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Central Waitemata Harbour - Meola Reef: Ecological Monitoring Programme - 2006 report

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Executive Summary

State of the Environment monitoring of Meola Reef began in 2001, with the objective of tracking long term trends in community composition. These trends were then to be placed into a regional context by comparing them with those of the Long Bay Marine Monitoring Programme (LBMMP). In addition, community changes were to be interpreted with respect to sedimentation and toxic urban discharges, which were considered the major threats to the local marine environment.

Intertidal and subtidal rocky reef communities were monitored at Meola reef. Subtidal sediment traps were also deployed to provide an indication of the amount and composition of water-borne sediments. This report presents the findings of this monitoring from 2001 until the present day.

Intertidal reef communities

The intertidal rocky reef at Meola is largely covered by oysters (*Crassostrea gigas*), bare rock or sediment. These substrate supports a community dominated by small grazing and filter-feeding molluscs (shellfish).

No temporal trends in community structure were detected on Meola reef that suggested ecological change. Spatial patterns of communities were detected on Meola reef and some of these were related to the percentage cover of sediment on the reef. Given the lack of comparable reference sites, it is hard to compare these intertidal basalt reef sites to communities elsewhere. Further investigations into contaminant levels in, and effects on, organisms on Meola reef would assist in establishing the causative mechanisms for some spatial patterns detected on the reef.

Subtidal rocky reef communities

Subtidal sites at Meola reef were characterized by a thin band (at times, no more than a metre wide), of large brown seaweeds. Below this the substrate was a patchy mix of mostly sand, shell hash and rocks covered by encrusting algae. Solitary ascidians (sea squirts) and gastropods (topshells) were the most numerous fauna present.

The most important ecological change detected was an increase in mobile substrates (sand, shell and sediment), on the bed which covered rocks encrusting with algae. This is important as it decreases food availability to reef grazers and stops settlement of juvenile reef fauna and canopy forming algae.

Patterns in faunal composition were detected and many of these were related to the change in currents with distance along (north to south) or across (east to west) the reef. Sediment, as measured by percentage cover of the bed or sediment traps, was also an important factor affecting the distribution of organisms on the reef. There was, however, no evidence to suggest that sediment cover, or the rate of sediment settlement was increasing over time.

Diversity at Meola reef was low compared to the diversity on the open coast from Campbells Bay to Waiwera, north of the Waitemata harbour. This is not surprising, given the small amount of reef present at Meola, and the large amount of fine sediment present on the bed and in the water column, compared with the open coast. The fauna present at Meola reef reinforce the patterns detected in the Long Bay Marine Monitoring Programme. Sites furthest north show the lowest densities of the cat's eye top shell *Turbo smaragdus*, and the highest densities of the seaweeds *Cystophora* sp. and *Zonaraia* sp. This pattern is correlated with reduced wave action and greater sediment loads and turbidity from inner to outer Hauraki Gulf.

2 Introduction

In December 2000 a long-term ecological monitoring programme for the intertidal and subtidal communities at Meola Reef was started. The monitoring programme is designed primarily to (Hewitt 2000):

- Determine trends of community change over time at and within the sites at this location.
- Compare community change over time to that recorded at other sentinel locations within the region.
- Interpret any community changes within the backdrop of the two major threats to estuarine health in the Auckland region:
  - Sedimentation from urban developments
  - Toxicity from urban discharges.

Meola Reef was chosen as one of a number of sentinel monitoring sites because it is a unique environment in the region (Morton and Miller 1968, Hayward et al. 1999) and its location near the mouth of the Waitemata harbour. The only other comparable basaltic intertidal reef in northern New Zealand is at Waitangi in the Bay of Islands (Hayward et al. 1999). The basaltic reef at Meola has been recognized as supporting a richer and more diverse fauna than the nearby Waitemata sandstone reefs (Hayward et al. 1999). The oyster *Crassostrea gigas* was first discovered in New Zealand in 1971 (Cranfield et al. 1998) and studies and photos prior to that show the area was covered in large clumps of the shelly tube worm *Pomatoceros caerulus* (Hayward et al. 1999). However, even in 1968, this reef was recognized as an area where sediment influenced community composition (Morton and Miller 1968). The Waitemata harbour is also affected by urban stormwater contaminants, and monitoring indicates that copper, zinc, and lead levels are elevated in the vicinity of Meola Reef (Williamson and Kelly 2003). The biological communities of the reef therefore reflect the combined influences of natural processes plus sediment and contaminant stress, and competition from invasive species.

This monitoring programme has now been running for 5 years. In this report we comment on any temporal variations in abundance of the more common intertidal and subtidal fauna as well as changes in percentage cover of different substrates and some measures of diversity. Multivariate analysis is used to quantify and characterize change over time and identify rarer taxa that may be contributing to changes. In addition sediment collected in traps from subtidal sites over time and available toxicity information are discussed as possible causative factors for changes seen in the ecology of Meola reef.

A glossary of technical terms used in this report is provided in Appendix A for quick reference. In some cases lengthier definitions will be given within the body of the report.

3 Methods

A detailed summary of all changes in methodology over time in this programme are given in Appendix B.

3.1 Intertidal surveys

This survey aimed to record the number, size, distribution and percentage cover of all benthic macroscopic flora and fauna (>4mm) inhabiting the intertidal reef. Intertidal sampling commenced in December 2000, and was carried out bimonthly until October 2001 (Ford et al. 2001). Yearly data presented in this report is therefore from October of every year, from 2001 onwards. It was recommended in that report that there be a reduction of ~70% in sampling intensity, with three intertidal sites either side of Meola reef (east and west), instead of the five previous sites (2 on the east and 3 on the west) and annual sampling instead of bimonthly sampling. The sampling methods used from 2002 onwards were different to those used previously, being designed around the findings of a power analysis (Ford et al. 2001). In particular, oyster densities were measured at a smaller scale and not all oysters were measured due to their high densities across all sites (Ford et al. 2001).

3.1.1 Site location

Surveys were carried out at 6 Sites (approximately 75 m² each), 3 sites on the East side (MIE1, MIE2 and MIE3) and 3 on the West side (MIW1, MIW2 and MIW3) of Meola reef. (M = Meola, I = Intertidal, E/W = East/West, 1-3 = 1= southernmost and 3 = northernmost site). MIE3 was introduced as a new site in October 2001 due to the recommendations of the previous report (Ford et al. 2001). The GPS location is given for each site (Appendix C) and its position on the reef has been mapped (Fig. 1).

3.1.2 Survey methodology

Within each site 10 permanent quadrat locations (1/4 m^2) were marked on the reef at 2-3m intervals (labelled stainless steel pegs were cemented to the substrate to mark 2 corners over which the quadrat was placed). Thus 60 quadrats were surveyed overall, 30 on each side of the reef. The approximate position of each quadrat was mapped for all sites (Appendix D).

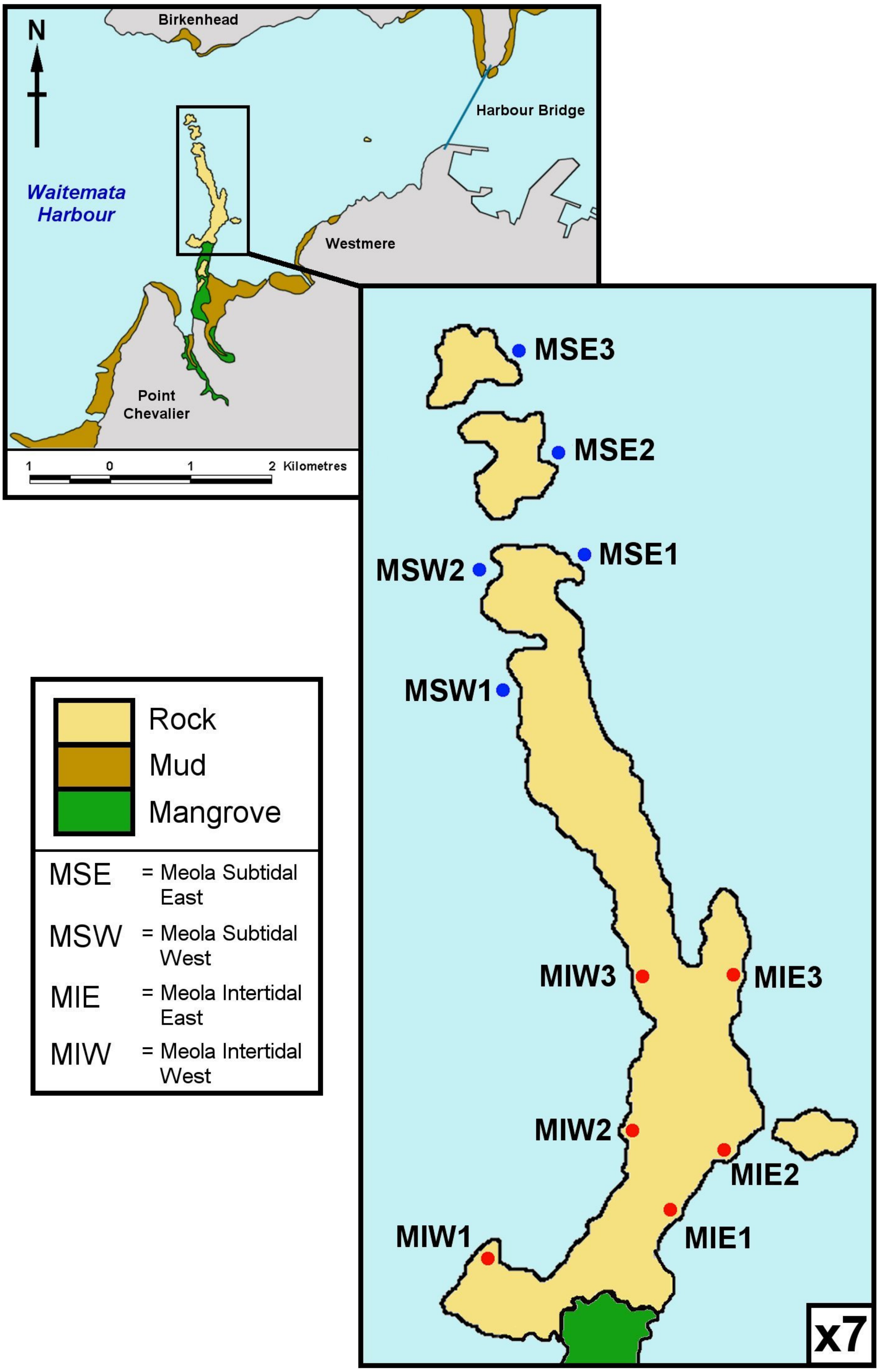
In each 1/4m^2 quadrat, organisms were identified down to the lowest practical taxonomic level. All organisms (excluding *Crassostrea gigas*, see below) were then counted and measured using vernier callipers. Measurements were always taken along the longest axis of the organism. In the case of gastropods either shell length or shell width (dependant on species shell form) were measured.

For each quadrat there was an assessment of substratum cover. The percentage cover of all substrate cover types was estimated. A digital photograph of each quadrat was also taken in case verification of visual percentage cover estimates was required.

Throughout all samplings on Meola reef, the Pacific oyster *Crassostrea gigas* has been the numerically dominant organism in all surveyed quadrats. To evaluate densities of oysters, each 1/4m^2 quadrat was divided into quarters and one quarter (1/16m^2) was evaluated. Within this quarter quadrat, each individual oyster was measured to the nearest millimetre using vernier callipers, until at least 100 oysters had been measured at each site. If less than 100 oysters were present within these (1/16m^2) areas within each site more oysters within quadrats were measured until the required 100 oysters were measured.

Figure 1

Map of Meola Reef showing all intertidal and subtidal sampling sites.



3.1.3 Intertidal models and hypotheses

Interest fundamentally lies in determining answers to the following questions:

(a) Are there differences along or across Meola reef in terms of the abundance and diversity of fauna they contain? If so, how may we characterize these differences?

(b) Are there changes in the faunal assemblages through time across all of Meola reef or a subset of sites that are related to the side of the reef or the distance along it? If so, are these (i) random changes, (ii) or are they due to significant increases or decreases in particular taxa (or in total abundance or diversity) through time?

These questions can be addressed through the use of statistical models. Particular hypotheses about how the faunal assemblage (as a whole) or how any individual variable (a given species or a summary variable like the total abundance of all organisms) may change in space and time can be articulated explicitly in a particular model formulation. These different models (hypotheses) can then each be fitted to the data, and the model with the best fit provides our current best estimate of what is happening (i.e. which hypothesis is most appropriate) for that variable.

For example, suppose we wish to model the average number of taxa per site, from a site that is sampled yearly. If the plot of the mean per unit time looked like that in Fig. 2a, one might consider fitting a linear model, with time as a linear predictor variable. If the mean number of taxa were varying randomly with no directional trend, then the best model would be to simply fit time as a non-directional factor, with a different mean for each time point (Fig. 2b).

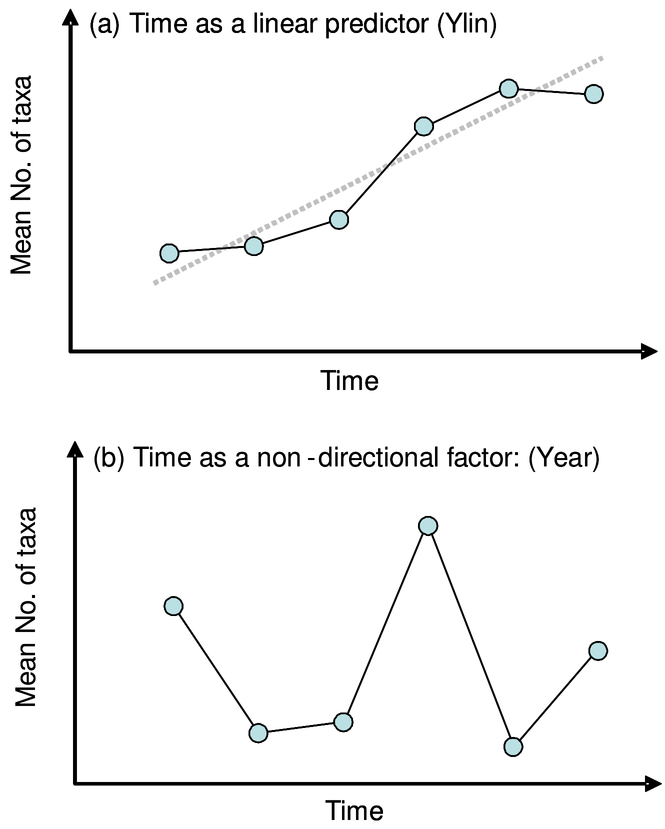
We have therefore outlined two different ways that temporal variation in the data can be modeled: with time overall as either a factor (year) or as a linear predictor (ylin),

In terms of spatial variation, sites are randomly allocated and are therefore considered our lowest level of replication. They also provide estimates of error variation. In addition, given the strong physical gradients at Meola reef, we wish to consider the contrast between the eastern and western sides of the reef (side) and the distance along Meola reef (dist). Distance will be taken as a relative measure within both subtidal and intertidal sampling and will be assigned a number (1, 2 or 3). The most southern site being 1 and the most northern site being 3.

The spatial and temporal components of each model can interact with one another. For example, in a model of the mean number of taxa, if the temporal effects are different at different sides of the reef, we would expect there to be an interaction between year and side, which is denoted by yearxside. A model with year (as a factor), side and their interaction would be denoted by year + side + yearxside. We shall use the shorthand method to write this full model (the two main effects and their interaction) year*side.

Figure 2

Patterns for various hypothetical models for a single response variable through time.



The important point here is to work out which model is "best" for a given set of data and, by virtue of this, to answer the questions posed above regarding competing hypotheses. Specifically, for each response variable of interest, we fit each of the models 1-4 shown in Table 1. The interpretation of each model (i.e. its associated underlying hypothesis) is also given in the Table. Of greatest interest was to see if any of the response variables had a best model fit which included the component ylin, which would indicate consistent increases or decreases through time. On the other hand, variables with a best model fit of either year or year*side or year*dist generally provide no cause for concern from a monitoring perspective, because this indicates simply that the variable of interest is spatially structured (in this case side and dist interactions) and is varying in a non-directional manner in time. For the subtidal data where the multivariate design is unbalanced we can only fit year and ylin factors so these are also included in Table 1, but they are included within the previous 4 models and are therefore not fitted for any other data.

As part of this exercise, it is important to remember that no model we can construct is ever going to fully describe natural variation. However, this statistical modelling approach allows us to distinguish among competing hypotheses in a rigorous manner. It also provides a sound basis for the detection and prediction of potential trends in the monitoring data at this point in time.

Table 1

Models investigated for the analysis of intertidal and subtidal data. Year= time as a factor with up to 6 levels (2001 to 2006), Ylin = time as a quantitative linear predictor with values from 1 up to a maximum of 6, Side = Side as a factor with two levels: east and west, Dist = distance as a quantitative linear predictor, values from 1 (most southern) to 3 (most northern). The asterisk is used to indicate the complete model with all main effects and interactions in each case. For example, Year*Site indicates the model: Year + Site + Year×Site.

	Model	*Interpretation (underlying hypothesis)*
1	Year*Side	Non-directional variation through time and a difference between sides of the reef
2	Year*Dist	Non-directional variation through time and a difference with distance along the reef
3	Ylin*Side	Increases or decreases through time and a difference between sides of the reef
4	Ylin*Dist	Increases or decreases through time and a difference with distance along the reef
5	Year	Non-directional variation through time across the whole of the reef
6	Ylin	Increases or decreases through time across the whole of the reef

3.1.4 Intertidal multivariate analyses

Multivariate analyses combine information across all taxa and analyse patterns of change for the entire faunal assemblage simultaneously. We used permutational multivariate analysis of variance (PERMANOVA, Anderson 2001, McArdle and Anderson 2001) to analyse the multivariate data according to each of the models. In order to compare the models, a "pseudo" Bayesian Information Criterion (BIC) method was used. This measure balances the value of the log-likelihood with a penalty for the number of parameters used in the model (e.g. Seber and Lee 2003). The BIC in the case of a normal (Gaussian) linear model for one variable can be written as:

$$BIC = N \times \ln(RSS / N) + (\ln(N) \times p),$$

where N is the total number of observations, p is the number of parameters and RSS is the residual sum of squares. We simply substituted RSS with the residual sum of squares calculated from PERMANOVA to obtain a straightforward multivariate analogue to the BIC. The analyses were done on the basis of the Bray-Curtis dissimilarity measure (Bray and Curtis 1957) on ln(x)+1 transformed abundance data, in order to balance the relative importance of abundant versus rarer species in the analysis (Clarke 1993).

Multivariate data were extremely variable at the scale of individual quadrats. Thus, to visualize patterns, non-metric multi-dimensional scaling (MDS, Kruskal and Wish 1978) ordinations were used on data lumped at the level of sites. Individual ANOSIM tests (999 permutations) were also done examining the effects of years for each site and the effects of site for each year on count data. In addition, the hypothesis of a gradient through time (a multivariate pattern of seriation in years) was investigated for each site on count data with a Mantel test (Mantel 1967) using Spearman's rank correlation (r). These three analyses were completed using the PRIMER v6. software (Clarke and Gorley 2001).

It was also of interest to examine and characterise compositional differences in communities from different sites or distances or sides. This was done in two ways (i) densities and covers for all fauna were tabulated per site in Appendix E, and (ii) MDS plots of all sites over time had arrows superimposed that correspond to strong correlations ($r < 0.4$ absolute) of individual variables to axes on the plot.

3.1.5 Intertidal univariate analyses

Several individual univariate variables were analysed according to models 1-4 in Table 1. These were: the total number of taxa, the total number of individuals, the number of cover classes and the five most abundant taxa (excluding *Crassostrea gigas* due to non-commensurate sampling over time) and the three most abundant recorded over the whole data set. In addition, to visualise patterns for each variable, plots were produced of the mean (± 1 standard error) for each site through time.

Counts of abundances of organisms are not well modelled using traditional linear models (with normal errors) for several reasons. First, organisms tend to multiply and divide, rather than to add and subtract. Therefore, rather than fitting a linear (additive) model directly, it is generally more appropriate to model the data on the log scale, making it multiplicative on the original scale. Second, organisms occur in discrete counts, rather than being continuous. Although the Poisson distribution is generally used to model random counts, this distribution has a variance equal to its mean (i.e. $E(Y) = var(Y) = \mu$). In contrast, organisms tend not to occur randomly, but instead tend to be highly aggregated, or overdispersed. This is generally caused by there being a great deal of zeros and quite a few counts that are extremely large. A consequence of this is that the variance, although a function of the mean, is generally much larger than the mean (e.g. Taylor 1961). The negative binomial distribution is a much better option here, where the variance is a function of both the mean and a dispersion parameter theta, θ, as follows: E(Y) = μ, var(Y) = μ + μ 2/q. The negative binomial distribution is given by:

$$f(y;\mu,\theta)=\frac{\Gamma(y+\theta)}{y!\Gamma(\theta)}\cdot\frac{\mu^{y}\theta^{\theta}}{(\mu+\theta)^{\theta+y}}$$ for y = 0, 1, 2,…; q > 0, μ > 0.

We analysed each univariate variable according to each of the models 1-4 in Table 1 and included a random site effect with a negative binomial generalized linear mixed model (GLMM, Booth et al. 2003) having a log link function using the R computer program (R Development Core Team 2005). The link function determines the relationship between the variable and the linear model; in this case:

$$\log(\mu)=\beta_0+\beta_1X_1+\beta_2X_2+\cdots$$

where X1, X2, … are the terms in the linear model and b0, b1, b2, … are the parameters associated which each term. This was achieved using a special library "glmmADMB", written by Skaug and Fournier (2004), which links the R computer program (R Development Core Team 2005) to an automatic differentiation model builder – random effects (ADMB-RE) program. The library is available from:

http://otter-rsch.com/admbre/examples/glmmadmb/glmmADMB.html

The variables which were analysed using a different approach from this were the total number of taxa and all four cover variables. These variables did not demonstrate overdispersion or a mean-variance relationship and were therefore analysed using a traditional linear model with normal (Gaussian) errors. The cover of bare rock, *Crassostrea gigas* and sediment were all square-root transformed before analysis to conform to the assumptions of normality and homogeneity.

In general, the greater the number of parameters one has in a model, the better the fit to the data will be. Therefore, some method is needed to choose among competing models that have different numbers of parameters. We determined the model having the best fit using Schwarz's "Bayesian Information Criterion" (BIC, Schwarz 1978). We used this criterion, rather than Akaike's "An Information Criterion" (AIC, Akaike 1973), because the AIC is known to have a tendency to overfit (e.g., Nishii 1984, Zhang 1992, Seber and Lee 2003). Smaller BIC values indicate a better model fit.

The model with the best fit (lowest BIC value) from Table 1 was then further scrutinized for a more parsimonious model by calculating BIC values for all subsets of the model. Thus, for example, if Tlin*B (which is Tlin + B + Tlin×B) was found to be the best model from Table 1, we then examined each of the following subset models as well: (i) Tlin, (ii) B, (iii) Tlin+B.

Size frequency of populations was examined for the three most common taxa from intertidal count data. These data were plotted using histograms and analysed for an effect of site and year using ANOSIM. For the ANOSIM analysis each size class of each taxa (separately) was entered as a multivariate response variable. SIMPER analysis was then used to analyse any significant differences to determine which size classes were causing the multivariate difference.

3.1.6 Analyses for the relationship between sediment cover and intertidal fauna

Regression analyses were used to compare the percent cover of sediments to the density of all intertidal taxa and the number of taxa and individuals. Significant correlations between these factors were plotted for visual examination.

3.2 Subtidal surveys

Previous studies of sheltered shallow subtidal reef assemblages have indicated minimal seasonal variability (e.g. Babcock et al. 1999), therefore one annual sampling of subtidal assemblages was conducted at five sites. Sediment collectors were placed at every site to quantify the amount of sediment entering the reef ecosystems. The methods used for this survey were the same as those used in the 2001 report (Ford et al. 2001), and are consistent with the Long Bay monitoring programme (Ford et al. 2003a) but for completeness are re-iterated below.

3.2.1 Site location

The five sites were distributed between the east and west facing sides of Meola reef (Fig. 1). Three sites were located on the eastern side and two on the western side. All sites were areas of macroalgal-dominated subtidal basaltic reef. These sites extended from between 1 and 2m depth below MLWS. Coordinates for each site were initially recorded by GPS (Global Positioning System) (Appendix C). Surface buoys (~10cm by 5cm) were deployed at each site, that were small enough to be hidden from the public, but large enough to be found when searching in the correct areas.

3.2.2 Survey methodology

Seven quadrats were randomly placed at each site within 20m of the sediment collectors. In five of these quadrats all macroalgae and invertebrates greater than 5cm and 5mm respectively, were identified, counted and measured. Percentage cover of substratum type (which included turfing algae, encrusting algae, large brown algae, encrusting invertebrates, bare rock, sediment (finer than sand) and sand) was also visually estimated in each quadrat. In 2 of the 7 quadrats identification, counts and percentage cover estimates were completed but no measurements were taken. The total lengths of all macroalgae were measured to the nearest 5cm. For the laminarian, *Ecklonia radiata*, this included both the stipe length and total length. The longest axis of solitary macroinvertebrates was also measured to the nearest 5mm. Mobile organisms (e.g. crabs) were not enumerated. It should be noted that during the 2001 survey between 5 and 7 quadrats were surveyed due to a sampling error. For a detailed account of the sampling methods please refer to the 1999 Long Bay monitoring report (Babcock et al. 1999).

3.2.3 Subtidal models and hypotheses

The models and hypotheses associated with the subtidal datasets are mostly the same as for the intertidal datasets (section 3.1.3). The exception is the multivariate analysis.

3.2.4 Subtidal multivariate analyses

As for the intertidal datasets, PERMANOVA was used to analyse the subtidal multivariate data according to models 5 and 6 (Table 1) and a pseudo BIC criterion was used to provide a rank of best fit. Due to the complexities of analysing multivariate data for unbalanced designs (5 subtidal cf. 6 intertidal sites), we focused here only on the last two models outlined in Table 1. This was done separately for the count data and for the percentage cover data. Analyses were done on Bray-Curtis dissimilarity measure and ln(x)+1 transformed abundances of 38 taxa (count) and 41 variables (cover).

MDS, ANOSIM and a Mantel test were used to visualise and test data in exactly the same way as for the intertidal (section 3.1.4) .

Due to the greater complexity of subtidal compared to intertidal data three methods were used to examine and characterise compositional differences in communities from different sites on the reef, distance along the reef, and side of the reef: (1) Densities at each site were tabulated in Appendix E, (2) strong correlations between individual variables and MDS axes were plotted, (3) the densities of the variables plotted in (2) were tabulated for sites on the edges of the MDS plot.

3.2.5 Subtidal univariate analyses

Several individual univariate variables were analysed according to models 1-4 in Table 1. These were: the total number of taxa, the total number of individuals, the number of cover classes, the percentage cover of mobile unconsolidated sediments (sand, shell and sediment) and (separately) the counts of each of the five most abundant taxa and cover classes recorded over the whole data set. To visualise patterns for each variable, plots were produced of the mean (± 1 standard error) for each site through time. Individual sediment variables were also analysed using univariate models, including (i) the average trap rate, (ii) the standard deviation of the trap rate (SD(trap rate)), (iii) the proportion of sediments < 63 mm in traps, (iv) the average trap rate of < 63 mm.

Modelling was done using the same approach outlined for the intertidal data for many variables (GLMM, section 2.1.5). The total number of taxa and the percent cover of crustose coralline algae (CCA), sediments and unconsolidated substrates, which conformed to traditional assumptions, were analysed using a linear mixed-effects model with normal errors (obtained by using the function "lme" in the "nlme" library in R). The percent cover of sediments was square root transformed and the percent cover of CCA log transformed before analysis to conform with the assumptions of normality and homogeneity. The models in Table 1 and all possible subsets of them were evaluated for each variable and the best model fit in each case was chosen using the BIC criterion.

Size frequency of populations was examined for the three most common taxa from subtidal count data using histograms, ANOSIM and SIMPER in exactly the same way as for the intertidal analysis (Section 3.1.5).

3.3 Sediment measurement

3.3.1 Introduction

One of the major concerns for the Meola Reef marine environment is the threat of increased sedimentation and turbidity. Information was therefore required on the types and quantities of sediment entering the marine ecosystem. To address this, an ongoing program was initiated in September 2001 to quantify sedimentation in the same locations where community sampling was undertaken. There have been several investigations into the effects of increases of sedimentation on subtidal communities, (Airoldi & Virgillio 1998; Gorostiaga et al. 1998). These studies have indicated that sediments and the associated effects of sedimentation (such as abrasion and smothering) can have profound and detrimental consequences on the structure and composition of subtidal reef communities. Degradation of species diversity (Gorostiaga et al. 1998) and the effects of reduced water quality are key issues within these studies.

3.3.2 Sedimentation rate definition

Sediment traps provide a measure of sediment deposition or flux at a site, but without the resuspension that may naturally occur to sediments deposited (referred to as sedimentation rate in this report).

3.3.3 Sediment traps and placement

Sedimentation rate and particle grain size were investigated by deploying sediment traps 1-2m below MHWS in areas surrounded by macroalgae at each of the 5 subtidal sites. These were placed at a set height (at least 25-30cm above the benthos) to preclude being inundated by resuspended sediment. The contents of the traps were analysed on an approximately monthly basis.

The sediment traps were 32mm in diameter and 500mm in length, and were consistent with those deployed in previous studies (Ford et al. 2003a). The chances of resuspension of trapped particles was therefore minimised due to the aspect ratio of at least 7:1 (Knauer & Asper 1989).

A new design for the trap holder was developed due to problems in the past retrieving the traps (particularly at the start of the sediment monitoring), either due to disturbance by extreme weather events or possible public interference. The new bases were larger, heavier steel plates, although trap mouths were still approximately 25–30cm above the reef. These new trap holders were deployed in May 2003. To decrease the influence of swell, a 1m length of chain was incorporated between the base and the buoy line, and smaller, lighter floats were used to mark the site.

3.3.4 Sediment processing

On collection, water was separated from the contents of sediment traps by filtering through Faggs brand coffee filter bags (bar code: 9403125008028). These were tested against 1.2 m pore size filter paper and found to be 99% equivalent. This sediment and filter bag was then oven dried at 80°C for 24 hours, cooled and weighed to obtain a total dry weight. These dry weights in combination with the trap surface area and length of time deployed were then used to calculate the rate of sedimentation (grams/day/cm^2). The material of less than 63mm in diameter is the mud fraction, which contains the coarse silts through to the very fine silts and clay. This size range contains the material most likely to have originated from a recent terrestrial source. Pretreatment of samples was completed as per Ford et al. (2003b). The pre-treatment involved addition of 10% Hydrogen peroxide to dissolve organics and 2g/l of Calgon (to disperse particles) prior to any grain size determination. To obtain textural information, the sediment was analysed using a Malvin Mastersizer 2000 laser particle size analyser and the results are shown as percentage volume.

3.3.5 Statistical analyses

Interest in the sediment data fundamentally lies in determining answers to the following questions:

What are the spatial and temporal patterns in the sediment data? Is there a relationship between spatial or temporal patterns in the biota and patterns in sediment data?

Sediment variables were analysed using traditional linear models on the same models as for the univariate biota (models 1-4, Table 1), but there was no random effect of sites for these, as data were obtained at the site level. The average trap rate, the trap rate for fine sediments and the SD (trap rate) were all log-transformed before analysis to conform to the assumptions of normality and homogeneity. Sediment percentage cover in the subtidal is analysed in the subtidal section.

A CAP analysis was used to test for a relationship between sediment variables and count and cover variables. If a significant relationship was found then univariate taxa which were strongly correlated with the CAP axis ($r>0.4$ absolute) were plotted against the sediment variable to visually examine the relationship. When the number of taxa or individuals also shows a strong trend ($P<0.10$) with the sediment response variable through regression analysis then these variables will also be plotted. Sediment percentage cover and trap data were both used in order to look for relationships between the sediments and biota.

4 Results

4.1 Intertidal analyses

4.1.1 Patterns in whole assemblages

A listing of densities of taxa at each site is given in Appendix E1. A total of 36 taxa and 12 cover classes were included in the intertidal analyses (Appendix E3, E4).

Analysis of both the longest available faunal datasets (2001-2005, n=7 replicates per site), and the most replicated data (2002-2005, n= 10 replicates per site), were carried out with PERMANOVA to investigate which of the models resulted in the best fit for these assemblages (Table 2). An effect of time and a linear effect of time were the selected models for the longest cover and count datasets respectively. Both datasets from 2002 onwards were balanced with respect to side of Meola reef (east vs. west) and distance along the reef (sites 1, 2 and 3, from south to north). When all models were examined, on the 2002-2005 dataset for the both count and cover data, the effect of distance was found in addition to the effect of time. These results suggest that there has been assemblage change at sites with time, for cover data; this change appears to be linear from 2002-2005, and the degree of this change differed with distance along Meola reef.

The strongest pattern to emerge from the MDS plots was that sites MIE1 and MIE2 were consistently located on the right of the plot (Fig. 3a and b). ANOSIM analyses showed significant differences among sites for intertidal count and cover data, however no significant differences were found between years (P>0.10, Table 3). In addition, significant linear patterns were seen over time for count data, but marginally non-significant linear patterns were seen for cover data (Table 3). Closer examination of MDS plots showed that count data showed little change over time, but for cover data the most northern sites (MIE3, MIW2 and MIW3), showed the largest changes (Fig. 3a and 3b). Therefore, the models and the MDS plots both suggest a relatively weak temporal effect whereby the magnitude of percent cover change was greatest at the northern intertidal sites. Consequently, the community composition of the northern sites (MIE3 and MIW3) has diverged from the southern sites over the past 4 years. This change occurred against a backdrop of communities that consistently differed between the western and eastern sides of the reef.

Table 2

Comparison of models for multivariate assemblages from the intertidal assemblages, using PERMANOVA and a pseudo-multivariate BIC criterion. F = the F-ratio for the analysis of the full model, % Var = the percentage of variance explained by the model = model SS/total SS, p = the number of parameters in the full model and BIC = N × ln(RSS / N) + (2 × p). Analyses were based on the Bray-Curtis dissimilarity measure and 4th-root transformed abundances of 35 taxa (count) and 13 taxa (cover). The best (most parsimonious) model has the lowest BIC; models are presented in increasing order of BIC value.

Model	*F*	*RSS*	*p*	*BIC*
Count data - 2001-2005				
Ylin	0.88	6.7	1	1300
Year	3.06	0.5	4	1304
Count data - 2002-2005				
Year*Dist	8.43	28.9	11	1698
Ylin*Dist	12.45	21.0	5	1723
Year*Side	6.37	16.1	7	1726
Ylin*Side	7.63	8.8	3	1746
Cover data - 2001-2005				
Year	4.38	9.4	4	1021.6
Ylin	0.86	0.5	1	1022.4
Cover data - 2002-2005				
Ylin*Dist	19.06	28.9	5	1363
Year*Dist	7.46	26.5	11	1404
Ylin*Side	9.77	17.4	3	1406
Year*Side	6.95	11.1	7	1410

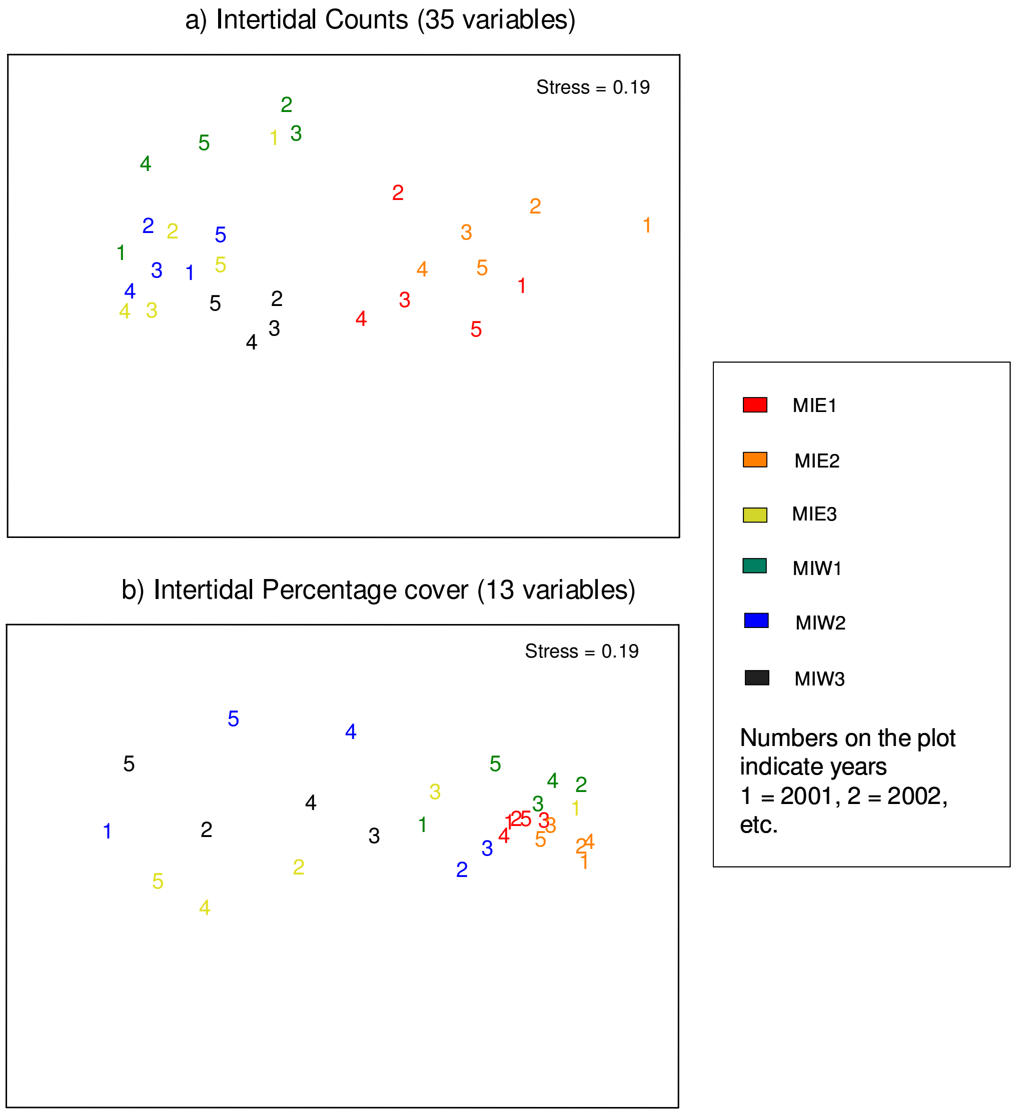
Table 3

ANOSIM R statistic and test for year and site effects (separately) as well as Mantels test for seriation through time (using Spearman's r) done for each site. All tests were completed on Bray-Curtis dissimilarities of log(x)+1 transformed intertidal data.

Response	Factor	Year effects		Seriation	
		R	*P*	ρ	*P*
Count	Site	0.610	0.001		
Count	Year	0.162	0.066	0.106	0.043
Cover	Site	0.352	0.001		
Cover	Year	0.152	0.095	0.101	0.073

Figure 3

MDS plots of intertidal community structure (lumped at the site level, n=7 in 2001 and 10 thereafter) showing Bray-Curtis dissimilarities of log(x+1) transformed values for count and cover data at different sites over time.



4.1.2 Patterns in diversity, individual taxa and groups

The six most numerous intertidal taxa, in decreasing order, were the Pacific oyster, *Crassostrea gigas*, the encrusting anemone, *Anthopleura* sp., the cats eye top shell, *Turbo smaragdus*, the snake-skin chiton, *Sypharochiton pelliserpentis*, the spotted top shell, *Melagraphia aethiops* and the small black mussel, *Xenostrobus pulex* (Appendix E3). Collectively, these six taxa accounted for over 85% of all the individuals counted.

The three cover classes that covered the most area, in decreasing order, were *Crassostrea gigas*, bare rock and sediment (Appendix E3). Collectively, these three cover classes accounted for, on average, 90% of the cover of each quadrat.

The taxa that were causing separation between communities were a mix of the common taxa already listed above, and some rarer taxa (Fig. 4). For count data, the taxa that were causing most of the separation between sites or years were the gastropods, *Melagraphia aethiops* and *Turbo smaragdus*, the anemone *Diadumene linaeta*, the mite *Acari* and the small black mussel *Xenostrobus pulex* (Fig. 4a). Generally, looking from the right to the left of this figure, there are more of these taxa to the left (site MIW2 in blue compared to site MIE2 in orange). For percentage cover data, the cover types that are mainly causing differences between sites or years are bare rock (as this increases, sediment and *Crassostrea gigas* decrease), barnacles and the algae *Gelidium* sp.. These cover types, and the others with more minor contributions to the dissimilarity (Fig. 4b), are causing the separation of communities in different directions; i.e. site MIW2 in 2004 (blue 4, which is in line with the positive correlation with bare rock) had on average 53% bare rock, 43% *Crassostrea gigas* (oysters) and 2.7% sediment cover. In contrast, site MIE3 in 2005 (yellow 5 on the opposite side of the plot, in line with the positive correlation for oysters), had relatively high oyster (66%) and sediment cover (16.5%) and relatively low bare rock cover (10%).

There was no consistent change in the densities for intertidal organisms over time, although some consistent spatial patterns were evident (Table 4, Fig. 5-7). Although the site factor was not selected as the best model for any density variables tested, the graphs showed a pattern for most variables to have relatively low densities at sites MIW1 and MIE2 (excluding *Crassostrea gigas* at all sites and *Zeacumantus lutulentus* at MIW2), variable densities over time at MIE1 and MIE3, and high densities at sites MIW2 and MIW3. The best model for explaining the densities of *Anthopleura* sp., *Sypharochiton pelliserpentis*, *Melagraphia aethiops* and number of individuals was year. Examination of the graphs showed a spike in densities was recorded for *Anthopleura* sp., *S. pelliserpentis* and the number of individuals at site MIW2 in 2004 (Fig. 6-7). The only species to show linear change (ylin) was *Xenostrobus pulex*, where numbers generally increased from 2001 until 2004 and then decreased at all sites. *Turbo smaragdus* showed a year*dist interaction which can be clearly seen in the graph; sites MIE3, MIW2 and MIW3 show high densities compared to the three sites furthest North. In addition most sites showed a peak in *T. smaragdus* densities in 2003. An effect of side of the reef was seen for *Zeacumantus lutulentus* which is not apparent in the graph, but was driven by the much higher densities at site MIW3 by comparison to other sites. The number of taxa showed an effect of distance which was driven by the fact that on average there were less than 4 taxa present per quadrat at site MIW1, all other sites had an average density of taxa closer to 6 taxa per quadrat (Fig. 7). Unfortunately because of inconsistent collection protocols density data for *Crassostrea gigas* could not be analysed using this GLMM, however both percent cover and size frequency information were analysed for this species.

Patterns in percentage cover also changed between variables (Table 4, Fig. 8), but because these classes were mutually exclusive, i.e. you cannot have bare rock and oysters covering the same spot, these patterns were somewhat easier to understand. Bare rock and *Crassostrea gigas* (oysters) both showed an effect of side of the reef which was inter-related, i.e. where oyster cover was high (e.g. MIE3), bare rock cover was low and vice-versa. Over time, sites on the eastern side of the reef generally had higher oyster cover and lower bare rock cover than sites on the western side. Sediment cover varied yearly, whereby generally all sites had higher sediment cover at the start and end of the monitoring compared to the middle. The number of cover classes per m^2 was best explained by distance; generally sites furthest South had ~ 4 cover classes present, and sites furthest North had closer to 5 cover classes present.

Table 4

Results of negative binomial GLMMs for several individual response variables in the intertidal. The best model in each case is shown, along with the number of parameters (p), degrees of freedom of the residual (dfres), log of the likelihood (logL) and the information criterion (BIC). The number of taxa and the percent cover information were analysed using a traditional linear model with normal errors, instead of the negative binomial, the bare rock, *C. gigas* and sediment percentages were square-root transformed prior to analysis to fulfil the assumptions of normality and homogeneity.

Variable	*Model equation*	*p*	*dfres*	*logL*	*BIC*
Anthopleura spp.	Year	6	269	-874.106	1781.913
Melagraphia aethiops	Year	6	269	2.7204	1369.619
Sypharochiton pelliserpentis	Year	6	269	-772.290	1578.281
Turbo smaragdus	Year+Dist	7	268	-674.476	1388.269
Xenostrobus pulex	Ylin	3	272	-590.554	1197.958
Zeacumantus lutulentus	Side	3	272	-429.536	875.9223
Number of individuals	Year	6	269	-1212.54	2458.781
Number of taxa	Dist	3	272	-490.074	1002.586
Percent cover of bare rock	Side	3	272	-528.494	1079.427
Percent cover of *Crassostrea gigas*	Side	3	272	-472.938	968.314
Percent cover of sediment	Year	6	269	-532.029	1103.247
Number of cover classes	Dist	3	272	-478.140	973.130

Figure 4

MDS plots of (i) intertidal count data and (ii) intertidal percent cover data at the site level showing correlations with variables >|0.4|. The longer the arrow the stronger the relationship between the taxa and the separation between samples in that direction. MDS plots of intertidal community structure (lumped at the site level, n=7 in 2001 and 10 thereafter) show Bray-Curtis dissimilarities of log (x+1) transformed values for count and cover data at different sites over time.

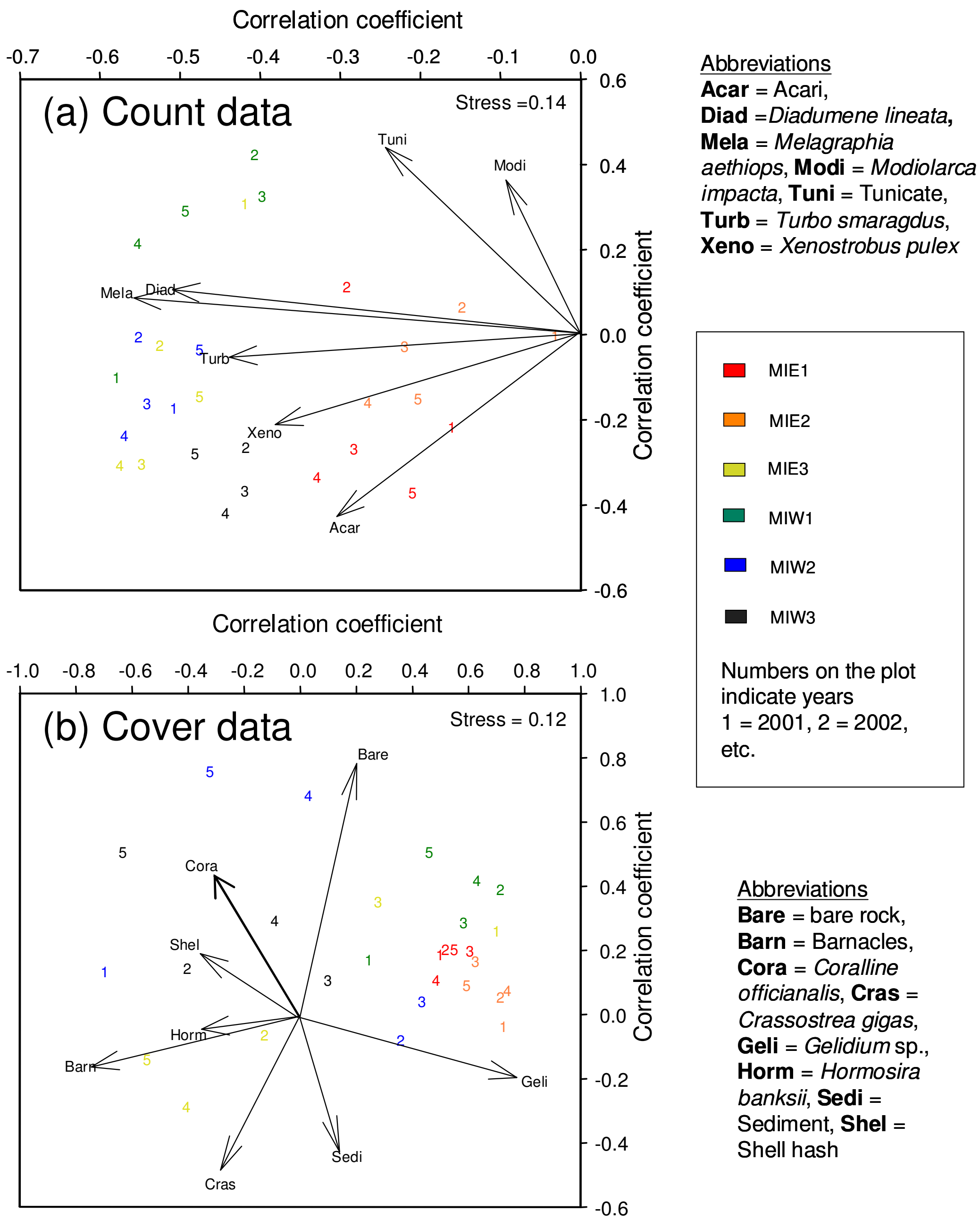


Figure 5

Line plots showing change in density of organisms per site (n=7 for year 1 and 10 thereafter, excluding MIE3 in 2001 – not sampled and 2002-3 *Crassostrea gigas* counts which range from 1-2 per site). Bars = standard errors.

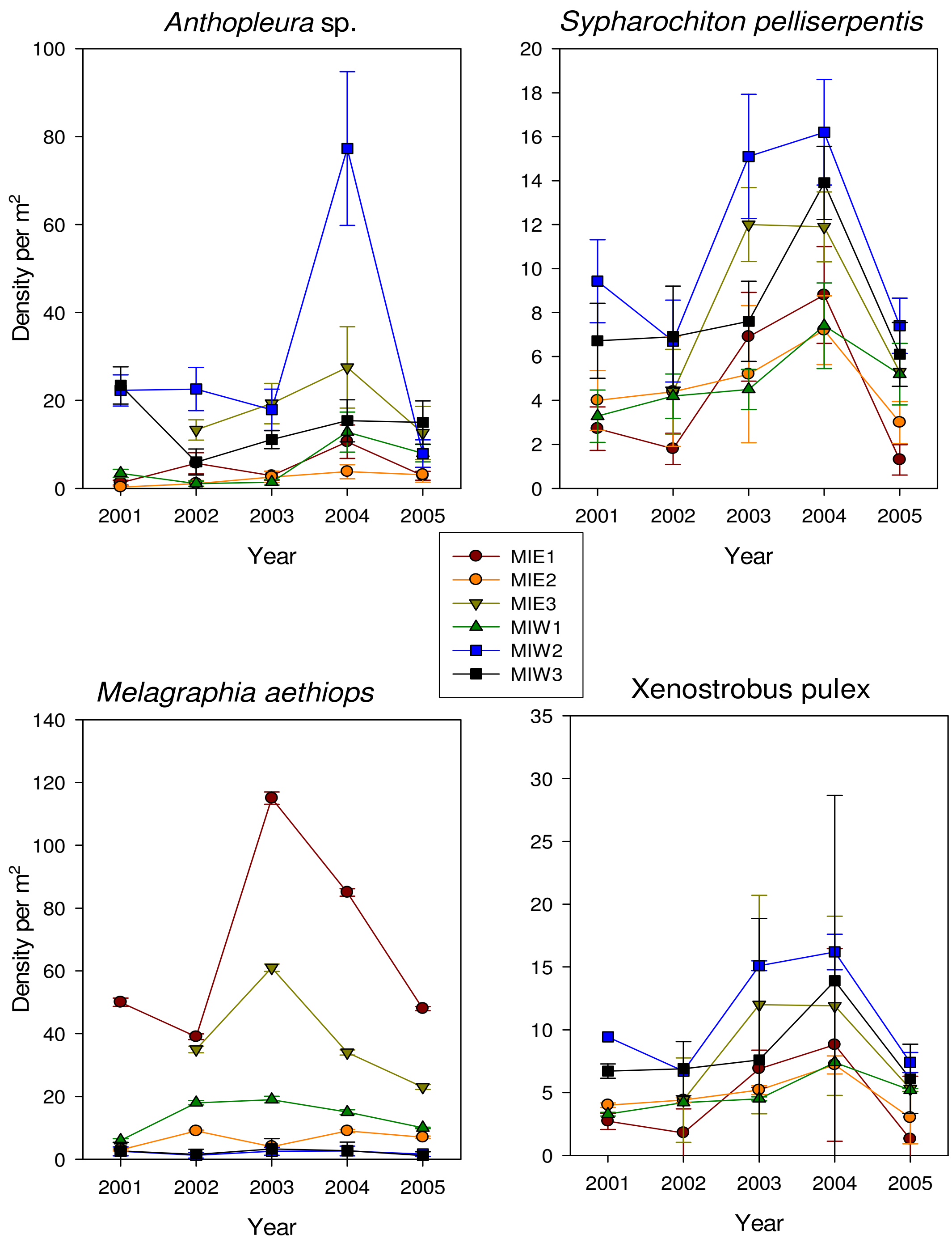


Figure 6

Line plots showing change in density of organisms per site (n=7 for year 1 and 10 thereafter, excluding MIE3 in 2001 – not sampled and 2002-3 *Crassostrea gigas* counts which range from 1 to 2 per site). Bars = standard errors.

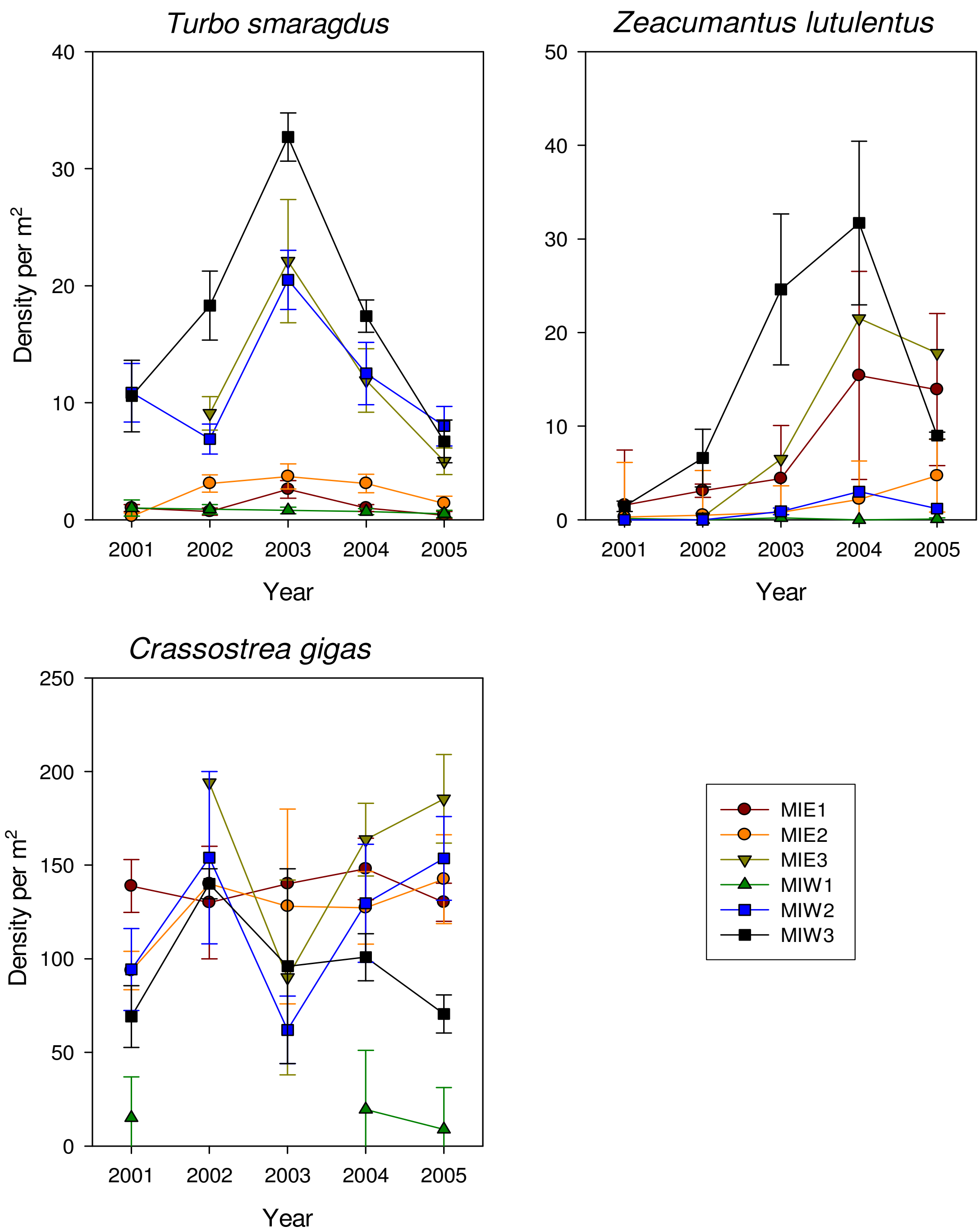


Figure 7

Line plots showing change in number of taxa and individuals per site (n=7 for year 1 and 10 thereafter, excluding MIE3 in 2001 – not sampled and 2002-3 *Crassostrea gigas* counts which range from 1 to 2 per site). Bars = standard error bars.

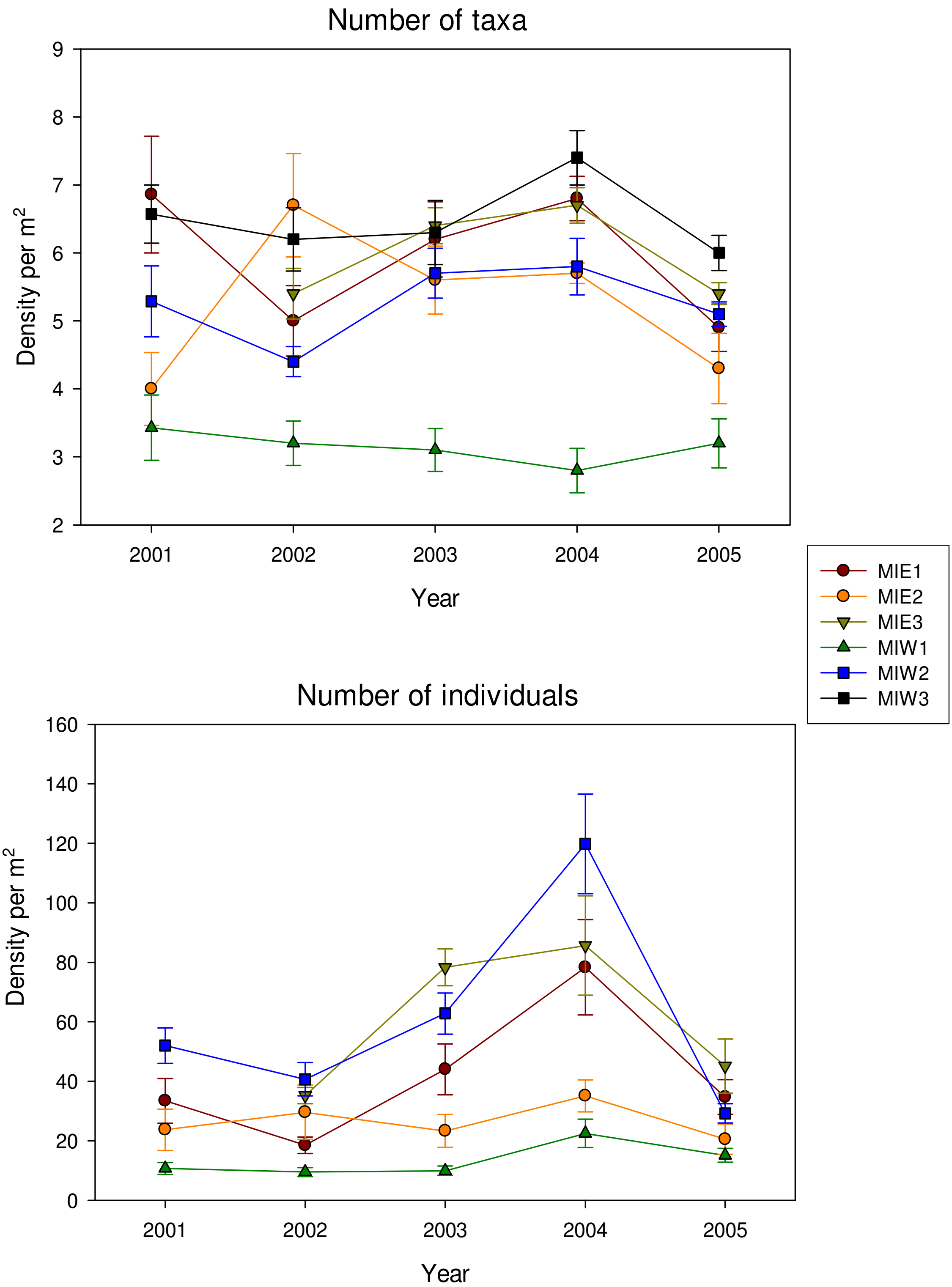
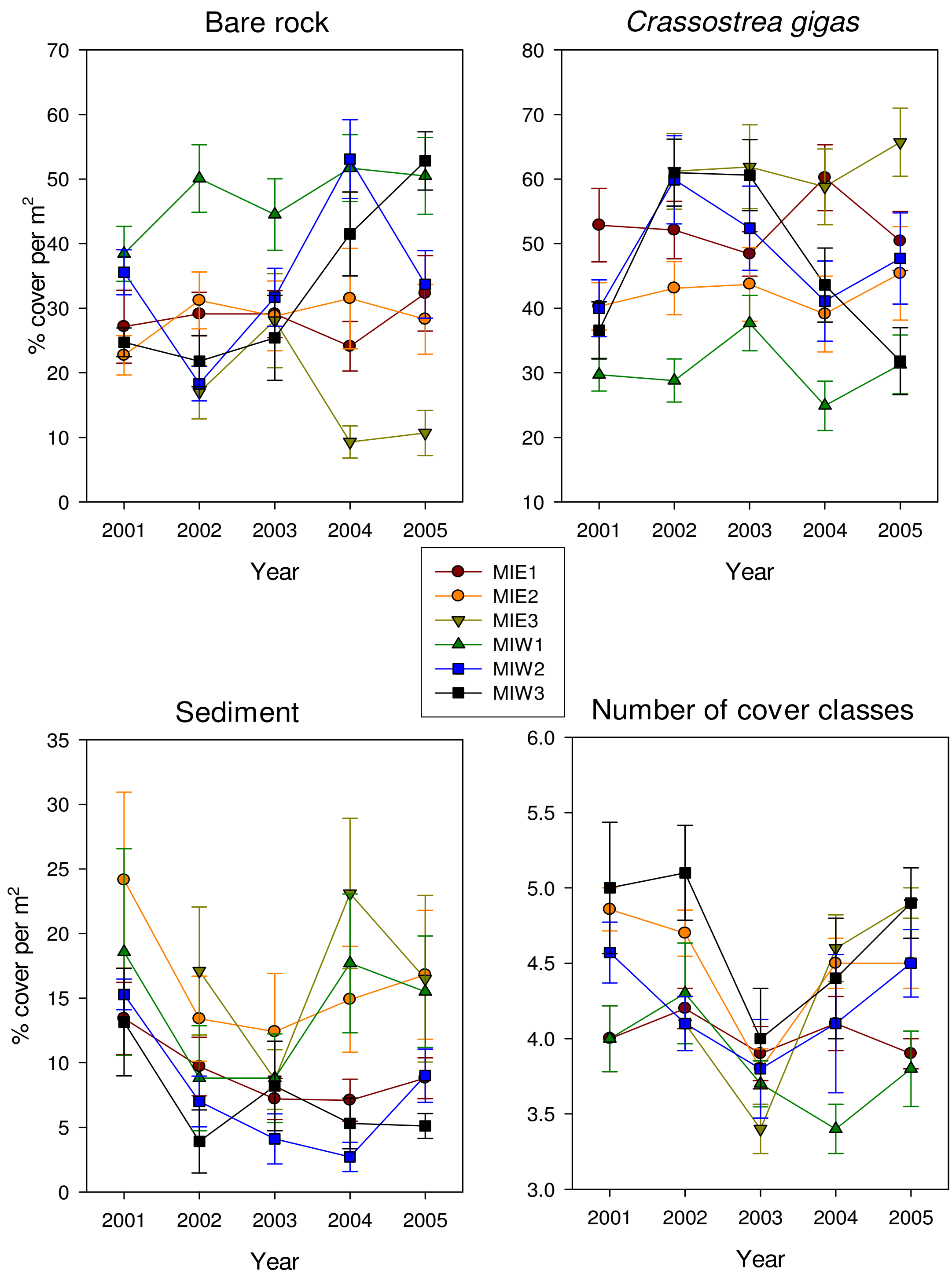


Figure 8

Line plots showing change in percent cover of substrate types per site (n=7 for year 1 and 10 thereafter, excluding MIE3 in 2001 – not sampled and in 2002-3 *Crassostrea gigas* counts which range from 1 to 2 per site). Bars = standard error bars.



4.1.3 Population size structure

Size frequency distributions for three common intertidal species, (*Crassostrea gigas*, *Turbo smaragdus* and *Sypharochiton pelliserpentis*), were examined across time (2001 to 2005) and site factors (MIE1, MIE2, MIE3, MIW1, MIW2 and MIW3) (Appendix F1-F3). (Note: MIE3 was not sampled in 2001). The size frequency of *Anthopleura* sp., the third most common taxa, was not examined due to its narrow size range (82% of all individuals were 5-10mm long).

ANOSIM showed that the population size structure of *Crassostrea gigas*, *Turbo smaragdus* and *Sypharochiton pelliserpentis* was significantly different between years (3.4%, 0.6% and 4.7% respectively). *C. gigas* population structures differed most in 2002 and 2003 (average dissimilarity = 56.66%), whereas *T. smaragdus* size distributions showed the highest dissimilarity for 2001 and 2005 (average dissimilarity = 65.98). Although *C. gigas* and *T. smaragdus* population size structures were found to vary significantly over time, SIMPER analysis revealed no clear pattern in the sizes causing this variation; there appeared to be no linear change in population size structure over time for either species.

4.1.4 Relationship between sediment variables and intertidal fauna

Sediment cover was the only sediment variable measured in the intertidal. When the average cover per site, is regressed against average count data per site, some interesting patterns emerge. The number of individuals and the densities of *Melagarphia aethiops*, *Turbo smaragdus*, and *Cominella virgata* all significantly declined as percent cover of sediment increased (Table 5, Fig. 9). The number of the mite *Acari*, was significantly positively correlated with sediment cover (Table 5, Fig. 9). The patterns for *Cominella virgata* and the mite *Acari* were driven by a few outlying densities, therefore we should place little reliance upon this pattern.

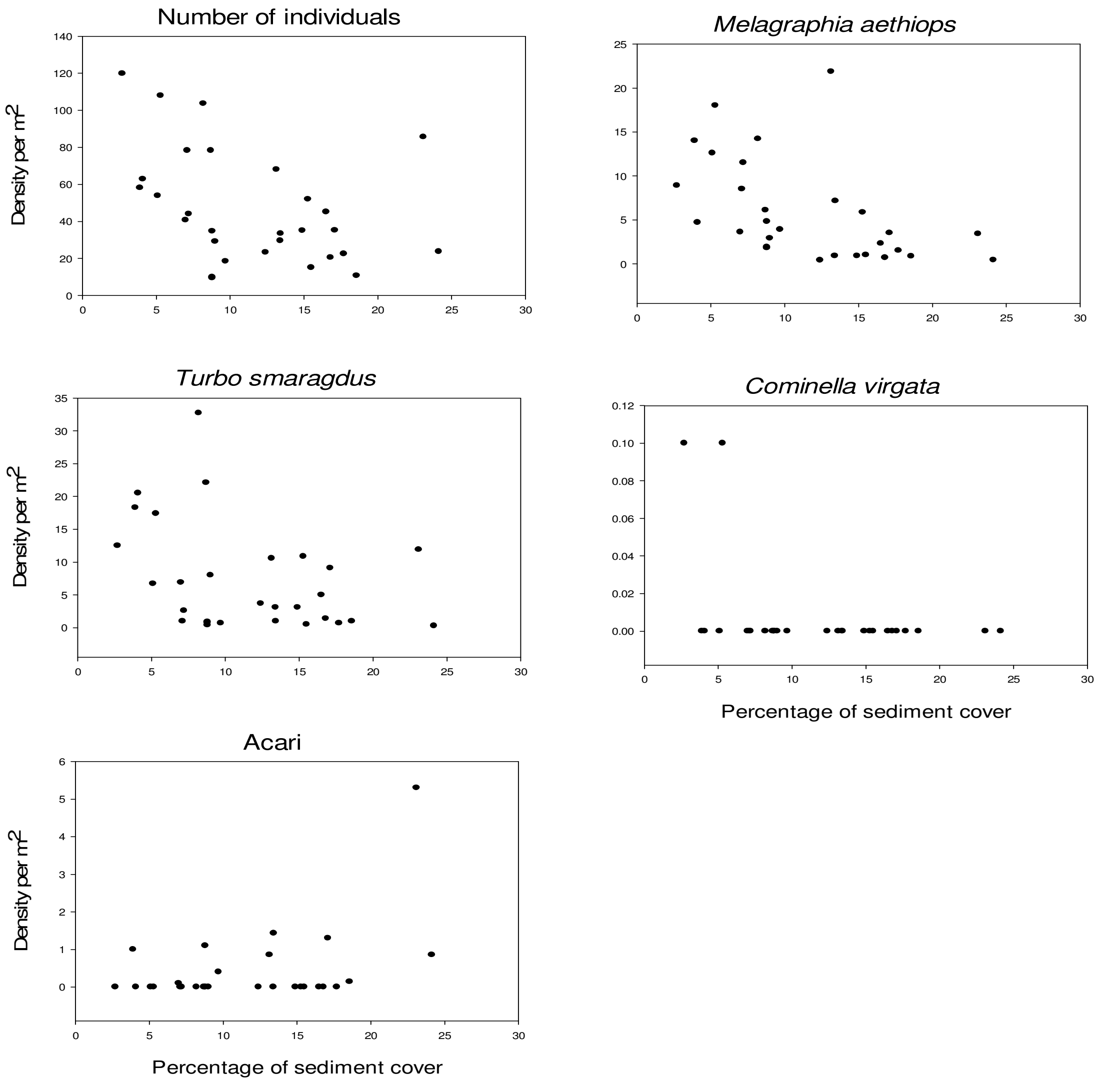
Table 5

Regression statistics between the average intertidal percentage cover of sediment per site and the average intertidal densities, and number of individuals and taxa, per site. All 36 taxa and the number of individuals and number of taxa were tested, only the significant results are displayed here.

Variable	R^2	*P*
Number of individuals	0.16	0.029
Melagraphia aethiops	0.25	0.005
Turbo smaragdus	0.15	0.040
Cominella virgata	0.14	0.047
Acari	0.19	0.048

Figure 9

Scatterplots of count variables significantly correlated with the percentage cover of sediments. All data are averaged at the site level, n = 7 (except in 2001; MSE1 n = 5, MSE3 and MSW2 n = 6).



4.2 Subtidal analyses

4.2.1 Patterns in whole assemblages

A list of the densities of taxa present at each site is given in Appendix E2. A total of 38 taxa and 41 cover classes were included in the analyses (Appendix E5, E6).

Analysis of both the longest available (2001 -2006, n=7 per site) and the most replicated dataset (2002-2005, n= 10 per site) using PERMANOVA showed that the best model to describe assemblage change for both density and percentage cover measures was year (Table 6). This suggests that change in assemblages was non-directional.

The MDS plots of the count data (Fig. 10) at the site level show that change is occurring in different directions and to different extents. This observation is supported by the test for year effects, site effects and seriation, which show that site effects are non-significant. There is a strong trend towards year effects, but the effect of year is not linear (non-significant seriation P-value, Table 7). Cover data was, however, significant linear over time as measured by the Mantels test (Table 7). Each site moves from left to right on the plot (years 1-4) and then back to the left (years 5 and 6) (Fig. 10).

Table 6

Comparison of models for multivariate assemblages from the subtidal assemblages, using PERMANOVA and a pseudo-multivariate BIC criterion. F = the F-ratio for the analysis of the full model, % Var = the percentage of variance explained by the model = model SS/total SS, p = the number of parameters in the full model and BIC = $N \times \ln(RSS / N) + (2 \times p)$. Analyses were based on the Bray-Curtis dissimilarity measure on ln(x)+1 transformed abundances of 38 taxa (count) and 41 taxa (cover). The best (most parsimonious) model has the lowest BIC; models are presented in increasing order of BIC value.

Model	*F*	*% Var*	*p*	*BIC*
Count data - 2001-2006				
Year	2.09	10.4	4	1068
Ylin	3.38	0.2	1	1069
Count data - 2002-2006				
Year	3.13	10.2	4	1233
Ylin	4.11	0.5	1	1235
Cover data - 2001-2006				
Year	1.77	12.7	4	1094
Ylin	3.16	0.4	1	1099
Cover data - 2002-2006				
Year	3.2	13.0	4	1267
Ylin	2.10	0.4	1	1276

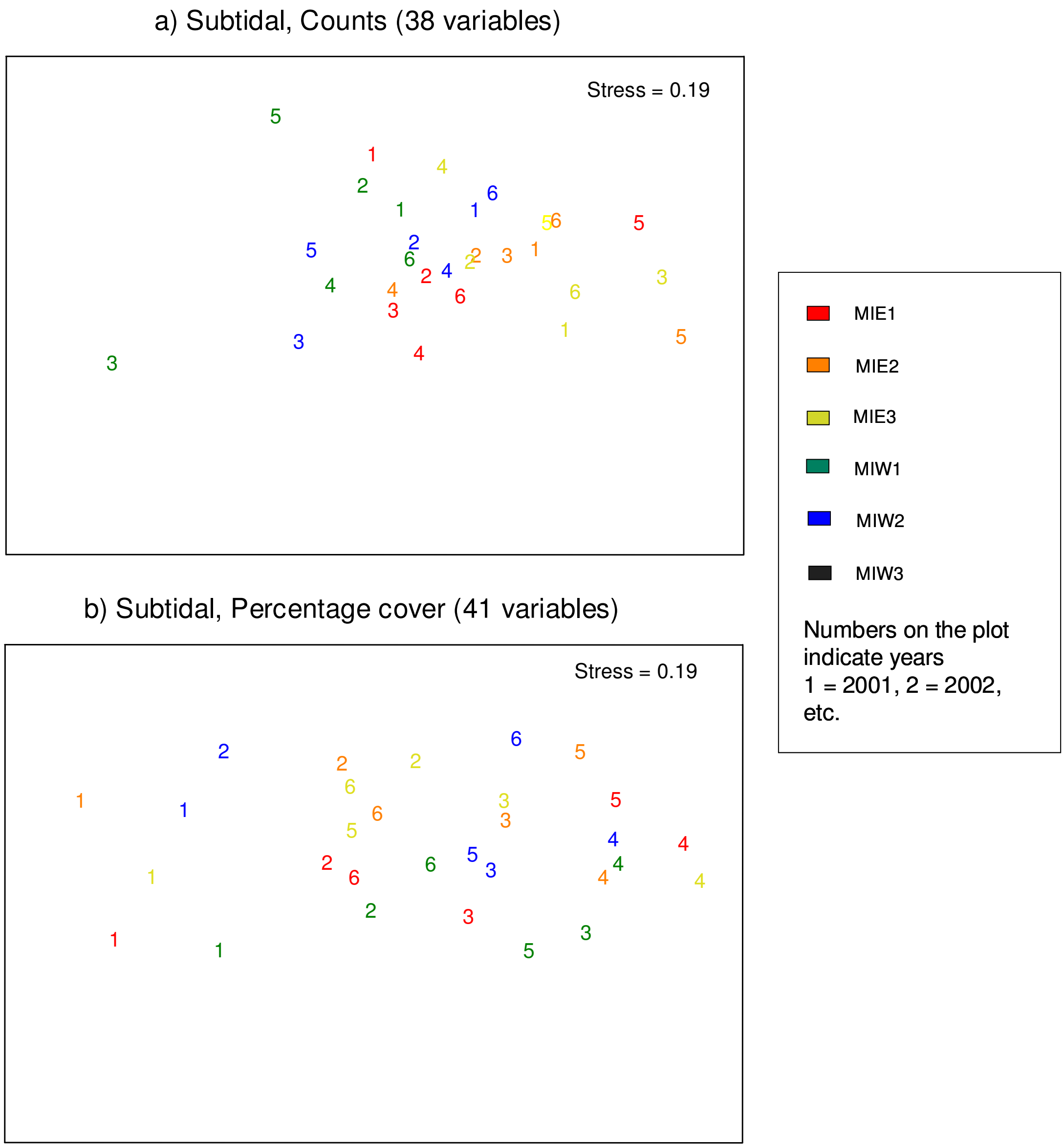
Table 7

ANOSIM R statistic and test for year and site effects as well as Mantels test for seriation through time (using Spearman's r) done across all sites at Meola reef. All tests were completed on Bray-Curtis dissimilarities of log(x)+1 transformed subtidal data.

Response	Factor	Year effects		Seriation	
		R	*P*	ρ	*P*
Count	Site	0.101	0.125		
Count	Year	0.186	0.056	0.018	0.381
Cover	Site	0.011	0.413		
Cover	Year	0.395	0.001	0.326	0.001

Figure 10

MDS plots of subtidal community structure (combined at the site level, n = 5-7 per site) showing Bray-Curtis dissimilarities of log(x+1) transformed values for count and cover data at different sites over time.



4.2.2 Patterns in diversity, individual taxa and groups

The most numerous five subtidal taxa were the Cats eye top shell *Turbo smaragdus*, the brown algae, *Carpophyllum maschalocarpum*, *Carpophyllum flexuosum* and *Ecklonia radiata* and solitary ascidians. These five taxa together accounted for over 92 percent of all the individuals counted. The five cover classes that covered the most area in decreasing order were sediment, sand, crustose coralline algae, *Ralfsia* sp. and shell. These five cover classes accounted for, on average, 77 percent of the cover of each quadrat. The percent cover of the mobile substrates (sand, sediment and shell), which together will be called unconsolidated substrate, are displayed and analysed both separately and collectively due to their mutual exclusion of settlement of hard-substrate reef fauna.

Common taxa contribute to the character of the reef community, but may not contribute to the differences detected between sites, therefore we detail here the taxa that cause separation in assemblage structure between sites. The variables causing the multivariate separation in the plot of subtidal count data are more numerous than in the intertidal (10 parameters with correlation coeffcicents >0.4 absolute) were found for the subtidal and 7 for the intertidal). Towards the top of the plot (Fig. 11a), sites are characterised by relatively high densities of the alga *Hormosira banksi*, oysters (*Crassostrea gigas*), the green lipped mussel (Perna canaliculus) and solitary ascidians. To the bottom-left of the plot, sites are characterised by relatively high densities of the alga *Carpophyllum maschalocarpum* and the gastropod *Haustrum haustorium*. To the extreme right of the plot sites are characterised by relatively high densities of the algae *Carpophyllum flexuosum*, the echinoderms, *Patiriella regularis* and *Evechinus chloroticus*, and the gastropod *Trochus viridus*. *Patiriella regularis* contributes to the differences between the sites and years by the change in their average density across all sites, however all the remaining taxa listed in this paragraph are absent in at least one of the sites at the extremes of the plot. To illustrate this pattern more clearly, densities of these taxa from the three extremes of the MDS plot have been tabulated (Table 8).

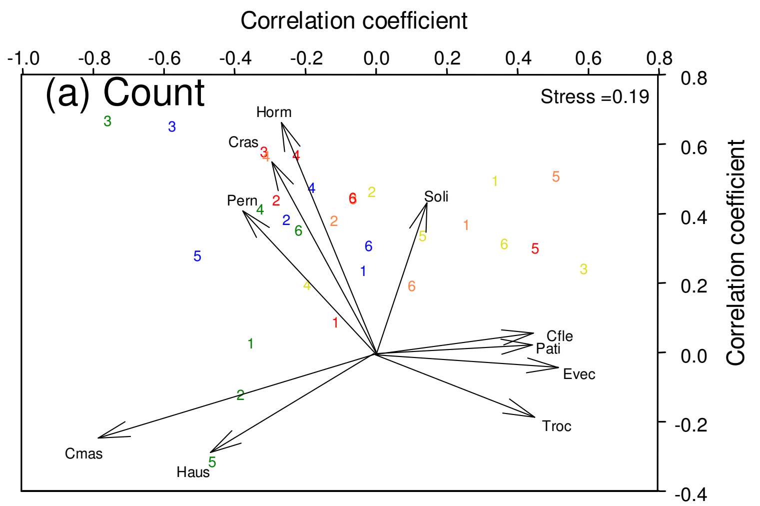
The percent cover plot has 19 variables, which were highly correlated with the axes on the MDS plot (Fig. 11b). Broadly speaking, 4 groups of variables were identified which correlated with assemblage structure in different directions on the MDS plot. The cover of taxa at sites with extreme communities are again tabulated, this allows the relative importance of different taxa to separation between sites to be gauged (Table 9). Crustose coralline algae, *Ralsfsia* sp., solitary ascidians, *Carpophyllum flexuosum* and *Ecklonia radiata* are characteristic of all the extremes of subtidal assemblages present on the reef. Changes in the percent cover of these common taxa between sites helps to determine characteristic site assemblages. All other variables listed in Table 9 contribute to the differences between sites by being recorded as a cover class only sporadically.

The models selected to best explain the density variables (Table 10), showed mostly spatial or non-linear temporal variation; only two taxa showed linear changes. Solitary ascidian densities decreased significantly over time (Fig. 12), which was mainly driven by large decreases in density at sites MSE1 and MSE2 before 2002. Densities of *Ecklonia radiata* were also best modelled by linear change (Table 9), three sites showed a general trend of increase in densities over time (Fig. 12). *Carpophyllum maschalocarpum* and *C. flexuosum* densities are both influenced by side of the reef generally *C. maschalocarpum* is most dense on the western and *C. flexuosum* on the eastern side of the reef (Fig. 12). *Turbo smaragdus* showed an effect of year with low densities for 2001, 2002 and 2006 and higher densities between these times (Fig. 13). The number of individuals recorded followed the pattern described for *Turbo smargdus*, although a year*dist interaction was detected, probably driven by low variability at southern sites (MSE1 and MSW1) compared to northern sites (MSE3 and MSW3). The number of taxa was best modelled using the year factor (Table 10), which showed that sites were temporally variable (Fig. 13).

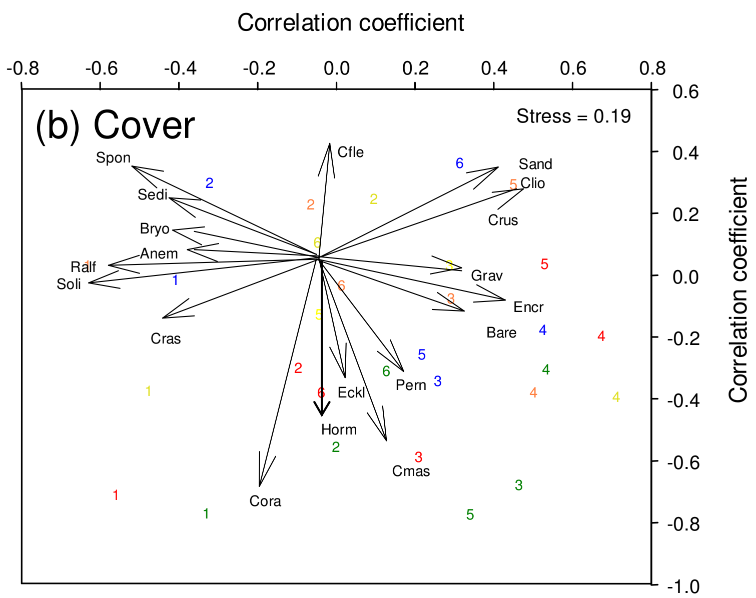
No consistent pattern was seen in terms of change in percent cover variables (Table 10). The effect of linear change (ylin) on unconsolidated substrates and *Ralfsia* sp. is complementary; generally unconsolidated substrate cover is increasing over time and the cover of *Ralfsia* sp. is decreasing over time (Fig. 14). The effect of the side of the reef on sediment and sand cover is also generally complementary; sediment percent cover is higher on the western and sand percent cover higher on the eastern side of the reef (Fig. 14). Distance is modelled as the most parsimonious explanation of the crustose coralline algae (CCA) data, although in the plots all sites appear highly variable over time (Fig. 15). The percentage cover of shell hash and the number of cover classes varied with year (Fig. 15, Table 10). The number of cover classes was generally lowest in 2001 and highest in 2004 (Fig. 15). The cover of shell hash was variable and no clear patterns could be identified (Fig. 15, Table 10).

Figure 11

MDS plots of (i) Subtidal count data and (ii) Subtidal percent cover data at the site level (n = 5-7 per site) showing correlations with variables >|0.4|. The longer the arrow the stronger the relationship between that taxa and the separation between samples in that direction. The numbers on the plot indicate years, 1 = 2001, 2= 2002 etc. The colours on the plots indicate sites Red = MSE1, Orange =MSE2, Yellow = MSE3, Green = MSW1, Blue = MSW2.



Abbreviations
Cfle= *Carpophyllum flexuosum*, **Cmas** = *Carpophyllum maschalocarpum*, **Crass** = *Crassostrea gigas*, **Evec** = *Evechinus chloroticus*, **Haus** = *Haustrum haustorium*, **Horm** = *Hormosira banksii*, **Pati** = *Patiriella regularis*, **Pern** = *Perna canaliculus*, **Soli** = Solitary Ascidian, **Troc** = *Trochus viridus*



Abbreviations
Anem = Anemone, **Bare** = Bare rock, **Bryo** = Bryozoan, **Cfle** = *Carpophyllum flexuosum*, **Clio** = *Cliona celata*, **Cmas** = *Carpophyllum maschalocarpum* **Cora** = Coralline Turfing algae, **Cras** = *Crassostrea gigas*, **Crus** = Crustose Coralline Algae, **Eckl** = *Ecklonia radiata*, **Encr** = Encrusting Ascidians, **Grav** = gravel, **Horm** = *Hormosira banksii*, **Pern** = *Perna canaliculus*, **Ralf** = *Ralfsia* spp., **Sand** = Sand, **Sedi** = Sediment, **Soli** = Solitary Ascidians, **Spon** = Sponges

Table 8

Densities per m^2 of taxa identified by their correlation coefficients as highly correlated (>|0.4|) with MDS axes 1 and 2, at the extremes of the subtidal count MDS plot (Fig. 11a). Direction of correlation refers to the direction of correlation arrows on the plot, and the positions of sites on the plot are given in order to easily match sites and directions of arrows.

Direction of correlation	*Taxa*	*Top left* MSW1 2003	*Bottom left* MSW1 2005	*Top right* MSE2 2005
Top left	*Crassostrea gigas*	0	0.7	0
Top left	*Hormosira banksii*	0	2.4	0
Top left	*Perna canaliculus*	0	4	0
Bottom left	*Carpophyllum maschalocarpum*	74.4	21.6	0
Bottom left	*Haustrum haustorium*	0.1	0	0
Top right	Solitary ascidians	0	1.1	1.6
Right	*Carpophyllum flexuosum*	0	6.1	9.3
Right	*Evechinus chloroticus*	0	0	0.3
Right	*Patiriella regularis*	0.3	0.4	1.6
Right	*Trochus viridus*	0.1	0	2.9

Table 9

Percent cover of parameters identified by their correlation coefficients as highly correlated (>|0.4|) with MDS axes 1 and 2, at the extremes of the subtidal cover MDS plot (Fig. 11b). Direction of correlation refers to the direction of correlation arrows on the plot, and the positions of sites on the plot are given in order to easily match sites and directions of arrows. C. in the taxa column is an abbreviation of *Carpophyllum*.

Direction of correlation	*Taxa*	*Top left* *2002* *MSW2*	*Bottom left* *2001* *MSE1*	*Top right* 2005 *MSE2*	*Far right* *2004* MSE3
Left	Anemone	0.0	0.0	0.0	0.1
Left	Bryozoan	0.0	0.6	0.0	0.6
Left	*Crassostrea gigas*	1.1	6.6	0.0	0.0
Left	*Ralfsia* sp.	25.0	24.2	1.4	1.7
Left	Sediment	42.8	30.3	25.6	14.8
Left	Solitary ascidians	0.6	4.0	0.4	0.7
Left	Sponges	1.5	1.0	1.5	0.0
Right	Bare rock	0.0	0.0	1.7	2.1
Right	*Cliona celata*	0.6	0.0	1.2	0.7
Right	Crustose coralline algae	15.7	3.0	6.4	32.2
Right	Encrusting ascidians	0.0	0.0	0.0	4.2
Right	Gravel	0.0	0.0	0.0	1.9
Right	Sand	0.0	2.0	44.4	15.0
Up	*C. flexuosum*	1.9	1.1	2.9	1.2
Down	*C. maschalocarpum*	1.1	0.8	0.0	0.8
Down	*Corallina officinalis*	0.0	23.3	0.0	7.1
Down	*Ecklonia radiata*	0.5	2.3	1.1	2.5
Down	*Hormosira banksii*	0.0	0.2	0.0	0.2
Down	*Perna canaliculus*	0.0	0.0	0.0	0.0

Table 10

Results of negative binomial GLMs for several individual response variables in the subtidal. The best model in each case is shown, along with the number of parameters (p), degrees of freedom of the residual (dfres), log of the likelihood (logL) and the information criterion (BIC). The number of taxa, the number of cover classes, crustose coraline algae (CCA) and sediment were analysed using a traditional linear model with normal errors, instead of the negative binomial. CCA and sediment were log and sqrt transformed respectively prior to analysis to fulfil assumptions of normality and homogeneity.

Variable	*Model equation*	*p*	*dfres*	*logL*	*BIC*
Carpophyllum flexuosum	Year*Side	13	192	-648.489	1366.18
Carpophyllum maschalocarpum	Side	3	202	-608.92	1233.81
Ecklonia radiata	Ylin	3	202	-418.809	853.59
Solitary ascidians	Ylin	3	202	-481.382	978.73
Turbo smaragdus	Year	7	198	-918.052	1873.37
Number of individuals	Year*Dist	13	192	-1019.46	2108.12
Number of taxa	Side	3	202	-421.231	863.71
Sediment	Side	3	202	-520.969	1063.82
Sand	Side	3	202	-649.154	1314.28
Shell	Year	7	198	-476.835	990.93
Crustose coralline algae	Dist	3	202	-356.023	733.29
Unconsolidated substrates	Ylin	3	202	-976.016	1968.00
Ralfsia sp.	Ylin	3	202	-687.777	1391.52
Number of cover classes	Year	7	198	-437.885	918.12

Figure 12

Line plots showing density per m-2 of taxa at each subtidal site over time (2001-2006). n = 7 (except in 2001; MSE1 n = 5, MSE2, MSE3 and MSW2 n = 6). Bars = standard errors. (Note: density scales may vary among graphs).

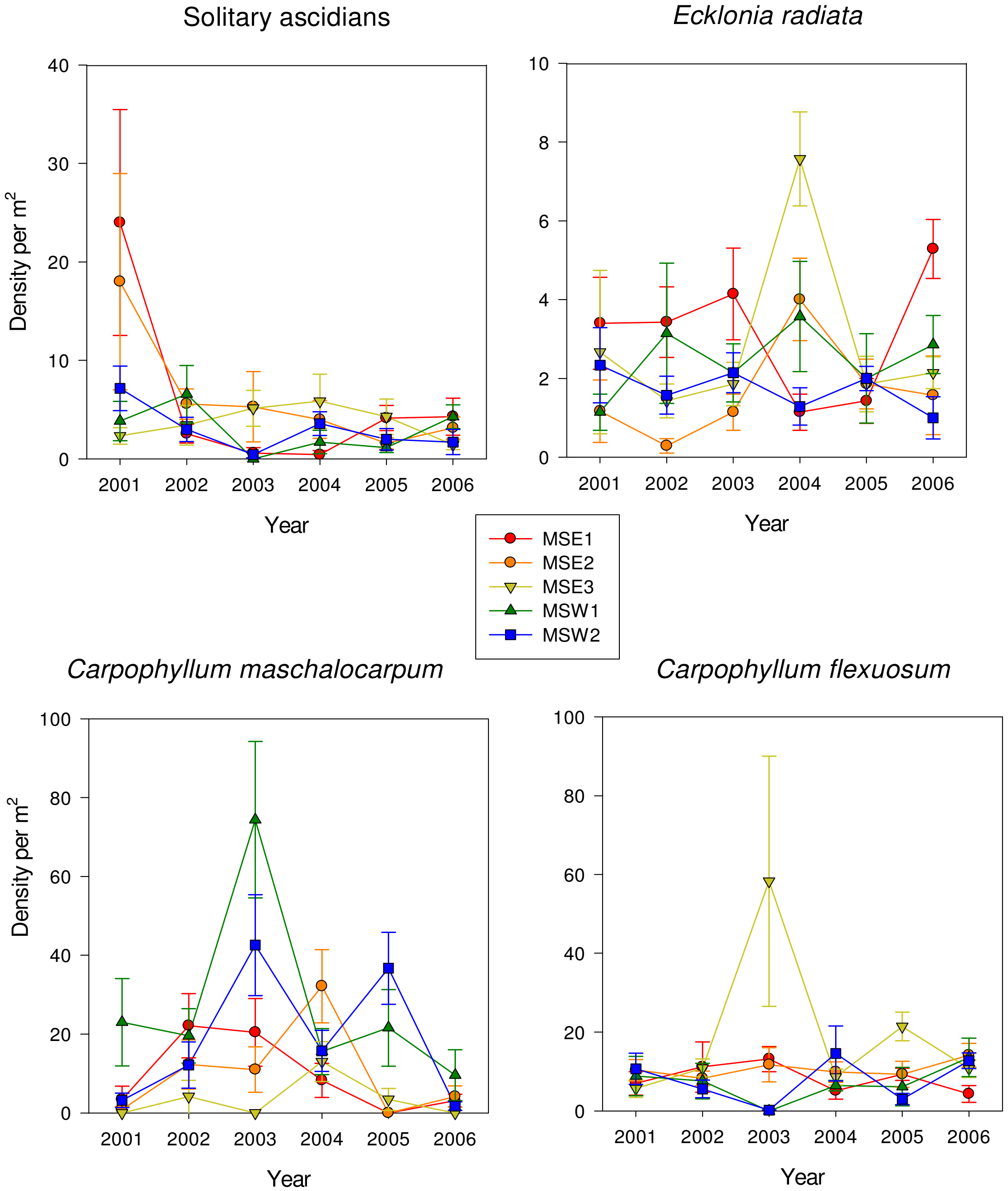


Figure 13

Line plots showing density per m-2 of taxa at each subtidal site over time (2001 to 2006). n = 7 except in 2001, MSE1 n = 5, MSE2, MSE3 and MSW2 n = 6). Bars = standard errors (Note: density scales may vary among graphs).

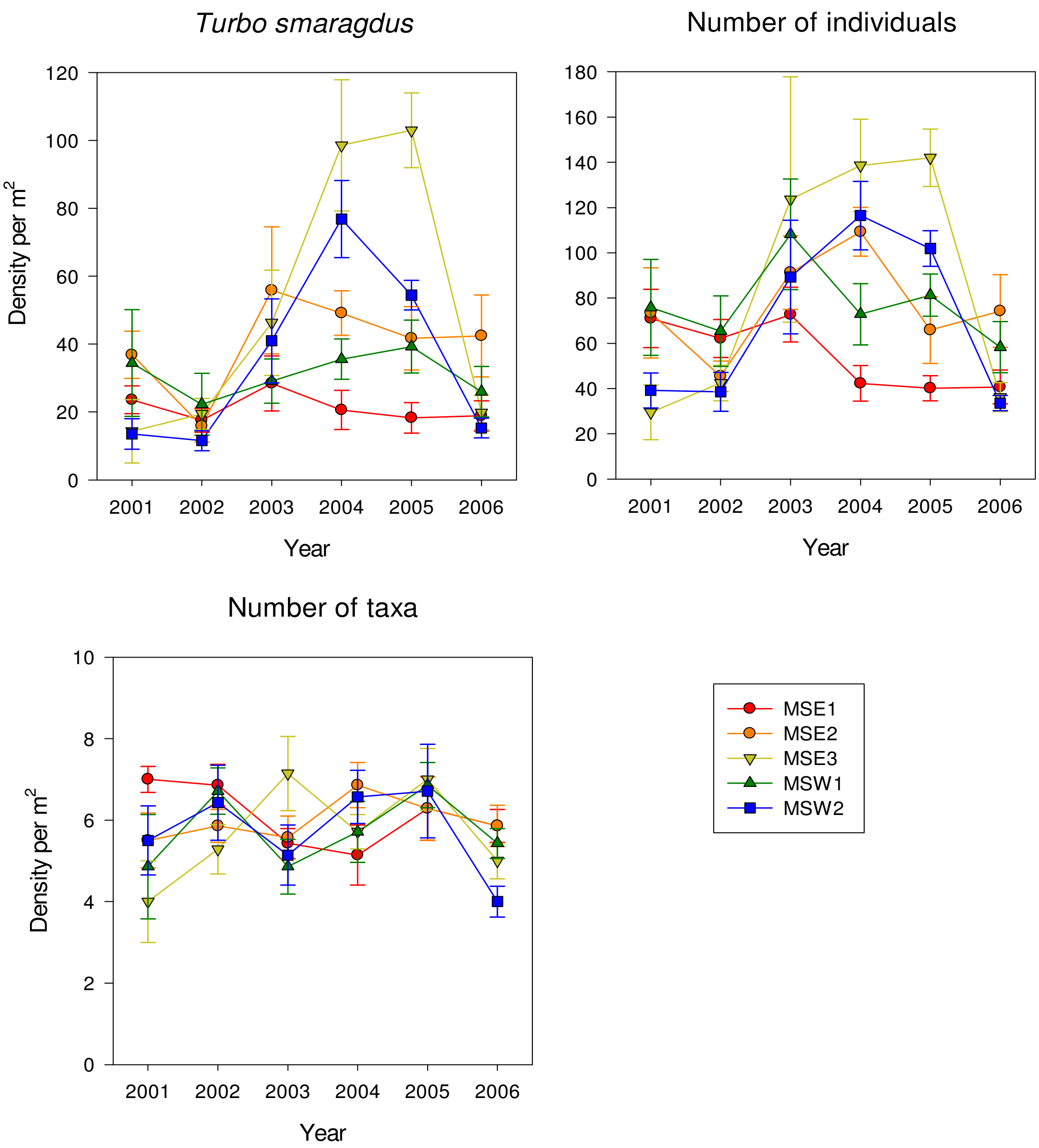


Figure 14

Line plots showing percentage cover (%) of cover types at each subtidal site over time (2001 to 2006). n= 7 except in 2001; MSE1 n = 5, MSE2, MSE3 and MSW2 n = 6). Bars = standard errors.

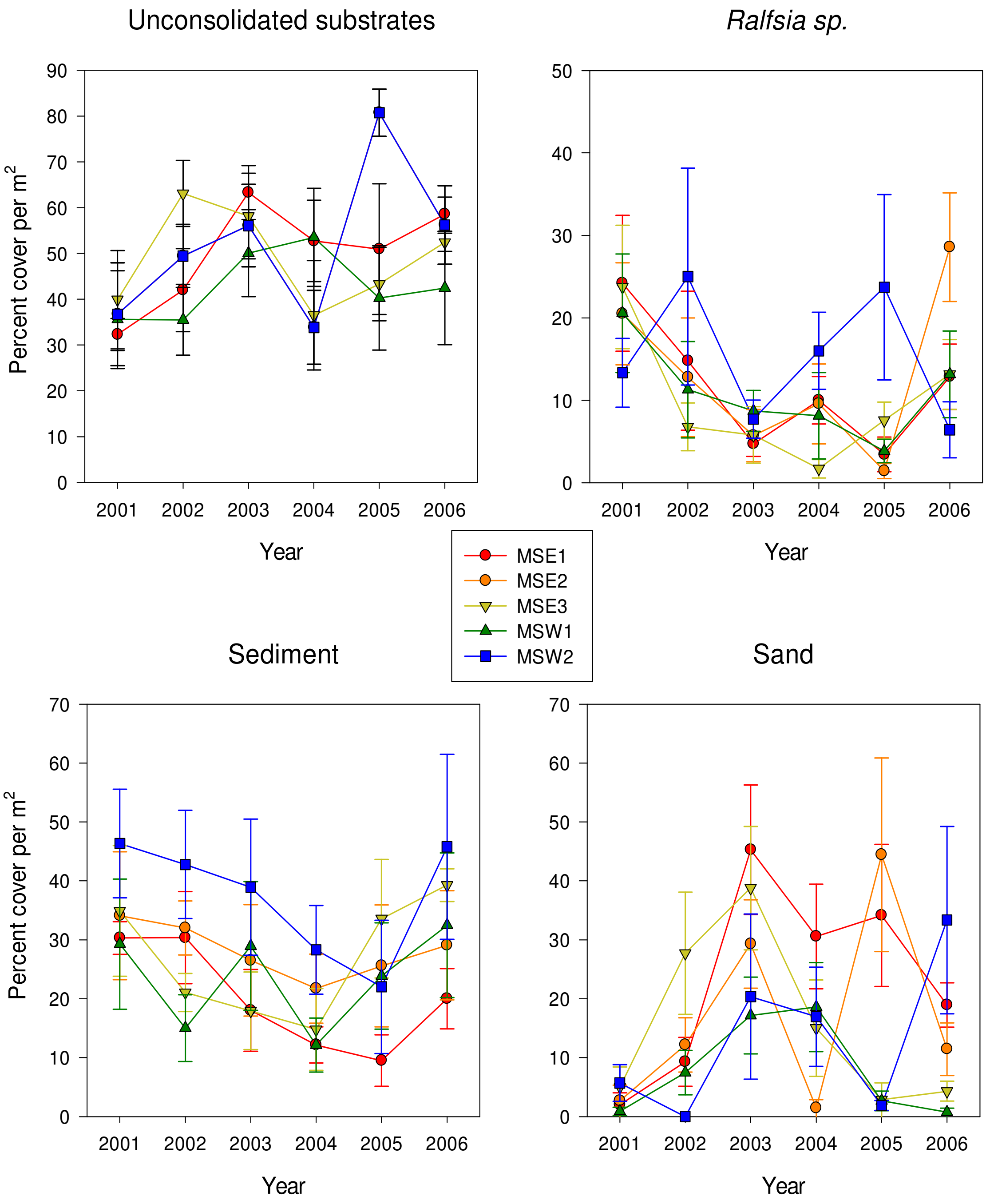
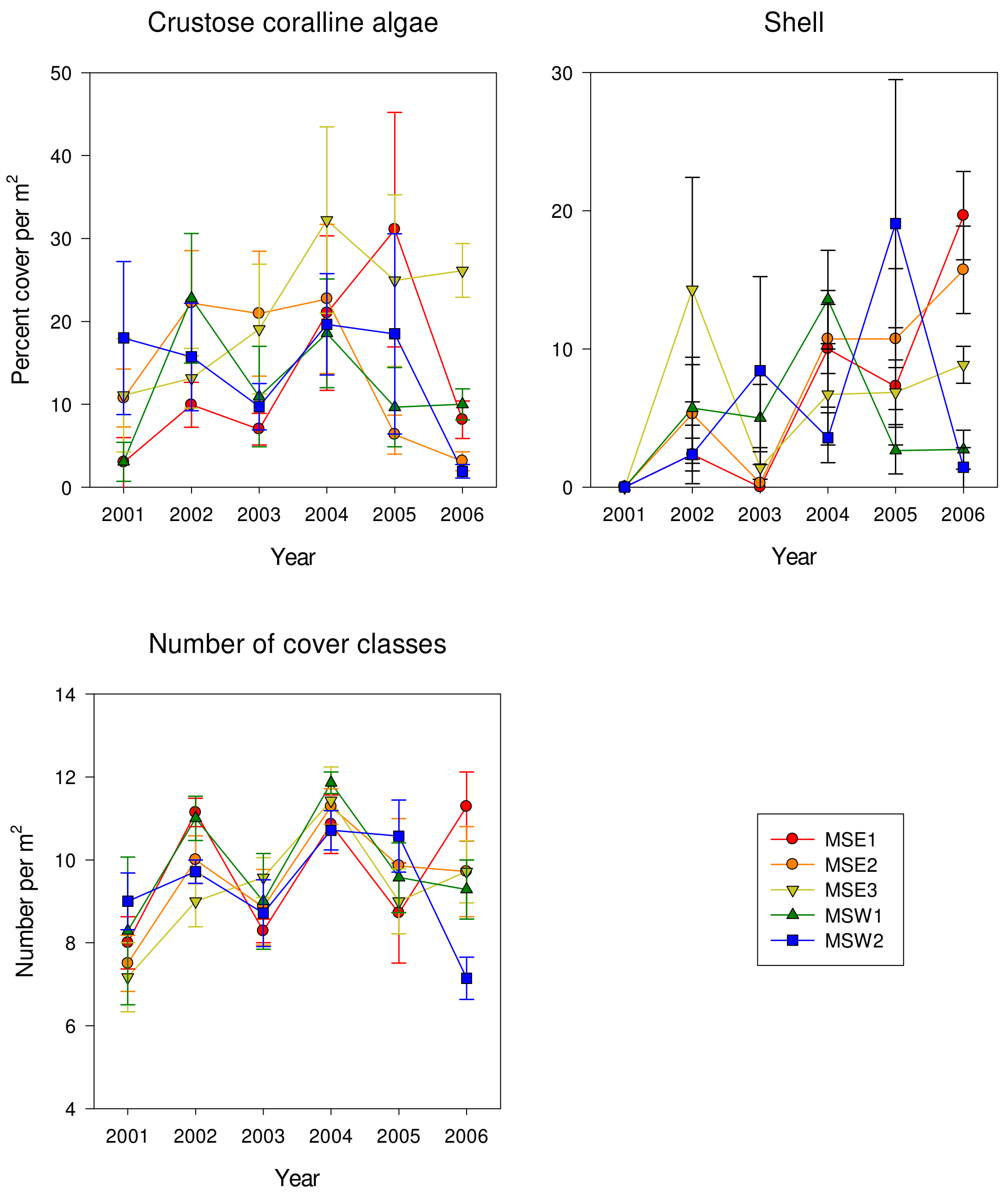


Figure 15

Line plots showing density per m-2 of taxa at each subtidal site over time (2001 to 2006). N = 7 (except in 2001, MSE1 n = 5, MSE2, MSE3 and MSW2 n = 6). Bars = standard errors (Note: density scales may vary among graphs).



4.2.3 Population size structure

Size frequency distributions for three common subtidal species (*Carpophyllum maschalocarpum*, *Carpophyllum flexuosum* and *Turbo smaragdus*), were examined across year (2001 to 2006) and site factors (MSE1, MSE2, MSE3, MSW1, MSW2 and MSW3) (Appendix G1, G2 and G3).

No significant differences ($P<0.05$) were detected in the population size structures of any of the chosen three taxa in response to either site or time factors. Three responses were however marginally non-significant; that of *Turbo smaragdus* to both site ($p = 0.08$) and year ($p = 0.05$) factors, and *Carpophyllum maschalocarpum* to the site factor ($p = 0.06$).

The three marginally non-significant results suggested some spatially consistent patterns and temporal variability, but no directional change over time. The difference in size frequencies for *Turbo smaragdus* were driven by differences between the site MSE1 and the year 2005 compared to other sites and years (average dissimilarities >30%). Proportionately site MSE1 had more 20mm or larger *T. smaragdus* than the other subtidal sites. This pattern can be seen in Appendix G1 where 25mm *T. smaragdus* individuals were recorded at this site in 5 of the 6 years; at no other site were this size class found so consistently. The 2005 year was characterised by proportionately more smaller (<20mm) *T. smaragdus* individuals than other years. Differences in the size structure of *Carpophyllum maschalocarpum* between sites was driven by the relatively low average proportion of plants at site MSE3 in some size classes (less than 100 cm in length), when averaged across all years, by comparison to other sites.

4.2.4 Patterns in sediment variables

Intertidal and subtidal sediment cover have already been investigated in the previous sections and were best explained by the year of sampling and side of the reef respectively, therefore this section will focus upon the trapped sediment results.

The patterns detected in sediment variables were mainly driven by high values recorded for average trap rates at all sites in 2001, and at site MSW1 in most years. Linear decreases in the average amount of trapped sediments and variation in the SD trap rate were detected over time (Table 11, Fig. 16). This was mainly due to high values for both of these variables in 2001, then relatively low and consistent values after 2001. Linear change with time (ylin) interacts with reef side in the case of the average trap sediments; in most years, MSW1 shows the highest amount of trapped sediments. The year+side model choice for proportion of fine sediments is seen in the graphs as variability over time, but generally a lower proportion of fine sediment was trapped on the western side of the reef (Fig. 16). The variation in the rate of fine sediment trapped is best explained by the year and side factors, again this difference is driven by the generally high rate of fine sediment trapped at MSW1 by comparison to the other sites (Table 11, Fig. 16).

Figure 16

Mean ± SE average trap rate and the standard deviation (SD) of the trap rate at monitored subtidal sites. Sample sizes varied from 5-10 for all years excluding 2001 when n = 3 and 2006 when the sample sizes varied from 1 – 3.

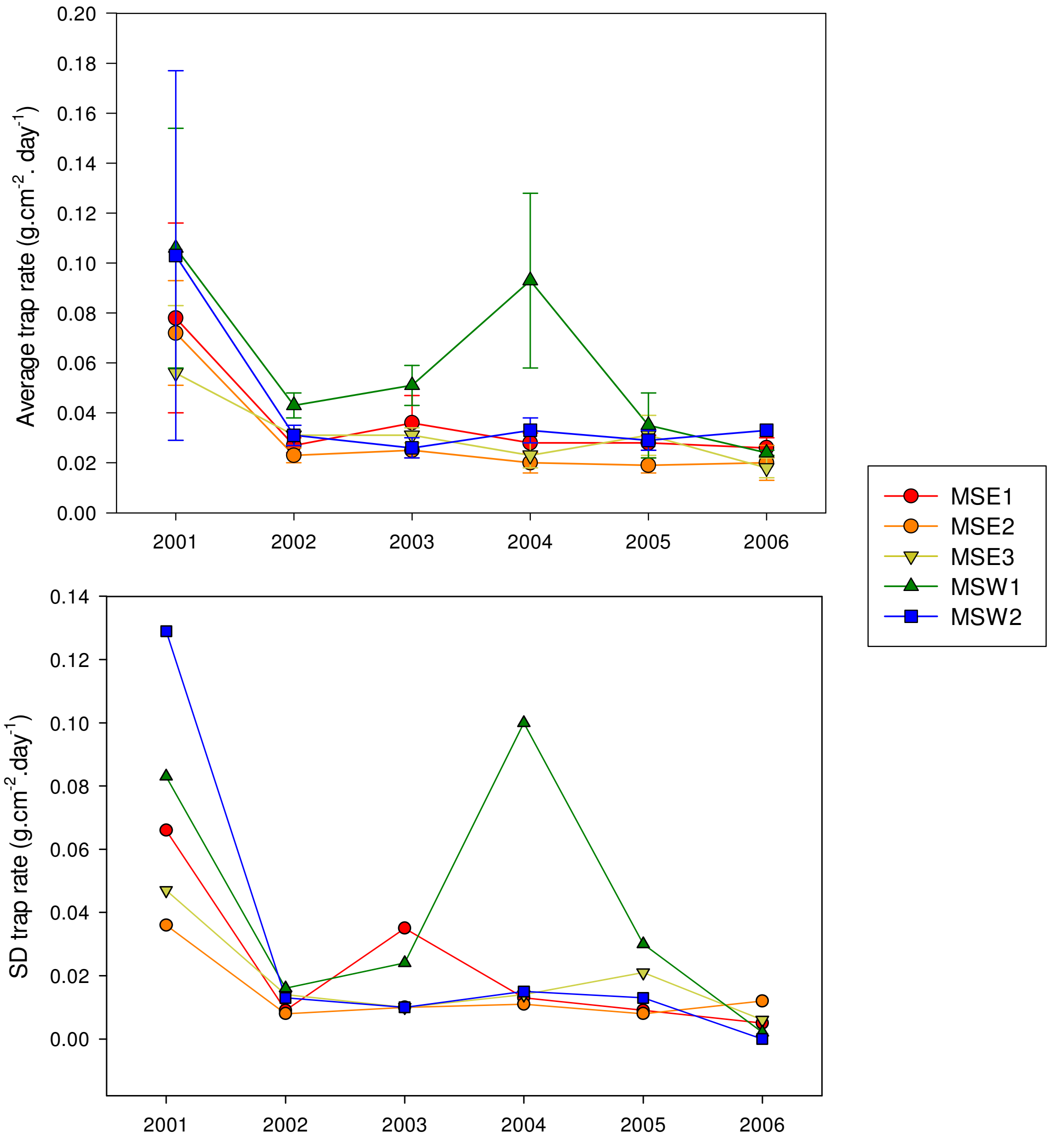


Table 11

Results of linear models for sediment variables. The best model in each case is shown, along with the number of parameters (p), degrees of freedom of the residual (dfres), log of the likelihood (logL) and the information criterion (BIC). The average trap rate and rate of fine sediment trapping and the SD trap rate were all log-transformed before analysis to fulfil assumptions of normality and homogeneity.

Variable	*Model equation*	*p*	*dfres*	*logL*	*BIC*
Average trap rate	Ylin+Side	7	23	0.721	25.768
SD trap rate	Year*Side	3	26	-17.965	75.595
Percentage of fine sediments	Year+Side	5	15	-62.566	140.114
Rate of fine sediment trapping	Dist	*2*	*18*	-0.966	7.924

4.2.5 Relationship between sediment variables and subtidal fauna

CAP analyses showed significant relationships existed between the sediment and faunal variables. Count data was significantly correlated with the percentages of sediment and unconsolidated substrates. Percentage cover data was also significantly correlated with the average trap rate and the proportion of fine sediments in traps (Table 12). CAP plots show the axis through the multivariate data cloud that is most correlated with sediment variables, whereas MDS plots show the axis of greatest variation. Examination of these plots together indicates that although some strong correlations exist between sediment variables and faunal measures, none of these are along the axis of greatest variation (Fig. 17). Therefore, sedimentation was not the dominant factor driving community structure on Meola reef.

Cover of sediments is, however, significantly, correlated with community structure and strongly, although not necessarily linearly, correlated with population density for a number of taxa (Fig. 18). The predatory whelk *Buccinulum* sp., the herbivorous echinoderm *Evechinus chloroticus*, the number of taxa and the herbivorous gastropod *Trochus viridus* and *Turbo smaragdus* were either absent, or present in less than maximum densities, at sites with an average of more than 20 - 30% sediment cover. The number of cover classes present decreased with increasing sediment cover. When the percentage cover of all mobile unconsolidated substrates are considered (sand, shell hash and sediment), which will all act to exclude settlement of hard substrate fauna, a slightly different set of fauna are strongly correlated. An increase in densities of the cushion star *Patireilla regularis* was observed (Fig. 19). Solitary ascidian densities decreased as unconsolidated substrate cover increased (Fig. 19). *Hormosira banksii* and *Crassostrea gigas*, both of which are primarily intertidal species, were both absent at sites with above ~ 40% cover of unconsolidated substrates (Fig. 19).

Some trapped sediment variables were also strongly correlated with percentage cover variables (Table 12). As the average trap rate increased, cover of green filamentous algae, *Crassostrea gigas*, anemones and solitary ascidians (which were all generally 1 percent cover or less), also generally increased (Fig. 20). The percentage cover of sand, shell hash and the sponge *Cliona cellata*, all showed a negative correlation with the average trap rate (Fig. 20). The percentage cover of barnacles, *Carpophyllum maschalocarpum*, *Crassostrea gigas*, encrusting ascidians, *Hormosiira banksii*, *Perna canaliculus*, and the number of cover classes were strongly negatively correlated with the percent of fine sediments in traps (Fig. 21). The percentage of fine sediments in traps was strongly positively correlated with the cover of unidentified brown turf (although this was only recorded once), Bryozoans, *Cliona celata* and sponges. It should be noted that many of these relationships appear to be exponential rather than linear (*Cliona celata*, sand and shell in Fig. 20, bryozoans, encrusting ascidians and barnacles in Fig. 21). This means that small changes in sediment variables could result in large changes in densities of these taxa.

Table 12

Results of CAP analyses examining the relationship between count and cover faunal data and sediment variables. % Var = the percentage of the total variation explained by the first m axes, m = the number of (PCO) axes used in the CAP procedure, P = Probability, obtained using 999 random permutations, delta_1^2 = the canonical correlation. The analysis was obtained from Bray-Curtis dissimilarities of ln(x) +1 transformed count and cover data. Observations were pooled at the site level (n =5-7 per site). Significant results are shown in bold P<0.05.

Response	*Factor*	*%Var*	*M*	*P*	*delta_1^2*
Count	Proportion of fine sediments in traps	0.89	6	0.099	0.5195
Count	Fine sediment trapping rate	0.62	3	0.253	0.2149
Count	Average trap rate	0.64	5	0.152	0.2778
Count	Percent sediment cover	0.74	5	**0.002**	0.5062
Count	Percent unconsolidated substrates	0.96	9	**0.012**	0.5920
Cover	Fine sediment trapping rate	0.69	4	0.432	0.2183
Cover	Average trap rate	0.91	8	**0.01**	0.5742
Cover	Proportion of fine sediments in traps	0.94	8	**0.006**	0.8003

Figure 17

MDS plots of faunal data and CAP plots of significant correlations between fauna and sediment variables for comparison. The analysis was obtained from Bray-Curtis dissimilarities of ln(x) + 1 transformed count and cover data. Observations were pooled at the site level (n = 5 –7 per site). Note: the bottom right plot shows a reduced data set (n = 20 cf. n = 30) due to non-commensurable methods for calculating fines before 2003. Numbers = years, 1 = 2001, 2 = 2002 etc. Colours indicate sites, Red = MSE1, Orange = MSE2, Yellow = MSE3, Green = MSW1, Blue = MSW2.

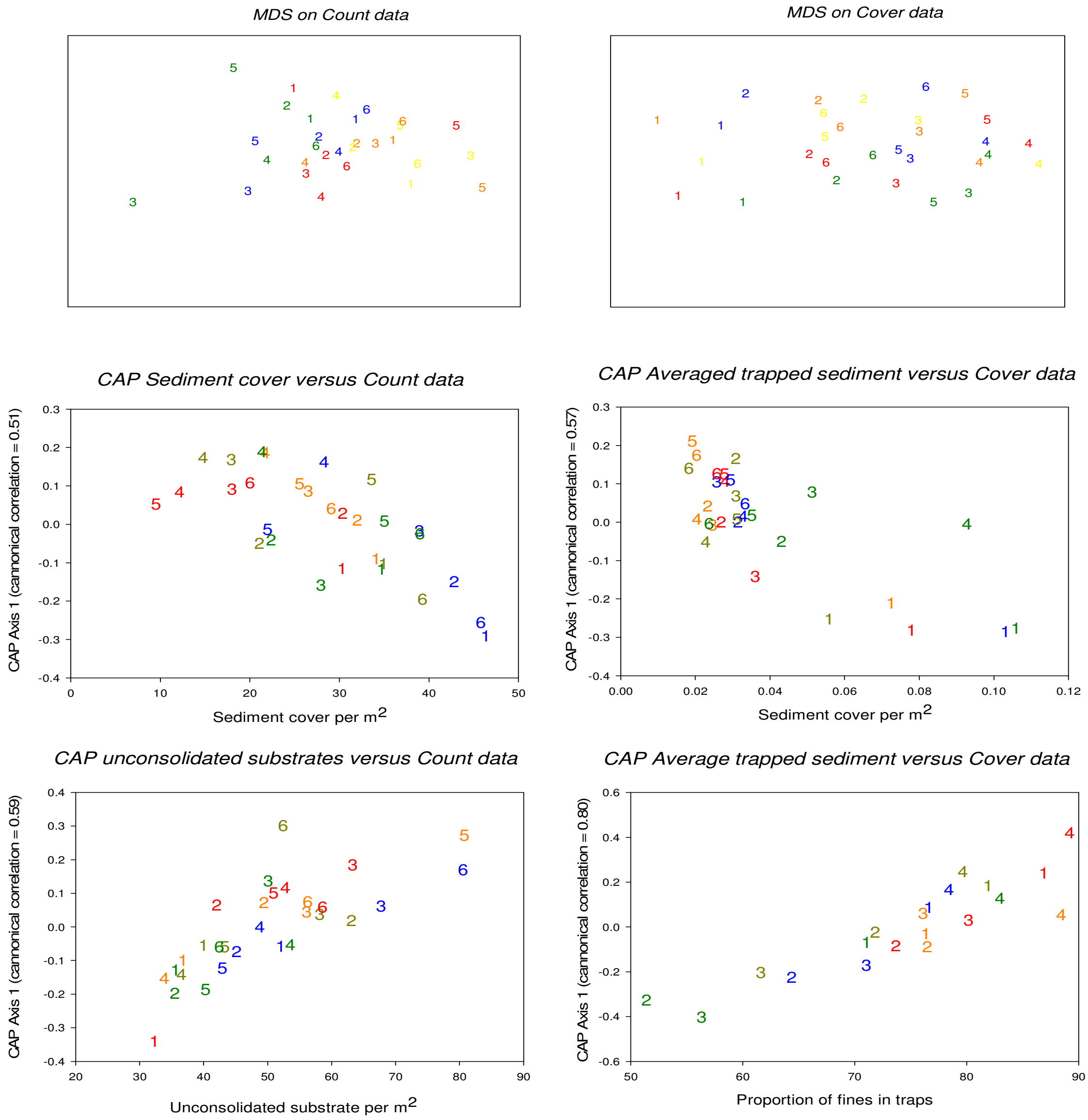


Figure 18

Taxa strongly correlated >|0.4| with the gradient in sediment cover and the relationship between the number of taxa (P=0.07) and the number of cover classes (P=0.02) plotted against sediment cover per site. Averages shown per site by year combination, n = 5 – 7 per site.

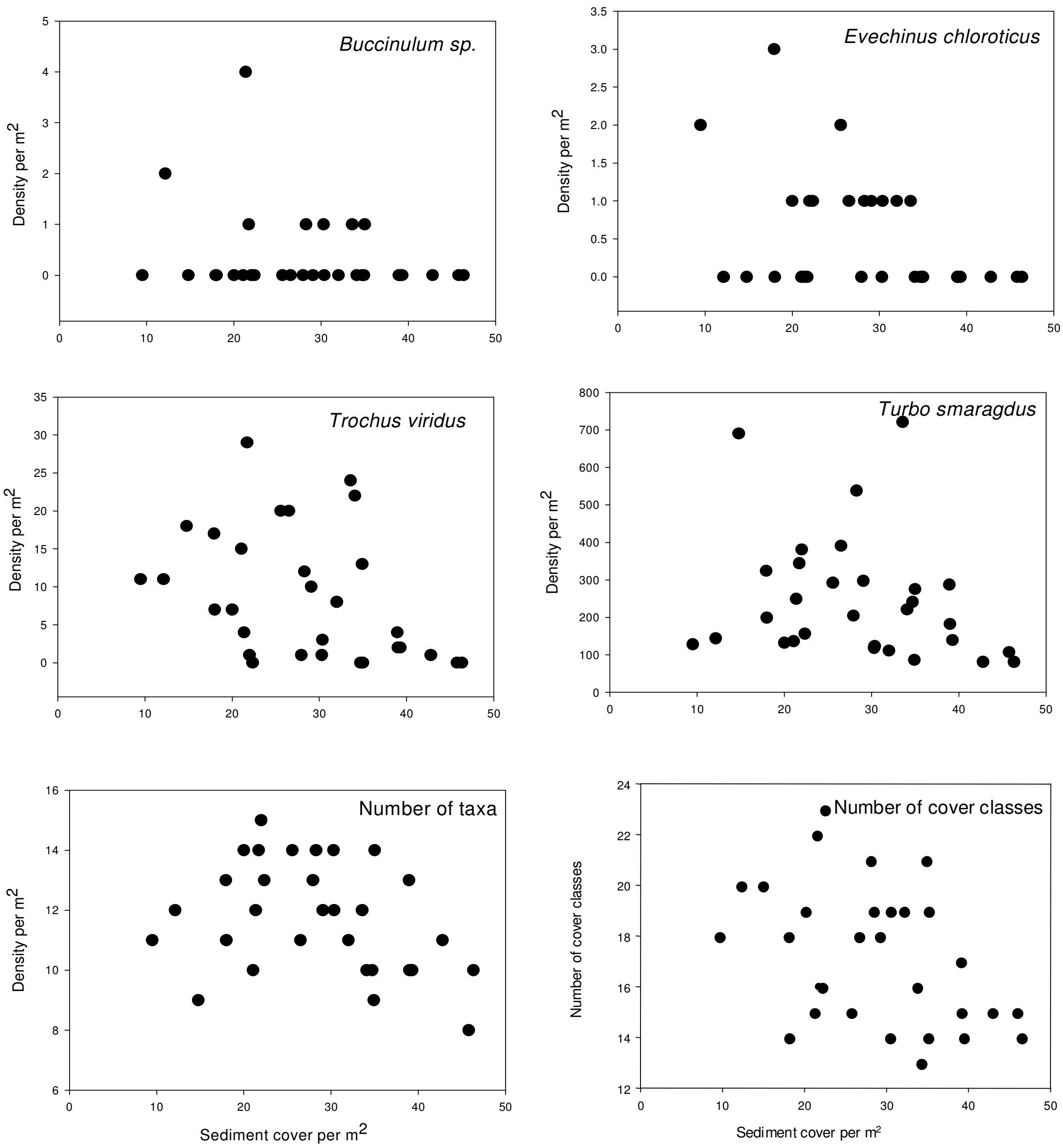


Figure 19

Taxa strongly correlated >|0.4| with the gradient in cover of unconsolidated substrate, plotted against unconsolidated substrate cover per site. Averages shown per site by year combination, n = 5 – 7 per site.

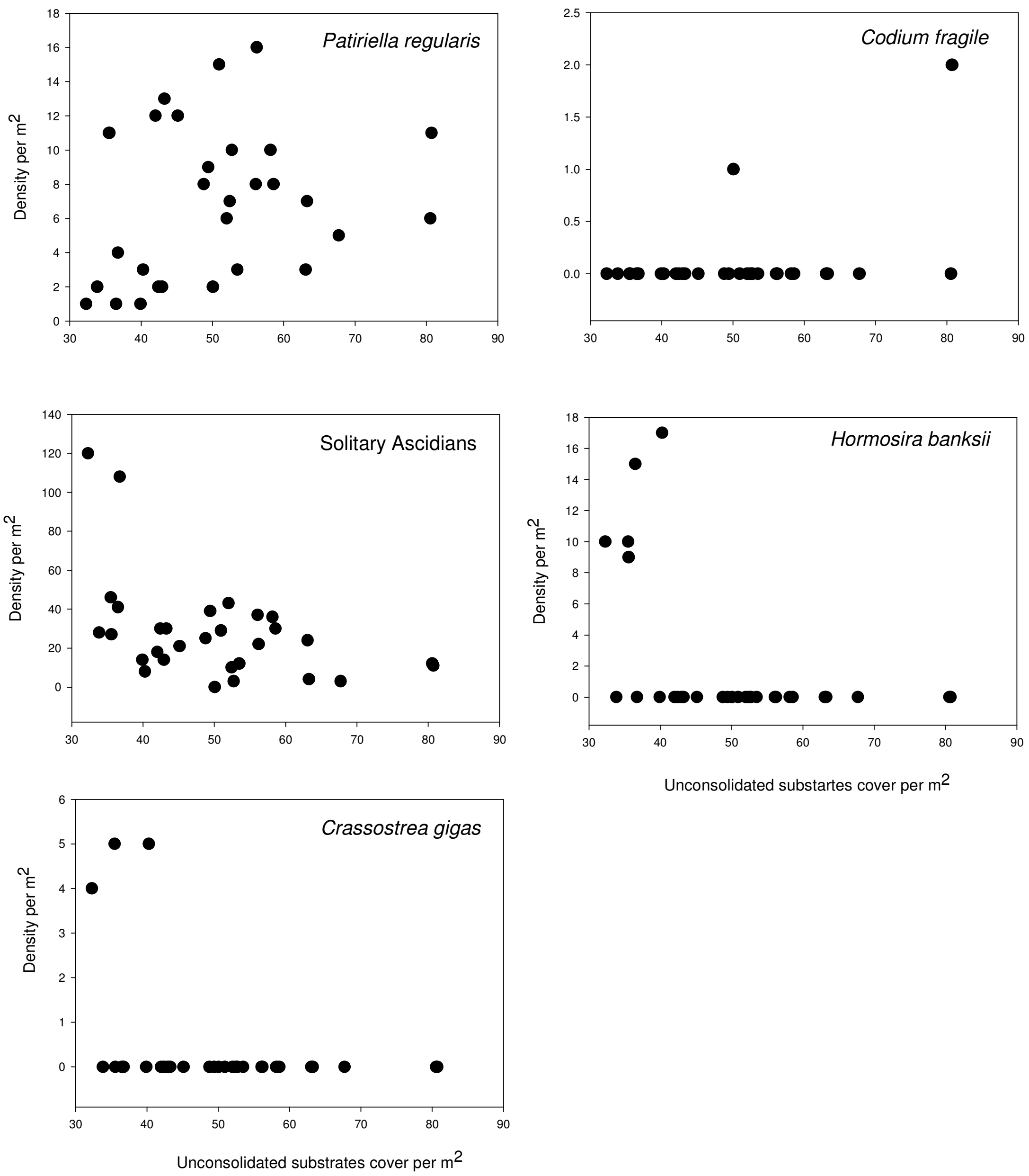


Figure 20

Subtidal percentage covers correlated (>|0.4|) with the gradient in the average rate of trapped sedimentation from the CAP analysis. Averages are shown per site by year combination, n = 5 –7 per site.

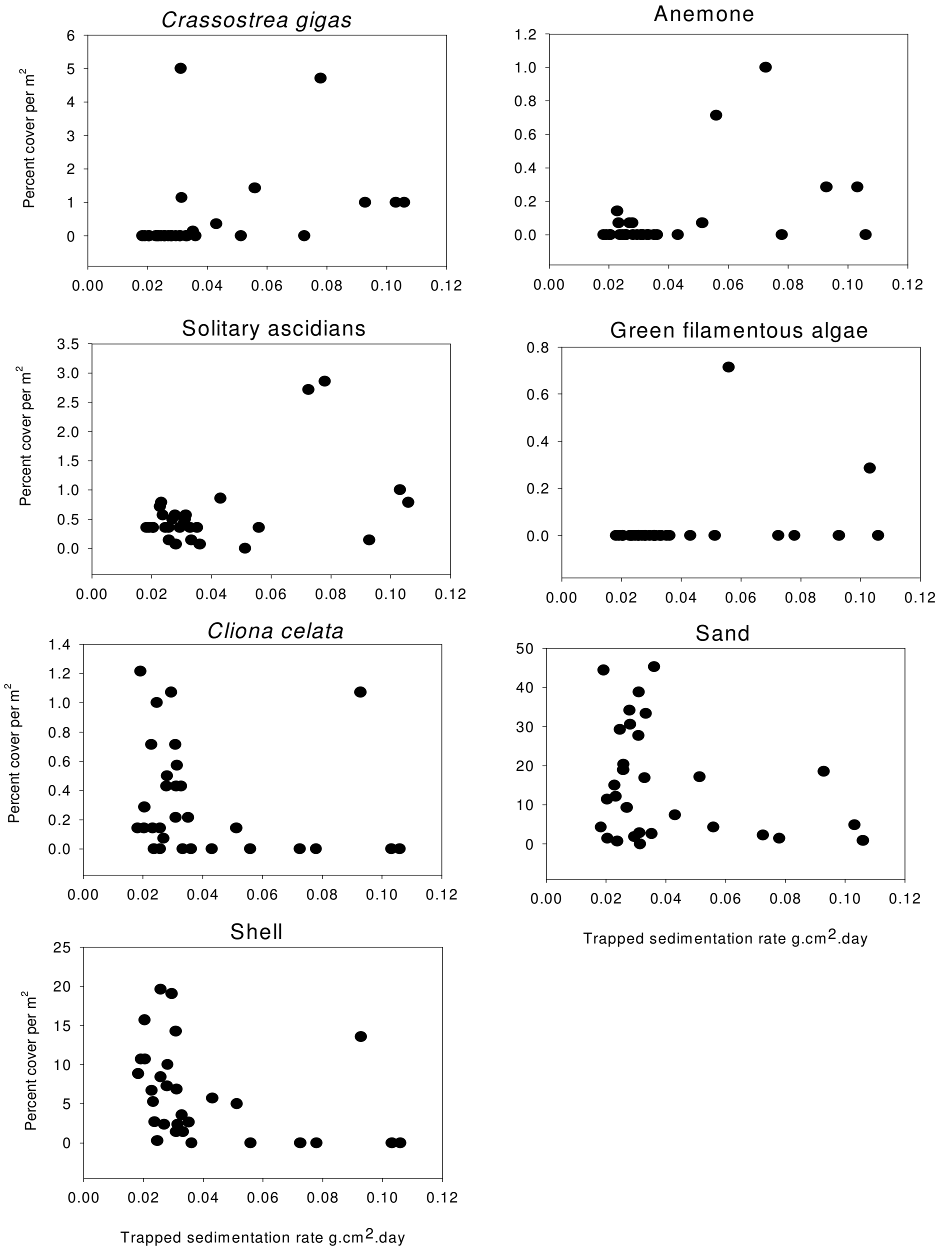
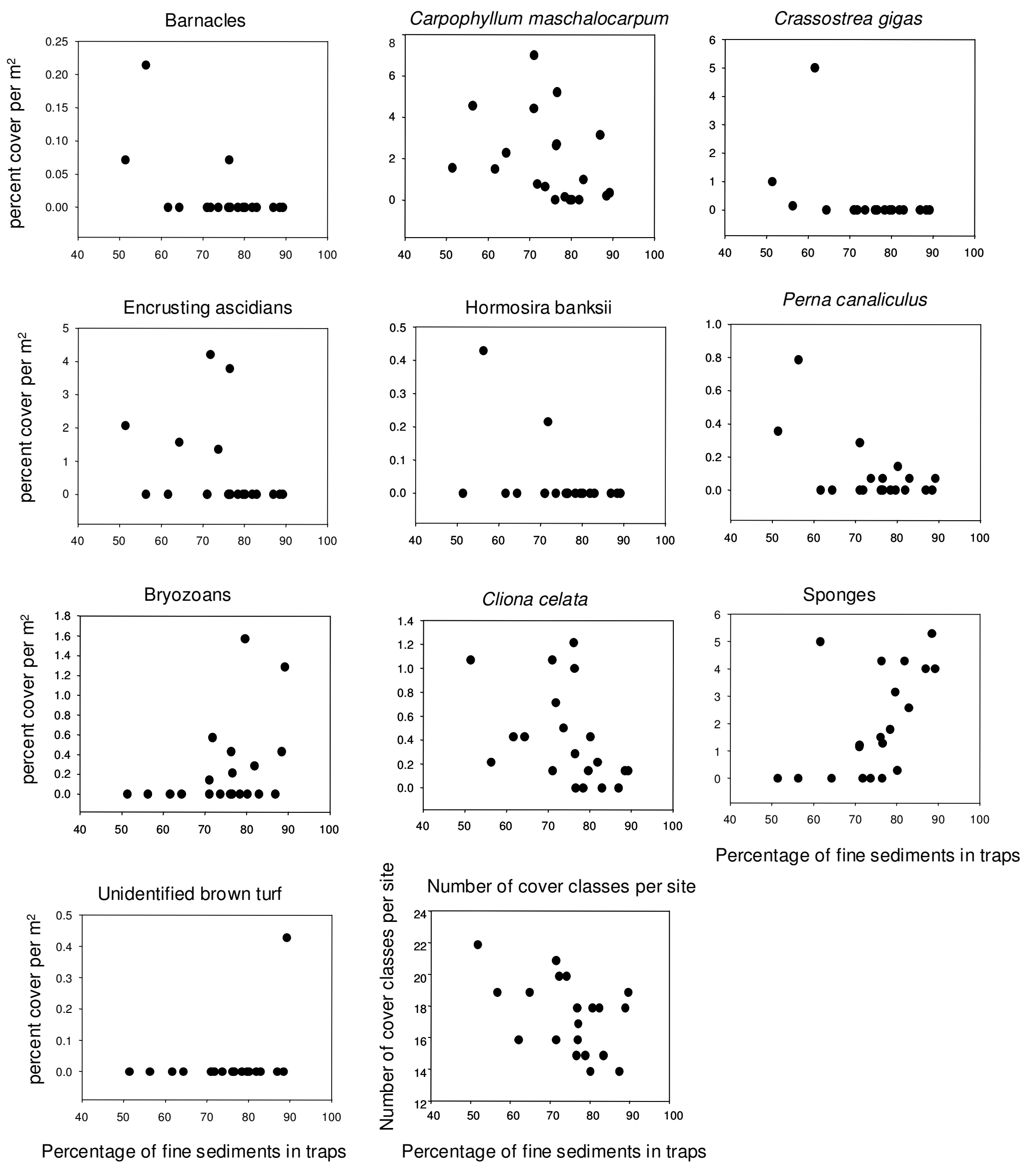


Figure 21

Average subtidal percentage covers correlated (>|0.4|) with the gradient in the percentage of fine sediments in traps from the CAP analysis. The average number of cover classes versus the percentage of fine sediments in traps is also shown. All data is shown per site by year combination, n = 7 per site.



5 Discussion

5.1 Intertidal results

5.1.1 Salient intertidal results

The most salient results found for the intertidal rocky reef assemblages were;

- A strong south-north gradient in community structure was detected along the reef for both count and cover data.
- A slight, linear trend in the pattern of percent cover occurred at the northern end of the reef between 2002 and 2005, such that the northern sites became more distinct over time.
- The taxa that were causing the most distinction between sites over time were the gastropods, *Melagraphia aethiops* and *Turbo smaragdus*, the anemone *Diadumene linaeta*, the mite *Acari* and the small black mussel, *Xenostrobus pulex*.
- For percentage cover data, the cover types that were mainly causing differences between sites or years were sediment, *Crassostrea gigas*, barnacles and the algae *Gelidium sp*.
- The cover of *Crassostrea gigas* was lowest on the western side of the reef and was highest on the eastern side of the reef.
- *Xenostrobus pulex* was the only taxa that showed a consistent or linear pattern of change over time; the density of *X. pulex* generally increased from 2001 to 2004 and then decreased at all sites.
- Size frequency data showed no changes that indicated any size specific mortality, movement or lack of recruitment.
- The number of taxa was relatively low at site MIW1, and the number of cover classes increased northwards, but neither these two measures nor the number of individuals showed any linear change with time.
- The percentage of sediment cover was significantly negatively correlated with the densities of *Melagarphia aethiops*, *Turbo smaragdus*, and the total number of individuals found per site.

5.1.2 Discussion of intertidal patterns

The intertidal rocky-reef assemblages at Meola reef were characterised by a substrate that is largely covered by the oyster *Crassostrea gigas*, bare rock or sediment. Within this structural matrix the fauna was dominated by the molluscs, *Turbo smaragdus, Sypharochiton pelliserpentis, Xenostrobus pulex, Melagraphia aethipos* and *Zeacumantus lutulentus*, and the anemone *Anthopleura sp*. All of these taxa were also recorded at Meola reef in the survey of Hayward et al. (1999), with the exception of *Anthopleura* sp.. Other anemones were, however, found in Hayward's survey; the lack of *Anthopleura* sp. in their survey is probably due to differences in identification rather than occurrence.

Spatial patterns in assemblage structure were detected on the reef. The number of taxa counted, the number of cover classes, the percentage cover of bare rock and *Crassostrea gigas*, and the densities of *Turbo smaragdus* and *Zeacumantis lutulentus* all showed significant spatial patterns on the reef. In particular, site MIW1 showed consistently low numbers of taxa and cover classes, and a high proportion of bare rock. This site is the most southern therefore it may experience lower availability of recruits or food due to slower flows away from the channel. Alternatively, organisms living on the reef may be affected by a contaminant gradient radiating out from Meola and Motions Creeks (Williamson and Kelly 2003). Further investigation would be required to test this theory.

Temporal changes in intertidal communities were relatively weak compared to spatial differences. Sites furthest from land showed the strongest trends over time; sites MIW3 and MIE3 showed linear changes in percentage cover variables. These changes were driven by a decline in bare rock cover and the increase in cover of oysters (*Crassostrea gigas*) at site MIE3, and exactly the opposite pattern at site MIW3. Increases in the density of the small black mussel, *Xenostrobus pulex*, over time were detected, but due to decreases in densities between 2004 and 2005, any change is likely to have been ecologically trivial and will not be discussed further.

The percentage cover of sediment in the intertidal is negatively correlated with the densities of a number of gastropods (*Melagarphia aethiops, Turbo smaragdus*, and *Cominella virgata*). Consequently, diversity was lowest in sites with high sediment cover. This spatial pattern is an indicator of what may happen if sediment cover increases over time on Meola reef; there could be changes in species composition and distribution. These changes are the most frequently reported effect of sedimentation on rocky reefs (Airoldi 2003).

No temporal trends were detected that signify directional ecological change over time at Meola reef. Given the lack of comparable sentinel sites, it is hard to compare these intertidal basalt reef sites to communities elsewhere. Sediment cover appears to be a key driver of community composition on the reef, but there is no evidence to suggest that the level of sediment cover has changed significantly during the period monitored.

5.2 Subtidal results

5.2.1 Salient subtidal results

- Change in community structure was mainly non-directional, although one statistical test showed a significant linear pattern in percentage cover data.

- Differences between subtidal site communities were weaker than between intertidal site communites.

- Differences between sites were characterized by changes in density of the algae, *Hormosira banksi, Carpophyllum maschalocarpum* and *Carpophyllum flexuosum*, the echinoderms, *Patiriella regularis* and *Evechinus chloroticus*, the bivalves *Crassostrea gigas* and *Perna canaliculus*, the gastropods, *Haustrum haustorium* and *Trochus viridus*, and solitary ascidians.

- Differences between sites were characterized by changes in percentage cover of the algae *Ralfsia sp*., crustose coralline algae, *C. flexuosum, C. maschalocarpum, Corallina officinalis, Ecklonia radiata* and *Hormosira banksii*, the bivalves, *Crassostrea gigas* and *Perna canaliculus*, encrusting and solitary ascidians, *Cliona celata* and other sponges, anemones, bryozoans, and the substrate types: sediment, sand, gravel and bare rock.

- Sediment percent cover is higher on the western side and sand percent cover higher on the eastern side of the reef.

- The models selected to best explain the density variables showed mostly spatial or non-linear temporal variation. Only two taxa showed linear changes over time.

- Averaged across the whole reef, densities of solitary ascidians decreased and densities of *Ecklonia radiata* increased over time.

- The percentage cover of unconsolidated substrates (sand, sediment and shell hash) increased and the percentage cover of the prostrate brown seaweed *Ralfsia sp*. decreased on the whole reef over time.

- Size frequencies were generally uniform over time for the three taxa tested (*Crassostrea gigas, Turbo smaragdus* and *Sypharochiton pelliserpentis*), but proportionately, site MSE1 had more 20mm or larger *T. smaragdus* than the other subtidal sites.

- The number of taxa and the number of percentage cover classes both increased northwards on Meola reef, but neither these two measures, nor the number of individuals, showed any linear change with time.

- The year 2001, and site MSW1 in most years, showed the largest average amount of trapped sediments and trapped fine sediments, with relatively low and consistent amounts recorded at other sites, and in other years.

- A significantly lower proportion of fine sediments were trapped on the western compared to the eastern side of the reef.

- Gradients in sediment variables were not the most important factor driving community differences on Meola reef. However, the cover of sediment, the cover of unconsolidated substrates (sand, sediment and shell hash), the average trap rate, and the proportion of fine sediments in traps were all significantly correlated with assemblage structure.

- Sites which had, on average, over 20-30% sediment cover had decreased densities of the predatory whelk *Buccinulum sp.*, the herbivorous echinoderm *Evechinus chloroticus* and the herbivorous gastropods, *Trochus viridus* and *Turbo smaragdus*. The number of taxa and number of cover classes present at these sites were also relatively low. Responses to sediment were not however always linear, therefore the pattern of response should be examined before predictions of change in abundances with change in sediment cover are made.

- The percentage cover of all mobile unconsolidated substrates (sand, sediment and shell hash), was positively correlated with the densities of the cushion star *Patireilla regularis*, and negatively correlated with the densities of solitary ascidians, *Hormosira banksii* and *Crassostrea gigas*. Responses to sediment were not however always linear, therefore the pattern of response should be examined before predictions of change in abundances with change in sediment cover are made.

- Average trap rate was positively correlated with the cover of green filamentous algae, *Crassostrea gigas*, anemones and solitary ascidians, and negatively correlated with the percentage cover of sand, shell hash and the sponge *Cliona cellata*. Changes in trap rate are likely to result in non-linear changes in the cover of *Cliona celata*, sand and shell hash due to the nature of these relationships.

- The percentage cover of barnacles, *Carpophyllum maschalocarpum*, *Crassostrea gigas*, encrusting ascidians, *Hormosiira banksii*, *Perna canaliculus*, and the number of cover classes, was negatively correlated with the percent of fine sediments in traps. The percentage of fine sediments in traps was positively correlated with the cover of unidentified brown turf, Bryozoans, *Cliona celata* and other sponges. Changes in the percentage of fine sediments in traps are likely to result in non-linear changes in the cover of bryozoans, encrusting ascidians and barnacles due to the nature of these relationships.

5.2.2 Discussion of subtidal patterns

Subtidal sites at Meola reef were characterized by a thin band (at times, no more than a metre wide), of mixed brown algal canopy, which was mainly composed of *Carpophyllum maschalocarpum*, *Carpophyllum flexuosum* and *Ecklonia radiata*. Underneath this canopy, the substrate was a patchy mix of mostly sand, shell hash, crustose coralline alage and the prostrate brown algae, *Ralfsia* sp. The Cats eye top shell *Turbo smaragdus*, and solitary ascidians were the other most numerous macrofaunal occupants of this habitat. These species were previously reported at Meola reef (Morton and Miller 1968, Hayward et al. 1999), and are typical of shallow sheltered northeastern New Zealand sites (Grace 1983, Cole 1993, Walker 1999, Shears and Babcock 2004, Shears et al. 2004). *C. maschalocarpum* was generally more abundant than *C. flexuosum* at Meola reef, in agreement with the findings of Shears and Babcock (2004) on shallow reefs less than 2m deep.

Weaker site effects were seen in the subtidal compared to the intertidal, but models that considered distance along the reef, or the side of the reef, were still the best descriptors for a number of cover and count variables. *Carpophyllum maschalocarpum* was generally found in highest densities on the eastern and *Carpophyllum flexuosum* was found in highest densities on the western side of the reef (although, for C. flexuosum this pattern was driven by one large density recording in 2003 at MSW1). Sediment cover was highest on the western side of the reef, and sand cover was highest on the eastern side. The number of taxa was generally slightly higher on the eastern side of the reef. The further north on the reef, the more individuals were present; this was mainly driven by high numbers of *Turbo smaragdus* at sites MSE3 and MSW2. All of these spatial differences are likely to be due to changes in hydrodynamics along and across the reef. The patterns in densities of the two *Carpophyllum* species and *Turbo smaragdus*, and the size frequency pattern for *Turbo smaragdus* (significantly more large individuals at site MSE1), which with either side of the reef or distance along the reef, could be driven by any number of factors related to the changing hydrodynamic setting, e.g. patchy recruitment is thought to be responsible for adult distribution patterns of *C. flexuosum* (Cole et al. 2001), and differences in epiphyte biomass have been correlated with densities of the Turbo genus (Frankovich & Zieman 2005). The number of taxa and the number of percentage cover classes both increased northward on Meola reef. This pattern is again probably indicative of small scale hydrodynamically driven patterns; but neither of these variables, nor the number of individuals, showed any linear change with time.

Some linear changes were detected over time in both count and cover variables. The average density of solitary ascidians significantly decreased. This was driven by high recorded densities at sites MSE1, MSE2 and MSW2 in 2001, and low values subsequently; therefore this pattern suggests a mortality event rather than a steady decline. The density of *Ecklonia radiata* plants were modeled to increase from a density of ~2 per m^2 in 2001 to ~3 per m^2 in 2006. This pattern could easily be explained by recruitment and does not indicate any great ecological change. The percentage cover of unconsolidated substrates (sand, sediment and shell hash) increased from 2001 to 2006 from an average across the whole reef of 39% to 58%. Over the same time period the cover of the prostrate brown seaweed *Ralfsia* sp. decreased across the whole reef from an average of 20 to 15 percent. This result represents gradual and real ecological change; sediments, both fine and coarse, are accumulating across subtidal Meola reef and excluding prostrate algae. This is important because it decreases the amount of food available to reef grazers and excludes settlement of hard-substrate organisms. Periodic inundations of sediments onto coastal reefs as a response to currents or storms is a natural process (Airoldi 2003).

The sediment trapping data is dominated by high quantities of sediment in traps at MSW1, and high trapping rates overall in 2001. The fact that site MSW1 is the most sheltered and inland of the reef suggests this site may be more quiescent, therefore more sediment may deposit here. This pattern is in agreement with the recordings of higher percent cover of sediments seen on the western side of the reef. The generally high trapping rate in 2001, which is driving the linear decrease in trap rates over time, was an isolated incident and is probably related to rainfall. Trapping results were only available for the last 3 months of 2001. Over this time ~430mm of rainfall was recorded in Oratia at Essex St.
(www.maps.arc.govt.nz/website/maps/map_hydrotel.htm),

inland of Meola Reef. This was the largest quantity of rainfall recorded in those three calendar months over the monitoring period, and more than a quarter of the annual rainfall that year. Due to this, the yearly average trap rates are likely to be unrealistically high for 2001, therefore the modelled linear decrease in average trap rate over time is not considered realistic.

Sediment variables were not the dominant factor driving assemblage structure at Meola reef, but they did affect the densities and percentage cover of a number of taxa. Most relationships with the percentage cover of sediments or mobile unconsolidated substrates were negative. The guilds most clearly affected by the change in sediment cover were microalgal and algal grazers (*Turbo smagagdus*, *Trochus viridus*, *Evechinus chloroticus*). Recent research suggests sediment induced mortality of larval and juvenile stages of Evechinus may play an important role in determining adult densities (J. Walker, pers comm.). The impacts of sedimentation upon grazing gastropods are thus far unstudied. The one reliable positive correlation seen between either of the two cover variables above and density was for *Patiriella regularis* (*Codium fragile* showed a positive relationship but only 3 plants were recorded). *Patiriella regularis* inhabits the rocky shore, but can also be seen in high densities in shallow, sandy areas where flow rates are high, e.g., Mangawhai and Whangateau estuary channel banks (pers. obs.). The increase in densities of the cushion star, with decreases in rocky habitat, is therefore, not unexpected. Whether these changes in assemblage structure occur due to decreased light, smothering, abrasion or habitat replacement (Airoldi 2003), they signal the likely direction of change, should sedimentation increase at Meola Reef.

By comparison to the Long Bay Marine Monitoring Programme (LBMMP) (Anderson et al. 2005) trapping rates of total and fine sediments are low (~0.03 and 0.02 for Meola, respectively, and ~0.2 and 0.05 g.cm2.day-1, respectively, for the LBMMP). The proportion of fines trapped, and the percentage of sediment cover at Meola, is however, relatively high (an average of ~70% fines trapped and 30% sediment cover at Meola, and an average of ~50% fines trapped and 20% sediment cover for the LBMMP). This trend of increased fine sediments present on the bed, and a greater percentage of fines present in the water column, is in agreement with the accepted pattern of increasing turbidity with distance into the Hauraki Gulf (Paul 1968, Grace 1983, Walker 1999), and also the fact that estuaries are sediment settling zones (Open University 1989).

Diversity on Meola's subtidal rocky reef was low in contrast to comparable habitats in the Long Bay marine monitoring programme (LBMMP) (Anderson et al. 2005). The average number of taxa per m2 ranged from 4-7 at Meola reef sites compared with 6-10 at LBMMP sites. The average number of individuals per m2 was also lower at some sites at Meola reef than had been recorded in the LBMMP (30-140 at Meola cf. 70-140 at LBMMP sites). In contrast, the average number of *Turbo smaragdus* was markedly higher at some Meola reef sites (up to 100) by comparison to the LBMMP (up to 40). The high density of *Turbo samargadus* is consistent with other studies, that have shown highest densities of this species in more sheltered sites (Walker 1999, Shears and Babcock 2004). The decreases in the number of individuals and number of taxa present at Meola reef compared to the LBMMP are likely to be a result of the relatively small size of Meola subtidal rocky reef and the stress placed upon that community by the large amounts of fine sediments on the bed and in the water column, which has excluded some species. For example, count data from this report and the LBMMP shows that the gastropod, *Cookia sulcata*, and the brown algae, *Zonaria* sp., were both consistently found in the LBMMP (751 and 26178 individuals respectively from 1999-2005), but never at Meola reef. Many rarer taxa (<101 individuals from 1999-2005) were also found at the LBMMP sites, but not at Meola reef. A list of count data from both monitoring programmes is provided in Appendix H for comparison.

The community structure seen at Meola reef reinforces the pattern of seriation in community structure seen along a North to South gradient in the LBMMP, for some taxa. When LBMMP densities are viewed in conjunction with the Meola Reef densities (which are located further south) an increase in densities of *Turbo smaragdus* can be seen from north to south. The occurrence of the algae, *Zonaria* sp. and *Cystophora* sp. decreased from North to South (no *Zonaria* sp. and only 1 *Cystophora* sp. plant have ever been found at Meola reef).

Few consistently directional changes were seen over time in the community structure of Meola Reef. The most ecologically important change over time was the increasing encroachment of mobile substrates, which affected the cover of *Ralfsia* sp., and will occupy space for recruitment of reef fauna. Strong spatial trends were seen, both within Meola reef, and across the region in community structure, that were correlated with sediment variables.

5.3 Recommendations

- The design of this monitoring programme is sensitive and has the power to detect spatial and temporal changes at Meola Reef, and should be continued.

- The information provided by the sediment traps is relevant for linking environmental conditions to biotic patterns, and should be continued.

- To aid in interpretation of spatial patterns it is recommended that sampling of concomitant factors such as sediment pollution, land use, rainfall and suspended sediments in other ARC funded projects are continued.

- Information on chemical body burdens of reef organisms should be collected to aid in the interpretation of ecological data.

- Brown algae are the dominant canopy cover on northeastern New Zealand's subtidal rocky reefs. In the absence of urchin grazing, gastropods are thought to be the main herbivores in the inner Hauraki Gulf subtidal rocky reef communities (Walker 1999). Gastropods also numerically dominate the fauna at Meola reef, and many other inner Hauraki Gulf sites (Anderson et al. 2005). Experimentation into the changes in both algal and gastropod community structure that are correlated with sediment variables would aid in interpreting the observed patterns in both the Meola reef and LBMMP projects.

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7 Appendices

7.1 Appendix A Definition of technical terms

A number of terms and abbreviations will be defined here for quick reference for the reader. In some cases lengthier definitions will be given within the body of the report:

AIC – Akiake's "An Information Criterion" an information criterion used to determine between model choices, which is known to have a tendency to overfit, which means to include more variables than is necessary. Smaller AIC values indicate a better model fit.

ANOSIM – Analysis of Similarities, a statistical technique to test if communities are significantly different (analogous to a multivariate ANOVA) , results include a probability (P) value and a Rho (R) value, The Rho value allows the reader to judge the scale of a significant difference and varies between 0 no difference and 1 maximum possible difference. This routine is part of the PRIMER suite of statistical analyses.

ANOVA - Analysis of Variance, a univariate test for a statistical difference between two or more groups.

BIC – Schwarz's "Bayesian Information Criterion", this measure balances the value of the log-likelihood with a penalty for the number of parameters used in the model. Smaller BIC values indicate a better model fit.

CAP – Cannonical Analysis of Principal Coordinates, a statistical technique that attempts to find a correlation between either a univariate factor or a multivariate matrix, and another multivariate matrix.

Location – An area that contains sites where replicate quadrats are sampled, e.g. Meola Reef in this report or Torbay in the Long Bay Marine Monitoring Programme

MDS – Multidimensional Scaling Ordination, a graphical technique used to show community data, greater distance apart in the ordination means less similarity in community structure. Part of the PRIMER suite of statistical analyses.

Multivariate data– data that incorporates more than one response variable, i.e. community data.

PERMANOVA – Permutational Analysis of Variance, a multivariate method that allows models to be fitted to data and significance tested.

SIMPER – A statistical analysis that quantifies the contribution of each taxa to the similarity/dissimilarity between groups of samples. Part of the PRIMER suite of statistical analyses.

Site – There are many sites within a location where replicate quadrats are sampled, i.e., MIE2 or MSW2 in this report which are comparable with site Campbells 2 (C2) in the Long Bay Marine Monitoring Programme.

Sediment – sediments finer than sand.

Seriation – to form a linear series, e.g. 1,2,3,4,5.

Trapped sediment – The sediment collected by sediment traps that incorporates deposition, but not resuspension, these sediments will be analysed for weight and grain size, therefore implying settlement rate and probable provenance (<63 microns diameter = probably terrestrial).

Univariate data - data that has just one response variable, i.e. the density of an organism.

7.2 Appendix B Chronological synopsis of sampling methodology

7.2.1 B1 Intertidal reef monitoring

2001 (Ford et al. 2001)

Intertidal sampling was initiated in December 2001 and five intertidal sites (~ 75 m2 each) were surveyed bimonthly until October 15, 2001 in order to assess temporal variability in macrofaunal communities. These surveys recorded the number, size frequency and percentage cover of all macroscopic (>4mm) fauna and flora inhabiting this rocky reef.

The five sites were distributed on both the eastern and western sides of Meola reef. All sites were positioned at similar tidal heights (Appendix A). Random positioning of quadrats was achieved by marking and numbering twelve potential quadrat locations on areas of reef with comparatively regular topographic profiles. This was considered necessary because the inclusion of large projections, such as oyster concretions in some quadrats, could potentially bias the data and introduce undesirable additional sources of variability. From these twelve potential quadrat locations five were chosen randomly using random number tables. Three sites were placed on the western side and two were placed on its eastern side (Fig. 1); these were relocated using Global Positioning System (GPS) coordinates and site view photographs. Within each site, seven permanent quadrats (¼ sq m-2) were positioned using stainless steel pegs hammered into the reef. These quadrats were relocated using individually numbered plastic tags attached to the pegs (quadrat markers).

In each quadrat organisms were identified down to the lowest practical taxonomic level. These organisms were then counted and measured to the nearest millimetre using vernier callipers (excluding oysters, see below). All measurements of organisms were taken on their longest axis. In the case of gastropods either shell length or shell width (dependent on species shell form) were measured.

To enumerate encrusting (e.g. sponges) and turfing (e.g. small articulating algae) organisms, the percent coverage of the substratum was estimated visually in the afore mentioned quadrats. In addition to this, each quadrat was photographed producing a digital record of any possible changes in the encrusting communities covering the reef.

The Pacific oyster *Crassostrea gigas* was the numerically dominant organism in all the surveyed quadrats. To evaluate the percentage cover of these encrusting bivalves, each quadrat was divided into quarters, with the quarter to the left of the quadrat marker evaluated. The overall percent coverage of the substratum by these bivalves was estimated visually, and then each individual was measured to the nearest millimetre using vernier calipers. All oysters surveyed were also categorized according to their position in relation to other oysters. Oysters were classified "clustered" if they were touching another oyster, "individual" if not touching another oyster, "loose" if not attached to the substratum and "loose-clustered" if touching another oyster, but not attached to the substratum.

2002-2003 (Ford et al. 2004)

From 2001 in accordance with recommendations in Ford et al. 2001 the intertidal sampling design was changed.

Sixty samples were taken on the reef (30 samples on each side of the reef, East and West, 10 samples at each of three sites) to incorporate the important variability in this habitat. This number of quadrats was a result of 1 new site being added (to balance the design regarding sides of the reef) and the number of quadrats increasing from 7 to 10 at each site. The sampling occurred annually in October of each year, as no seasonal trends were detected from the initial temporally intense sampling. The number of oyster counts decreased, given the consistency of the population structure of this organism. Each individual oyster was measured within a quarter of each 1/4m² quadrat (1/16m²). No recording of the position of oysters, i.e. clustered, individual, loose, as stated in (Ford et al. 2001) was recorded as this data had not proven useful.

All other methods remained identical to those implemented in 2001 (Ford et al. 2001).

2004-2005 (Current report)

Sixty samples were taken again (30 on each side) in October of 2004 and 2005. Due to concerns about the sometimes small numbers of oysters used to generate size frequencies at some sites the following change was made to the measuring of oysters in the 2004 and 2005 samplings. If <100 oysters were measured within each site more oysters within quadrats were measured until 100 oysters were measured at each site. Unfortunately measurement of density of oysters in each 1/16m² quadrat was forgotten in the 2005 sampling therefore this data was not available for analysis. All other methods remained identical to those stated in the 2004 report (Ford et al. 2004).

7.2.2 B1 Subtidal reef monitoring

2001 (Ford et al. 2001a)

Previous studies of sheltered shallow subtidal reef assemblages have indicated minimal seasonal variability (Babcock et al., 1999), therefore one annual sampling of subtidal assemblages was conducted at five sites in late summer. The methods used for this survey are consistent with the Long Bay monitoring programme (Anderson et al., 2003a).

The five sites were distributed between the east and west facing sides of Meola reef (Fig. 1). Three sites were located on the eastern side and two on the western side. All sites were areas of macroalgal-dominated subtidal basaltic reef. These sites extended between 1 and 2m depth below MLWS. Coordinates for each site were initially recorded by GPS. Sediment collectors were deployed at each site. Surface buoys (~10cm by 5cm) were attached to the steel bases of the sediment collectors. The buoys were small enough to be missed by the public, but large enough to be found when searching in the correct areas.

Seven quadrats were randomly placed at each site within 20m of the sediment collectors. In five of these quadrats all macroalgae and invertebrates greater than 4cm and 4mm respectively, were identified, counted and measured. Percentage cover of substratum type (which included turfing algae, encrusting algae, large brown algae, encrusting invertebrates, bare rock, sediment (finer than sand) and sand) was also visually estimated in each of the five quadrats. In 2 of the 7 quadrats identification, counts and percentage cover estimates were completed but no measurements were taken. The total lengths of all macroalgae were measured to the nearest 5cm. For the laminarian kelp, *Ecklonia radiata*, this included both the stipe length and total length. The longest axis of solitary macroinvertebrates was also measured to the nearest 5mm. Mobile organisms (e.g. crabs) were not enumerated. It should be noted that during the 2001 survey between 5 and 7 quadrats were surveyed due to a sampling error. This sampling was completed in June 2001.

2002-2005 (Ford et al. 2004, Current report)

Each year in late summer the same 5 sites have been re-surveyed using the same methodology.

7.2.3 B1 Sediment trap monitoring

7.2.3.1 Sediment collection and total sedimentation rate calculation

2001 (Ford et al. 2001- present)

One sediment collector was placed at every site to quantify the amount of sediment entering the reef ecosystems in October 2001.

Sediment collectors were constructed from PVC piping, metal piping and bulldozer track. The inner 'trap' was made from PVC pipe, 32mm in diameter and 500mm in length, with one end of the pipe sealed by a plastic cap. A length to diameter ratio of at least 7:1 was incorporated in this design to mitigate the effects of a resuspension of the trapped material (Knauer & Asper, 1989). This first pipe (the trap) was then inserted into a metal pipe (the trap holder), 40mm in diameter and 400mm in length, which had been welded to a large, heavy, bulldozer track. This construction ensured the 'trap' had a stable platform and anchor, decreasing the chance of its movement through wave or tidal action.

All collectors were placed on the subtidal reef in areas surrounded by macroalgae. All traps were oriented vertically and placed at least 1m below MLWS with the trap aperture at least 25-30 cm above the benthos. A surface buoy was attached to aid in the relocation of sediment collectors. Collectors were deployed in early August 2001, and were sampled monthly when possible. All sediment collection has continued using the same methodology until the present day.

After collection, the contents of traps were filtered through pre-weighed filter bags (equivalent to 1.2 micron filter papers), then oven dried at 65-80ºC for 24 hours. The filter and contents were then weighed to determine total dry weight, which was then converted into a daily rate of sediment within traps using the number of days a trap had been deployed and the surface area of the opening of the trap (g/cm2/day). The yearly averages per site were then generated from these values. This sedimentation rate calculation has continued using the same methodology until the present day. Total trapped sedimentation rate is therefore comparable from 2001 until the present day.

7.2.3.2 Sediment textural analysis

October 2001- 2002 (Ford et al. 2001)

In 2001, six sieve sizes (1mm+, 500μm, 250μm, 125μm, 63μm and <63μm) were used for textural analysis. The <63μm size class contains the material of greatest interest with respect to potential terrestrial inputs resulting from the construction phase of urban development.

Samples were processed as in the Long Bay Monitoring over the same period (Anderson et al. 2005), by drying and processing with a mechanical shaker. Sediments less than 63μm were further analysed using a Galai particle size analyser. This apparatus measures grain sizes and can detect particles as small as 2µm. According to the Wentworth grain size scale (Lewis 1984), grains of this size are clay. From each of the less than 63µm samples, a small proportion was suspended in solution and pumped past a laser which in turn measured the size of the grains in each sample. Each sample was analysed for either five minutes, or until a confidence indicator reached 96-98%. This confidence indicator is an estimate of the confidence that some given percentage of the sample has been analysed.

2002 – March 2003 (Ford et al. 2003a)

Samples were individually analysed using a Galai particle size analyser to determine the percentage of the sample sediments volume that was less than 63µm in diameter. Note that samples were not sieved into separate size classes using the mechanical shaker first, instead the Galai particle analyser was used to analyse the whole sediment sample.

2003– 2005 (Current report)

Following the 2003 report, the analysis of grain size fractions was modified to take account of the influence of organic material. This followed a rationalisation of benthic ecology methods for ARC monitoring programmes (Ford et al. 2003b). Ford et al. (2003b) recommended the following grain size analysis technique be used across a number of ARC projects:

Pre-treatment of samples for grain size analysis should include:

1. Hydrogen peroxide treatment (6-30%) until frothing ceases
2. Bulking, homogenisation and sub-sampling
3. Dispersion with Calgon (2g.l-1)

Drying should be employed if samples are to be stored prior to pre-treatment or at an appropriate time to obtain a dry weight for wet-sieving (end of step 2).

According to (Ford et al. 2003b), previous analyses conducted without the use of a pre-treatment to remove organics would have resulted in a small overestimation of fine grains (<63µm).

A sub-sample up to 60 grams of each individual dried sediment sample was then taken. Samples were thoroughly mixed beforehand to insure a representative sub-sample was taken. Many sample weights were less than 60 grams in these situations the whole sample was processed. Each sub-sample was then treated with hydrogen peroxide to remove organic material. Samples were left in hydrogen peroxide for 24-48 hours and then oven dried and the dry weight recorded. Following this second oven drying, samples were treated with a particle disperser, Calgon (5g.l-1), before being analysed for the percentage volume of fine sediments (<63µm) using a Malvern laser particle analyser. Note: the Calgon concentration was increased from 2 to 5 g.l-1 after concerns about clumping of the clay fraction, but appeared to make little difference to the results.

7.2.3.3 Summary of methodology for sediment textural processing

2001 (Ford et al. 2001)

Sediments from each trap were oven dried, then sieved through a series of sieves using a mechanical shaker. Sieve sizes were 1mm+, 500µm, 250µm, 125µm, 63µm and <63µm. The <63µm fraction (fines) was further analysed using the Galai particle analyser.

2002-May 2003 (Ford et al. 2003a)

Sediments from each trap were oven dried and the total dry weight of sediments determined. The percentage of sediment <63µm (fines) was determined by analysing the entire sample (with no pre-sieving) using the Galai particle analyser.

April 2003 -2006 (Current report)

Sediments from each trap were pre-treated with hydrogen peroxide (to remove organics) and Calgon (to prevent clumping) prior to laser analysis. The percentage of sediment <63µm was determined by analysing the entire sample using a Malvern particle analyser.

In this report fine sediments are compared from April 2003 onwards.

7.3 Appendix C GPS positions

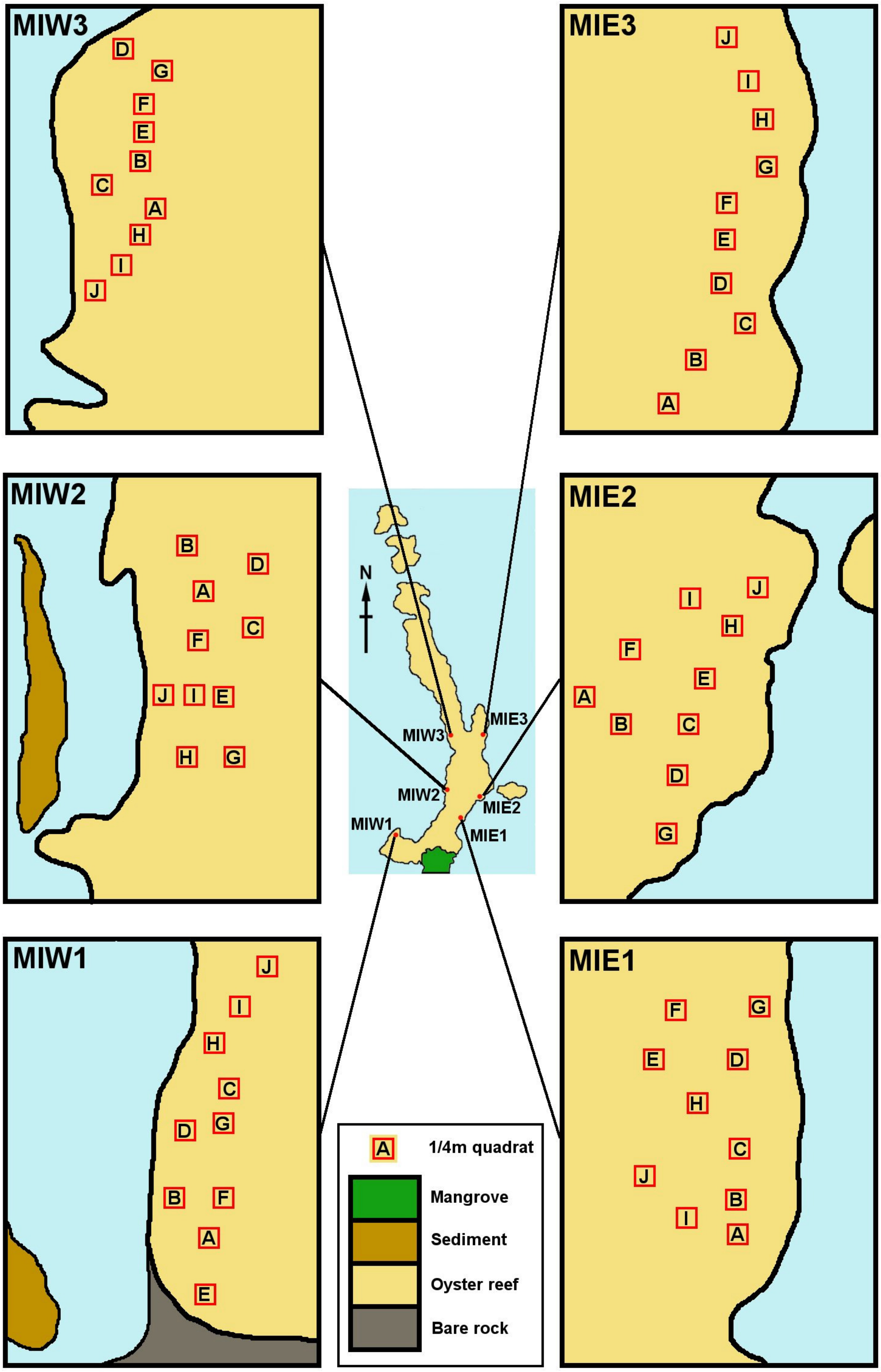
Meola intertidal site locations

Site	Height above MLWS (m)		Side of reef
MIE1	1.78-2.04	S 36° 50.83' E 174° 42.72'	East
MIE2	1.44-1.97	S 36° 50.78' E 174° 42.74'	East
MIE3	1.40-1.93	S 36° 50.65' E 174° 42.77'	East
MIW1	1.40-1.93	S 36° 50.84' E 174° 46.33'	West
MIW2	0.59-1.21	S 36° 50.71' E 174° 42.72'	West
MIW3	1.08-1.28	S 36° 50.65' E 174° 42.72'	West

Meola subtidal site locations

Site	Height below MLWS (m)		Side of reef
MSE1	1.00-2.00	S 36° 50.10' E 174°42.58'	East
MSE2	1.00-2.00	S 36° 50.05' E 174° 42.57'	East
MSE3	1.00-2.00	S 36° 50.05′ E 174° 42.54'	East
MSW1	1.00-2.00	S 36° 50.13' E 174° 42.54'	West
MSW2	1.00-2.00	S 36° 50.10' E 174° 42.53'	West

7.4 Appendix D Map of intertidal sites



7.5 Appendix E List of taxa

For both intertidal and subtidal count data:

aa = very abundant (>10m-2),

a = abundant (1-10m-2),

r= rare (<1m-2)

For both intertidal and subtidal percent cover data:

aa = very abundant (>10%),

a = abundant (1-10%),

r = rare (<1%)

Note that results for count data are given in black text while results for percent cover data are highlighted in red text.

Appendix E1 Intertidal taxa list (Eastern sites)

Species	MIE1					MIE2					MIE3			
	01	02	03	04	05	01	02	03	04	05	02	03	04	05
Macroalgae														
Carpophyllum sp.													r	
Gracilaria chilensis	r	r	r			a	a		a	a	r		r	r
Hormosira banksii														
Ulva lactuca														
Encrusting algae														
Corallina officinalis		r											r	r
Gelidium sp.	a	a	aa	a	a	aa	a	aa	aa	a	r	a	r	
Ralfsia sp.														
Bivalves														
Austrovenus stutchburyi			r											
Crassostrea gigas	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa
Modialarca impacta														
Musculista senhousia														
Nucula nitidula			r											
Limaria sp.														
Xenostrobus pulex	a	aa	aa	aa	aa	a	a	a	a	aa	a	aa	aa	aa
Herbivorous Gastropods														
Bulla quoyii														
Crepidula monoxyla							r							
Diloma subrostrata	a	a	a			aa	aa	a						
Melagraphia aethiops	aa	aa	aa	aa	aa	a	a	a	a	a	aa	aa	aa	a
Notoacmea helmsi			r	a								r	r	
Turbo smaragdus	a	a	aa	a	a	a	aa	aa	aa	a	aa	aa	aa	aa
Zeacumantus lutulentus	aa	a	aa	aa	aa	aa	aa	aa	aa	aa				
Zegalerus tenuis														
Predatory Whelk														
Buccinulum sp.													a	
Cominella adspersa	a			r			r				a	r	a	
Cominella glandiformis	aa		a	a	a	a		a	aa	a				
Cominella maculosa		a					a				r			r
Cominella virgata														
Crustacea														
Elminius modestus				r							a	r	a	a
Helice crassa							r				r			
Petrolisthes elongatus														
Sphaeromatid Isopod							r							

Appendix E1 continued   Intertidal taxa list (Eastern sites)

Species	MIE1					MIE2					MIE3			
	01	02	03	04	05	01	02	03	04	05	02	03	04	05
Other Species														
Acanthochiton zelandicus								r		r	r	a		
Acarini	a	a				a					a		aa	
Anthopleura spp.	a	aa	aa	aa	aa	a	a	aa	aa	aa	aa	aa	aa	aa
Diadumene lineata									r	r			a	a
Nerita melanotragus			r											
Onchidella nigricans	a		a	a	a	a	a	a	aa	r	aa	aa	a	a
Patiriella regularis													r	
Perinereis novaehollandiae												a		
Solitary Ascidian													r	
Sypharochiton pelliserpentis	aa	a	aa	aa	a	aa	aa	aa	aa	aa	aa	aa	aa	aa
Unidentified Amphipod							r							
Unidentified Polychaete							r							
Unidentified Tunicate														
Substrate														
Bare rock	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	a	aa
Sediment	aa	a	a	a	a	aa	aa	aa	aa	aa	aa	a	aa	aa
Shell hash														r

Appendix E1 Intertidal taxa list (Western sites)

Species	MIW1					MIW2					MIW3				
	01	02	03	04	05	01	02	03	04	05	01	02	03	04	05
Macroalgae															
Carpophyllum sp.														r	
Gracilaria chilensis	r	r		r	r				r	r	r	r			r
Hormosira banksii											a	r	r	r	
Ulva lactuca		r										r			
Encrusting algae															
Corallina officinalis						r			r	a	r	r		r	r
Gelidium sp.	aa	aa	a	a	a	a	aa	aa	a		r	a	a	a	
Ralfsia sp.														r	
Bivalves															
Austrovenus stutchburyi															
Crassostrea gigas	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa	aa aa
Modialarca impacta									r						
Musculista senhousia													a		
Nucula nitidula														r	
Limaria sp.														a	
Xenostrobus pulex	r		r		r			a	aa	a	a	aa	aa	aa	aa
Herbivorous Gastropods															
Bulla quoyii											r				
Crepidula monoxyla															
Diloma subrostrata										r	r				
Melagraphia aethiops	a	a	a	a	a	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Notoacmea helmsi				r					r			r			
Turbo smaragdus	a	a	a	a	a	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Zeacumantus lutulentus					r			a			a	aa	aa	aa	a
Zegalerus tenuis														r	
Predatory Whelk															
Buccinulum sp.												r		r	
Cominella adspersa						a			r		r	r		r	
Cominella glandiformis								r	r	a		r	a	r	a
Cominella maculosa												r			
Cominella virgata									r					r	
Crustacea															
Elminius modestus		r				a	a	r	a	a	aa	aa	a	a	a
Helice crassa	r						r								
Petrolisthes elongatus						r		r					a		
Sphaeromatid Isopod															

Appendix E1 continued Intertidal taxa list (Western sites)

Species	MIW1					MIW2					MIW3				
	01	02	03	04	05	01	02	03	04	05	01	02	03	04	05
Other Species															
Acanthochiton zelandicus						r		a	r				r	r	
Acarini	r	a					r				a	a			
Anthopleura spp.	aa	a	a	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Diadumene lineata									a					a	aa
Nerita melanotragus															
Onchidella nigricans	a	a	a		r	aa	a	aa	a	a	a	a	aa	a	a
Patiriella regularis						a			r						
Perinereis novaehollandiae															
Solitary Ascidian														r	
Sypharochiton pelliserpentis	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Unidentified Amphipod															
Unidentified Polychaete															
Unidentified Tunicate										a					
Substrate															
Bare rock	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Sediment	aa	a	a	aa	aa	aa	a	a	a	a	aa	a	a	a	a
Shell hash					r										a

Appendix E2 Subtidal taxa list (Eastern sites)

Species	MSE1						MSE2						MSE3					
	01	02	03	04	05	06	01	02	03	04	05	06	01	02	03	04	05	06
Macroalgae																		
Carpophyllum flexuosum	a a	aa a	aa a	a r	a a	a r	aa a	a a	aa a	a r	a a	aa r	a a	aa a	aa a	a a	aa a	aa r
Carpophyllum maschalocarpum	a r	aa a	aa a	a r		a r	r r	aa r	aa a	aa a		a r		a r		aa r	a a	
Carpophyllum plumosum				a r														
Codium convolutum																		
Codium fragile											r r							
Colpomenia sinuosa		r																
Cystophora sp.																		
Ecklonia radiata	a a	a r	a a	a r	a a	a a	a r	r r	a r	a a	a a	a r	a a	a r	a r	a a	a a	a r
Halopteris sp.					a r			a									r r	
Hildenbrandia sp.		aa						a						a				
Hormosira banksii	a r															a r		
Red foliose algae		r	r r	r	a	a		r	r r			r						
Sargassum sinclairii	a r	a r	a r	r r		a r	r r	r r		a r			a r	r r	a r			r r
Encrusting algae																		
Corallina officinalis	aa	a	a	r	r	a		r	r	r		a	aa	r	a	a	a	
Crustose coralline algae	a	a	a	aa	aa	a	aa	aa	aa	aa	a	a	aa	aa	aa	aa	aa	aa
Ralfsia sp.	aa	aa	a	a	a	aa	aa	aa	a	a	a	aa	aa	a	a	a	a	aa
Green turf		r		r	a	a	a	a	r	a	a	r	a	r	r	a	r	a
Unidentified brown turf						r												
Bivalves																		
Crassostrea gigas	r a												a				a	
Perna canaliculus				r r	r r	r r				r r								
Herbivorous Gastropods																		
Bulla quoyii																		
Cabestana spengleri																		
Cantharidus purpureus	r		r			r			a	r	r				r			r
Cryptoconchus porosus					r							r					r	
Maoricolpus roseus										r	r		r					
Trochus viridus	r	r	r	a	a	r	a	a	a	a	a	a	a	a	a	a	a	r
Turbo smaragdus	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa

Appendix E2 continued Subtidal taxa list (Eastern sites)

Species	MSE1						MSE2						MSE3					
	01	02	03	04	05	06	01	02	03	04	05	06	01	02	03	04	05	06
Predatory Whelk																		
Buccinulum sp.	r			r						r							r	
Cominella adspersa	r	r				r					r							
Cominella maculosa						r												
Cominella virgata																		
Haustrum haustorium																		
Thais orbita												r						
Echinoderms																		
Coscinasterias muricata	r	r			r		a	r	r	r	r	r	r	r	r		a	r
Evechinus chloroticus		r			r	r		r	r		r	r			r		r	
Patiriella regularis	r	a	r	a	a	a	r	a	a	r	a	a	r	r	a	r	a	r
Stegnaster inflatus															r			
Sponges																		
Aaptos aaptos											a r							
Ancorina sp.									r			r			r		r	
Cliona celata		r		r	r	r		r	r	r	a	r		r	r	r	r	r
Other encrusting sponges	r	r	a		r	a	aa	a	a		a	a	a	a	a		a	a
Polymastia sp.																		
Tethya aurantium		 r	r r	 r		r r		r r				a r			a a	r r		r r
Tethya ingalli															r r			
Other Species																		
Anemone		r			r		a	r					r			r		
Ascidians - colonial																		
Ascidians - solitary	aa a	a r	r r	r a	a r	a r	aa a	a r	a r	a a	a r	a r	a r	a r	a r	a a	a r	a r
Barnacles									r									
Bryozoan	r					a	a		r			r			r	r		a
Dendrodoris citrina							r			r	r			r				
Eudoxochiton nobilis		r																
Hydroids					r						r	r				r		
Ishnochiton maorianus																		
Notomithrax minor																		
Sypharochiton pelliserpentis				r														
Substrate																		
Bare rock			a	a	a				a	aa	a				a	a		
Gravel				a												a		
Sand	a	a	aa	aa	aa	aa	a	aa	aa	a	aa	aa	a	aa	aa	aa	a	a
Sediment	aa	aa	aa	aa	a	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Shell hash		a		a	a	aa		a	r	aa	aa	aa		aa	a	a	a	a

Appendix E2 Subtidal taxa list (Western sites)

Species	MSW1						MSW2					
	01	02	03	04	05	06	01	02	03	04	05	06
Macroalgae												
Carpophyllum flexuosum	a a	a r		a r	a r	aa a	aa a	a a	r r	aa a	a r	aa a
Carpophyllum maschalocarpum	aa a	aa a	aa a	aa a	aa a	a r	a r	aa a	aa a	aa a	aa a	a r
Carpophyllum plumosum									r r			
Codium convolutum		r	r									
Codium fragile			r r									
Colpomenia sinuosa	a	r										
Cystophora sp.									r r			
Ecklonia radiata	a r	a a	a r	a r	a a	a r	a r	a r	a r	a r	a a	r r
Halopteris sp.				a r								
Hildenbrandia sp.		a						a				
Hormosira banksii	a r	a r			a r							
Red foliose algae	r	r	r r	r				r		r		
Sargassum sinclairii	r r	r r	r r	a r		a r	r r	a r	r r	r r	r r	r r
Encrusting algae												
Corallina officinalis	aa	aa	aa	a	aa	a			a	r	a	
Crustose coralline algae	a	aa	aa	aa	a	a	aa	aa	a	aa	aa	a
Ralfsia sp.	aa	aa	a	a	a	aa	aa	aa	a	aa	aa	a
Green turf	a	a	r	r	r	r	a	a	r	r	r	r
Unidentified brown turf												
Bivalves												
Crassostrea gigas	r	r r		r	r r		a	a				
Perna canaliculus	r r	a r		r r	a r	r r					a r	
Herbivorous Gastropods												
Bulla quoyii										r		
Cabestana spengleri								r				
Cantharidus purpureus			r	r					r			
Cryptoconchus porosus			r		r	r				r	r	r
Maoricolpus roseus												
Trochus viridus			r	r		r		r	r	a	r	
Turbo smaragdus	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa

Appendix E2 continued Subtidal taxa list (Western sites)

Species	MSW1						MSW2					
	01	02	03	04	05	06	01	02	03	04	05	06
Predatory Whelk												
Buccinulum sp.				r	r					r		
Cominella adspersa		r								r		
Cominella maculosa												
Cominella virgata											r	
Haustrum haustorium			r									
Thais orbita							r					
Echinoderms												
Coscinasterias muricata	a	r	r		r		r	r	r		r	
Evechinus chloroticus		r								r	r	
Patiriella regularis	a	a	r	r	r	r	r	a	r	a	r	r
Stegnaster inflatus												
Sponges												
Aaptos aaptos												
Ancorina sp.		r	r							r		r
Cliona celata			r	a	r			r		r	a	
Other encrusting sponges	a	r	a			a	a	a	a		a	a
Polymastia sp.			r									
Tethya aurantium		r		r	a r					r		
Tethya ingalli												
Other Species												
Anemone			r	r			r					
Ascidians - colonial	r											
Ascidians - solitary	a r	a r		a a	a r	a r	a a	a r	r r	a a	a r	a r
Barnacles				r	r							
Bryozoan	r		r						r			
Dendrodoris citrina			r						r	r	r	
Eudoxochiton nobilis												
Hydroids				r	r							
Ishnochiton maorianus								r				
Notomithrax minor							r					
Sypharochiton pelliserpentis					r						r	
Substrate												
Bare rock	r	r	a	a	a	aa			a	a	a	a
Gravel			r							a		
Sand	r	a	aa	aa	a	r	a		aa	aa	a	aa
Sediment	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Shell hash		a	a	aa	a	a		a	a	a	aa	a

Appendix E3 Intertidal taxa average densities

Scientific Name	Common Name	Average density per m^{-2}
Crassostrea gigas	Pacific oyster	480.1
Anthopleura sp.	Anemone	49.1
Turbo smaragdus	Cat's Eye top shell	30.1
Sypharochiton pelliserpentis	Snake-skin chiton	27.9
Xenostrobus pulex	Small black mussel	24.8
Melagraphia aethiops	Spotted top shell	22.9
Zeacumantus lutulentus	Horn shell	18.3
Onchidella nigricans	Reef slug	7.1
Cominella glandiformis	Mud whelk	1.9
Acari	Mite	1.7
Diloma subrostrata	Mudflat top shell	1.2
Diadumene lineata	Orange striped anemone	1.0
Cominella maculosa	Spotted whelk	0.5
Acanthochiton zealandicus	Bristle chiton	0.3
Cominella adspersa	Speckled whelk	0.3
Notoacmea helmsi	Keyhole limpet	0.1
Petrolisthes elongatus	Half crab	0.1
Buccinulum sp.	Lined whelk	<0.1
Helice crassa	Mud crab	<0.1
Patiriella regularis	Cushion star	<0.1
Musculista senhousia	Asian date mussel	<0.1
Solitary Ascidian		<0.1
Perinereis novaehollandiae	Green nereid	<0.1
Limaria sp.	File shell	<0.1
Unidentified Tunicate		<0.1
Nucula hartvigiana	Nut shell	<0.1
Cominella virgata	Variegated whelk	<0.1
Zegalerus tenuis	Small circular slipper shell	<0.1
Unidentified Polychaete		<0.1
Unidentified Amphipod		<0.1
Sphaeromatid Isopod		<0.1
Nerita melanotragus	Nerita	<0.1
Modialarca impacta	Nesting mussel	<0.1
Crepidula monoxyla	Slipper limpet	<0.1
Bulla sp.	Bubble shell	<0.1
Austrovenus stutchburyi	Cockle	<0.1

Appendix E4 Intertidal taxa average percent covers

Scientific Name	Common Name	Average % cover per m^{-2}
Crassostrea gigas	Pacific oyster	46.92
Bare rock		31.9
Sediment		11.3
Gelidium sp.		6.3
Barnacles		2.5
Gracilaria chilensis		0.5
Corallinia officinalis	Coralline turf	0.4
Shell hash		<0.1
Hormosira banksii	Neptune's necklace	<0.1
Ulva lactuca	Sea lettuce	<0.1
Carpophyllum sp.		<0.01
Ralfsia sp.		<0.01

Appendix E5 Subtidal taxa average densities

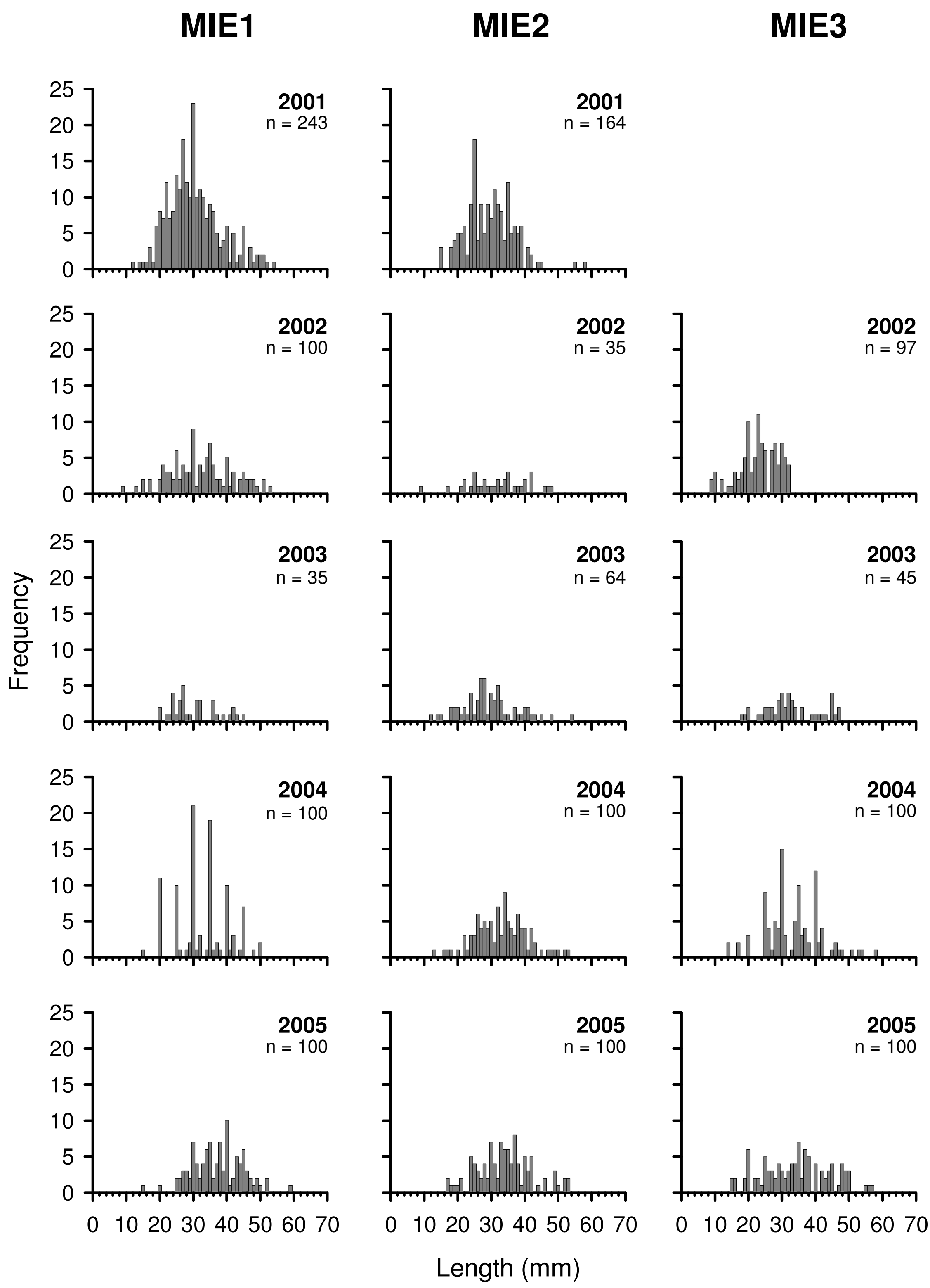
Scientific Name	Common Name	Average density per m^{-2}
Turbo smaragdus	Cat's Eye top shell	35.7
Carpophyllum maschalocarpum	Flapjack	13.8
Carpophyllum flexuosum		10.6
Ascidians - solitary		4.4
Ecklonia radiata	Kelp	2.4
Trochus viridus	Green top shell	1.3
Patiriella regularis	Cushion star	1.0
Sargassum sinclairii		1.0
Coscinasterias muricata	Eleven-armed sea star	0.4
Tethya aurantium	Golf ball sponge	0.4
Hormosira banksii	Neptune's necklace	0.3
Perna canaliculus	Green-lipped mussel	0.3
Halopteris sp.		0.3
Aaptos aaptos		0.2
Cantharidus purpureus	Oval top shell	0.1
Carpophyllum plumosum		0.1
Evechinus chloroticus	Kina	<0.1
Crassostrea gigas	Pacific oyster	<0.1
Red foliose algae		<0.1
Cryptoconchus porosus	Butterfly chiton	<0.1
Buccinulum sp.	Lined whelk	<0.1
Cominella adspersa	Speckled whelk	<0.1
Dendrodoris citrina	Nudibranch	<0.1
Sypharochiton pelliserpentis	Snake-skin chiton	<0.1
Maoricolpus roseus	Turret shell	<0.1
Thais orbita	Dogwhelk	<0.1
Codium fragile		<0.1
Eudoxochiton nobilis	Chiton	<0.01
Ishnochiton maorianus		<0.01
Tethya ingalli	Golf ball sponge	<0.01
Notomithrax minor	Camoflaged crab	<0.01
Bulla quoyii	Bubble shell	<0.01
Cabestana spengleri	Spengler's trumpet	<0.01
Cominella maculosa	Spotted whelk	<0.01
Cominella virgata	Varigate whelk	<0.01
Cystophora sp.		<0.01
Haustrum haustorium	Dark rock shell	<0.01
Stegnaster inflatus	Elevated cushion star	<0.01

Appendix E6 Subtidal taxa average percent covers

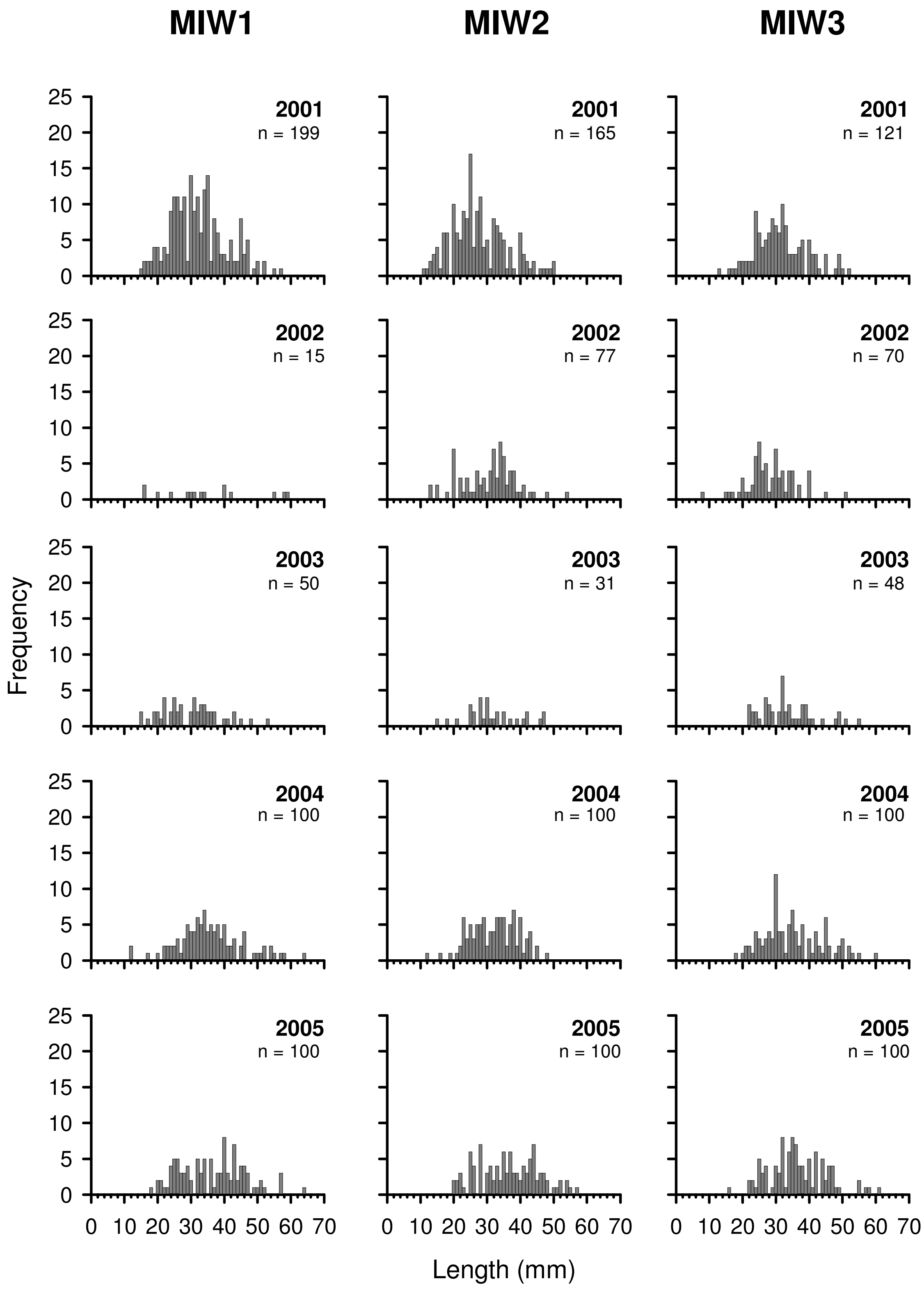
Scientific Name	Common Name	Average % cover per m^{-2}
Sediment		28.5
Sand		15.4
Crustose coralline algae	Crustose coralline algae	15.0
Ralfsia sp.		12.2
Shell hash		6.2
Corallina officinalis	Coralline Turfing Algae	5.5
Bare rock		3.6
Other encrusting sponges		2.5
Carpophyllum maschalocarpum	Flapjack	1.7
Carpophyllum flexuosum		1.7
Green turf		1.5
Hildenbrandia sp.		1.3
Ascidians - solitary		1.1
Ecklonia radiata	Kelp	1.0
Crassostrea gigas	Pacific oyster	0.6
Bryozoan		0.5
Gravel		0.3
Cliona celata	Yellow boring sponge	0.3
Red foliose algae		0.2
Sargassum sinclairii		0.2
Anemone		0.1
Tethya aurantium	Golf ball sponge	<0.1
Ancorina sp.		<0.1
Colpomenia sinuosa		<0.1
Halopteris sp.		<0.1
Perna canaliculus	Green-lipped mussel	<0.1
Hydroids		<0.1
Hormosira banksii	Neptune's necklace	<0.1
Aaptos aaptos		<0.1
Codium convolutum		<0.1
Unidentified brown turf		<0.1
Barnacles		<0.1
Carpophyllum plumosum		<0.01
Codium fragile		<0.01
Ascidians - colonial		<0.01
Polymastia sp.		<0.01
Tethya ingalli	Golf ball sponge	<0.01
Cystophora sp.		<0.01

7.6 Appendix F Intertidal size frequency histograms

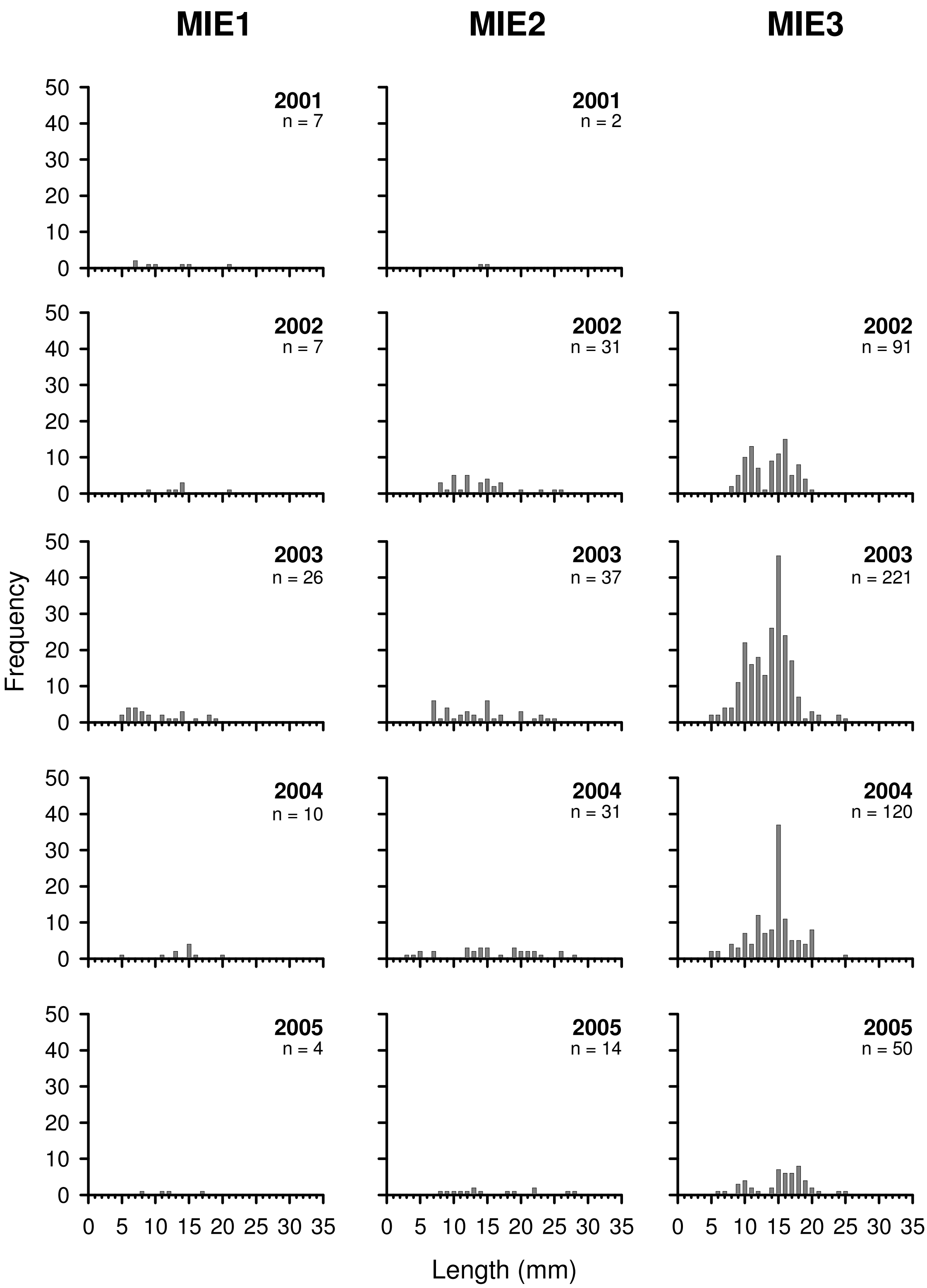
Appendix F1 Size frequency distributions for *Crassostrea gigas* at Meola intertidal reef



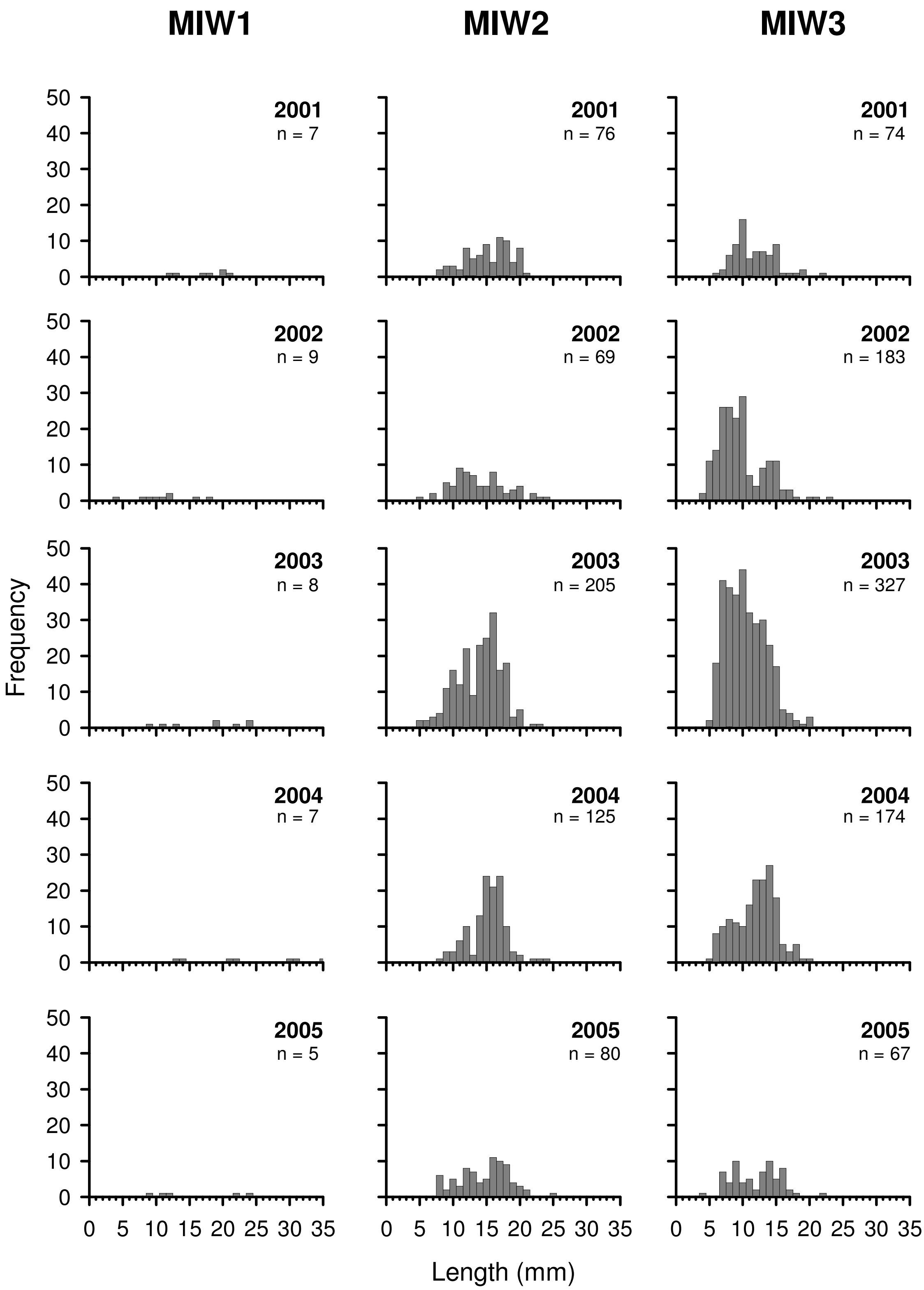
Appendix F1 continued Size frequency distributions for *Crassostrea gigas* at Meola intertidal reef



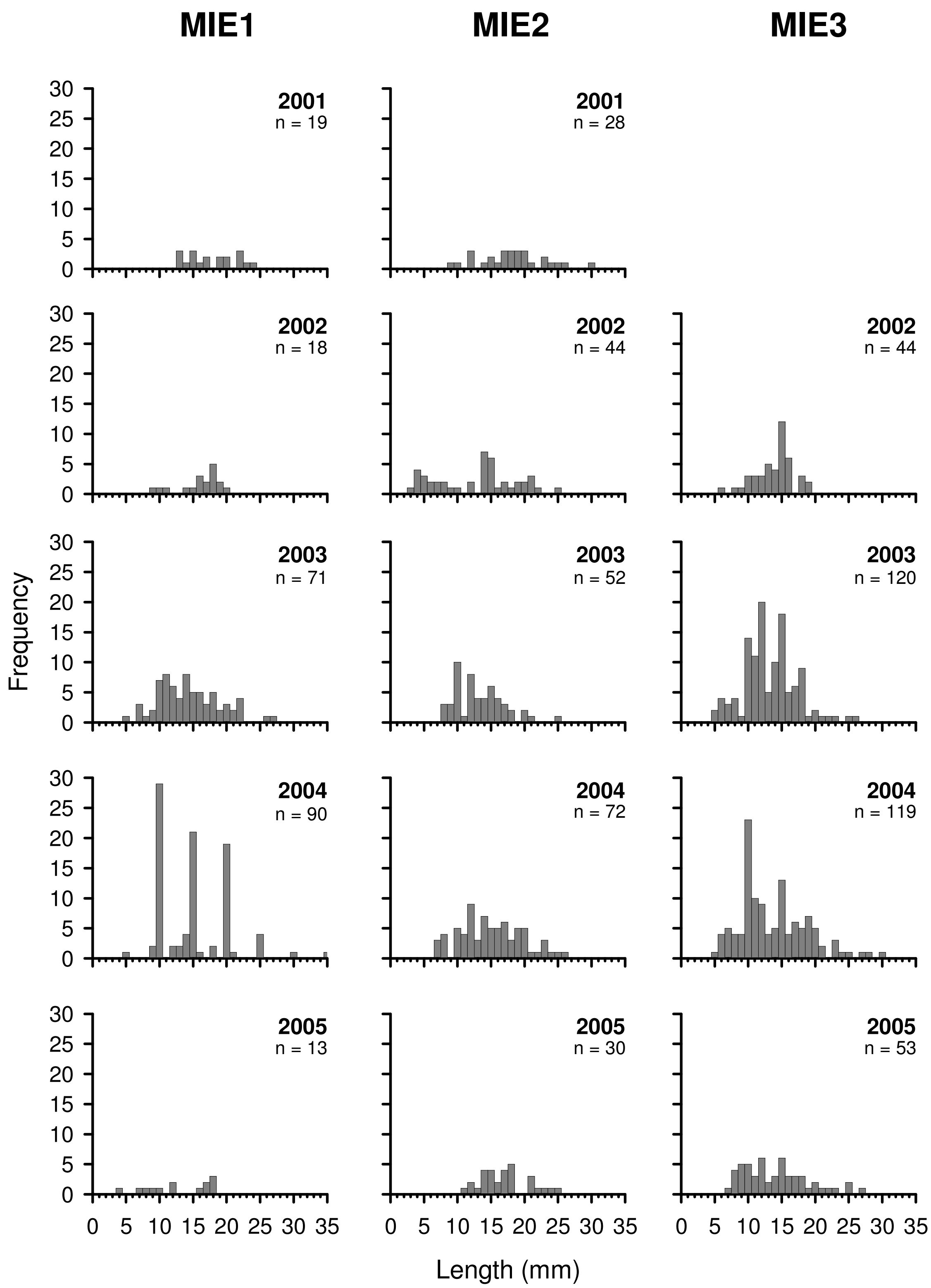
Appendix F2 Size frequency distributions for *Turbo smaragdus* at Meola intertidal reef



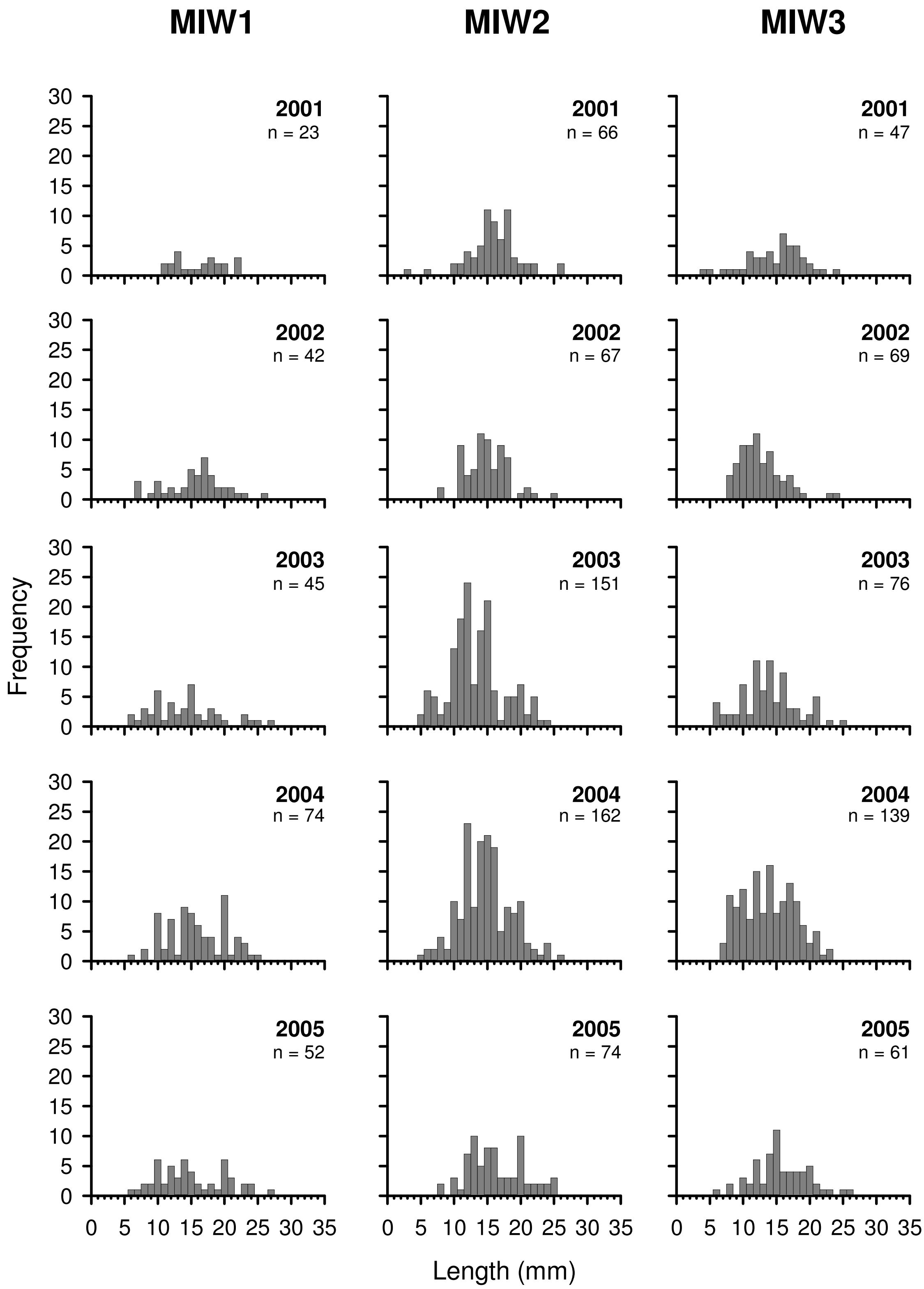
Appendix F2 continued Size frequency distributions for *Turbo smaragdus* at Meola intertidal reef



Appendix F3 Size frequency distributions for *Sypharochiton pelliserpentis* at Meola intertidal reef

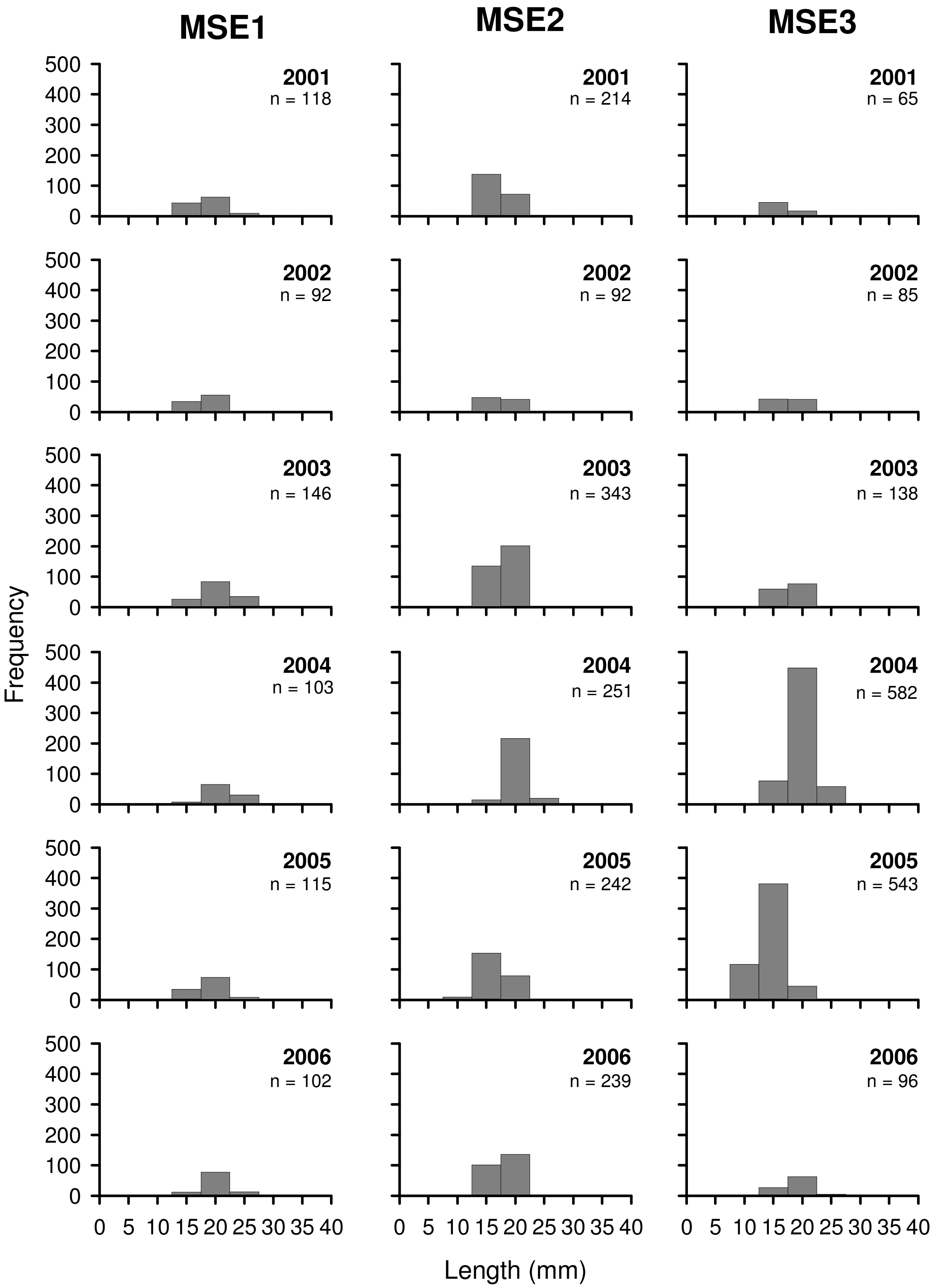


Appendix F3 continued Size frequency distributions for *Sypharochiton pelliserpentis* at Meola intertidal reef

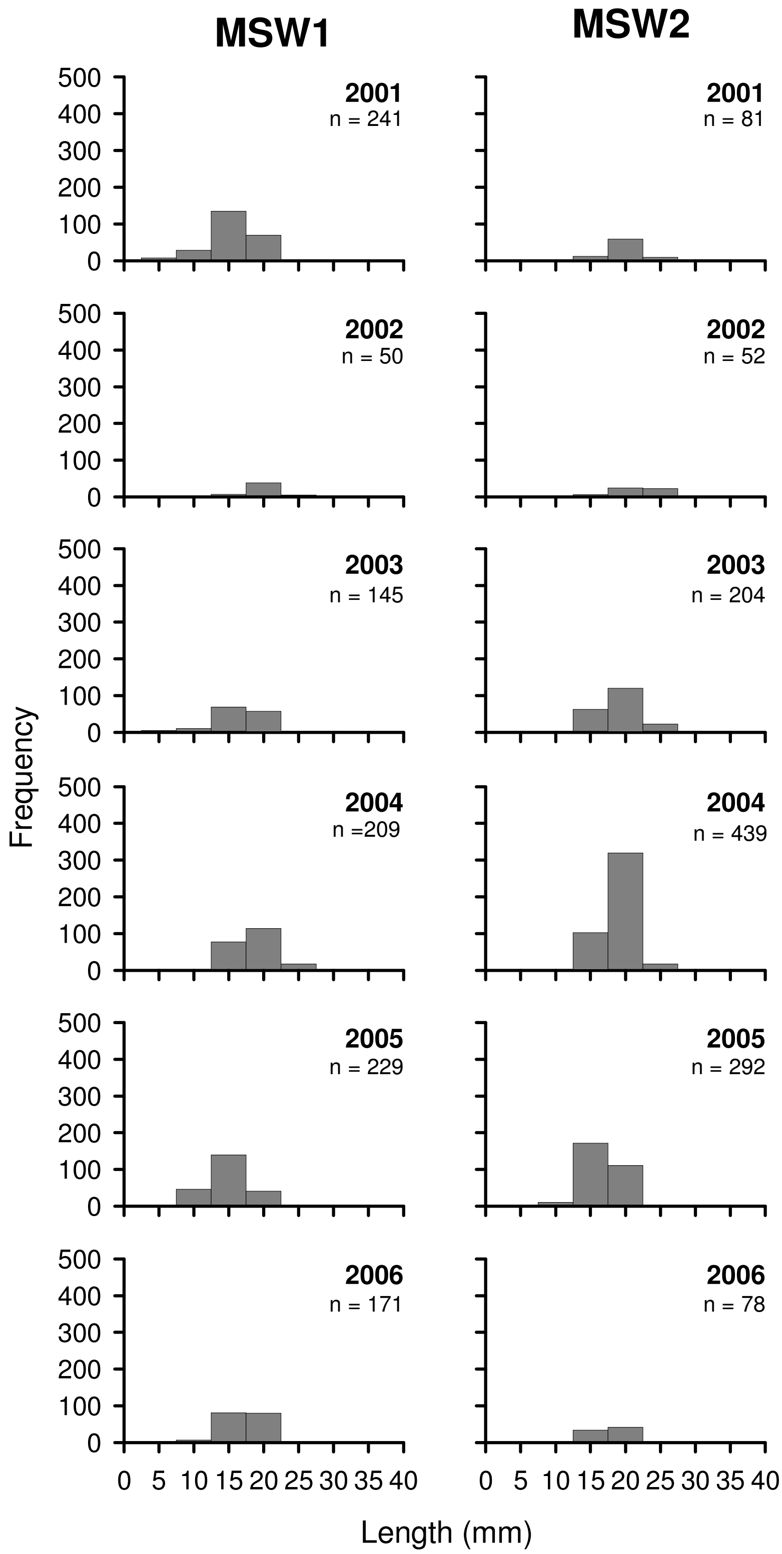


7.7 Appendix G Subtidal size frequency histograms

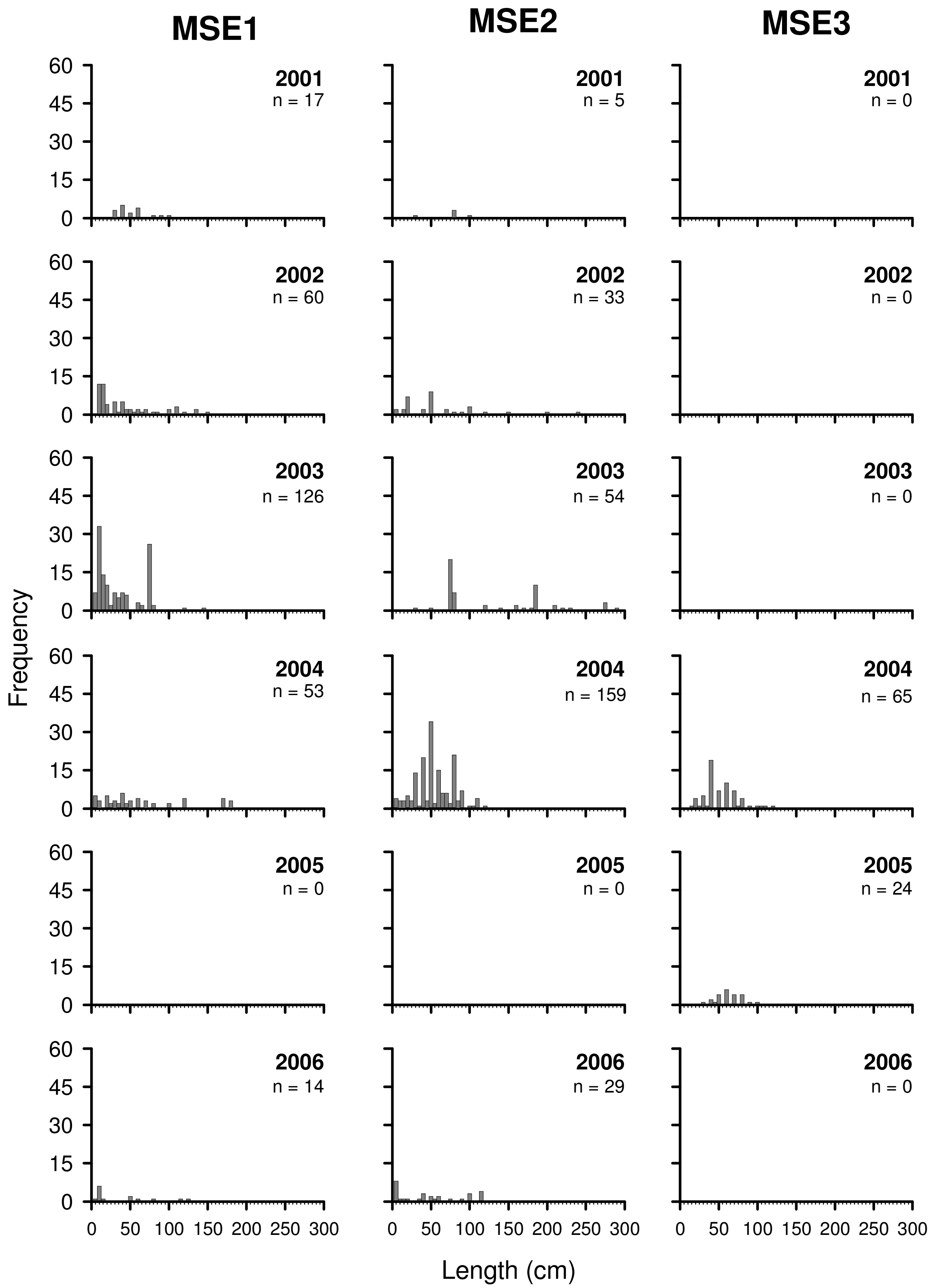
Appendix G1 Size frequency distributions for *Turbo smaragdus* at Meola subtidal reef



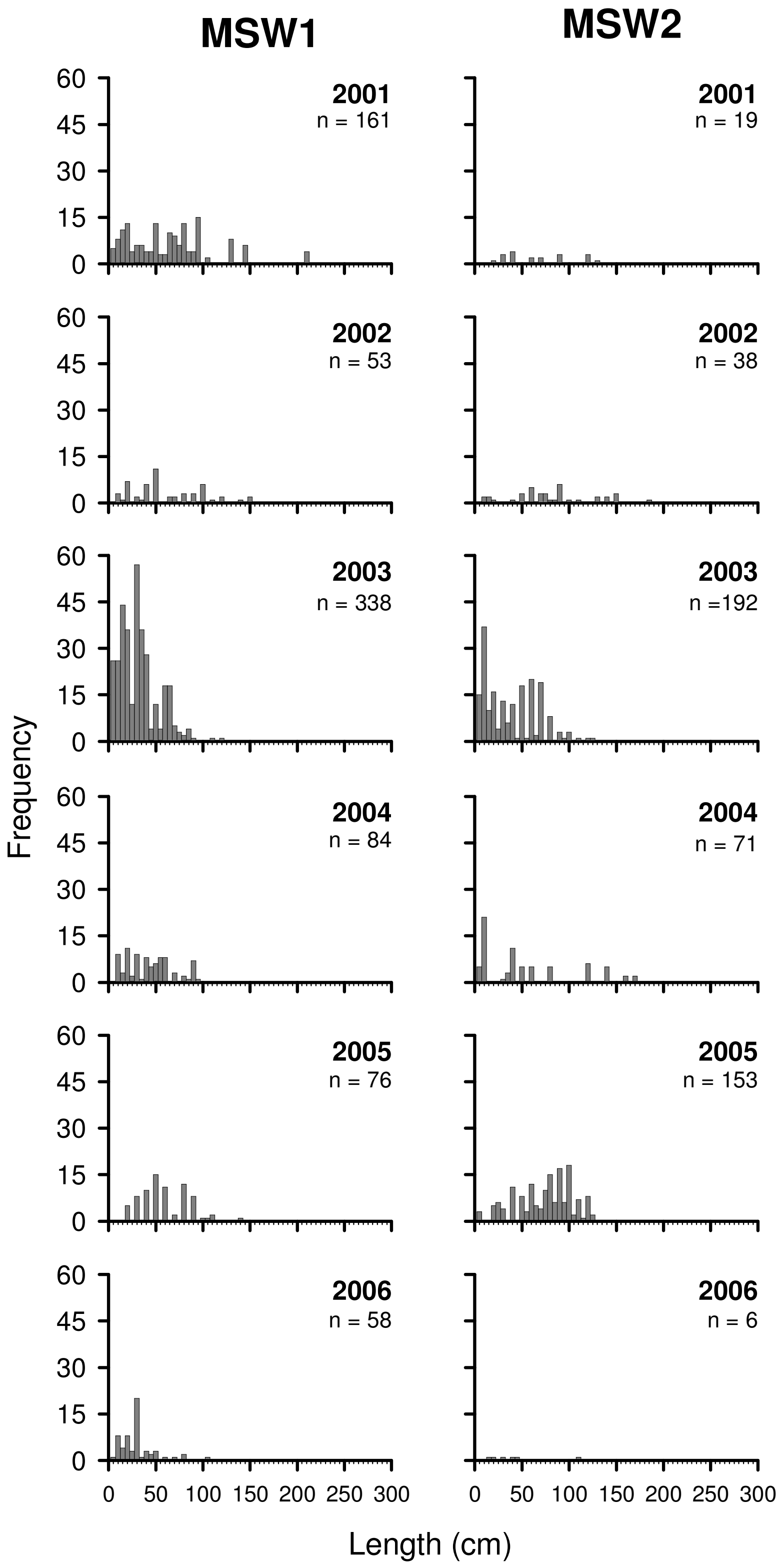
Appendix G1 continued Size frequency distributions for *Turbo smaragdus* at Meola subtidal reef



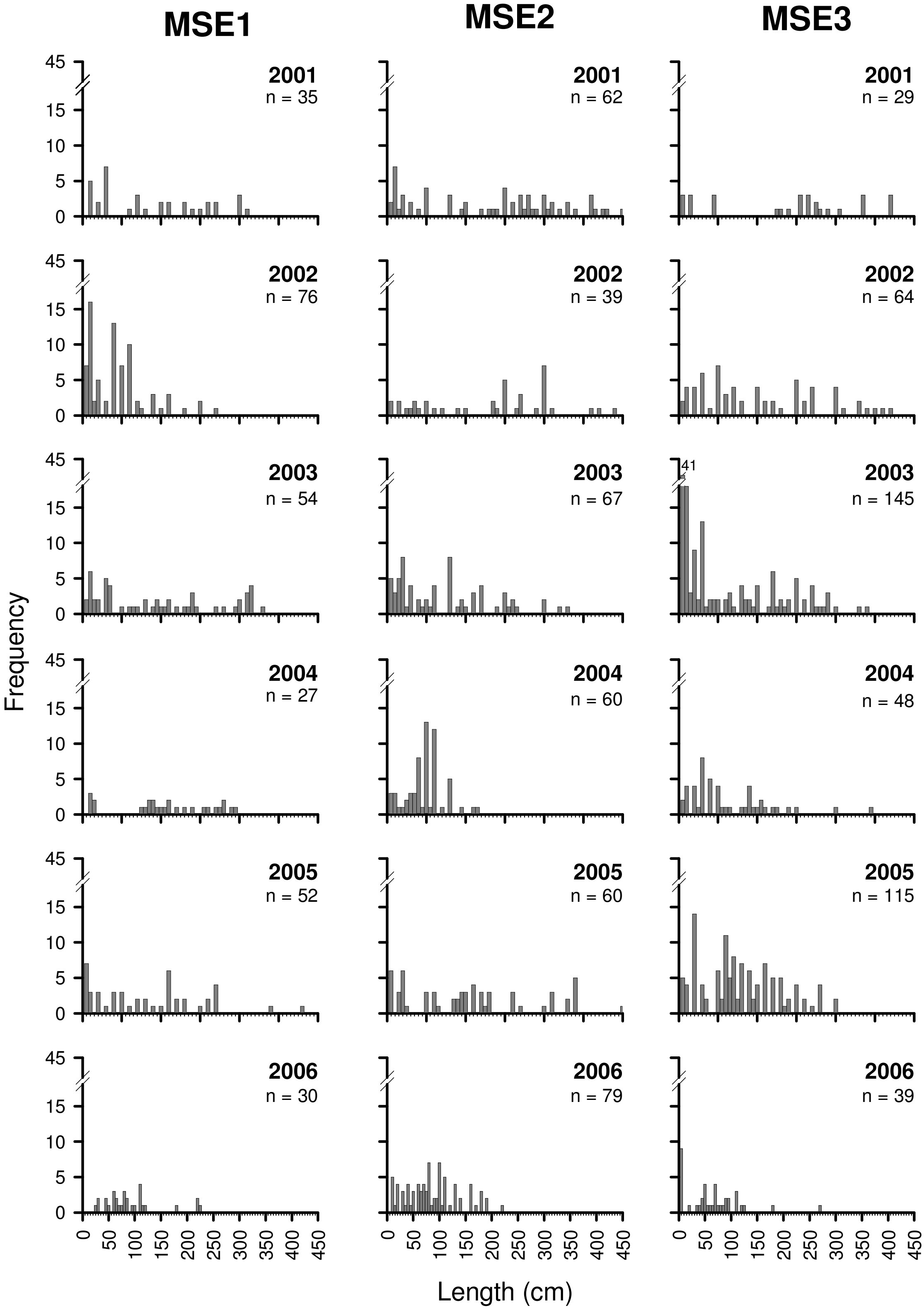
Appendix G2 Size frequency distributions for *Carpophyllum maschalocarpum* at Meola subtidal reef



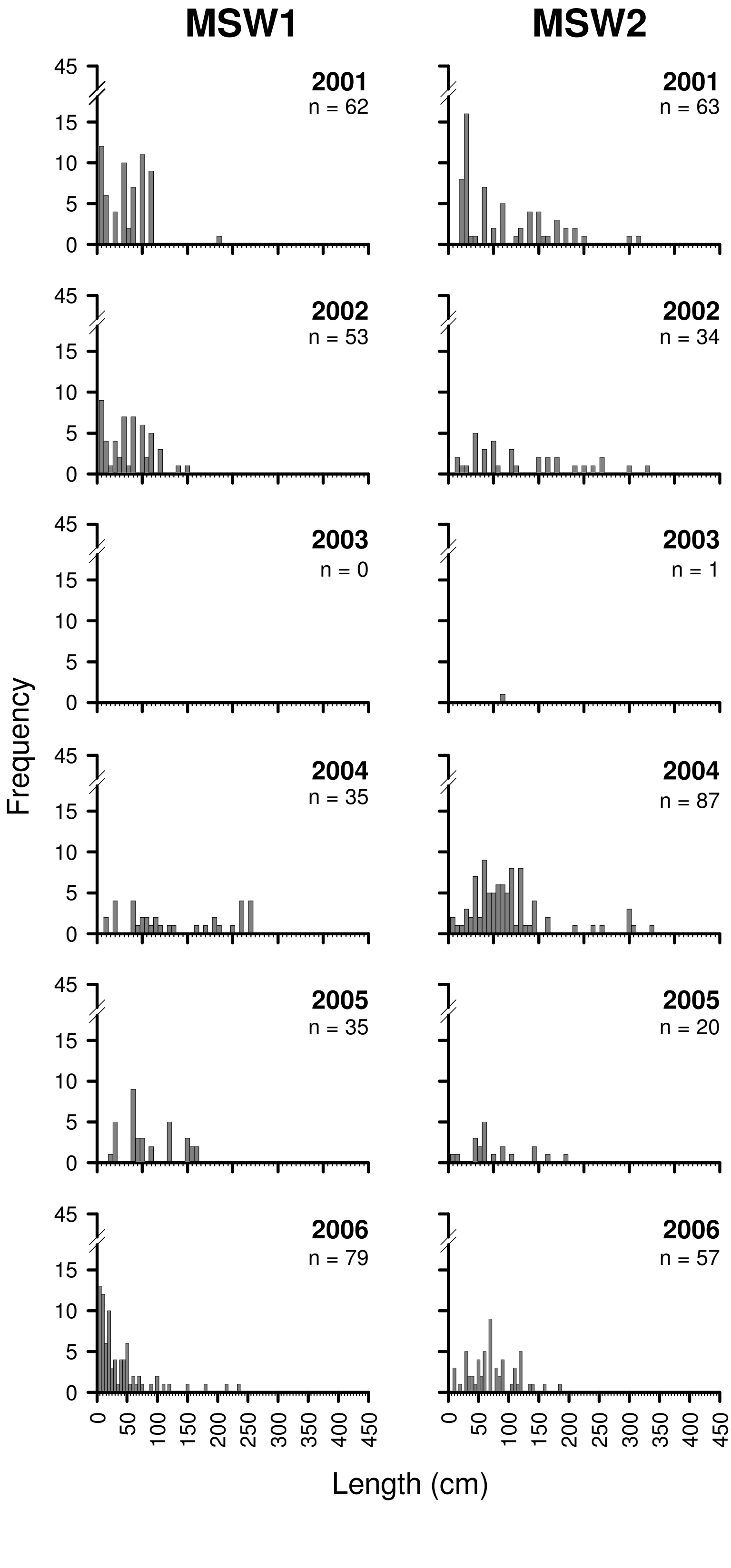
Appendix G2 continued Size frequency distributions for *Carpophyllum maschalocarpum* at Meola subtidal reef



Appendix G3 Size frequency distributions for *Carpophyllum flexuosum* at Meola subtidal reef



Appendix G3 continued   Size frequency distributions for *Carpophyllum flexuosum* at Meola subtidal reef



7.8 Appendix H List of all subtidal count data from the Long Bay marine monitoring Programme (LBMMP) (1999-2005, n = 35 sites per year) and Meola reef (2001-2006, n = 5 sites per year).

Taxa	LBMMP	Meola
Aaptos aaptos	31	37
Ambliopnuestes	1	0
Aplysia dactylomela	1	0
Buccinulum sp.	583	11
Bursatella leachii	14	0
Bulla quoyii	0	1
Cabestana spengleri	4	1
Cantharidus purpureus	3535	21
Carpophyllum flexuosum	6855	2188
Carpophyllum maschalocarpum	43563	2888
Carpophyllum plumosum	11910	21
Charonia spp_	4	0
Chlamys sp_	1	0
Cellana sp	3	0
Ceratosoma amoena	2	0
Codium (globular)	5	0
Codium fragile	0	3
Cominella adspersa	21	10
Cominella glandiformis	2	0
Cominella maculosa	2	1
Cominella virgata	1367	1
Cookia sulcata	751	0
Coscinasterias spp_	331	85
Crassostrea gigas	0	14
Cryptoconchus porosus	162	13
Cystophora sp	2921	1
Dendrodoris citrina	11	8
Dictyota sp	2	0
Ecklonia radiata	7264	488
Eudoxochiton nobilis	0	2
Evechinus chloroticus	838	16
Gastropod (unknown)	6	0
Glossophora kunthii	28	0
Halopteris sp	6	58
Haustrum haustorium	234	1
Hippocampus abdominalis	1	0
Hormosira banksii	109	61
Ishnochiton maorianus	0	2
Maoricolpus roseus	723	3
Micrelenchus sp.	100	0
Microcosmus kura	3	0
Notomithrax minor	0	1
Nudibranch (other)	15	0
Opisthobranch	1	0
Paratrophon quopyi	1	0
Patiriella regularis	1036	209
Penion sulcatus	9	0
Perna canaliculus	2	60
Phlyctenactis tuberculosa	3	0
Plagusia chabrus	13	0
Platyhelminth	2	0
Poiriera zelandica	2	0
Red foliose algae	229	13
Sargassum sinclairii	1558	191
Scutus breviculus	2	0
Solitary ascidians	3411	845
Stegnaster inflatus	312	1
Stichopus mollis	15	0
Sypharochiton pelliserpentis	6	4
Tethya aurantium	1156	83
Tethya ingalli	103	2
Thais orbita	109	3
Trochus viridus	5427	263
Tugali elegans	1	0
Turbo smaragdus	26976	7378
Xiphophora chondrophylla	21	0
Zonaria turneriana	26178	0