

## Further reading on the studies of marine life and habitats around Lundy Island

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English Nature, 1994. *Managing Lundy's wildlife: a management plan for the Marine Nature Reserve and Site of Special Scientific Interest*. Peterborough. English Nature

Eno, N C, 1992. *Lundy Marine Nature Reserve littoral monitoring report, 5-9 October 1991*.

Peterborough. Joint Nature Conservation committee Report  
Fowler, S L & Pilley, G M, 1992. *Report on the Lundy and Isles of Scilly marine monitoring programmes: 1984-1991*. Peterborough. English Nature Research Report No 10.

Hiscock, K, 1983. *Lundy Marine Nature Reserve management plan*. Unpublished

Irving, R A (Ed.), 1995. *Report of the Marine Conservation working party to the Lundy Marine Nature Reserve, 3-10 June 1995*. Unpublished

Marine Conservation Society – Marine Reserves  
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The 'Seasearch' project – A national project using recreational divers to survey the marine flora, fauna and habitats of the British Isles seabed  
[www.seasearch.org](http://www.seasearch.org)

There are also a number of unpublished reports from survey dives carried out by the Seasearch project which may be available from the Marine Conservation Society or the National Seasearch co-ordinator.

This paper was due to be presented at the Porcupine Marine Natural History Society meeting in Bournemouth, 20 March 2004, but due to technical difficulties on the day, it was not. However, it was published in the Society's Newsletter, and should be referred to as:

Irving, R.A. 2004. *Leptopsammia pruvoti* at Lundy – teetering on the brink? Porcupine Marine Natural History Society Newsletter, 15: 29-34.

## ***Leptopsammia pruvoti* at Lundy – teetering on the brink?**

Robert Irving

### ABSTRACT

In the UK, the sunset cup coral *Leptopsammia pruvoti* is a species of particular marine natural heritage importance: it is nationally rare and has its own Biodiversity Action Plan (BAP). As a Mediterranean-Atlantic species, *L. pruvoti* is at the northern extreme of its range at Lundy. In south-west Britain, it is also found in the Isles of Scilly, off Plymouth Sound, in Lyme Bay and at Portland Bill. Of concern, however, is that there seems to be very little new recruitment to the present populations in south-west Britain and the number of individuals is declining. A population of *L. pruvoti* re-photographed at Lundy on an annual basis between 1983 and 1990 was found to have lost 8% of its individual corals, and between 1984 and 1996 part of this same population had declined by 22%.

A number of possible factors affecting this decline are considered. *L. pruvoti* is thought to be slow-growing and long-lived. Recruitment (i.e. the successful production and settlement of larvae) is likely to be slow for a population at the limit of its distribution, with failure probably due to the water temperature being unsuitable for promoting gamete production and/or the synchrony of gamete release. Fertilised eggs have been found to survive for up to six weeks in aquaria, though planula larvae are likely to settle close to the adults within 24 hours. Besides the difficulties of recruitment, a number of organisms have been identified as possibly being responsible for the decline in the adult population. In particular, it is thought that certain boring organisms are capable of weakening the attachment of the adult skeleton to the substratum, increasing the likelihood of it becoming detached from the rock surface.

### INTRODUCTION

The sunset cup coral *Leptopsammia pruvoti* is a Mediterranean-Atlantic species of particular marine natural heritage importance in the UK: it is nationally rare and since 1999, it has had its own Biodiversity Action Plan (UK Biodiversity Group, 1999). However, in spite of this 'important' status, there has yet to be any significant improvement in the measures required to ensure its continued presence in British waters. It remains unprotected under any UK or European legislation.

### DESCRIPTION AND HABITAT

*Leptopsammia pruvoti* is a scleractinian stony coral, typically found growing as single individuals or as 'pseudocolonies' (i.e. where a number of individuals are attached at their bases). Although the calcareous skeleton (or corallum) of the coral is described as being external, it is typically hidden from view by the bright yellow soft tissue of the polyp. The corallum is porous and grows as an inverse cone in shape, circular in young individuals though becoming more oval with age. Its distal end (from where the polyp's tentacles extend) reaches 17 mm in width, and it grows to 60 mm in height (Manuel, 1988). This is noticeably taller than the more common Devonshire cup coral

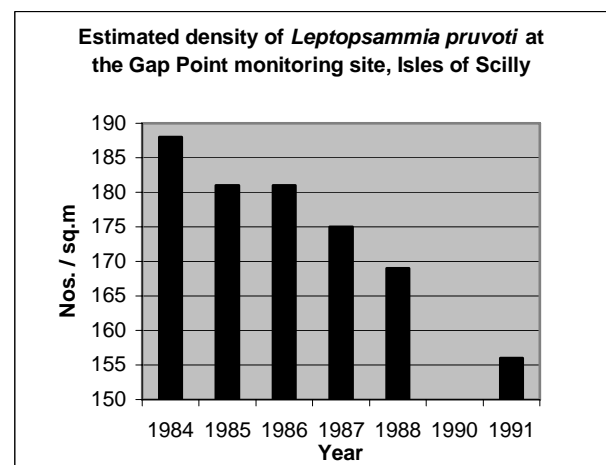
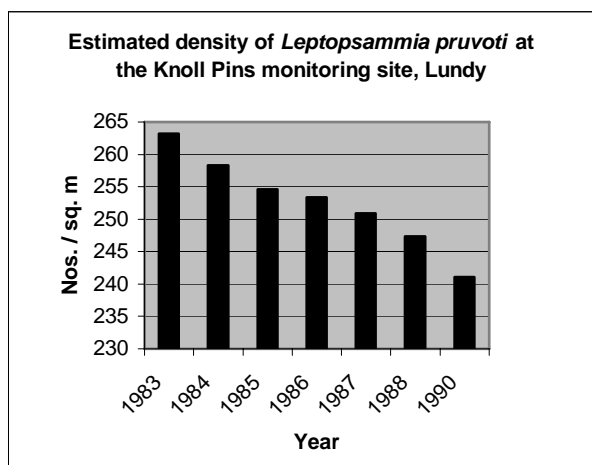
*Caryophyllia smithii*, which has a maximum height of just 15 mm (Manuel, 1988). *L. pruvoti* is found on shaded, bedrock habitats, such as on the underside of overhangs, in gullies or in caves, on open coast locations preferably in the lee of prevailing winds (Jackson, 2003). It typically occurs within the depth range of 10 to 30 m in this country, though its depth range extends to over 100 m in the Mediterranean (Goffredo *et al.*, in prep.).

## DISTRIBUTION

*L. pruvoti* is at the very northern extreme of its range at Lundy. Its distribution centres on the western Mediterranean, extending northwards along the coast of Portugal, Brittany and the Channel Islands (Sark) to the south-west peninsula of Britain. Besides occurring at Lundy, *L. pruvoti* is also found in the Isles of Scilly, off Plymouth Sound, in Lyme Bay and at Portland Bill. It has been suggested that these few, isolated populations are ‘relict’ populations – all that is left of an historically much wider distribution – managing to survive because of localised ‘ideal’ conditions (Jackson, 2003).

### LEPTOSAMMIA PRUVOTI AT LUNDY

Sunset cup corals appear to be restricted to the northern half of the east coast of Lundy, wherever suitable habitat occurs between 8 – 32 m depth (below chart datum). Based on surveys undertaken by Marine Conservation Society divers in the late 1990s, the total *Leptopsammia pruvoti* population at Lundy is estimated as being in the region of 1000 to 1200 individuals (Irving & Northen, in prep.). These are mostly to be found off the island’s NE coast, though recently a location off the west coast with about 100 individuals has been recorded (K. Hiscock, pers. comm.). The corals tend to occur in groups, ranging in size from a few tens to several hundred individuals. One such group on the Knoll Pins, numbering at least 250 individuals, was re-photographed on an annual basis between 1983 and 1990, as part of a long-term monitoring study (Hiscock, 1984; Irving, 1990). Over this period of time, annual counts of individual corals from the photographs revealed that 8% of them had been lost (Fowler & Pilley, 1992) (Fig. 1A); and from 1984 to 1996, part of this same population had declined by 22% (Hiscock, 2003). A similar photographic monitoring study was undertaken off the east coast of St Mary’s in the Isles of Scilly over a comparable period of time (1984 - 1991). Although the density of *L. pruvoti* here is considerably less than at Lundy, it was found that numbers of *L. pruvoti* fell during this time by 17% (Fowler & Pilley, 1992) (Fig. 1B).



**Figs. 1A & 1B.** Densities of *Leptopsammia pruvoti* at the Lundy and Isles of Scilly photographic monitoring sites respectively (after Fowler & Pilley, 1992).

It would appear that these findings are the result of death rates within the population far exceeding recruitment rates. The level of new recruitment to the population at Lundy since the early 1980s (and at other *L. pruvoti* sites in the south-west) appears to be very low indeed. Hiscock (2003) believes the level of recruitment over a 13 year period during the 1980s and early 1990s to be less than 1%. Fowler & Laffoley (1992) reported a new recruit to the Isles of Scilly population in 1991 (the first detected during the period of photographic monitoring), presumed to have occurred sometime between 1988 and 1991. In 1998, several very small individuals of between 3-5 mm in diameter were reported from Lundy (Irving & Northen, in prep.). However, as is apparent in the evidence presented in this paper thus far, the numbers of new recruits to these populations are far outweighed by the loss of adult individuals. The obvious consequence of this is that overall numbers are declining.

What cause or causes might be responsible for this decline? Should this decline be expected for a population on the edge of its distribution? Is the cause (or causes) likely to be part of a natural cycle or are there anthropogenic influences at work? And can anything be done to halt the decline?

## REPRODUCTION AND RECRUITMENT

There are several possible factors which may have an influence on the size of the *L. pruvoti* population at Lundy. Although the lifespan of *L. pruvoti* is as yet undetermined, individuals are thought to be slow-growing and long-lived (possibly surviving 100 years or more). However, it is not known at what age an individual reaches maturity. The species is gonochoristic – that is, the sexes are separate. The eggs take two years to develop and they are then brooded by the female (Goffredo *et al.*, 2004). In Mediterranean populations, gonad development increases significantly during December and January, fertilization takes place from February to May, and planulation (the release of the planula larvae, which have a maximum diameter of 1 mm) in June (Goffredo *et al.*, 2004).

Recruitment (i.e. the successful production and settlement of larvae) is likely to be slow and spasmodic for a population at the limit of its distribution, with failure probably due to the water temperature being too low for promoting gamete production and/or the synchrony of gamete release. Optimum water temperatures in the Mediterranean for the successful production of viable larvae are 20-21°C, whereas maximum summer temperatures of water masses affecting the Lundy populations are 17-18°C (Hiscock & Dymond, 1974; Irving & Northen, 1999). Hiscock (2003) reports that adult *L. pruvoti* brought into aquaria have produced viable larvae within a few days (at most two weeks), and he suggests that an increase in sea temperature might be a required stimulus for the production of larvae. Alternatively, it may just be a shock reaction of the adults to the translocation procedure. *In situ*, planula larvae are likely to settle close to the adult within a period of 24 hours, though observations from aquaria suggest that the larval stage may exist for up to six weeks before settling (Jackson, 2003). Apparently, mature adult corals in aquaria are very robust and cope well with extremes of temperature, starvation and slight variations in salinity (K. Hiscock, pers. comm.).

Significantly increased water temperatures in 1989 and 1990 (Fowler & Pilley, 1992) did not seem to result in higher abundances of declining species (including *L. pruvoti*) in the following years, although temperature must have some effect in triggering reproduction, especially for warmer water species (Hiscock, 2003). It may be that these isolated *L. pruvoti* populations in south-west England are reliant on viable larvae being periodically brought from populations further to the south to replenish their numbers. There is some evidence that appropriate warmer water masses move into south-west

England every 25-30 years, a phenomenon known as the Russell cycle (Cushing & Dickson, 1976).

#### HAZARDS FACED BY RECENTLY SETTLED LARVAE

As with many sessile marine organisms, the process of choosing a suitable site for settlement and then becoming properly established is full of dangers. There is a very high risk of becoming devoured by a variety of mobile animals or even other sessile organisms (particularly other anthozoans or hydrozoans). Within the circalittoral rock community of which *L. pruvoti* features, there is likely to be strong competition from fast-growing bushy bryozoans and hydroids in particular, severely reducing access to food particles suspended in the water column. There will also be periodic non-selective browsing by *Echinus esculentus* sea urchins and other grazers (see below), though for sea urchins such grazing will be reduced where the rock face is overhanging.

#### POSSIBLE CAUSES OF ADULT LOSS FROM POPULATIONS

The decline in the numbers of adult *L. pruvoti* from the monitoring site at the Knoll Pins on Lundy may be due to a number of causes, several of which are discussed below.

**Ballan wrasse *Labrus bergylta*.** These fish are frequently observed in the same habitat and depth range of *L. pruvoti*. They are known to feed on molluscs (particularly mussels) and crustaceans, including crabs and even barnacles. As well as their 'normal' teeth, there is a set of powerful crushing teeth in the throat which enable the fish to tackle such rough fare (Dipper, 2001). Unwanted or indigestible material is passed out through the gill openings or the mouth. A diver may witness a ballan wrasse taking a mouthful of faunal turf growing on a rock face, presumably targeting a specific species of crustacean or mollusc. It seems quite likely that individual *L. pruvoti* corals may become collateral damage from such attacks from time to time. Indeed the author has photographic evidence of the crushed yellow remains of a *L. pruvoti* coral at the foot of a cliff face, likely to have been the victim of such action.

**Accidental contact from inanimate objects or other organisms.** Individual corals could become dislodged (albeit inadvertently) by the dropping or lifting of anchors, shot lines or fishing pots (all of these activities are prohibited in the vicinity of the Knoll Pins at Lundy, but they still occur from time to time); by the fins of divers undertaking awkward movements; or even by the fins of grey seals, though this last suggestion seems fairly unlikely.

**Epizooic barnacle *Boscia anglica*.** This barnacle is frequently found growing on the corallum of scleractinian corals, especially the Devonshire cup coral *Caryophyllia smithii*, usually at the margin of the calyx. Hiscock & Howlett (1976) estimated 30-50% of *Caryophyllia smithii* corals in south-west Britain as having *Boscia anglica* attached. The barnacle has also been found on *L. pruvoti* at Lundy, not just around the margin of the calyx but also attached to the column. Manuel (1988) points out that the exact nature of the relationship between the barnacle and its host species is unknown – the barnacle may cause irregular septal growth of the coral, but otherwise the coral appears to suffer little inconvenience. It would seem probable, however, that with as many as eight barnacles present (the maximum number observed on one individual coral in 1999 at the Knoll Pins), there would be considerable competition for planktonic food. In 1999, of 138 *L. pruvoti* corals inspected at the Knoll Pins, 56% had one barnacle attached to them and 10% had three or more barnacles attached to them (Irving & Northen, in prep.).

**Boring organisms.** A number of boring organisms are capable of weakening the attachment of the adult cup coral skeleton to the substratum. The chief suspect here is

the horseshoe worm *Phoronis hippocrepia*, which was first recorded at Lundy in 1995, being associated with limestone cannonballs found on the Gull Rock wreck site (Irving *et al.*, 1996). In 1998, *P. hippocrepia* was found to be present around the base of 9% of the *L. pruvoti* cup corals inspected at the Knoll Pins, and 7% of those inspected at Gannets' Rock pinnacle (Irving & Northen, in prep.). A number of dead skeletons of both *L. pruvoti* and *C. smithii* were located within the silt at the foot of walls where these corals were growing, both of which had evidence of small tunnels bored into their bases by horseshoe worms.

Although other boring organisms are reported to infest cup coral skeletons, such as the sabellid fan worm *Pseudopotamilla reniformis* or the wrinkled rock borer *Hiatella arctica* (Jackson, 2003), there is no evidence to date of these being found at Lundy.

**Painted topshell *Calliostoma zizyphinum***, an algal grazer, has been observed feeding on *Balanophyllia regia*, a similar coral species to *L. pruvoti*, in an aquarium (K. Hiscock, pers. comm.). This gastropod has also been reported feeding on a snakelocks anemone *Anemonia viridis* in an aquarium (Manuel, 1988), though this observation was qualified as likely to have been an exceptional instance, possibly caused by a lack of its normal food. It is suggested here that *Calliostoma* may well become an opportunistic feeder when unable to graze on algae, but that *L. pruvoti* would be an exceptional and unlikely prey species *in situ*.

## CONCLUSIONS

It is clear that the population of *Leptopsammia pruvoti* cup corals at Lundy has recently been in decline. Numbers appear to be falling at an alarming rate. Accurate measurements of the number of adult individuals were made by contractors working for the Nature Conservancy Council between 1984 and 1990. Subsequent photographs taken by Dr Keith Hiscock in 1996 confirmed that the downward trend in numbers was continuing (Hiscock, 2003). The same situation also appears to hold true for the *L. pruvoti* population at Gap Point in the Isles of Scilly over a similar period of time. Very little recruitment of new individuals at either site appears to have taken place during this time. More recent studies at Lundy, utilising volunteer divers, have concentrated on providing a figure for the total population size (estimated as being in the region of 1400 - 1500 individuals) and in assessing the possible causes of the decline in numbers.

The main target for the UK Biodiversity Action Plan for *Leptopsammia pruvoti* is to "maintain the distribution and the size of known viable populations" (UK Biodiversity Group, 1999). Clearly, should the decline in numbers be continuing, then maintaining the size of the populations will require some assistance if the target is to be met. Little 'hands-on management' is possible in the wild, but it may be possible to breed viable corals from individuals in aquaria under closely controlled conditions. Such '*in vitro* recruits', if they were able to be transplanted back into wild populations, may make an important contribution to bolstering the size of existing populations or possibly establishing completely new populations. However, the costs of such a breeding programme would have to be weighed carefully against the likely success rate of transplantation. In addition, such 'management by intervention' may prove futile if the environmental conditions *in situ* are not suitable for the survival of transplanted individuals.

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# **PILOT WORK TO REFINE SAMPLING PROTOCOLS FOR MONITORING THE LUNDY ISLAND FISHERIES NO-TAKE ZONE**

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**Final report to:**



**August 2004**

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### PILOT WORK TO REFINE SAMPLING PROTOCOLS FOR MONITORING THE LUNDY ISLAND FISHERIES NO-TAKE ZONE

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## EXECUTIVE SUMMARY:

A program of monitoring is required to assess potential fisheries and ecological benefits of the Lundy Island NTZ. The subjects of interest for monitoring are populations of scallops, lobsters and crabs that were once harvested in the area and species of long-lived, sessile epibiota that were potentially impacted by commercial fishing (*e.g.* erect sponges, Ross coral, pink sea fans, etc.). The aim of the Pilot Study was to plan and trial sampling methods for monitoring these biota.

The Pilot Study trialled two methods for surveying scallop populations. Both used scuba divers to monitor the numbers and sizes of scallops *in situ*; (i) a 'catch per unit effort' (CPUE) method and (ii) a 'catch per unit area' (CPUA) method. Both methods showed that there were already more scallops inside the NTZ than in control sites, but the difference was greatest with CPUA data. The CPUA method also had the advantage that data were more precise (*i.e.* less variable), and therefore provide relatively greater power to detect potential future increases in abundance. Given the time per site required with the CPUA method, a monitoring experiment for scallops has been designed with 12 sites inside the NTZ and 12 sites in an adjacent control location. Each site comprises four 10 x 30 m transects, resulting in 48 replicate transects per site. With this level of replication, however, the NTZ would have to raise scallop densities by 50 % before the effect would be significant statistically.

In regard to long-lived, sessile epibiota, the first aim of the Pilot Study was to identify sites around Lundy that might be usefully compared in any controlled assessment of effects of the NTZ. Prior to the Pilot Study, two candidate monitoring sites were identified inside the NTZ (Brazen Ward and Quarry Bay) and two control sites on the west coast of Lundy (Dead Cow Pt, and St Philips Rock). Reconnoiter dives at these sites confirmed that they had many important species in common and were sufficiently comparable for the purpose of monitoring. The Pilot Study also trialled two methods for surveying long-lived sessile epibiota. In each case, densities of indicator taxa were sampled within a 75 x 75 cm quadrat. The first method placed quadrats randomly along a straight line, the second method used a 'random walk' to place quadrats randomly within an area. The aims of this trial were (i) to find the method that produced the least variance among quadrats and (ii) to collect pilot data to refine the monitoring design. The straight line method produced the least variance

among quadrats in both sites sampled for the pilot study and it was also quicker and more straightforward. The monitoring experiment has been designed to use 8 transects of 10 quadrats in each of the two NTZ sites and two control sites. Eighty quadrats per site provides for approximately maximal precision of density estimates. With this level of replication, however, densities of sessile epibiota would have to increase by 80 % in the NTZ before the effect was significant statistically.

It was planned that lobsters and crabs would be monitored using the same sorts of baited pots as used by commercial fishers. One of the authors (Hoskin) has used this method with success in a study of another NTZ at St Agnes in Cornwall. The scheme devised used potting gear bought specifically for the study and deployed from vessels chartered for the purpose. Because of the costs involved and the perceived low risk of practical failure, the potting experiment was not subject to a practical trial during the Pilot Phase, but was first deployed at full scale. There were 5 locations of sampling for this study. The NTZ, 2 control locations at Lundy Island and 2 more-distant reference locations, one in South Wales (Solva) and one on the North Devon coast (Hartland Pt.). Each location was sampled with 8 strings of 10 pots on 5 consecutive days. Although the potting was done outside of the Pilot Phase and is therefore, strictly speaking, outside the planned scope of this report, interim results are presented here. Experimental potting was a practical success and a scientific success, since it was found that there were approximately three times as many landable sized lobsters in the NTZ compared to any control or reference location.

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# 1 GENERAL INTRODUCTION

## 1.1 Project brief for monitoring the Lundy Island NTZ

English Nature require a scheme of monitoring to test for the following hypothesised effects of the Lundy Island NTZ:

1. The density and sizes (age-structure) of scallops inside the NTZ will increase relative to populations in other control locations at Lundy outside the NTZ.
2. Assemblages of epibiota on subtidal rocky reefs inside the NTZ will change relative to the composition of similar assemblages in other control locations at Lundy outside the NTZ.
3. Numbers and sizes of crabs and lobsters caught by potting in the NTZ will increase relative to numbers and sizes in (i) 'control' locations outside the NTZ at Lundy and (ii) broader-scale 'reference' locations (10s – 100s km away).

## 1.2 Pilot work and experimental design

Since July 2003, pilot work has been underway to plan and refine sampling methodologies for testing these hypotheses. For each hypothesis, the general aim has been to determine a monitoring method and sampling design that represents the optimum compromise between the following needs:

1. The need for monitoring to be scientifically and technically sound (*i.e.* use methodologies of known or demonstrable reliability);
2. The need for monitoring to have adequate statistical power to detect sizes of effects that could realistically occur as a result of the NTZ;
3. The need for monitoring to be practically achievable;
4. The need for monitoring to be financially achievable within the agreed budget.

This pilot work involved desk-based planning combined with field-work at Lundy Island to trial methodologies and collect 'pilot data'. Diving surveys (for rock epibiota and scallops) were piloted on Lundy between May 22<sup>th</sup> and 27<sup>th</sup>. It was not originally intended that pilot-work would include a practical trial of the potting survey for

lobsters and crabs. This was because we have successfully deployed the relevant methods in previous study of another NTZ at St Agnes in Cornwall (Hoskin 2002). Pilot-work for the potting study of the Lundy NTZ was only intended to involve experimental design, site-selection and logistical planning. At the time of writing this report, however, we had successfully completed the first full monitoring survey for lobsters and crabs (during July 6<sup>th</sup> to 31<sup>st</sup>). Since the results for lobsters were so strikingly positive, it was decided to include them in this report; even they were not strictly pilot-work results.

For the surveys requiring diving, this report summarises the results of pilot-work and presents recommendations for monitoring methods and designs. Methods for surveying scallops are addressed in Section 2 of this report and Section 3 deals with epibiota on subtidal rock habitats. Pilot-work for the potting element of the project and results of the first full survey are presented in Section 4. Each section comprises its own 'introduction', 'materials and methods', 'results' and 'conclusions' sub-sections).

## 2 SCALLOPS

### 2.1 Introduction

Within the British Isles there are two main species that are exploited commercially; *Pecten maximus* and *Aequipecten (Chlamys) opercularis* (Haywood and Ryland 1998). *P. maximus* is found on a range of substrata from fine sand and gravel to a mixture of mud (Mason 1983). The scallop fishery on Lundy Island is one of two commercial fisheries on the island. Since scallop dredging has been banned around Lundy the only human removal of scallops is by divers. On the east side of the Lundy is the recently established no-take zone (NTZ). Assessing the potential benefits of the NTZ requires comparisons of the age structure and density of populations inside versus outside the NTZ. Collecting data on the age structure of populations of *P. maximus* provides an ability to assess the current state of stocks (Jory 2000). Ageing scallops is made possible via growth rings that scallops lay down annually in their shells (Mason 1983, Macleod *et al.* 1985, Allison *et al.* 1994, Beukers-Stewart *et al.* 2003). Although, it is sometimes difficult to determine the exact location of the first growth ring as it is often indistinct (Orensanz *et al.* 1991, Allison *et al.* 1994). Problems can also occur when ageing older scallops (>10 years) as the rings near the edge of the shell are tightly packed and often indistinguishable (Orensanz *et al.* 1991). Age structure can also be studied using size data and knowledge of the size-for-age relationship (Macleod *et al.* 1985). To obtain data on population structure two methods were trialled. First, Catch Per Unit Area (CPUA), which is an area-based approach and second, Catch Per Unit Effort (CPUE), which was a time-based search.

The key objectives of the Pilot Study on scallops were:

1. Provide baseline data on scallop populations inside an outside of the NTZ.
2. Trial two competing methodologies differing in their logistical complexity and data-gathering abilities.
3. Use the data obtained from objective 2 to generate power estimates so that optimised designs can be developed that reliably test hypotheses of differences in population structure.
4. Recommend a sampling method to be used in the main sampling work planned to start in September, 2004.

## 2.2 Materials and methods

**Ageing scallops:** All scallops encountered during the dives were measured *in situ* to the nearest 5 mm. To age scallops without removing from the seabed, it was necessary to determine the size-for-age relationship. This was done separately for scallops inside the NTZ and those outside. For scallops inside the NTZ, this relationship was determined from shells of dead scallops collected on dives. For scallops outside the NTZ, the size-for-age relationship was determined from shells of both live and dead individuals encountered on dives. All shells were cleaned of epibiota and aged from their growth rings (Allison *et al.* 1994).

A two-sample Kolmogorov-Smirnov test was done to test for a difference in age structure between scallop populations inside versus outside the NTZ. Every scallop measured was included in the test regardless of survey method. Histograms were used to visualise the distribution of ages inside and outside of the NTZ. A t-test was done to test for a difference in the average age of scallop populations inside versus outside the NTZ.

### 2.2.1 Sampling methodologies

The Catch per Unit Effort (CPUE) method put no constraint on the area sampled. The available bottom-time of divers was the only limiting factor. For each sampling event, divers swam for 10 minutes in a pre-determined randomly chosen direction. For the purpose of recording data, the 10 minute swim was broken down into two 5 minute blocks. Every scallop seen was measured for width to the nearest 0.5 cm and then returned to the seabed. After 10 minutes, divers swam in a second pre-determined direction for a further 10 minutes, repeating the same sampling procedure. There were 3 replicate dives inside the NTZ and 3 outside the NTZ.

The basic sampling unit for the Catch per Unit Area (CPUA) method was a 10 x 3 m transect. This area was accurately delineated on the seabed using a rigid 3 m uPVC plastic pipe (10 cm diameter) and a 30 m measuring tape. One end of the tape was fixed to the middle of the pipe, the other to the bottom of the divers' shot line. The pipe was swum horizontally along the seabed with one diver on each side (as per

Figure 1). Each diver recorded the numbers and sizes of scallops in their respective half of the transect (*i.e.* each diver sampled a transect 1.5 x 10 m). On each dive, the pair of divers sampled four 10 x 30 m transects in total. This involved swimming two transects, separated by a gap of 10-20 m, on one pre-determined, random compass bearing, then returning to the shot line and repeating the procedure on a second bearing. As with the CPUE method, all scallops encountered within the transect were counted and measured for width to the nearest 0.5 cm. Each dive was considered as one site. There were 3 sites inside the NTZ and 3 outside.



**Figure 1.** Sampling scallop densities using the pipe to establish a transect of uniform width (CPUE)

### 2.2.2 Analysis

Mean densities of scallops inside versus outside the NTZ were compared by analysis of variance (ANOVA). Scallop densities from the CPUA method were converted to the number of scallops per 100m<sub>2</sub>.

CPUE was calculated as per Jory (2000):

$$\text{CPUE} = \frac{\text{No. of scallops measured}}{\text{Dive Duration (mins)}}$$

Dive duration was 10 minutes; this was considered as one CPUE 'transect'.

**Optimising the design for future studies:** Whilst *post-hoc* power analyses are illogical in the context of experiments said to be completed (Underwood 1997), evaluating the power of a comparison for a given effect size and sample size obtained from a pilot study allows for the development of a more effective design for future experiments. Conventionally, 80 % power is considered the minimum acceptable to reliably avoid type-2 error (*i.e.* failure to detect real differences or changes). In the context of the area-based sampling of scallops, we carried out three power analyses. The formal comparison of densities in and out of the NTZ, whilst being a factor in a mixed-model ANOVA, is that of a fixed factor t-test (Underwood 1997) so the procedures in Cohen (1977) were used to qualify the test and establish the power of the comparison of inside and outside the NTZ. We then used the sample size tables of Cohen (1977) to work out the number of samples needed to reliably detect an increase in the population of scallops inside the NTZ. We tested estimates of increase from 0.5 % to 50 %.

The next level of the ANOVA is the test for ‘site’, which is a random factor that examines small-scale spatial variation with NTZ and control locations. We used the random factor procedures in Underwood (1997) to firstly calculate power of the sample size used (4 quadrats in each of 3 sites) in the pilot study. Then, by using measures of existing spatial variation as an estimate of effect size, we obtained the sample size necessary to achieve 80% power in avoiding type-2 error for the null hypothesis of no difference in density between NTZ and control locations. For a given fixed sampling effort, power can be altered by varying the number of sites and the number of transects per site. For instance, one could have a small number of sites, with a large number of replicates per site, or one could have a large number of sites, with only few replicates per site. We used the ‘F-critical’ value (Underwood 1997) to find the allocation of transects per site that optimizes power.

## 2.3 Results

### 2.3.1 Age Structure

For the scallops that were measured and aged in the laboratory, a curvilinear relationship significantly explained the variation in the relationship between age and size. (Figures 1 & 2). The equation for the scallops inside the NTZ was:

$$\text{age} = (0.0407\text{width}^2) + 0.269 \text{ width} \quad (r^2 = 0.928, F_{(2,7)} = 45, P < 0.001)$$

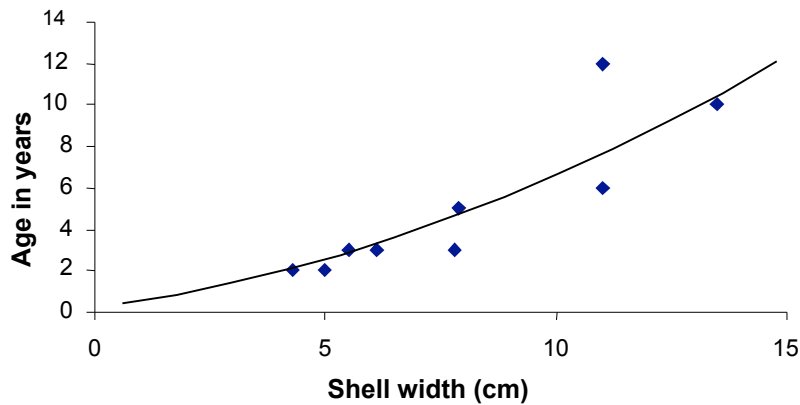
The relationship for scallops outside the NTZ was:

$$\text{age} = (0.071 \text{ width}^2) - 0.268 \text{ width} \quad (r^2 = 0.967, F_{(2,37)} = 548.738, P < 0.001)$$

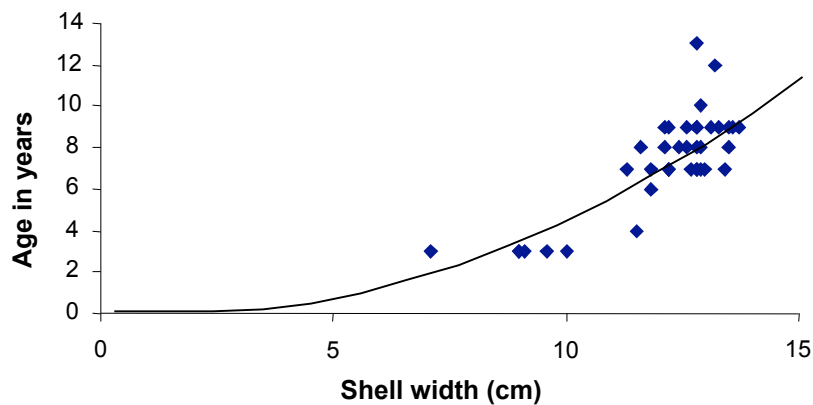
These equations enabled all scallops that were measured during the survey to be aged.

**Figure 2.** Relationship between age and size (shell width) for scallops (A) inside and (B) outside the NTZ

### 2A. Scallops inside the NTZ



### 2B. Scallops outside the NTZ

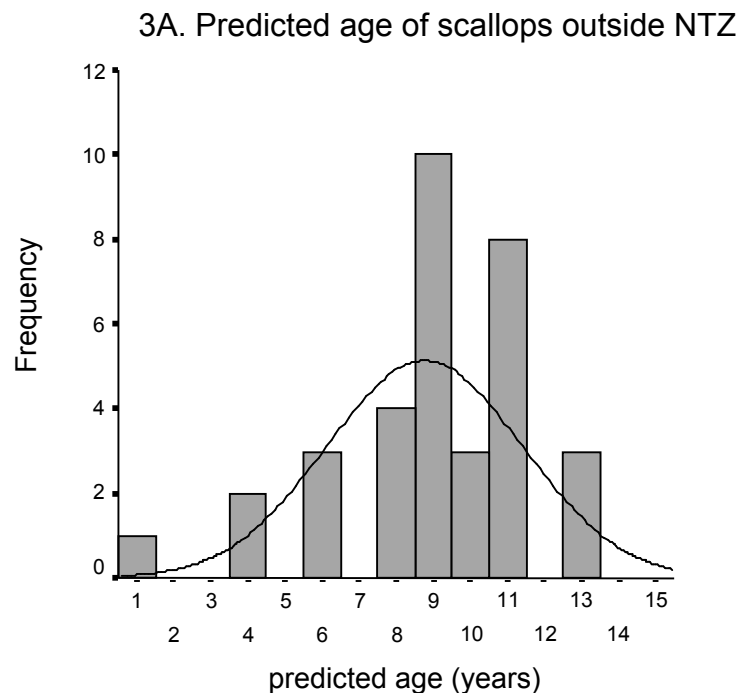


The number of scallops measured inside was greater than that measured outside the NTZ, but there were still clear differences in age structure; *i.e.* different age-frequency distributions (two-sample Kolmogorov-Smirnov test,  $Z_{(160,34)} = 1.149$ ,  $P < 0.05$ ). The actual distribution of scallop ages are shown in Figures 3A and 3B. The mean age of scallops outside the NTZ was 8 years, compared to 9 years inside the NTZ, but this difference was not statistically significant ( $t_{(192)} = 1.615$ ,  $P > 0.05$ ). The oldest scallops found outside the NTZ were 13 years old, compared to 15 years for the

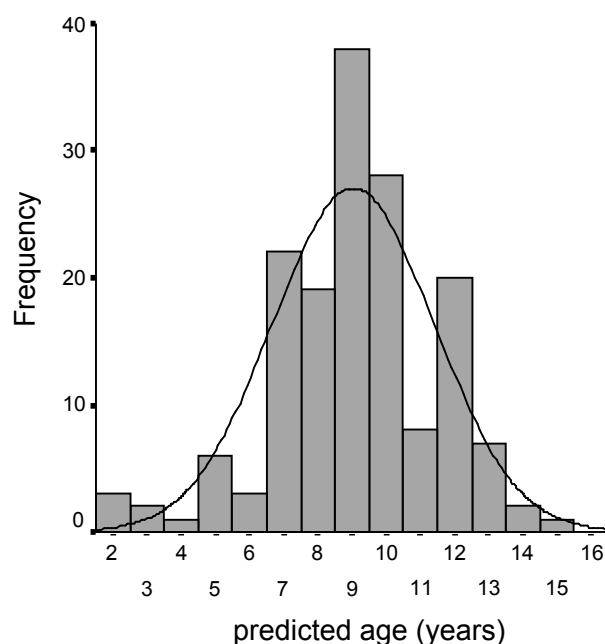
oldest scallops inside the NTZ. Off the coast of Port Erin, scallops have been recorded as having 22 growth rings, but there is uncertainty as to their age. Beyond the ninth or tenth ring in scallops, subsequent rings are close together and hard to distinguish (Mason 1983). The overall trend indicates that, as well as being younger on average, the scallop population outside the NTZ has fewer very old or very young individuals than the population inside the NTZ. This is possibly a result of a bias caused by the smaller total number of scallops measured outside of the NTZ.

For scallops to be harvested they must have a shell width of  $\geq 10$  cm. Using the above regression analyses (Section 2.3.1) it is possible to calculate the age at which the scallops could be harvested. On average, scallops inside the NTZ reach harvestable size after 6\_ years. Outside the NTZ, however, scallops need only live for 4\_ years to reach harvestable size.

**Figure 3.** Predicted age frequency histograms for scallop populations (A) inside and (B) outside the NTZ.



### 3B. Predicted age of scallops inside NTZ



#### 2.3.2 Scallop densities

Both CPUE and CPUT methods showed a greater abundance of scallops inside the NTZ compared to outside.

CPUE measures the rate at which divers encounter scallops and serves as an index of relative abundance. The average standardised CPUE inside the NTZ was 1.48 scallops  $\text{min}^{-1}$  ( $n = 6$ ,  $\text{SE} = 0.11$ ), compared to only 0.45 scallops  $\text{min}^{-1}$  ( $n = 6$ ,  $\text{SE} = 0.06$ ), outside the NTZ. These means were significantly different ( $t_{10} = 5.247$ ,  $P < 0.001$ ).

CPUT data also showed that mean densities of scallops inside the NTZ were significantly greater than those outside the NTZ (see results of ANOVA in Table 1). The mean density inside the NTZ was 7.78 individuals per 100m  $\text{m}^{-2}$  ( $\text{SE} = 1.1847$ ) whereas there were only 1.11 individuals per 100m  $\text{m}^{-2}$  ( $\text{SE} = 0.8541$ ) outside the NTZ.

**Table 1.** Analysis of variance of scallop densities inside and outside the NTZ with 3 sites in each area. Variances were homogenous (Cochran's  $C = 0.41$ , NS)

Source	SS	DF	MS	F	P
Position relative to NTZ	266.7	1	266.73	28.83	< 0.01
Site(Position)	37.0	4	9.25	0.68	> 0.60
Residual	244.5	18	13.59		
Total	548.3	23			

### 2.3.3 Optimising sampling via power analysis

#### Power Analysis for Fixed Factor:

The analysis of the scallop densities inside versus outside of the NTZ had an estimated power of 78 %. Table 2 below indicates that detecting a further 50 % increase in numbers in the NTZ with 80% power, would require around 20 quadrats per treatment. If only a 5 % increase was to be detected, however, more than 1200 quadrats would be needed. This is based on two assumptions, (i) fishing effort  $\geq$  recruitment, and (ii) that the number of individuals inside the NTZ increases at a greater rate than outside the NTZ.

**Table 2.** Power analysis for a test of difference in scallop densities inside versus outside the NTZ.

Mean Density in 2004 (m <sup>-2</sup> )	Potential increases (%)	Potential population in next year	Cohen's (1977) effects size d	Power				
				Replicates needed				
				0.95	0.8	0.75	0.7	0.6
7.78	0.1	7.78778	0.00	>2200	>1200	>1000	>940	>720
7.78	1	7.8578	0.02	>2200	>1200	>1000	>940	>720
7.78	2	7.9356	0.03	>2200	>1200	>1000	>940	>720
7.78	3	8.0134	0.05	>2200	>1200	>1000	>940	>720
7.78	4	8.0912	0.06	>2200	>1200	>1000	>940	>720
7.78	5	8.169	0.08	>2200	>1200	>1000	>940	>720
7.78	10	8.558	0.16	1191.2	680.8	592.4	518.4	397
7.78	20	9.336	0.32	240	140	120	105	81
7.78	25	9.725	0.40	136	78	68	60	46
7.78	33	10.3474	0.53	87	50	44	38	30
7.78	50	11.67	0.80	61	<b>20</b>	31	15	12

## Power Analysis for Random Factor

To determine sampling effort needed to reliably detect natural spatial variation in scallop abundance, three sites were considered and the sampling effort varied at each site. Power analysis indicated that for natural differences among sites to be significant (with a minimum of 80% power), at least 12 quadrats would be needed per site. Assuming 4 quadrats per site and varying the number of sites showed that a minimum of 7 dives would be needed inside and outside the NTZ to achieve 80 % power.

## 2.4 Conclusions

Based on the pilot study at Lundy Island four main conclusions can be drawn.

1. Although the results indicate that there is no significant difference in mean age between inside and outside the NTZ, there were ratio differences based on CPUTA and CPUE methods. Using the CPUTA method there were 7 times more scallops inside the NTZ than outside. Whereas using the CPUE method there were 3 times more scallops inside the NTZ than outside.
2. To establish densities of scallops inside and outside the NTZ only data collected using the CPUTA method can be used. This is because calculating densities using the CPUE model requires knowledge of population dynamic parameters (see Begon, Harper and Townsend 1999). Results have shown that there was a greater density of scallops inside the NTZ than outside the NTZ.
3. It is possible to get very good measures of natural spatial variations within sites with a minimum of effort, using 7 sites and 4 quadrats at each site ( $n = 28$  per site). It is recommended that at least 12 sites are planned to allow for potential unforeseen problems. This will ensure that the comparison of scallop densities between NTZ and control locations will be minimally affected by small-scale patchiness among sites. With this level of replication, however, the NTZ would have to increase scallop numbers by around 50 % before the effect would be statistically significant.
4. Having analysed data and assessed the practical pros and cons of CPUE versus CPUTA (Table 3), we recommend use of the CPUTA method for annual surveys of scallop populations at Lundy.

**Table 3.** The advantages and disadvantages of CPUA and CPUE methods for surveying scallops.

	<b>ADVANTAGES</b>	<b>DISADVANTAGES</b>
<b>CPUA</b>	Area based Standardised for Effort Permits power calculations More reliable, there was an average difference of 1.7 scallops per observer (SE = 0.8)	Logistically complex
<b>CPUE</b>	Simple	Less reliable, there was an average difference of 3.2 scallops per observer (SE = 0.45 ) Less precision When calculating density requires using an assumption of search width measurement, thus more like the CPUA but without precision

On review of the table, it is evident that CPUA is the most useful and appropriate method to use for the main survey to assess the affect of the NTZ on scallop populations.

### 3 EPIBIOTA OF SUBTIDAL ROCK HABITATS

#### 3.1 Introduction

Subtidal rocky reefs are one of the key designated features of the Lundy Special Area of Conservation (SAC) (English Nature 2000). There are two key assemblages within this feature (*i*) the circalittoral kelp and algal assemblages and (*ii*) a deeper assemblage dominated by sponges (*e.g.* *Axinella* spp., *Raspalia* spp.) and sedentary animals *e.g.* the cnidarians *Alcyonium digitatum* (dead man's fingers), *A. glomeratum* and *Eunicella verrucosa*, the bryozoan *Pentapora foliacea*.

In terms of impacts of fishing, a major concern prior to the Lundy NTZ was impacts of shellfish potting on assemblages of sponges and sessile animals. These taxa are slow-growing and long-lived, so they are extremely sensitive to physical disturbance via pots or pot ropes. Continuous potting would be expected to remove or damage existing colonies and limit the potential for growth of new colonies. Whilst reefs at Lundy support important algal assemblages, including several species that are nationally rare (*e.g.* *Zanardinia prototypus* and *Carpomitra costata*), their annual life-cycles and relatively fast growth rates should make them much less sensitive to disturbance from potting. For this reason, it has been decided that efforts to monitor effects of the Lundy NTZ on subtidal reef epibiota should focus on sponges and sedentary colonial animals.

The key objectives for the Pilot Study on sponges and sessile colonial animals were:

1. Identify replicate sites inside and outside the NTZ which support comparable assemblages;
2. Trial two competing methodologies that potentially differ in precision (*i.e.* level of sampling error)
3. Use the data obtained from objective 2 to generate power estimates so that optimised designs can be developed that reliably test hypotheses of differences in abundance.
4. Recommend a sampling method to be used in annual surveys.

## 3.2 Materials and methods

### 3.2.1 Identification of monitoring sites

Using Keith Hiscock's extensive knowledge of dive sites and subtidal habitats around Lundy Island, we were able to identify two candidate monitoring sites inside the NTZ and two sites outside the NTZ that would potentially have comparable assemblages of long-lived sessile epibiota. Local names and map co-ordinates for these sites are given in Table 4.

**Table 4.** Sites inside and outside the NTZ at Lundy that were targeted for observation to assess their comparability in terms of reef epibiota.

Site	Latitude	Longitude
<u>Inside the NTZ/east coast</u>		
Quarry Bay	51 10.719N	004 39.637W
Brazen Ward	51 11.441N	004 39.770W
<u>Outside the NTZ/west coast</u>		
Dead Cow Point	51 10.528N	004 41.023W
St Philip's Stone:	51 11.137N	004 40.861W

On visiting Lundy Island during the pilot field-trip (May 22-27<sup>th</sup>, 2004), one 35-45 minute dive was made at each site to make a rapid visual assessment of the assemblages present. The only data recorded on these dives were the identities of any species of erect sponges and large sessile animals encountered.

### 3.2.2 Trial of sampling methods

Andrew and Mapstone (1984) recommend that the size of sampling unit should be around 1 order of magnitude large than the size of the organisms being counted. On this basis, it was judged that a 75 x 75 cm quadrat was a useful size for surveying the taxa of interest. The methodological issue investigated in pilot trials was whether quadrats should be arranged either randomly along a straight line, or randomly within an area. The decision to compare these two methods was prompted by the concern that, whilst the 'straight line' method was simpler, it might increase the likelihood that the sampler would be inadvertently taken out of the targeted habitat, necessitating repositioning of the transect (and wasted time).

For the 'straight line' method, quadrats were placed at predetermined random distances along each transect. Only quadrats falling on 90-100 % rock habitat were sampled. Where this condition was not satisfied, the diver moved onto the next random position and so on. All transect lines were laid out parallel to the shore, and adjacent quadrats were typically 1-3 m apart. For the area-based method, quadrats were placed according to a predetermined 'random walk'. Each step of the walk was 3 m in the prescribed direction. Each random walk was planned so that the diver was never directed back to an area that had already been sampled. The method also had a rule that steered the diver back into the targeted habitat if they were directed to cross its boundary (*i.e.* up into the algal zone or down on to sand).

For the pilot study, two runs of each sampling method were done in each of two sites inside the NTZ; (i) Quarry Cove and (ii) Brazen Ward. At least 6 quadrats were sampled in each run, however, up to 12 quadrats were sampled on some runs. Having collected data, the methods were evaluated using ANOVA to test for differences in variances among estimates of densities. All other factors being equal, the method yielding the least variance is preferable, because it would increase power to detect significant spatial differences, including effects of the NTZ.

As a prelude to power analyses, ANOVA was used to test whether estimates of density differed between methods. If no difference occurred, the method for placing quadrats could be ignored and data for both methods pooled. This would double the number of replicates available per site and increase the accuracy of any exploration of the relationships between replication, precision and statistical power.

### 3.2.3 *Analysis of precision and statistical power*

To investigate the relationship between precision and the number of quadrats per site, precision (p) of sample data was calculated as:

$$P = 1 - (\text{mean}/\text{SE})$$

For each data set, precision was calculated for random sub-samples of data of size  $n = 2, 3, 4$ , etc. up to the total number of samples. The relationship between sample size and precision was then examined graphically. The shape of the curve provides an approximate indication of whether sufficient samples have been taken to maximise

precision. (*i.e.* minimize sampling error). For any variable, there reaches a point where increased sampling effort fails to yield any appreciable increase in precision.

Power analyses similar to those done for scallops were also done for epibiota of subtidal rock habitats. The purpose of these analyses were to determine numbers of samples needed to detect (*i*) significant natural variation between sites (Quarry Bay vs Brazen Ward) and (*ii*) potential effects of the NTZ. As per scallops, 80 % was taken as the minimum acceptable power for identifying real differences. Power analysis for the random effects of natural variation between sites was done first without quadrats grouped within transects and then with grouping in transects.

Procedures for random effects were used to determine the total number of quadrats that would be needed for means for Quarry Bay and Brazen Ward to be statistically significant (if not already significant with  $n=12$  quadrats). Power analysis for random effects was also done to determine the number of transects needed to produce a significant difference. This was done based on there being 6 quadrats per transect.

Procedures for a fixed effect (the effect of the NTZ) were then done to determine the number of samples per site needed to detect effects of the NTZ ranging in magnitude from 0.1 to 200%. Because pilot sampling of rock epibiota was only done inside the NTZ, this power analysis differed slightly to that for scallops. The difference involved assuming that means inside and outside the NTZ are initially the same. In the absence of data indicating the contrary, this is the safest assumption from which to proceed with power analysis. If sites inside and outside the NTZ were assumed to differ initially, the estimate of sample size needed to detect an additional difference due to the NTZ would be less. Ecologically, it is a reasonable starting assumption given the short time elapsed since cessation of fishing in the NTZ and the generally slow growth rates of sponges. To effect this assumption, mean densities for the two sites were equalised by addition of a constant to data for one site. Importantly, this transformation did not affect the variance of those data, so two independent estimates of variance within sites were retained. It was subsequently assumed that the total variance among all data for two sites inside the NTZ would approximate the variance for one site inside the NTZ and one site outside. This assumption should be sufficiently accurate enough for gauging the order of magnitude of replication needed to detect stated effect sizes due to the NTZ.

### 3.3 Results

#### 3.3.1 Identification of monitoring sites

Initial observations of the two sites inside the NTZ (Quarry Bay and Brazen Ward) and the two sites outside the NTZ (Dead Cow Point and St Philip's Rock) indicated that they were broadly comparable in terms of habitat and the assemblages of sponges and large sessile animals present.

Physically, the two most important differences were (i) that control sites on the west coast were approximately 5 m deeper than sites inside the NTZ (~20-25 m vs 15-20 m average depth respectively) and (ii) control sites were characterised by bedrock outcrops whereas those inside the NTZ were dominated by large boulders (~ 1m diameter). Boulders on the east coast appeared equally viable habitat for long-lived epibiota as the bedrock of the west coast, probably because of the relatively sheltered conditions there.

As can be seen from Table 5, these four sites had many important species in common, including the sponges *Axinella dissimilaris*, *Homaxinella subdola*, *Raspalia hispida* and *Cliona celata*, the cnidarians *Alyconium digitatum*, *Eunicella verrucosa* and *Caryophyllia smithii* and the bryozoan *Pentapora foliacea*. Other similar, related species were present in at least 3 of the four sites. Based on the similarity of these assemblages, it was concluded that the four sites targeted could usefully serve as monitoring sites for testing effects of the NTZ.

**Table 5.** Species of erect sponge and long-lived sessile animals observed in a single dive at each of two sites inside the NTZ (east coast) and two sites outside (west coast).

Taxa	Inside the NTZ/ E coast		Outside the NTZ/ W coast	
	Quarry Bay	Brazen Ward	Dead Cow Point	St Philip's Rock
<b>Porifera</b>				
<i>Axinella dissimilaris</i>	+	+	+	+
<i>Axinella infundibuliformis</i>	+	+		
<i>Axinella damicornis</i>	+	+		
<i>Homaxinella subdola</i>	+	+	+	+
<i>Raspalia ramosa</i>	+	+		+
<i>Raspalia hispida</i>	+	+	+	+
<i>Polymastia boletiforme</i>	+	+	+	
<i>Cliona celata</i>	+	+	+	+
<b>Cnidaria</b>				
<i>Alyconium glomeratum</i>		+	+	
<i>Alyconium digitatum</i>	+	+	+	+
<i>Eunicella verrucosa</i>	+	+	+	+
<i>Caryophyllia smithii</i>	+	+	+	+
<b>Bryozoa</b>				
<i>Pentapora foliacea</i>	+	+	+	+
<i>Bugula plumosa</i>		+	+	+

### 3.3.2 Trial of sampling methods

For all species sampled, mean densities were low (typically 0–2 individuals per quadrat), regardless of site or sampling method (Table 6).

**Table 6.** Mean densities (per 75 x 75 cm quadrat) for species of sponge and sessile animals sampled in a trial of two sampling methods; (i) random placement of quadrats along a straight line and (ii) placement of quadrats in two dimensions using a ‘random walk’. N=6 quadrats for each run of each method.

	Mean density							
	Quarry Bay		Brazen Ward		Quarry Bay		Brazen Ward	
	Straight 1	Straight 2	Rand. 1	Rand. 2	Straight 1	Straight 2	Rand. 1	Rand. 2
<b>Sponges</b>								
<i>Axinella dissimilaris</i>	1.50	0.00	2.17	0.67	0.17	0.00	0.00	0.50
<i>Axinella infundibuliformis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
<i>Axinella damicornis</i>	0.17	0.00	0.33	0.00	0.00	0.00	0.17	0.17
<i>Homaxinella subdola</i>	0.00	0.00	0.00	0.00	0.00	0.50	3.00	1.67
<i>Raspalia ramosa</i>	0.00	0.00	0.00	0.00	0.00	0.67	1.00	2.50
<i>Raspalia hispida</i>	0.00	0.00	2.17	0.00	0.83	0.00	2.17	3.50
<i>Polymastia boletiforme</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Polymastia mammilaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
<i>Cliona celata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL SPONGES	1.67	0.00	4.67	0.67	1.00	1.17	6.33	8.67
<b>Cindaria</b>								
<i>Alyconium glomeratum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Alyconium digitatum</i>	0.00	0.00	0.17	0.00	0.00	0.17	0.00	0.00
<i>Eunicella verrucosa</i>	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.33
<b>Bryozoa</b>								
<i>Pentapora fascialis</i>	0.00	0.00	0.33	0.00	0.00	0.17	0.00	0.17

Because of low densities for individual species, it was decided to compare sampling methodologies in terms of a composite variable, ‘total sponges’. This was the only variable that yielded sufficient large numbers to enable meaningful comparisons between sites and methods. Contrary to expectations, the variance among quadrats was greater in both sites when using the random walk method (Table 7), although the difference was not significant statistically (Table 8)

**Table 7.** Average variance in the abundance of 'total sponges' at two sites using straight line and random walk sampling methods.

Method	Average variance among quadrats	
	Quarry Bay	Brazen Ward
Straight line	9.83	9.83
Random walk	11.67	11.33

**Table 8.** ANOVA test of the difference in variance between two methods of estimating densities of total sponges (straight line vs random walk). There were two runs of each method ( $n = 6$  quadrats) in each of two sites within the NTZ.

Source	SS	DF	MS	F	P
Site	0.0556	1	0.0556	0.00	0.9482
Method	5.5556	1	5.5556	100.00	0.0635
Si x Me	0.0556	1	0.0556	0.00	0.9482
RES	46.5556	4	11.6389		
TOT	52.2222	7			

The straight line produced marginally smaller variances among quadrats and was also much more straightforward to use. On average, the straight line method allowed for 12 quadrats per dive, whereas the random walk method allowed for just over 9. This was mainly due to the random walk's more-complex, time-consuming method for re-positioning the quadrat in the event of it falling on non-target habitat. Since there was also no effect of method on sponge densities (Table 9), it was concluded that the straight line method was the better method for the main survey.

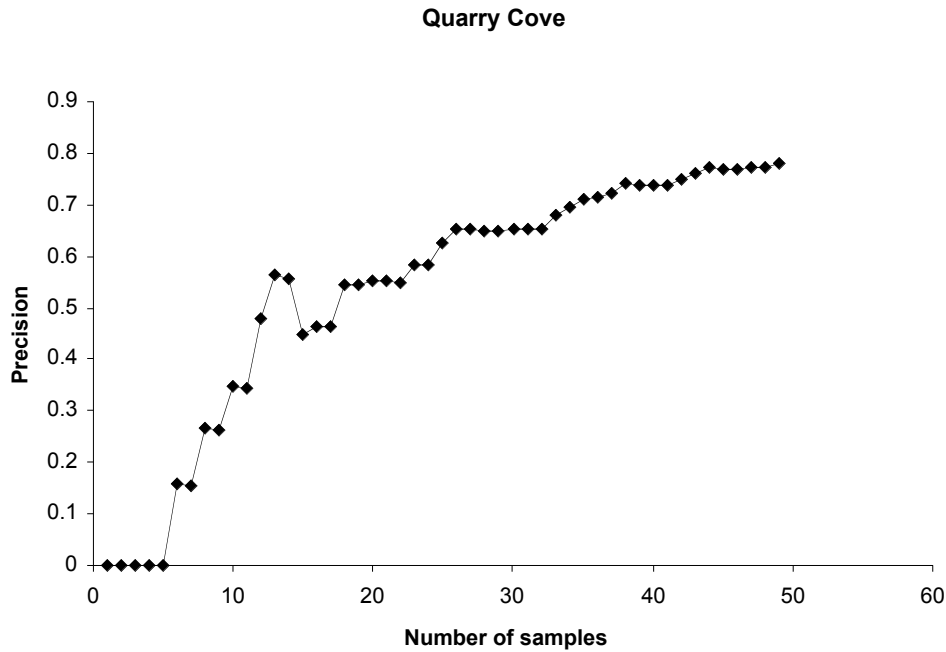
**Table 9.** Analysis of variance for densities of total erect sponges. The analysis compares densities in  $n=6$  quadrats collected by two methods for placing quadrats (straight line vs random walk) at each of two sites within the NTZ. Two transects of each method were done in each site. Variances were homogenous (Cochran's  $C = 0.3386$ , NS)

Source	SS	DF	MS	F	P
Site	77.5208	1	77.5208	4.26	0.1079
Method	204.1875	1	204.1875	3.24	0.3228
Tr(SiXMe)	72.7500	4	18.1875	2.53	0.0553
SiXMe	63.0208	1	63.0208	3.47	0.1362
RES	287.5000	40	7.1875		
TOT	704.9792	47			

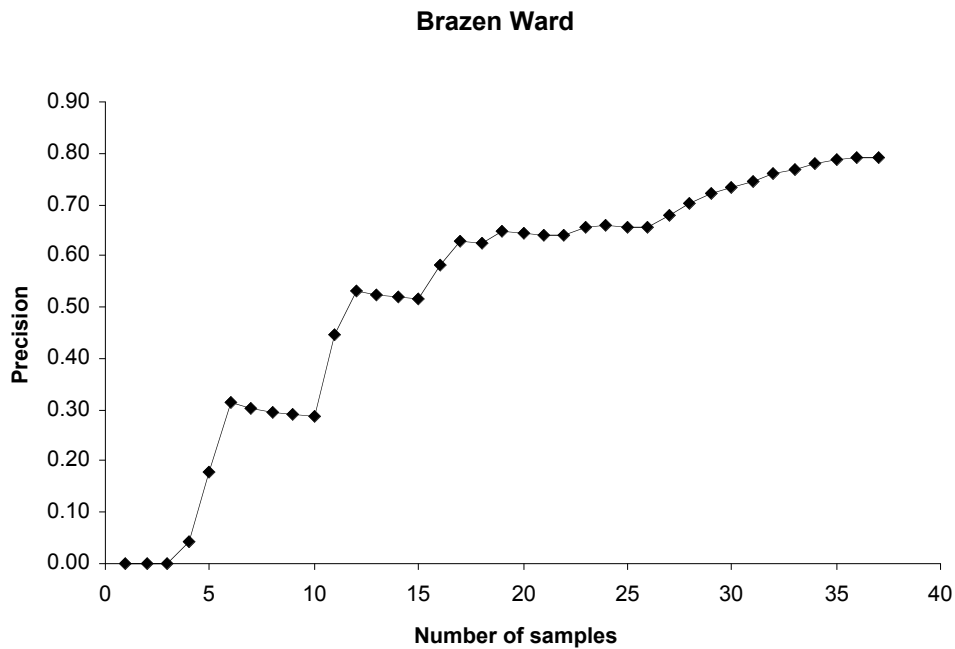
### 3.3.3 Analysis of precision and statistical power

Since ANOVA tests showed no statistically significant effect of method (straight line vs random walk) on mean sponge density or its variance (Table 9), data for the two methods could be pooled for the purpose investigating the relationship between sample size and precision. After pooling, there was a total of 49 replicate counts of total sponges for Quarry Bay and 37 for Brazen Ward. Plots of sample size versus precision for Quarry Bay (Figure 4a) and Brazen Ward (Figure 4b) show that precision showed a close approach to the asymptote in both cases; *i.e.* beyond ~40-50 quadrats/site, there is very little appreciable gain in precision. With the sample sizes available, the maximal precisions attained are almost identical for Quarry Bay and Brazen Ward (78 % and 79 % respectively).

**Figure 4a.** Relationship between sample size and precision of estimates of mean density of total sponges at Quarry Cove (using a 75 x 75 cm quadrat).



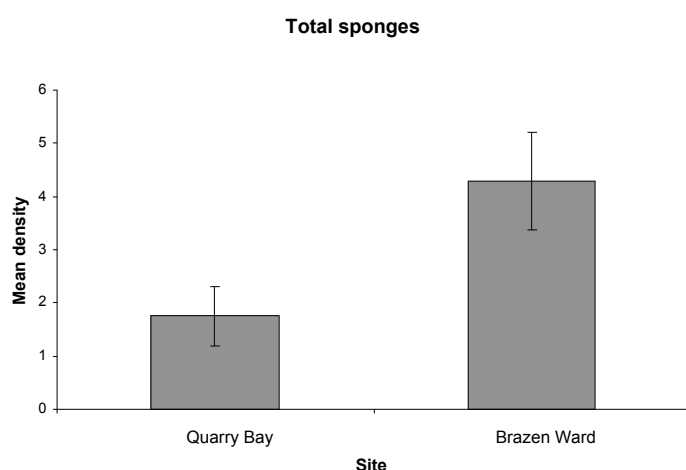
**Figure 4b.** Relationship between sample size and precision of estimates of mean density of total sponges at Brazen Ward (using a 75 x 75 cm quadrat).



### Power analysis for a random factor

The magnitude of replication needed to approximate maximum precision (40-50 quadrats per site) is similar to that needed to provide 80 % power to detect real natural differences between sites. Based on 4 transects per site and 6 quadrats per transect (24 quadrats per site), mean densities ( $\pm$  SE) of total sponges were 1.8 ( $\pm$ 0.6) at Quarry Bay and 4.3 ( $\pm$ 0.9) at Brazen Ward (Figure 5). With the number of quadrats available, this difference was non-significant. Power analysis determined that finding this difference significant with 80% power would require either 61 ungrouped quadrats per site or 48 quadrats arranged in 8 transects of 6 quadrats. So, with quadrats in transects, fewer quadrats per site are needed to find significant natural differences among sites.

**Figure 5.** Mean density of 'total sponges' at two sites on the east coast of Lundy Island.



### Power analysis for a fixed factor

Power analyses for potential effects of the NTZ show that the upper level of replication contemplated thus far, approximately 60 quadrats per site, would only provide adequate power (80 %) to detect a doubling in the density of total sponges (*i.e.* a 100 % increase). Doubling the level of replication to ~120 quadrats would provide power to detect a 75 % increase in density.

**Table 10.** Results of a 'fixed effects' power analysis to determine levels of replication (numbers of quadrats) needed to detect different sized effects of the NTZ on densities of 'total sponges'.

Mean density in NTZ in year 1	% increase	Putative mean in NTZ year 2	Cohen's effect size 'd'	Power				
				Replicates needed				
				95 %	80 %	75 %	70 %	60 %
1.75	0.1	1.75	0.000	>2200	>1200	>1000	>940	>720
1.75	1	1.77	0.005	>2200	>1200	>1000	>940	>720
1.75	5	1.84	0.023	>2200	>1200	>1000	>940	>720
1.75	10	1.93	0.05	>2200	>1200	>1000	>940	>720
1.75	25	2.19	0.11	2003	1144	995	871	667
1.75	50	2.63	0.23	452	258	225	197	151
1.75	75	3.07	0.34	199	114	99	87	67
1.75	100	3.50	0.45	112	<b>64</b>	56	49	38
1.75	150	4.38	0.68	48	28	25	21	16
1.75	200	5.26	0.90	29	17	15	13	10

### 3.4 Conclusions

1. Quarry Bay and Brazen Ward inside the NTZ and Dead Cow Point and St Philip's Rock outside the NTZ have sufficient common taxa of large, sessile epibiota that they could usefully be compared to assess potential effects of the NTZ.
2. The straight line method for placing quadrats is preferable to the random walk because it is easy, quicker and generally produces smaller variances in estimates of density (providing greater power to detect effects of the NTZ, if they occur).
3. Given four sites (two inside the NTZ and two outside) and the total numbers of dives planned for the main epibiota survey in September (32) it should be possible to collect data for at least 80 quadrats per site.
4. Based on data for total sponges, 80 quadrats per site would be sufficient to provide maximum precision of estimates of mean density per 75 x 75 cm quadrat. It would also allow for reliable detection of significant natural differences among sites. 80 quadrats per site would, however, only provide adequate power to detect an effect size of ~80-90 % due to the NTZ, if it occurred.

5. Although there was insufficient time to fully trial the methodology, it is also planned that photographs will be taken during transect surveys to allow monitoring of the sizes of pink sea fans. Quadrats to sample large epibiota will also be sub-sampled photographically to allow monitoring of smaller epibiota that might be missed during diver counts, including recruits of important long-lived species.

## 4 LOBSTERS AND CRABS

### 4.1 Introduction

A major obstacle to the setting up of the Lundy NTZ was the opposition of commercial lobster and crab potters. One argument attempted upon them to overcome their opposition was that they would benefit from NTZs via improved catches in neighbouring areas. This assumes that the absence of fishing mortality will cause lobsters and crabs to increase in size and number within the NTZ. It then assumes that this will enhance stocks in outside areas via either adult migration and/or planktonic dispersal of reproductive propagules. Having made this argument, it is necessary to test the hypothesis that the NTZ causes lobsters and crabs to increase in number and size. It was decided that this would be best done via experimental potting rather than direct observation by divers. Because crabs and especially lobsters are very cryptic, diving would require prohibitively expensive amounts of dive-time to gather adequate data. Another advantage of a potting study is that it should have far more credibility with fishermen.

During the Pilot Phase, a program of experimental potting was designed to test potential effects of the Lundy NTZ on sizes and abundances of:

1. Lobster (*Homarus gammarus*)
2. Brown crab (*Cancer pagurus*)
3. Spider crab (*Maja squinado*)
4. Velvet crab (*Necora puber*)

It was also decided that the sex of each individual lobster and crab should be recorded as an ‘exploratory variable’; *i.e.* a variable that theoretically could respond to the NTZ, but for which potential mechanisms of response have not been proposed. Other exploratory variables were (i) numbers & identities of taxa appearing in pots as by-catch, (ii) the numbers of lobsters and brown crabs with missing limbs and (iii) the numbers of berried (egg-bearing) lobsters.

In addition to planning monitoring to investigate potential effects of the NTZ on lobsters and crabs, a parallel study was planned to test an important assumption of the potting methodology. That is, that in all locations sampled, there is the same

relationship between the relative abundance of lobsters and brown crabs (as estimated via potting) and their absolute abundance; *i.e.* that differences in relative abundances between locations reflect proportionate differences in absolute abundance. If the relationship between relative and absolute abundance varies substantially among locations, this would complicate any comparisons among locations to assess the effect of the NTZ. There are a number of reasons why two areas of the same size might have the same absolute abundance, but produce different relative abundances. For instance, relative abundance of lobsters might be suppressed in an area where an over-abundance of their predators reduces the average distance and duration of feeding excursions. Alternately, these aspects of feeding might be affected by seabed topography, the degree of wave-exposure (potentially related to depth) and/or the average size of populations.

## 4.2 Materials and methods

### 4.2.1 Locations of sampling

The program of experimental potting was designed to allow comparisons between the Lundy NTZ and non-NTZ locations at both small (< 1 km) and large (10-100 km) spatial scales. At the smallest scale, there were comparisons between the NTZ and two 'control' locations at Lundy Island. At the larger scale, there was an additional comparison between the NTZ and two 'reference' locations, one on the North Devon coast (near Hartland Point) and another on the coast of Pembrokeshire, South Wales (near Solva). At all locations, the planned sampling areas were approximately the same size as the NTZ at Lundy. During the Pilot Phase, it had initially been intended to have a third reference location near St Ives in Cornwall, but this was abandoned because of bad weather during the planned 'window' for work there. It may have been possible to re-schedule potting there, but because of various unanticipated costs for other parts of the study, it was decided to suffice with two reference locations.

### 4.2.2 Practicalities of experimental potting

The plan for monitoring crabs and lobsters involved taking shellfish pots (bought for the project) to each of the different locations and working them from a chartered fishing vessel. The pots selected were 71 cm long 'parlour pots' with 25 cm entrances.

This kind of pot will catch both crabs and lobsters. The alternative, the circular ‘ink well’ pot, is much less efficient at catching lobsters because they can escape from them with relative ease. Pots were baited with salted mackerel, which is cheap, readily available and attracts both crabs and lobsters. For the study, pots were rigged in strings of 10, with approximately 15 metres between each pot. The most pots that could be afforded were 80 per location (*i.e.* enough for 8 strings). Strings of pots, rather than individual pots were the sampling unit for the study. Adjacent pots on a string are close enough that they cannot safely be considered as independent replicates (an important requirement of good sampling practice).

Within each location, 4 strings of pots were allocated to each of two sites. Each site, spanned ~1 km of coastline and there was a gap of 0.5-1 km between sites. Each site spanned. Within each site, strings were set end to end along parallel to the shoreline, with 50-100 m between the end of one string and the beginning of the next. After every haul, each string was re-set in the same general area as it was set on the first day ( $\pm$  10-20 m in any direction).

Whilst NTZ and control locations at Lundy were fished simultaneously during July 25<sup>th</sup>-31<sup>st</sup>, reference locations were fished in sequence beforehand, first Solva during July 6<sup>th</sup> 14<sup>th</sup>, then Hartland Pt., during July 18<sup>th</sup>-24<sup>th</sup>. This arrangement meant that the study could be done with fewer pots in total, which, with a fixed budget, allowed a relatively greater number of pots per location. It is also mean that one team of people could do all the potting, ensuring consistency of method. The potential problem with this approach was that spatial differences among Lundy, Pembrokeshire and Hartland Pt might be confounded with short-term temporal variations due to say, climatic or tidal factors. To counteract this potential problem, each location was sampled on 5 separate occasions over 5-6 days to ensure representative population estimates. Fishermen would normally leave pots 2-3 days before hauling them to maximise catches, so our catches per haul were probably reduced. The advantage of shooting and hauling pots on consecutive days, however, is that it minimises the amount of time pots are left unattended. This greatly reduces the opportunity for tampering. In the potting study of the NTZ at St Agnes, pots were left out for 2-3 days before hauling and there was repeated evidence of fishermen having hauled the pots and removed their catch.

#### 4.2.3 *Methods of data collection*

Sizes of crabs were measured as the greatest carapace width using a Vernier calliper. Sizes of lobsters were measured as carapace length, from the rear of the eye socket to the posterior edge of the carapace. Individuals were sexed based on gross external features. For crabs, the key diagnostic features were the size and shape of the abdomen. For lobsters, it was the shape of the first pleopods (swimmerets) and the structure of the reproductive opening.

The relationship between relative and absolute abundance was investigated via a 'mark-release-recapture' study. At each location, all lobsters and brown crabs caught in the first four days sampling were given a waterproof pen mark to show the day of first capture. Having been marked, all individuals were returned to the same general area from which they had been taken. Whenever a marked individual was recaptured, the day of its first capture was noted and it was given an additional mark indicating the day of subsequent recapture. If the relationship between relative and absolute abundance is similar among locations of sampling, the proportion of recaptures within the total catch should also be similar among locations.

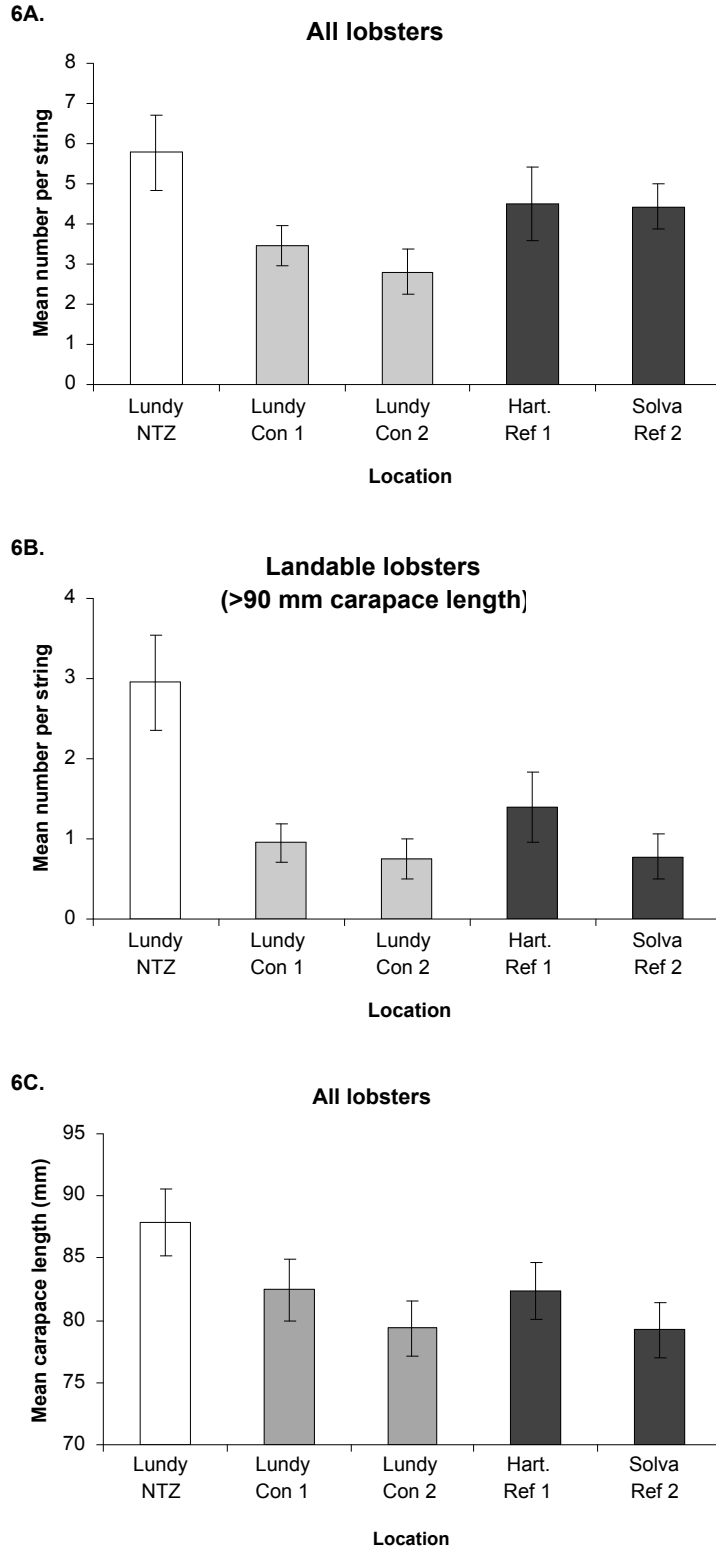
### 4.3 **Results**

The scheme of experimental potting planned during the Pilot Phase was a practical and a scientific success. No problems were encountered that will necessitate major changes in subsequent years of the study.

Given the need to finalise this report on the pilot phase prior to diving surveys (which begins at Lundy on August 31<sup>st</sup>-September 16<sup>th</sup>), there has only been time to do preliminary analyses of data on the numbers and sizes of lobsters. These data were chosen for analysis because lobsters were observed to be conspicuously larger and more numerous inside the NTZ compared to control or reference locations. This was observation was subsequently confirmed (Figure 6). In interpreting the results below, please note that the proper statistical tests have not yet been done to determine the significance of differences among NTZ, control and reference locations. Results are merely presented as a comparison of means.

Lobsters of all sizes were approximately 50% more numerous per string in the NTZ (mean  $\pm$  95 % CI;  $5.8 \pm 0.9$ ) compared to either control or reference locations (overall mean  $\pm$  95 % CI;  $3.8 \pm 0.6$ ) (Figure 6A). The difference was even more pronounced when only legally ‘landable’ sized lobsters ( $\geq 90$  mm carapace length) were considered (Figure 6B). The mean ( $\pm$  95 % CI) number of landable lobsters per string was  $3.0 (\pm 0.6)$  in the NTZ compared to only  $1.0 (\pm 0.3)$  in control and reference locations. Lobsters in the NTZ were also around 7 mm larger, on average, than lobsters in control and reference locations (Figure 6C). The mean carapace lengths for lobsters were 87.8 mm ( $\pm 2.7$ ) in the NTZ and 80.8 ( $\pm 2.8$ ) in control and reference locations.

**Figure 6.** Results for lobsters from experimental potting in the NTZ and two control locations at Lundy Island and two reference locations, Hartland Pt, N Devon and Solva, S Wales. Data are (A) the mean number of lobsters per string, (B) the mean number of landable lobsters (carapace length  $\geq 90$  mm) per string and (C) the mean carapace length of lobsters.



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#### 4.4 Conclusions

1. The scheme of experimental potting planned for monitoring effects of the NTZ on crabs and lobsters was a practical success and requires no methodological change in subsequent years.
2. Initial results indicate that the NTZ has already caused an increase in both the numbers and sizes of lobsters.
3. A planned third reference location in Cornwall was not sampled this year, initially because of bad weather. Sampling at this location could have been re-scheduled, but this was decided against given that certain other costs of the project had proved greater than expected. The possibility of using a third reference location in subsequent years will be explored at the end of this year's work, when all other costs are better known.

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# Procedural Guideline No. 3-7 in situ quantitative survey of subtidal epibiota using quadrat sampling techniques

Eleanor Murray, English Nature<sup>1</sup>

## Background

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Quadrats provide a quantifiable technique for measuring changes in diversity and abundance of conspicuous species. They provide quantitative data that can be analysed statistically, which helps us understand changes in communities in a monitoring context.

Quadrats facilitate accurate abundance measurements of numbers of species, thus reducing the errors incurred by inter-worker variability and achieving more consistent results, in both a spatial and temporal context.

Quadrats are traditionally used for monitoring the distribution of plant species. They are generally large in area, made of string, and laid out using pegs. Such a quadrat is impractical to use for subtidal quantitative sampling, where frame quadrats of 1m<sup>2</sup> or smaller are used.

## Purpose

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Quadrats are generally used for the quantitative assessment of biodiversity for a particular feature occurring within a site. The objective generally relates to the quality of a particular feature or biotope, where species richness may be an important or valued attribute of that feature.

Quantitative counts using quadrats provide a structured way to estimate abundance of species to estimate their population size, and/or to assess species richness and diversity of a biotope. The quadrat provides a simple, repeatable method, which is also suitable for a whole series of statistical tests; this makes it ideal for use in a long-term monitoring strategy. Quadrats are very versatile in terms of shape and size, and can be easily tailored to provide the best application for a whole range of different community types.

Quantitative counts in quadrats can also be used to determine biotopes, but it is generally easier and less labour intensive to use semi-quantitative methods to assign biotopes to particular areas.

It is important to recognise when communities and habitats are not appropriate for monitoring using quantitative quadrat methods. Ephemeral communities may change annually and could not be reliably monitored at the species level on a long-term basis. Similarly, mobile substrata are subject to considerable seasonal disturbance and would be inappropriate to monitor using quantitative methods.

## Advantages

Quantitative sampling by quadrat is advantageous as it:

- is generally non destructive;
- can be applied to a wide range of habitats, is easily repeated, and thus provides consistency to sampling;
- can provide very accurate and precise estimates of abundance;
- does not require any specialist equipment;
- provides a robust dataset for statistical analysis.

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## Disadvantages

The disadvantages include:

- one quadrat size will generally not encompass all of the species being monitored;
- it is time-consuming compared to semi-quantitative or qualitative methods;
- it only samples very discrete areas within a larger feature.

## Logistics

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A pilot survey of the area should be undertaken to identify representative examples of species or biotope, depending on the monitoring objective. For the assessment of species richness within a biotope, areas representative of a biotope encompassing most of the characterising species should be chosen. Where key species are being recorded, a transect or individual quadrat locations encompassing the majority of those species in reasonable numbers should be established.

It is essential that the following steps be undertaken:

- (1) Define the area in which the quantitative sampling will take place. Moore (2000) recommended an area of uniform habitat, e.g. with consistent characteristics of substratum, inclination, water movement and depth.
- (2) Determine community composition of the chosen area by undertaking a broad-scale baseline survey, using MNCR methods<sup>2</sup> or 'by eye' percentage cover estimates.
- (3) Decide which species will be monitored within the quadrat and create a 'pro-forma' to aid quadrat counting.
- (4) Determine what is the most appropriate quadrat size to use, depending on the size of species and community you wish to monitor.

## Equipment

The appropriate transport, navigation and safety equipment is required for undertaking all types of subtidal survey work. The appropriate diving equipment and underwater recording equipment, such as writing boards, underwater communication equipment and cameras (if required) are also necessary to undertake subtidal surveys.

The following additional equipment would also be necessary for quantitative recording work.

### *Species 'pro-forma'*

A list of species should be compiled from the pilot study, including the commonly occurring and characterising species of the community. Moore (2000) recommended that unreliably recorded species not be included, such as cryptic species, very small species, very infrequently encountered species, or ephemeral species that are not characteristic of the chosen community. Mobile species such as crustacea and fish should not be recorded due to their transient nature. There are dangers in adopting this approach, as you are already limiting the assessment of species richness and community information (de Kluijver 1993), and particularly sensitive species groups may be missed: e.g. amphipod species are known to be sensitive to dispersed oil (SEEEC 1998).

Pro-formas should also have space for adding species that perhaps were not recorded during the pilot exercise. They should also provide identification notes for the species which are more difficult to identify in order to aid consistency of recording.

### *Transects*

A transect can be used to help place the quadrats. The transect can be located either randomly or fixed in space; the quadrats can be located randomly the length of the transect, or at fixed positions along its length. Belt transects can be used for the quantitative counts of larger, more widely dispersed species (see Munro 1998; Howson *et al.*). 2000. A transect should be constructed with reasonably thick rope to avoid excessive tangling or knotting and should be weighted or negatively buoyant to prevent it moving in any water current.

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2 See Procedural Guideline No. 3-3.

### *Fixing materials*

If fixed stations are to be used, suitable fixing materials such as ring bolts are needed. The method of fixing to the rock depends on the geology and accessibility of the site.<sup>3</sup>

### *Quadrats*

The design of quadrat will vary depending on the species or biotope to be surveyed. Quadrats are of a known area and may be round or rectangular, but are generally square, as these are easiest to construct, easily subdivided into grid-squares and are most amenable to percentage cover estimates (Kingsford and Battershill 1998). Quadrats can be made of any corrosion-resistant material, but should be neutrally or slightly negatively buoyant. When working in areas of kelp where it is difficult to place a full quadrat on seabed, a quadrat with an 'open' end may be used, where the open end can be 'closed' by a line to make a full quadrat; alternatively a two-sided quadrat may be used, with the position of the other two sides judged by eye.

The size of quadrat will vary depending on the survey objective, and the following conditions:

- (1) The size range and distribution of organisms to be surveyed. This must take into account the fact that the larger, widely spaced organisms may need to be sampled by a different sized quadrat/transect approach. If there is a high species richness, then smaller quadrats should be considered in order to cut down the time of recording within a single quadrat.
- (2) The heterogeneity of the community in terms of species patchiness or variability of substrata. The quadrat should aim to cover a representative range of species/substrata in order to obtain a representative sample of the community.
- (3) The diving conditions: e.g. currents and limited visibility make recording by quadrat difficult, so it may be easier to take smaller quadrats to ease the diver's movement through the water. Depth is also a limiting factor in terms of survey time, and the appropriate size quadrat and counting method should be used in order to enable sufficient replicate samples to be taken in a single dive.

The table below provides guidance on the appropriate size of quadrat for the particular community sampled.

<i>Quadrat size</i>	<i>Community to sample</i>
1m <sup>2</sup>	Areas with widely spaced, larger species and colonies, e.g. seafans
0.25m <sup>2</sup>	Areas with cover of foliose and filamentous algae, e.g. kelp forests
0.1m <sup>2</sup>	Areas of densely packed small, e.g. circalittoral faunal turfs

### *Personnel*

Divers should possess the required diving qualifications to undertake underwater survey work (for the specified requirements, see Holt 1998).

Experienced marine surveyors, who possess the appropriate identification skills, should undertake this work. The workers should be familiar with the community and the species present: it is recommended that they are shown the checklist in advance of the survey so they can familiarise themselves with the species to be recorded. Pre-survey training in estimating percentage cover in quadrats would also be advantageous to ensure consistent records.

## **Method**

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Divers should be fully briefed on how to deploy the quadrat before commencing the survey work. Instructions include the positioning of the quadrat to the relevant marker or transect line, and the rules of what species to count must be established.

In areas where the topography does not vary too greatly, belt transects may be used instead of placing quadrats along a single transect line. These are generally a fixed width and marked into intervals; counts/cover estimates are made in the marked area within the transect.

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3 See Procedural Guideline No. 6-2 for site fixing methods.

### Sampling strategy: how many samples to take?

To achieve an efficient and cost-effective monitoring programme, a minimal sampling strategy must be designed in order to gain the correct amount of information with the least effort. This will vary depending on the biotope/species being surveyed.

To determine the number of samples to be taken, a baseline survey has to be undertaken to preferably over-sample the area to gain enough records to undertake analysis. The number of quadrats to reliably monitor change can be assessed using power analysis. Power analysis is a statistical technique which enables estimates to be made of the number of samples required to detect a given level of change (Snedeker and Cochran 1980).<sup>4</sup>

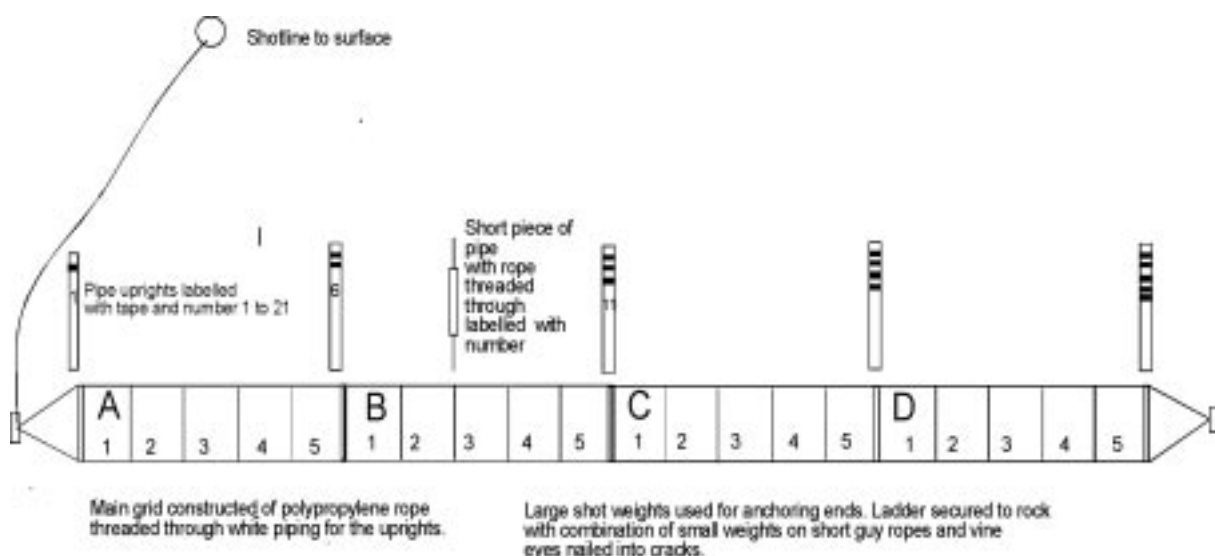
Cumulative species curves can also be used to assess when a population has been sufficiently sampled by a number of quadrats. The cumulative number of species is recorded with each increase in quadrat number until a point is reached when all of the common species have been identified and a further increase in quadrat number will not lead to any further significant increase in species number. Gamble (1984) gave a rough guide to the minimum number of samples as 'that which, if doubled, would yield only a 10% increase in information'.

Kingsford and Battershill (1998) and Moore (2000) recommended that 10 quadrats sampled within a discrete area would give adequate precision to detect notable changes in the whole community. Howson *et al.* (2000) concluded that between 8 and 12 quadrats would be adequate to detect a change in community of between 15 and 20%.

### Sampling strategy: fixed or random quadrats?

In areas where it is difficult to establish fixed locations, random sampling by quadrat may be the most appropriate technique to assess species richness/presence in a monitoring context. Random quadrats have also been used where destructive sampling techniques have been undertaken, e.g. population and condition of seagrass beds (Fowler and Pilley 1992).

The distribution of random quadrats is subject to bias by the worker. It is essential that the placing of a quadrat is not influenced by a diver trying to include a particular species, and it is important to stipulate this prior to sampling. In order to achieve even coverage of an area it may be appropriate to divide the area into compartments, and take random samples within each compartment, or use a randomly placed transect and take random samples along its length. Howson *et al.* (2000) used a 'ladder' transect to aid with randomising quadrats on sublittoral reef communities (see Figure 1). For a full explanation of different methods of randomisation, see Kingsford and Battershill (1998).



**Figure 1** Construction of ladder transect. Each square on ladder measures 1m x 1m (drawing not to scale). To aid orientation by both the divers, the ladder was divided into four blocks, A–D, of five squares, 1–5. Each quarter of a square was a potential position for a quadrat. This enabled random positions to be selected for the quadrat sampling.

<sup>4</sup> A comprehensive review of software for power analysis is available at: <http://sustain.forestry.ubc.ca/cacb/power/review/review.html>

Sites for single quadrats may be established and marked for relocation. A permanent marker for the site should be established (possibly a ring bolt in the rock face) and instructions or photographs for relocation constructed. Relocation time will vary with the quality of this information, and the familiarity of workers with the site. One or a number of the corners of the quadrat should be marked for exact repositioning. Moore (2000) used a permanently fixed transect to locate a number of permanent quadrats.

### Counting in quadrats

The quantity of a species within a quadrat can be assessed either by numbers of individuals, percentage cover or frequency of occurrence. Usually, for most recording schemes, there will be either a mixture of counts or % cover, depending on the species being assessed. The rules for deciding which is the most appropriate technique are given below:

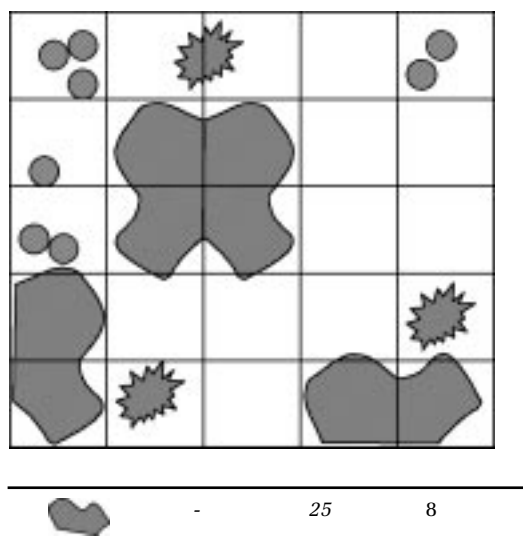
<i>Counts</i>	<i>% Cover</i>
Mobile fauna	Flora and fauna forming crusts, mats or turfs
Sessile animals in low abundance, e.g. cup corals	Other ground-covering sessile fauna in high abundance, e.g. barnacles
Sessile erect animals, e.g. hydroids	Canopy cover of foliose algae
Tall algae, e.g. kelp	

There are exceptions to these rules, which will have to be judged on a species-by-species basis, e.g. small patches of hydroids may be easier to assess using % cover, and uniformly sized sponge colonies may be easier to count.

For smaller quadrats ( $\leq 50\text{cm} \times 50\text{cm}$ ), it is easy to assess percentage cover by eye (de Kluijver 1993), although the accuracy of visual assessment is increased if the quadrat is subdivided into smaller grid-squares (Dethier *et al.* 1993). These smaller squares represent a percentage of the whole quadrat, and the number of squares filled by a single species can be easily counted which will give a percentage for the whole quadrat, with part records from the smaller squares also contributing to percentage cover. This method increases accuracy and may be appropriate where there is a complicated mosaic of species, such as algal turfs, but is much more time-consuming than unaided visual assessment.

Using the gridded quadrat also allows species to be recorded using frequency of occurrence scores. This is where the occurrence of a species within each of the grid squares is counted, giving a 'score' for each species between zero and the maximum number of grid squares. There are advantages in this approach in that it gives a single, simple measure for all species, and is potentially quicker to assess, although Moore (2000) found that the latter was not the case for small  $0.25\text{m}^2$  quadrats. Frequencies are used as an indicator of abundance, and should not be directly related to actual counts or abundance of a particular species.

A diagram representing species counted in a gridded quadrat is given in Figure 2 below.



<i>Species</i>	<i>Count</i>	<i>%</i>	<i>Freq.</i>
	8	-	4
	3	-	4

**Figure 2** Representation of a quadrat with corresponding abundance estimates

## Data analysis

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It is essential that prior to data analysis, the species records are closely scrutinised to eliminate any 'noise' which may affect the analyses. This may involve removing species that are unreliably recorded, e.g. those which are inconspicuous or difficult to identify. Species may be 'grouped' to genus level or higher where there is doubt or some discrepancy between workers as to the identification.

Multivariate and univariate statistics can be used for data analyses. Clustering and ordination methods can look at the variation of replicate samples within a single sampling area, to assess whether sampling had been restricted to a single biotope, and also to assess the variability of the biotope. Packages such as DECORANA and MVSP are very effective at undertaking these analyses. Ordination and clustering methods for community assessment are adequately described in Mills (1994) and Clarke and Warwick (1994).

Multivariate methods can be used to calculate the statistical significance to changes in the whole community (ANOSIM<sup>5</sup>) and highlight the species or suite of species responsible for the changes in community composition (SIMPER<sup>5</sup>). Multivariate techniques are relatively straightforward to interpret as they can present the extent of community change in a single visual graph.

Univariate analyses should be used to assess the significance of any change in the abundance of an individual species, or any changes in the diversity of a biotope. A student's t-test can be used to assess the change in abundance of individual species over time. There are numerous diversity indices that can be used to assess changes in species diversity over time, e.g. the Shannon–Weaver diversity index.

For fully worked through examples of all the statistics mentioned above, refer to Moore (2000) or Howson *et al.* (2000).

## Accuracy testing

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The assessment of abundance within a quadrat may vary between workers; hence recorders must concentrate on giving an accurate assessment of abundance for each organism. Recording protocols must be prescriptive and carefully adhered to by the survey team. It should be written on the survey pro-formas whether an assessment by actual counts, % cover or frequencies should be undertaken for each species. Pre-survey training out of the water may be useful to familiarise the divers with the recording protocols.

For species counts, knowledge of all species to be counted is essential, especially with the more difficult taxonomic groups where there may be similar species within one quadrat. This should be achieved by using experienced surveyors who have been shown the species checklist in advance so that they can familiarise themselves with the species concerned.

An example of a survey protocol for Plymouth Sound is given in Box 1 (from Moore *et al.* 1999).

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5 Both SIMPER and ANOSIM are available as part of the 'Primer' software (see: <http://www1.npm.ac.uk/primer/>).

**Box 1** Recording rules established for Plymouth sound monitoring study  
(from *Moore et al.* 1999)

The primary rule is to ensure that all records are obtained from the same precisely defined habitat. The habitat should be as uniform as possible, i.e. should not include any significant proportion of sub-habitats. This may require the surveyor to exclude or ignore certain sub-habitats (e.g. epiphytes on kelp stipes or the undersides of boulders). The communities present in these sub-habitats may need to be monitored separately; possibly with a different methodology from that used on the main habitat.

A survey duration should be defined. The length of the survey time will depend on the size of the quadrat/transect and on the biotope type. The time spent should be within 10% of the defined time, but the application of this rule will need to take account of the diving conditions. [Note: it should be possible for the diver to set a watch to beep at the end of the defined time.]

Although not proven by the available data, it is considered likely that the quality of the diving conditions will affect the quality of the recorded data. While some environmental factors cannot be controlled, operating rules should specify the threshold conditions for conducting the survey. These should include: available light and clarity of water, water currents, sea state. At the least, a record of the conditions should be maintained. It may also be appropriate to define the required torch beam characteristics (e.g. bright, medium or broad beam torch with fully charged batteries).

A series of rules should also be developed to define the types and forms of animals and plants that need to be surveyed. The abundance of some taxa is very difficult to record with any reliability because of their growth form, mobility or other characteristic. The presence of these taxa in data that are to be analysed quantitatively could reduce the power of the analysis, by introducing a much greater level of recording variability. It should be possible to reduce this variability by eliminating these species from the analysis. It may also speed up the survey if they are not even recorded. Thus, recording checklists should exclude such species and only include species which can be recorded most reliably.

The following species selection guidelines are considered to be appropriate for most situations where the conservation objectives are based on the composition and species richness of seabed communities of conspicuous species.

*Quantitative* monitoring should focus on species/taxa that are:

- sessile; i.e. not mobile like fish, crabs and gastropods. This is mainly because the presence of mobile species in full view (i.e. not hidden in crevices) can depend on factors such as time of day and other very short-term environmental fluctuations.
- attached to or living on the hard substratum surface (i.e. not epiphytic, except on encrusting coralline algae). This is partly to do with defining the sub-habitat, but also because it is often very difficult to estimate abundance of epiphytes.
- adult or near adult (i.e. not juveniles, spat, sporelings or eggs). This is because the presence of large numbers of juveniles etc. are usually temporary and can bias multivariate analyses. Furthermore, the juveniles of some species (e.g. *Metridium senile*) are produced in large numbers and often settle in habitats for which they are not suited; thus they may not survive there and cannot be considered true members of the community.
- easily recorded with the chosen units (i.e. either percentage cover or counts). Thus, if the chosen units are percentage cover (which will normally be the most appropriate) this rule will probably exclude many solitary erect species (in particular, many hydroids). This rule would need to be defined in greater detail for the specific biotope.

Note: it is emphasised that the application of these guidelines should not prevent the surveyor recording other species or taxa, either qualitatively or quantitatively. On the contrary, additional information will often be useful for more subjective and qualitative assessment of the data. However, objective analysis of the quantitative data should be restricted to those taxa that can be recorded most reliably and which are true members of the community.

## QA/QC

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For monitoring purposes, it is essential that sites are relocated accurately to give a continuous accurate dataset. A good map of the site is required, and each quadrat should be given a unique reference, so that time series data for a single station can be easily accessed. In terms of sampling the following rules must be applied:

- (1) Re-survey of a site should take place at the same time of year (if appropriate).
- (2) The same size and shape of quadrat must be used each time.
- (3) The same method of counting species (counts or % cover) should be used each time.
- (4) For random samples, the same number of quadrats across a broadly similar area are to be counted each time.

Survey personnel must familiarise themselves with the fauna and flora of the area, and should undertake an inter-worker calibration exercise before starting the monitoring.

## Cost and time

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A full review of the costs and times involved in subtidal quantitative sampling is given in Moore (2000).

The preparation of a checklist of species and the establishment of recording rules may result in reduced survey time or allow more quadrats to be surveyed in the same number of dives. These benefits must be offset against any additional time for undertaking a pilot study to define appropriate recording rules.

If fixed quadrat locations are used, they reduce the spatial variability element in the data and therefore reduce the number of quadrat records needed to detect any temporal changes. However, this saving must be set against the extra time, and therefore cost, required to establish and maintain the fixed locations. In many locations these costs may be very limited, particularly if it is necessary to mark the site for relocation purposes anyway. However, if there are potential problems with marking the site – e.g. on very mobile mixed substrata or at very popular diving sites – these costs may become excessive.

## Health and safety

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All field staff must follow approved safety procedures published by their host institution, or that of the contracting agency, whichever are the more stringent.

All diving operations are subject to the procedures described in the Diving at Work Regulations 1997<sup>6</sup> and must follow the Scientific and Archaeological Approved Code of Practice.<sup>7</sup>

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<sup>6</sup> The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997. ISBN 0 11 065170 7 (see: <http://www.hse.gov.uk/spd/spddivex.htm>)

<sup>7</sup> Scientific and Archaeological diving projects: The Diving at Work Regulations 1997. Approved Code of Practice and Guidance – L107. HSE Books 1998. ISBN 0 7176 1498 0.

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