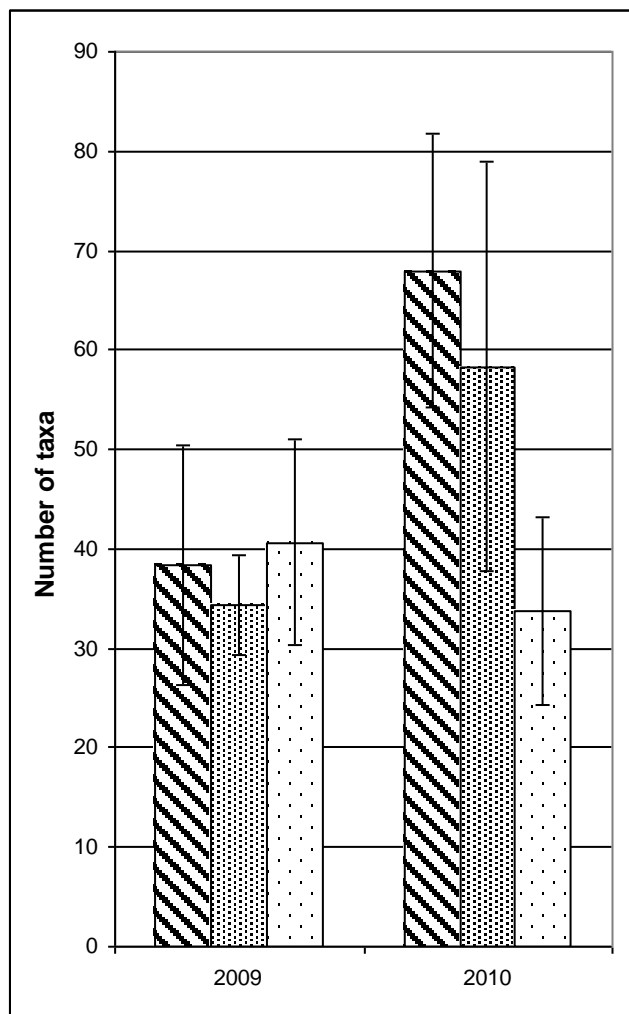
*Figure 2*0*: Fixed transects - total number of taxa recorded (area: 8m2)(Mean □ 2x SE, Key: diagonal hash - Closed Controls, dense stipple - New Closure, sparse stipple - Open Controls).*

Counts of selected taxa within the 8m long fixed transects (Figure 22) showed low numbers of erect branching sponges, *Alcyonium digitatum* and *Phallusia mammillata* at the Open Control sites with very variable but higher numbers of these taxa at Closed Control and New Closure locations in both years where data for all three treatments exists (2009 and 2010). *Pentapora fascialis* at the Open Control sites occurred largely as small, unattached fragments in contrast to securely attached, though often small colonies at sites in the other two treatments.
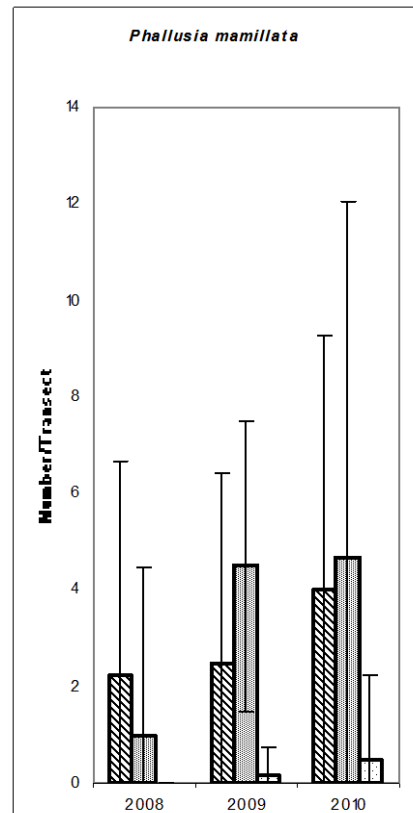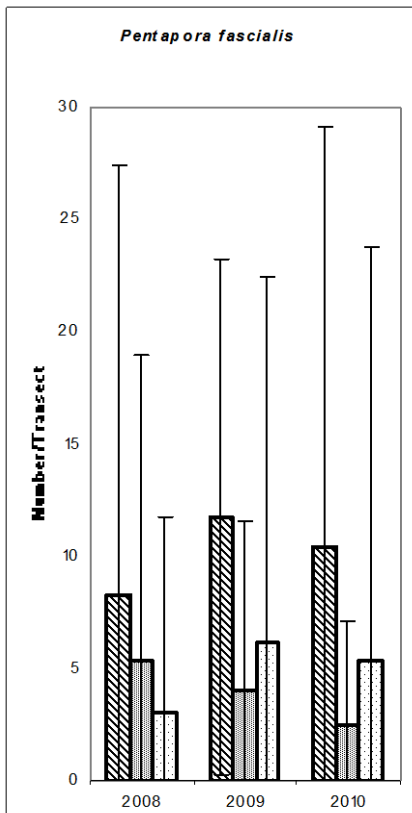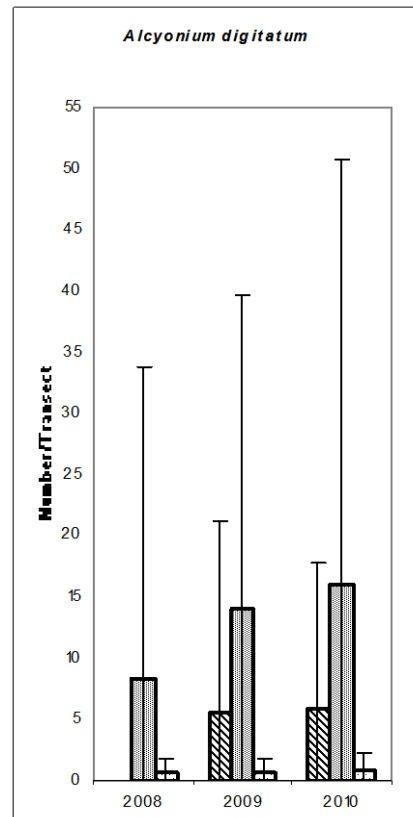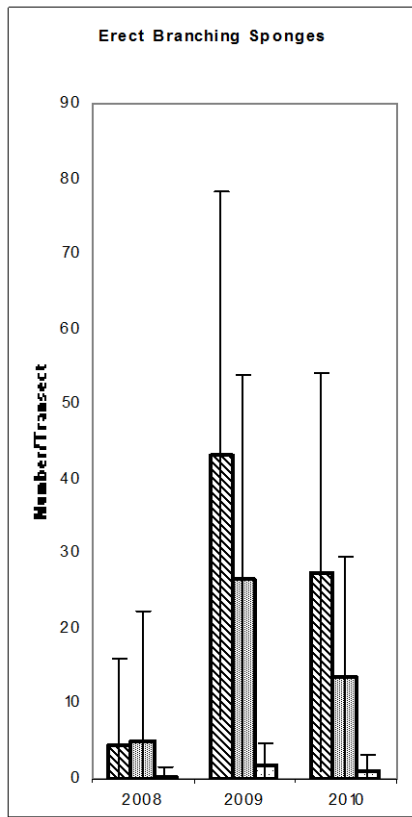
28

Figure 21: Numbers of selected taxa per 8m2 from fixed transects.(Mean ☐ 2x SE, Key: diagonal hash - Closed Controls, dense stipple - New Closure, sparse stipple - Open Controls). Note: vertical scale varies.

5   DISCUSSION

5.1   Hypothesis

The purpose of the present study was to monitor change in subtidal benthic species assemblages in boulder and cobble reef habitats in Lyme Bay following the exclusion of towed bottom fishing gear in July 2008.

The hypothesis the study was required to test was that, over time, species assemblages within sites in the new statutory closure (NC) but outside the pre-existing voluntary closures, would change to more closely resemble those in the pre-existing voluntary closures (CC) and less similar to nearby sites where fishing by towed bottom gear was still permitted (OC). No evidence was found to support this hypothesis. Additionally the Open Controls appeared significantly different, in terms of total number of species and assemblage composition from both New Closure and Closed Control sites in year one of the study (2008) and remained so 2009 and 2010. In particular, key taxonomic groups branching and encrusting sponges were much lower in the Open Controls than either New Closures or Closed Controls in all years, as were the soft coral *Alcyonium digitatum* and the large solitary ascidian *Phallusia mammillata* (Figures 16 and 22). The most likely explanation is that this reflects the differences across Lyme Bay, specifically the differences in benthic conditions (environmental gradients) east and west of the closed area, despite efforts to standardise habitats as far as possible. Consequently direct comparison of changes in assemblage composition and taxon abundances between treatments inside and outside the statutory closure are more likely to reflect environmental differences in habitat and environmental conditions than differences in exposure to towed bottom fishing. This does not mean there is no fishing impact outside the closure, simply that they cannot be differentiated from the differences due to environmental conditions. Further evidence of this can be seen by noting how different Open Control sites east and west of the statutory closure are. The differences in assemblage composition between Open Control Sites 9 and 10 (east) and the third Open Control (Site 11 - west) are more likely to reflect differences in the benthic conditions across Lyme Bay from east to west (Figures 17 and 20) than any difference in fishing effect. Thus little can be read in to differences between OC sites and NC or CC sites with regard to effects of the closure.

Convergence of the New Closure with the Closed Controls sites does not appear to have occurred. This may due to subtle differences in habitat outside of the initial voluntary protected area of Lane's ground Reef (the CC sites) or it may be due to the short duration of the study in relation to the slow growth rates of many of the species under consideration. Consequently, it may simply be too early to see such convergence of treatments. There are, however, a number of observations that can be made from the data, including some that do suggest some early recovery within the New Closure. PERMANOVA pair-wise test of assemblage composition for quadrat data for treatments (Closed, New and Open Controls) showed that the three treatments were all statistically significantly different from each other (Table 10).

5.2   Differences between treatments

The most diverse assemblages, in terms of numbers of taxa, were found at the Closed Control sites. The total number of taxa did not change greatly over the study period. Open Controls did not change significantly over the three year period although mean totals were consistently lower than those of Closed Controls or New Closures. The New Closure sites were similar to the Closed Controls in 2009 but showed a decline in 2010 (Figure 15).

The mean total number of taxa recorded from all replicates over the three year period for each treatment showed the Open Controls (three sites) supporting fewer taxa in total than either the Closed Controls (four sites) of the New Closure (three sites) (Table 4).

The MDS plots for both key taxa and total taxa in quadrats within the New Closure (in 2010) showed the samples for New Closure sites to be more widely dispersed (i.e. more dissimilar to each other) than Closed Controls and comparable to the dissimilarity of the Open Controls. The estimate of the multivariate dispersion was higher than among the Closed Controls and the Open Controls in both 2009 and 2010 and the New Closure in 2010. It has been proposed that a change in the multivariate dispersion of assemblage data provides a measure of pressures (stresses) impacting on marine benthic communities (Warwick & Clarke, 1993), more impacted assemblages tending to show greater dispersion. This suggests that the assemblages at the New Closure and Open Control sites show evidence of stress of which disturbance by scallop dredging may be one component.

Differences between treatments in terms of species richness reflect the sensitivity to disturbance of the various taxa. Within the Closed Control sites there was greater cover by encrusting sponges than at either of the other two treatments; this difference was statistically significant for Open Controls. Growth of encrusting sponge species is known to be slow (Ayling, 1983) but, if damaged, rapid regeneration can take place much faster than undisturbed growth provided that disturbance is intermittent. Historically less disturbance at Closed Control sites allowed more crusts to survive to the start of the monitoring programme, hence the greater cover. Three years is likely to be too short a time period for the encrusting sponge species at New Closure sites to have reached a comparable density.

Hydroid turf showed a statistically significant difference between years declining to less than 5% mean cover in 2010 under all treatments. The turf was made up predominantly of short growth (<3cm high) which might be expected to be composed of species which have an annual life cycle. There are no clear explanations for this. Given the probable short life span of these species it may simply be due to natural fluctuations in recruitment. Larger hydroids (>3cm high) were rare at all sites. Cover of bryozoan turf tended to be higher though extremely variable at New Closure and Open Control sites (up to 4% cover) with no measurable change evident over the study period.

5.3   Signs of early recovery

Branching sponges were present in very low numbers at the Open Control sites while quadrat estimates showed highly variable numbers were recorded at Closed Control and New Closure sites. It was noted by surveyors, based on fixed transect surveys, that branching sponges seemed to increase in abundance over the study period within both the New Closures and Closed Controls. Given that the rationale for creating the statutory closure was that there were numerous reports of infringement within the voluntary closures (and a significant number of apparently markedly degraded locations within Lane's Ground Closed Controls during the initial site selection phase of this study) then a recovery of branching sponges within both New Closure and Closed Control treatments would be entirely consistent with what might be expected following more stringent exclusion of towed bottom fishing gear.

Sponge assemblages are considered the single most important feature of the boulder and cobble reefs within Lyme Bay, and regionally appear unique to the central nearshore benthos of Lyme Bay, the sponge diversity having been previously described as possibly unsurpassed Southwest Britain (Devon Wildlife Trust, 1995). Sponge species, in particular, have been identified (through qualitative comparsion of video data from the same site within Lane's Ground reef shot in 1996 and 2008 as described in the introduction) as appearing to have declined markedly in the twelve years prior to establishment of the statutory closure, whilst Kefalas *et al.* (2003) identified erect branching sponges as particularly sensitive to damage from scallop dredges. Thus an indication of recovery in sponges would be a very positive sign and, if confirmed by fuuture monitoring, would provide a strong endorsement of the statutory closure.

It has been shown that recovery of sponge assemblages after cessation of disturbance is very slow, with one study showing no improvement after two years (Kefalas *et al.,* 2003). Hiscock (1994) showed that branching sponges including *Stelligera* and *Raspailia* species grew very slowly if at all over a four year period and recruited only intermittently. This may explain why recovery is also noted within the Closed Control sites; Lane's Ground reef (the Closed Control area) had been protected (through a voluntary agreement) for only seven years prior to commencement of this study, additionally considerable anecdotal evidence suggested there had been numerous incursions by towed bottom fishing gear during this period. It seems likely

that, if recovery of sponge assemblages is indeed occurring as initial data indicates, it will take require several more years monitoring to confirm this.

Numbers of small individuals of the octocoral *Alcyonium digitatum* in fixed transects were very variable, reflecting the patchy distribution and clonal growth through creeping stolons of this species. However an increase in mean numbers was observed over the three year period at both Closed Control and New Closure sites with consistently low numbers at Open Control locations. The species is known to be intolerant of disturbance (Hiscock, *et al.*, 2005) thus one might expect an increase in abundance following cessation of towed bottom fishing in both NCs and CCs for the reasons explained in relation to branching sponges. It is also known to be a long-lived species (at least 28 years, Lundalv pers. comm. cited in Hartnoll, 1977) and slow growing species with recently settled colonies taking some considerable time to grow to a size that's easily spotted (Mathews, 1917) thus it may take several more years before statistically significant data on any increase in abundance is available.

Over the three year study period the assemblages in the three different treatments remained distinct. Assemblages in the New Closure showed evidence of instability in composition changing considerably between years.

It needs to be kept in mind that many of the key taxa selected and the species characterising the assemblages under the different treatments are slow growing and some are known to recruit only intermittently. Consequently evidence of recovery, within these taxa, at New Closure sites will be very likely to take several more years of data gathering to confirm.

5.4   Effects of differences in substrate

Site 5 (flat silted, bedrock rather than boulder and cobbles) in the New Closure is clearly an outlier in terms of its taxon assemblages, reflecting the different assemblages occurring on different reef habitat types occurring in geographically close and in similar depth zones. Whilst it has clearly shown the importance of ensuring habitats are as similar as possible if data from different sites is to be comparable, it does not appear to aid interpretation of change within species assemblages on boulder and cobble reefs within the statutory closure. It is therefore recommended that monitoring at this station is discontinued and effort re-allocated to other boulder and cobble reef sites within the closure.

6   RECOMMENDATIONS

6.1   Closed Controls and New Closure

The slight recovery noted in erect and encrusting sponges within both the New Closure and Closed Controls is very encouraging, particularly so given that sponge species had been highlighted as appearing to have declined notably within the Closed Control area during twelve years prior to establishment of the statutory closure, and the assemblages are considered a particularly important feature of the boulder and cobble reefs within Lyme Bay, having previously been assessed as of exceptional diversity. However, as described in the discussion, erect and encrusting sponges are known to grow and recover from disturbance extremely slowly. It is therefore considered vital that monitoring is continued in order to assess whether this recovery proves statistically significant over time and whether it is sustained. A minimum of four years further monitoring is considered essential to determine this.

6.2   Open Controls

It appears that the Open Controls (outside the statutory closure) do not provide good comparisons with boulder and cobble reef species assemblages inside the statutory closure simply because conditions are too different. It is unlikely that reef species assemblages directly comparable with those inside the New and Closed Controls exist within Lyme bay outside the statutory closure; the more distant from the closure the more different seabed composition, tidal regime and water column turbidity become. Thus further monitoring of Open Controls (for this purpose) would seem of little benefit. However, such monitoring may provide useful data on changes occurring on the boulder and cobble habitats outside the

statutory closure if towed bottom fishing continues (e.g. if the noted decline in sponge species continues) or whether there is any recovery if towed bottom fishing declines of ceases in this area.   Alternatively it may be worthwhile re-allocating effort to additional sites within the Closed and New Controls.

6.3   Open Control Site 5

Site 5 (flat silted, bedrock rather than boulder and cobbles) in the New Closure is clearly an outlier in terms of its taxon assemblages, reflecting the different assemblages occurring on different reef habitat types occurring in geographically close and in similar depth zones. Whilst it has clearly shown the importance of ensuring habitats are as similar as possible if data from different sites is to to be comparable, it does not appear to aid interpretation of change within species assemblages on boulder and cobble reefs within the statutory closure. It is therefore recommended that monitoring at this station is discontinued and effort re-allocated to other boulder and cobble reef sites within the closure.

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8 APPENDIX

Amphilectus fucorum	*Inachus dorsetensis*	*Ascidia virginea*
Clathrina coricea	*Inachus phlanagium*	*Ascidiella aspersa*
Cliona sp boring form	*Necora puber*	*?Aplidium incrustatum*
Dysidea fragilis	Macropodia sp	*Aplidium* sp
Ciocalypta penicillus	Maja squinado	*Botryloides leachi*
Halichondria sp	Paguridae indet	*Botrylus schlosseri*
Halichondria soft pink	*Pagurus bernhardus*	*Ciona intestinalis*
Haliclona sp	*Pagurus cuanensis*	*Clavellina lepadiformis*
Haliclona simulans	*Pagurus prideauxi*	*Corella paralellogramma*
Haliclona fistulosa	*Solidobalanus fallax*	*Dendrodoa grossularia*
Haliclona occulata	*Verruca stroemia*	Didemnidae indet
Oscarella cf lobularis	*Buccinum undatum*	*Didemnum maculosum*
Raspailia hispida	*Caliostoma zizyphinum*	*Diplosoma* sp
Raspailia ramosa	*Crepidula fornicata*	*Diplosoma spongiforme*
Rhaphydostyla kitchingi	*Gibbula cineraria*	*Distomus variolosus*
Sycon ciliata	*Hinia incrassata*	*Lissoclinum perforatum*
Stelligera rigida	*Hinia reticulata*	*Molgula* sp
Stelligera sp	*Janolus cristatus*	*Molgula cf manhattensis*
Suberites sp on crab	*Polinices* sp	*Morchelium argus*
Actinothoe sphyrodeta	*Polycera faeroensis*	*Morchelium/Aplidium*
Adamsia carcinapodos	*Polycera quadrilineata*	Polyclinidae indet 1
Calliactis parasitica	*Ocenebra erinacea*	Polyclinid cf *Aplidium*
Cerianthus lloydii		Polyclinid indet 2
Sagartia troglodytes?	Anomiidae indet	*Stolonica socialis*
Sagartia sp	*?Cardium* sp	*Styela clava*
Caryophyllia smithii	*Chlamys varia*	*Sydnium turbinatum*
Aglaophenia pluma	*Gastrochaena dubia*	*Sydnium elegans*
Aglaophenia tubulifera	*Pecten maximus*	*Callionymus* sp
Halecium sp	*Bicellariella ciliata*	*Pomatoschistus* sp
Halecium halicinum	*Bowerbankia citrina*	*Pomatoschistus pictus*
Kirchenpaueria sp	*Bugula* sp	Leopard spot goby
Plumularia setacea	*Bugula flabellata*	*Gobius niger*
Sarcodictyon roseum	*Bugula plumosa*	*Parablennius gattorugine*
Sertularellidae indet	*Cellaria* sp	*Diplecogaster bimaculat*
Sertularella gayi	*Cellaria fistulosa*	*Aglaothamnion* sp
Sertularella polyzonias	*Cellepora pumicosa*	*Rhodymenia ardissonei*
Sertularia argentea		Encrusting red algae
Lanice conchilega	*Chartella /Securiflustra*	Encrusting corallines
Megalomma vesiculosum	Crissidae indet	Folios red algae
Pomotoceros sp	*Disporella hispida*	Filamentous red alga
Polychaete tubes indet	*Flustra foliacea*	*Hypoglossum hypoglossoides*
Sabellidae indet small	Pagurid bryozoan	*Halarachnion ligulatum*
Serpulidae indet	cf *Scizobrachiella sanguinea*	
Terebellidae indet	*Schizomavella* sp	
	*Asterias ruben*s	
Balanus crenatus	*Thyone roscovita*	
Boscia anglica	*Ophiura albida*	
Galathea sp	*Ocnus lactea*	
Galathea strigosa	*Archidistoma productum*	
	Ascidia mentula	

Table 9: Additional taxa recorded in quadrats

Table 10: Visually prominent taxa recorded by divers in situ on fixed transects

Sponges	Annelids
Amphilectus fucorum	*Bispira voluticornis*
Axinella dissimilis	*Chaetopterus variopoditus*
Axinella sp	Terebellidae (cf *Eupolymnia nebulosa*)
Clathrina coriacea	*Lanice conchilega*
Dysidia fragilis	Leach (indet) (Hirundinea)
Haliclona occulata	*Megalomma vesiculosum?*
Hemimycale columella	*Myxicola infundibuliformis* (black tips)
Iophon/Iophonopsis	*Myxicola cf sarsi* (lacks black tips)
Oscarella lobularis	*Pomatoceros*
Pachymatisma	*Serpula/Protula*
Polymastia bolitiformis	*Serpula vermicularis* (with operculum)
Polymastia penicillus	*Protula tubularia* (lacks operculum)
Pseudosuberites	*Sabella* sp cf *pavonina*
Raspalia ramosa	*Salmacina/Filigrana*
Raspalia hispida/Stelligera sp.	
Suberites sp	**Crustacea**
Suberites on hermit crab	*Cancer pagurus*
Tethya citrina	*Goneplax rhomboides*
	Inachus sp
Cnidaria	*Liocarcinus depurator*
Hydroids	*Necora puber*
...ria abietina	Paguridae indet
Aglaophenia sp	*Pagurus* sp
...enia tubilifera	*Pagurus bernhardus*
Halecum sp	Prawns
Halecium halecinum	
Hydrallmania falcata	**Mollusca**
Kirchenpaueria pinnata?	**Gastropoda**
Nemertesia antennina	*Acanthodoris pilosa*
Nemertesia ramosa	*Archidoris pseudoargus*
Sertularella gayi	*Calliostoma zizyphinum*
	Crepidula fornicata
Octocorallia	*Doto* spp
Alcyonium digitatum	*Flabellina pedata*
...a verrucosa	*Hinia reticulata*
Hexacorallia (Anemones)	*Janolus cristaus*

Actinothoe sphyrodeta	*Polycera faroensis*
Calliactis parasitica	*Polycera quadrilineate*
Caryophyllia smithii	*Tritonia nilsodhneri*
Epizoanthus couchii	
Sagartia elegans	
Bivalves	**Tunicates**
Aequipecten opercularis	*Morchelium/Aplidium punctatum?*
Anomiidae	*Ascidea virginea*
Clams?	*Ascidia mentula*
Gastrochenaea dubia	*Ascidiella sp*
Pecten maximus	*Botryllus schlosseri*
	Ciona intestinalis
Bryozoa	*Corella parallelogramma*
Alcyonidium cf *diaphanum*	*Dendrodoa/Polycarpa scuba*
Bugula sp	Didemnidae indet
Cellaria spp	*Diplosoma sp*
Cellepora pumicosa	*Lissoclinum perforatum*
Crisia spp	*Polycarpa* cf *pomaria*
Flustra foliacea	*Stolonical socialis*
Schizobrachiella sanguinea	
Securiflustra/Chartella	**Fish**
	Callionymus sp. ?*lyra* (Dragonet)
Echinodermata	*Ctenolabrus rupestris* (Goldsinny)
Asterias rubens	*Diplecogaster bimaculata* (Two-spotted clingfish)
Astropecten irregularis	*Gobius niger* (Black goby)
Ophiura albida	*Parablennius gattorugine* (Tompot Blenny)
Ocnus lactea	*Pomatoschistus* spp (painted & sand gobies)
Thyone roscovita	*Scyliorhinus stellaris* (Bull huss)
	Solea solea (sole)
	Zeugopterus punctatus (Topknot)