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Meola Reef Ecological Monitoring: 2001 - 2008

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Prepared for
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Environmental Research

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1 Executive Summary

This report updates the results of the Meola Reef Monitoring Programme, (MRMP), established in 2001 as an initiative of the Auckland Regional Council. The original programme was designed to track long-term trends in community composition. These trends were then to be put 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 programme from its establishment in 2001 until February 2008.

The key findings of this report are:

1. Intertidal sites at Meola Reef are distinguishable by their assemblage densities and percentage covers, but subtidal sites are not easily distinguishable from each other.
2. There is no evidence of directional change in assemblage structure (over time) at the Meola Reef sites.
3. The community composition is generally more even and more stable over time at intertidal sites further south (closer to the base of Meola Reef), compared to the northern sites.
4. No significant change over time was seen at Meola Reef over the same period of time that significant change was seen in the LBMMP. These monitoring programmes are only broadly comparable, but when the seven taxa that were driving change in the LBMMP were examined at Meola Reef, only the alga *Sargassum sinclairii* showed a similar linear change over time to what was observed in the LBMMP¹.
5. An increase in percentage cover of sediment was correlated with declines in abundance of many species (although the sediment grazing pulmonate slug *Onchidella nigricans* showed the opposite relationship). The relatively ubiquitous nature of the correlation between abundance and sediment cover suggests that an increase in sediment cover may result in declines in the diversity (and abundance) of most species presently occupying Meola Reef.
6. In the subtidal sites, increased sediment deposition into traps was correlated with declines in total abundance of solitary ascidians, the algae *Carpophyllum flexuosum* and the cat's eye snail, *Turbo smaragdus*. This pattern is consistent with the effect of sediment cover, and suggests that the present rates of

¹ Notably, three of the species causing change in the LBMMP, *Cominella virgata*, *Dicathais orbita* and *Cystophora* sp. were not found in sufficient numbers to analyse over time in the MRMP.

sediment deposition on some parts of the reef are sufficient to affect the densities of some species on the reef.

7. The invasive crab *Charybdis japonica* and the invasive tunicate *Styela clava* have been identified at Meola Reef in the past two years. In total, eight invasive species have now been documented at Meola Reef. However, over the period of this study, no invasive species has shown an ecologically concerning increase in density.
8. This monitoring programme should be continued in its present form. Although the time series is of sufficient length to show some correlations between the biological assemblages and long-term climatic phenomena (ENSO); the estimates are highly variable due to the comparatively short time series. A longer time series of data is needed so that any decline or improvement in this State of the Environment monitoring site can be placed in an appropriate temporal context.
9. Although correlations are not yet robust, due to the limited number of time points, there appear to be many correlations between faunal variables and climatic variables that are characteristic of the El Niño Southern Oscillation, (ENSO). These relationships may be better explained with a longer time series.

2 Introduction

The Meola Reef monitoring programme (MRMP) started in December 2001. The MRMP is a State of the Environment (SOE) monitoring programme for the intertidal and subtidal communities, of this reef, and is designed primarily to:

1. Determine trends in community change over time at and within sites at this location.
2. Compare community changes over time to those recorded at other sentinel locations within the region.
3. Interpret any community changes within the backdrop of two major threats to estuarine health in the Auckland Region:
 - a. Sedimentation from urban development
 - b. Toxicity from urban discharges (Hewitt 2000).

Meola Reef was chosen as one of a number of sentinel monitoring sites because it is a unique environment within Auckland (Morton and Miller 1968, Hayward et al 1999) and is located near the mouth of the Waitemata Harbour (and should consequently integrate pollutant effects from the overlying water body). The basaltic reef at Meola supports a richer and more diverse fauna than the nearby Waitemata sandstone reefs (Hayward et al 1999). The only other comparable basaltic intertidal reef in northern New Zealand is at Waitangi in the Bay of Islands (Hayward et al 1999). However, the Central Waitemata Harbour monitoring programme has monitored a soft-sediment intertidal site adjacent to Meola Reef every two months from October 2000 (Halliday et al 2006). In addition, the Long Bay Marine Monitoring Programme (LBMMP) monitors a number of subtidal rocky reef sites in the inner Hauraki Gulf using methods that are directly comparable to those used in the MRMP. Qualitative comparisons may be possible between the results of these monitoring programmes to see if patterns of change are widespread or habitat specific.

2.1 Threats to harbour/estuarine health

Sedimentation and toxic urban discharges are the main threats highlighted as probable causative factors for anthropogenic change in the Auckland marine environments. Invasions of exotic marine fauna also have the potential to alter Meola Reef.

2.1.1 Sedimentation

Sediment loads to the coastal receiving environment are predicted to increase as a result of rural and residential development (Auckland Regional Growth Forum 1999). Sediment can adversely affect benthic organisms in various ways: coarse sediment may scour surfaces and abrade tissue, suspended particles may interfere with filter

feeding of benthic invertebrates, and the deposition of fine sediments can interfere with grazing, settlement, growth and photosynthetic activity (Airoldi 2003, Ellis et al 2002, Schiel et al 2006, Airoldi and Hawkins 2007). All of these processes may affect assemblage structure, and greater levels of sedimentation have been universally recognised as a major threat to marine biodiversity (Ryan 1991, United Nations Environment Programme 1995, Norkko et al 1999, Thrush et al 2003).

In the Auckland Region, the response to sedimentation has only been documented for a few hard-substrate taxa. Some species that co-occur in hard and soft-substrates (e.g. the anemone *Anthopleura aureoradiata*, the gastropods *Diloma subrostrata* and *Zeacumantus lutulentus*²) have had their response to sedimentation tested either using mensurative or manipulative experiments (Gibbs and Hewitt 2004). *Anthopleura* and *Diloma* only occur in sediments that are 0-15% mud (it should be noted that *Anthopleura* requires hard substrates to live in soft sediments, therefore its occurrence in soft sediments is probably tightly linked to the occurrence of bivalves or rocks exposed above the sediment (Morton and Miller 1968). *Zeacumantus* showed no response to suspended sediment manipulations in the laboratory (Gibbs and Hewitt 2004). However, diversity has been observed to decline and the density of *Turbo smaragdus* has been observed to increase with increased turbidity further south in the Hauraki Gulf (Ford et al 2006). Additionally, Walker (2007) reported that the sea urchin *Evechinus chloroticus* was relatively rare in the inner Hauraki Gulf, possibly due to the settlement and survivorship of its recruits and juveniles being affected by the occurrence of fine sediments.

2.1.2 Toxic urban discharges

Meola Creek and Motions Creek, on either side of Meola Reef, discharge some of the most heavily polluted stormwater in the Auckland Region (Williamson and Kelly 2003). There are also numerous other stormwater discharges up and down-harbour of Meola Reef (Williamson and Kelly 2003) that could affect biota on the reef. The high flow rates at Meola Reef are unlikely to promote widespread deposition of fine materials (which stormwater pollutants are often bound to) over Meola Reef, but that does not preclude fauna at the reef being impacted by these pollutants, e.g. filter feeders or those in depressions where sediment may deposit.

The impact of these pollutants upon soft-sediment faunal assemblages has been modelled across the Auckland Region (Anderson et al 2006b). Ecological assemblages generally reflect pollution gradients well, via compositional changes. Several Auckland soft-sediment species have also had their individual response to contaminants tested (Appendix 2 in Halliday et al 2006). No equivalent tests have been carried out examining the response of hard substrate fauna to chemical contamination in the Auckland Region.

² For simplicity, every taxon will generally be referred to by its genus after an initial introduction. The exceptions to this are the Carpophyllum kelps (referred to as *C. maschalocarpum*, *C. flexuosum* and *C. plumosum*) and the Cominella gastropods (*C. adspersa*, *C. glandiformis*, *C. virgata* and *C. maculosa*).

2.1.3 Invasions

The Waitemata Harbour supports a number of invasive species (see Inglis et al 2005, Halliday et al 2006 (Appendix 3). The MRMP has enumerated a number of invasive taxa: the oyster *Crassostrea gigas*, the sponges *Cliona celata* and *Tethya burtoni*, the polychaete *Chaetopterus sp.* and the anemone *Diadumene lineata* (Ford et al 2006). The invasive crab *Charybdis japonica* has also been identified but not enumerated in the 2007 subtidal survey.

2.2 Research investigations

This report provides a quantitative analysis of the monitoring data in order to examine the SOE programme aims. To achieve this, several specific fundamental questions need to be addressed:

1. *Can we characterise the Meola Reef sites? Are there spatial patterns (i.e. differences along or across the reef) in terms of the abundance and diversity of fauna?*
2. *Are there changes through time in the faunal assemblages across the entire Meola Reef (or some subset of sites)? Are these changes related to the side of the reef or the distance along it? Are changes through time: (i) random, or (ii) due to significant increases or decreases in particular taxa (or in total abundance, diversity or community composition)?*
3. *Do changes correlate with any measured environmental variables?*

3 Methods

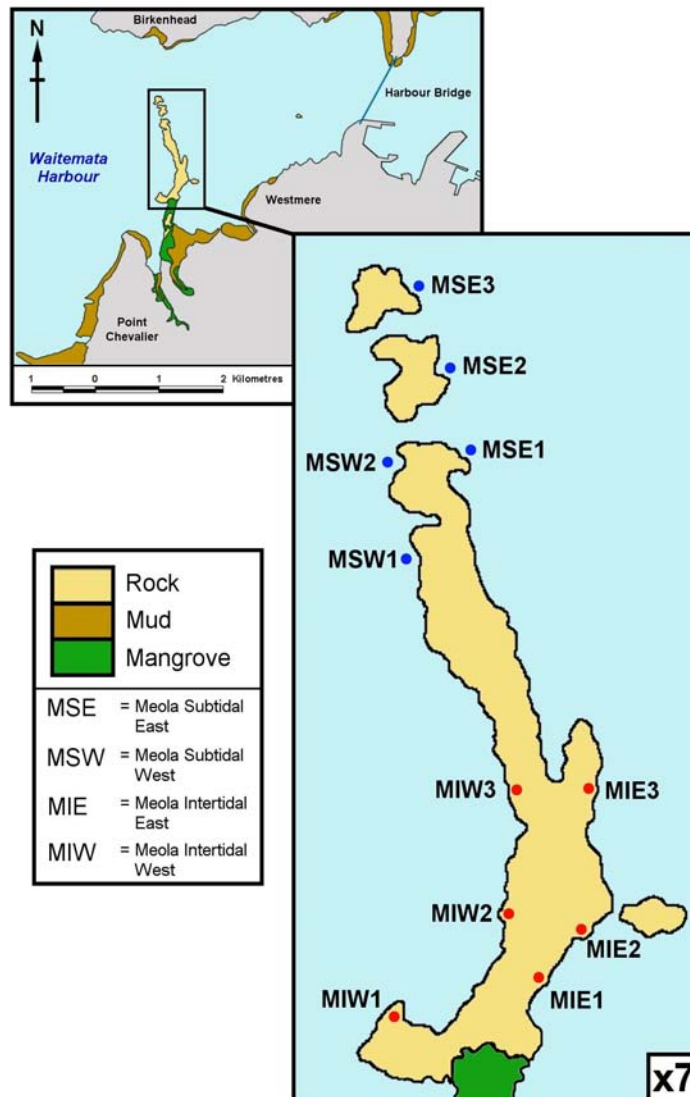
Note: A chronological synopsis of changes in methods since the inception of the programme is given in Appendix A (Section 8.1).

3.1 Site locations

Surveys were carried out at six intertidal sites and five subtidal sites on Meola Reef. A diagram of site locations on the reef is shown in Figure 1 and Global Positioning System (GPS) coordinates are given in Appendix A, Section 8.1.

Figure 1

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



3.2 Intertidal surveys

Intertidal sites measured approximately 75m² each, with three sites on the east side (MIE1, MIE2 and MIE3) and three on the west side (MIW1, MIW2 and MIW3). Labelling of these sites follows the convention whereby M = Meola, I = Intertidal, E/W = east/west, and 1-3 where 1 = the southernmost and 3 = the northernmost site. MIE3 was introduced as a new site in October 2001 due to the recommendations of the previous report (Ford et al 2001). Within each site, 10 permanent quadrat locations (1/4m²) 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 to aid relocation (Appendix B, Section 8.2).

The intertidal surveys aim to record the number, size, distribution and percentage cover of all benthic macroscopic flora and fauna (greater than 4mm) inhabiting the intertidal area of Meola Reef. Sampling commenced in December 2000, and was carried out bimonthly until October 2001 (Ford et al 2001). 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 (two on the east and three on the west), and annual sampling instead of bimonthly sampling. Data presented in this report is therefore annual, from October of every year, from 2001 onwards. 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).

3.2.1 Faunal data

Each year, organisms have been identified down to the lowest practical taxonomic level in every 1/4m² intertidal quadrat. All organisms (excluding *Crassostrea*, see below) were counted and measured using vernier callipers. Measurements were always taken along the longest axis of the organism. For gastropods, either shell length or shell width (dependant on species shell form) was measured.

Substratum cover was also assessed for each quadrat. The percentage cover of all substrate cover types was estimated. Each quadrat was photographed to produce a digital record of substratum cover and provide verification of visual percentage cover estimates if required (Figure 2 is an example photograph).

Throughout all samplings on Meola Reef, *Crassostrea* has been the numerically dominant organism in all intertidal quadrats. To evaluate oyster density, each 1/4m² quadrat was divided into quarters and all oysters in one quarter (1/16m²) were counted. A minimum of 10 oysters were measured to the nearest millimetre. Since there are 10 quadrats per site, at least 100 oysters were measured at each site. If less than 100 oysters were present in all the measured quadrat-quarters, then more oysters were randomly chosen until a total of 100 oysters were measured.

Figure 2

A photograph of intertidal site MIW1. Photographs are used for recording and verifying coverage estimates.



3.2.2 Environmental data

3.2.2.1 Sediment

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 locations where community sampling was undertaken.

In the intertidal sites, the percentage cover of sediment was measured along with other encrusting (e.g. sponges) and turfing (e.g. small articulating algae) organisms. The percent coverage of the substratum was visually estimated in each quadrat (grouped into: sediment, live *Crassostrea*, dead *Crassostrea*, the algae *Gelidium caulacanthum*, barnacles, and any other type found).

3.2.2.2 Climate – the El Niño Southern Oscillation (ENSO)

The "El Niño - Southern Oscillation" (ENSO) phenomenon is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on an inter-annual time scale (Vasquez et al 2006). ENSO refers to the major systematic global climate fluctuation that occurs at the time of an "ocean warming" event, and 'El Niño' and 'La Niña' events refer to opposite extremes of the ENSO cycle. It is known to have an important influence on New Zealand's climate (Gordon 1986) and may also be a useful predictor of organism abundances.

During El Niño events, New Zealand tends to experience stronger or more frequent winds from the west in summer, typically leading to drought in east coast areas and more rain in the west. In winter, the winds tend to be more from the south, bringing colder conditions to both the land and the surrounding ocean. In spring and autumn, south-westerly winds are more common. In contrast, La Niña events are characterised by north-easterly winds which tend to bring moist, rainy conditions to the north-east of the North Island, and reduced rainfall to the south and south-west of the South Island. Warmer than normal temperatures typically occur over much of the country during La Niña, although there are regional and seasonal exceptions (Gordon 1986, Mullen 1996).

To model ENSO, we chose a Multivariate ENSO Index (MEI) that is derived from tropical Pacific COADS (Comprehensive Ocean Atmospheres dataset) records. The MEI is derived from the first principal component of six variables: sea level pressure, surface zonal wind components, meridional wind components, sea surface and surface air temperature, and cloudiness. The index data is available at:

<http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html>.

We felt that ENSO effects might vary depending on the temporal scale of the ENSO signal, so we averaged MEI values over two different time scales. Intertidal MEI values were averaged using:

1. the year prior to sampling (i.e. October_{Year-1} – October_{Year})
2. the three months leading up to sampling (i.e. August - October).

In the univariate biotic models, both 3-month and 12-month ENSO lag terms were initially fit. However, both terms usually showed a degree of collinearity, so one of the ENSO terms could usually be discarded without much loss of predictive power (the choice of which term was discarded was determined by their respective predictive power.³

3.3 Subtidal surveys

Three sites were located on the eastern side and two on the western side of Meola Reef (Figure 1). All sites were areas of macroalgal-dominated subtidal basaltic reef. Sites depths extended between 1 and 2 m below Mean Low Water Springs (MLWS).

³ Standard Bonferroni correction rates were applied to the two ENSO variables to control the rate of spurious significance (Chandler, 1995).

Coordinates for each site were initially recorded by GPS (Appendix A, Section 8.1.2). Surface buoys (of approximately 15 cm diameter) were then deployed at each site.

3.3.1 Faunal data

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 has been conducted at five sites since 2001. The methods used for this survey were the same as those used in the 2001 MRMP report (Ford et al 2001), and are consistent with those used in the LBMMP (Ford et al 2003a). These are briefly outlined below.

Seven quadrats were randomly placed at each site within 20 m of the sediment collectors which served as location markers. In five of these quadrats all macroalgae and invertebrates (greater than 5 cm and 5 mm respectively), were identified, counted and measured. The percentage cover of substratum types (which included turfing algae, encrusting algae, large brown algae, encrusting invertebrates, bare rock, sediment [finer than sand] and sand) were also visually estimated in each quadrat. In two of the seven 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 5 cm. For the laminarian kelp, *Ecklonia*, this included both the stipe length and total length (stipe length plus laminae length). The longest axis of solitary macro invertebrates was also measured to the nearest 5 mm (and nearest 1 mm from 2007). Mobile organisms (e.g. crabs) were not enumerated. It should be noted that during the 2001 survey, between five and seven 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).

3.3.2 Environmental data

3.3.2.1 Sediment

The percentage cover of sediment, along with other encrusting and turfing organisms and substrate types, was visually estimated at within quadrats each subtidal site.

Sedimentation rate and particle grain size were also investigated by deploying sediment traps 1-2 m below MLWS in areas surrounded by macro-algae at each of the 5 subtidal sites. These were placed at a set height (500 mm above the benthos) on a heavy steel base to preclude movement or inundation by resuspended sediment. The traps were collected approximately monthly and their contents were analysed.

The sediment traps were cylinders 37 mm in diameter and 500 mm in length (consistent with those deployed in previous studies (Ford et al 2003a)). The chance of resuspension of trapped particles was minimised due to the high initial aspect ratio of 7:1 (Knauer and Asper 1989).

3.3.2.2 Trap rate definition

Sediment traps provide a measure of sediment deposition or flux at a site. The high-aspect ratio means that traps are likely to preclude resuspension within the trap. However, traps may also capture sediment resuspended locally from the neighbouring bed, so sediment deposition in traps is referred to as the 'trap rate' within this document.

3.3.2.3 Sediment processing

On collection, water was separated from the contents of the sediment traps by filtering through pre-weighed 'Faggs' brand coffee filter bags. These were tested against 1.2µm pore size filter paper and found to be 99% equivalent. This sediment and filter bag was then oven dried at 60°C for 24 hours, cooled and weighed to obtain a total dry weight of sediment. These dry weights in combination with the trap surface area and length of time deployed were then used to calculate the rate of trapped sediment (grams per cm² per day). Textural information of trapped sediments was gained via laser particle size analysis. Pre-treatment of samples involved the addition of 10% hydrogen peroxide (to dissolve organics) and 5g/l of Calgon (to disperse particles) prior to any grain size determination (Ford et al 2003b). To obtain textural information, the sediment was analysed using the 'Malvin Mastersizer 2000' laser particle size analyser and the results are shown as a percentage volume.

3.3.2.4 Climate

The ENSO climate data (as described in Section 3.2.2.2) was also used in the modelling of the subtidal analyses. MEI values were calculated using the following periods:

1. The month prior to trap collection (used to correlate with sub-tidal trap data).
2. The three and 12 month periods preceding faunal sampling. It should be noted that the month of subtidal sampling differed between years due to inclement weather

3.4 Statistical Methods

A number of terms and abbreviations mentioned here are also defined in Appendix C (Section 8.3) for quick reference for the reader. In some cases, lengthier definitions are given within the body of the report.

3.4.1 Site characterization

To determine the level at which generalizations can be made about the community data, a permutational multivariate analysis of variance (PERMANOVA, Anderson 2001, 2005) was run to examine the effects of the factors: (i) year (2001, 2002 ... 2008), (ii)

side of reef (east or west) and (iii) distance north to south [1 (furthest south), 2 and 3 (furthest north)], on both count and cover data. These analyses also quantified the amount of variation in the data explained by spatial (side and distance) and temporal (year) factors. To visualise these patterns, a non-metric multi-dimensional scaling ordination (MDS) was run on the average community composition of each site and year combination (e.g. 2001MIE1, 2001MIE2 ... 2008MIW2).

All multivariate analyses (excluding tests of dispersion) were completed using Bray-Curtis similarities on presence/absence and natural log (\ln) transformed data. Only the results from the Bray-Curtis analysis on \ln transformed data were reported, unless the results differed between transformations.

Due to changes in assemblages over time, classification trees were used to find those variables (or levels of particular variables) that discriminated between sites in the MRMP (Breiman et al. 1984, Ripley 1996). Classification trees are a data mining technique used to predict membership of cases (quadrats) in the classes of a categorical dependent variable (bays), from their measurements of one or more predictor variables (e.g. biotic and environmental variables). They systematically try to split samples into two parts, examining one predictor variable at a time and splitting the records on the basis of a dividing line in that variable (e.g., *Trochus viridus* abundance > 11 or 'sediment cover' <= 35%).

To use the classification trees, a separate binary factor was created for each site. This factor identified 'site membership' as: (i) the site of choice (e.g., 'MIE1') vs (ii) 'other', (e.g. all other sites that were not MIE1). Each classification tree used this factor as a response, thereby attempting to find those predictor variables that differed between the site of choice and all other sites.

3.4.2 Assessment of changes over time

3.4.2.1 Multivariate models assessing change over time

Change over time can be characterised either by magnitude or direction. For example, a site may be highly variable, but in no particular direction; or it could change relatively little, but in a consistent direction. To test these facets of temporal change we examined both multivariate dispersion and seriation. Temporal dispersion is a measure of the amount of change in a community over time, i.e. a more dispersed community changes more over time. Seriation is a measure of directional change over time. MDS plots of all sites over time also include arrows corresponding to strong correlations ($\rho > |0.4|$) of individual variables to axes on the plot.

Multivariate dispersion was tested using a permutational analysis of multivariate dispersions (PERMDISP, Anderson 2004) using site as a factor and each time as a replicate. A range of dissimilarity measures that do not intrinsically affect dispersion were tested using PERMDISP as recommended in Anderson et al (2006a). The four chosen dissimilarity measures (Jaccard's, Manhattan and Modified Gower (base 10 and base 2)) were applied to raw count and cover data. Jaccard's measure emphasises compositional change, while Manhattan distance emphasises changes in abundance.

The modified Gower indices strike a balance between compositional and abundance change, with greater emphasis on abundance change for the base 2 compared to the base 10 measure (Anderson et al 2006a). A significant result in this test would indicate that the variability of a community over time is influenced by which site is considered. To visualise these dispersions, MDS plots of the centroids of each site by time combination were plotted for each dissimilarity measure.

Multivariate seriation was tested using a Mantels test in the RELATE function of PRIMER (Clarke and Gorley 2006). This test was applied across the whole reef for average count and cover data from each year, as well as separately at each site. A significant result in this test would indicate directional change over time. The MDS plots previously generated were used to visualise any directional change, although additional MDS plots of count and cover data were generated showing the change between years averaged across the whole reef.

Intertidal changes in size frequency over time

Temporal impacts can be manifested as changes in abundance, changes in size structure of a population over time, or as a combination of both. Previous analyses have addressed changes in abundance over time; this section will address changes in population size structure over time. Size frequency data were examined for the seven most abundant intertidal taxa, which constitute over 95% of the individuals (see Section 4.2.3).

Size frequency data was calculated proportionately for each site by year level, e.g. 2001MIE1, 2001MIE2, etc., and then entered into PRIMER with the variables being the different size classes e.g. 5, 6, 7 mm etc. PERMANOVA analyses were then used to examine the impacts of site and year, although the interaction of these factors could not be tested as only one replicate existed at each site by year combination. When a significant effect of time was detected, size frequency histograms tracking each site over time was generated and visually examined for ecological significance. Particular ecological importance was placed upon the presence of juveniles, as juveniles are considered more vulnerable than adults, so their absence could be a precursor of community change.

Subtidal changes in size frequency over time

Subtidal size frequency data were analysed similarly to those for the intertidal zone. However, with *Ecklonia*, stipe length was used as opposed to total length (because total length can be affected by processes such as abrasion or herbivory). In addition, PERMANOVA analyses showed significant effects of time and site for *Ecklonia* and *Turbo*. For these taxa, size frequency histograms tracking each site over time were generated and examined.

3.4.2.2 The univariate model assessing change through time

In terms of spatial variation, quadrats within sites were randomly allocated and are therefore considered our lowest level of replication and provide estimates of error variation. In the intertidal data, quadrats were stationary through time, and plots that tracked the abundance of each individual quadrat within each site through time were produced. In addition, a summary plot of the mean for each site through time was produced. In the subtidal data, quadrats were randomly placed each year, so plots tracked those variables (as described above) after averaging at the site and reef spatial scale.

Using a Generalised Linear Mixed Model

Counts of abundances of organisms are more appropriately modelled using a generalised linear model due to the following reasons:

1. A population of organisms tends to change by multiplying (rather than individuals being added or subtracted). Therefore, rather than fitting a linear (additive) model directly, it is generally more appropriate to model the data on the log (multiplicative) scale.
2. Organisms occur in discrete counts, rather than being a continuous distribution.
3. Abundance data tends to be clumped (aggregated) rather than randomly dispersed.

To account for these factors, each univariate variable was analysed using a quasi-Poisson error distribution with log link. Since the primary interest was in examining changes across the reef as a whole (rather than at the site level) a Generalised Linear Mixed Model (GLMM, Booth et al 2003) using the R computer program (R Development Core Team 2005) was used. The mixed model regarded the six intertidal and five subtidal sites as samples from the intertidal and subtidal reef areas respectively (although see below for a discussion about spatial interactions and spatial inference).

Exploratory Data Analysis

Exploratory Data Analysis (EDA) was performed to check the assumptions of the model (i.e. linearity of the response, independence of observations and heteroscedasticity). Following Bence (1995), if significant temporal autocorrelation was found, the shortness of the time series meant it was modelled by fitting *AR1* ('autoregressive errors order one') errors

Note that 'total number of taxa', 'diversity' and all four cover variables did not demonstrate over-dispersion or a mean-variance relationship and were therefore modelled using a linear mixed-model with normal (Gaussian) errors.

Creating confidence intervals for parameters

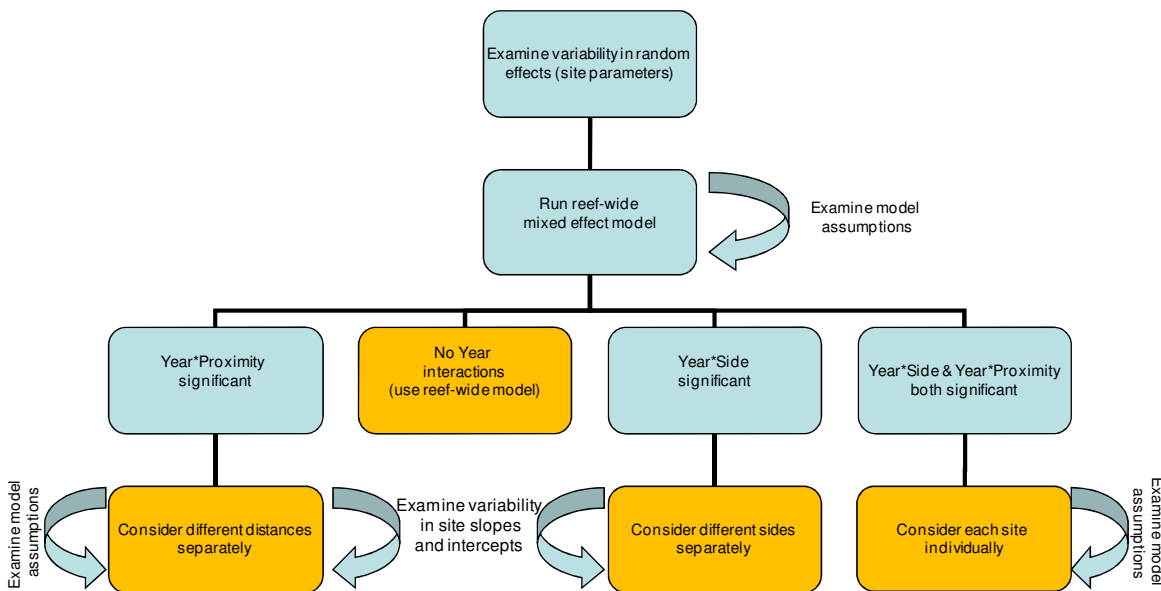
Credible intervals (a Bayesian analogue to confidence intervals) for each parameter were generated using a Markov Chain Monte-Carlo (MCMC) approach. 1000 random samples from the posterior distribution of the parameters were simulated using a non-informative prior distribution and the 2.5% and 97.5% quantiles were used to determine the required credible intervals.

The spatial scale of inference

The univariate modelling examined interactions between various spatial factors and changes over time (see Figure 3).

Figure 3

A flow chart showing the basic steps used in the univariate analyses of major species abundance, univariate indices, percent cover and environmental variables.



Of particular interest was whether any of the response variables included a significant component of the variable 'year', which would indicate a consistent increase or decrease over time (in abundance) after accounting for the effects of other covariates (e.g. climate).

The rationale behind examining the interaction between (i) Distance and Year, and (ii) Side and Year, was that these terms still give some degree of generality across the reef without compromising the analysis.⁴ A significant 'Year*Side' interaction term means that there is evidence that each side is changing differently over time. In such circumstance, it would make sense to make inferences for each side of the reef separately. The same principle holds with the 'Year*Distance' term.

⁴ Note: a significant interaction between Year*Site states that the effect of year depends on the site. This does not allow any degree of spatial generality beyond the site level.

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.

3.4.3 Correlation of change with environmental variables

3.4.3.1 Multivariate analyses

Two causative factors were quantitatively compared to community composition: sediment measures and the MEI. The large spatial dislocation between intertidal and subtidal sites (Figure 1) means that it would be incorrect to apply any sedimentation measures from the subtidal to the intertidal. Two versions of the MEI were calculated: a short-term MEI (the two months before monitoring) and a medium-term MEI (the year before monitoring) (see Section 3.2.2.2 for details).

A DISTLM analysis (Anderson 2003) was used to test for a significant linear relationship between the intertidal sediment cover and MEI measures (alone or in combination) with intertidal community structure from both count and cover⁵ data. The DISTLM analysis was completed at the site by year level. For individual factors that were significant, CAP plots were used to visualise the relationship (Anderson and Willis 2003).

For the subtidal analyses, two different DISTLM were completed. One used the entire biological dataset at the site by year level and compared this with ENSO and sediment cover variables. The other analysis also included the following sediment trap variables (calculated over both (i) the previous month ('short-term') and (ii) previous year ('medium-term')):

1. 'trap rate' [weight of trapped sediment (grams per cm² per day)] (short and medium-term)
2. '% fines in trap' (percentage of sediment <63µm) (short and medium-term)
3. 'rate of fines' (weight of fines (grams per cm² per day) (short and medium-term).

Missing sediment measurements reduced the temporal scale of this dataset.

3.4.3.2 Univariate analyses

Sediment variables can be used to quantify their effects within the species abundance models. To determine this, the following sediment variables were examined:

1. percentage sediment cover (for intertidal and subtidal spline analyses)
2. (subtidal) trap rate.

⁵ Cover variables in this case excluded sediment cover.

Modelling sediment trap rate

Although ENSO variables were included in initial mixed model analyses, respective sediment variables were not. The rationale behind excluding sediment variables was to determine whether abundance was changing over time after considering fluctuations in 'natural environmental variability' (e.g. ENSO) as a covariate. When the 'sedimentation variables' are included as a covariate, temporal trends in abundance are quantified given the changes in sediment that may also have occurred over time, i.e. the linear trend in abundance may be different because the model might be partitioning some of the changes in abundance to the effect of sediment.

The trap rate was averaged over the previous 12 months. This averaged rate was then normalised using a log transformation and used as an explanatory variable in the mixed model. Its importance was assessed using a χ^2 -square test of deviance in the quasi-Poisson GLMM.

Modelling percentage sediment cover

To examine possible changes in component fauna with chronic longer-term increases in sediment cover, the most abundant taxa in the intertidal and subtidal datasets (see Section 4.3.2 and Section 5.2.3) were modelled individually along the gradient of percentage sediment cover. Following Anderson et al (2007), quantile regression splines of the 95th percentile of the distribution were used to model the abundance of dominant species along the regional gradient of percentage sediment cover using the 'quantreg' package in R (Koenker 2007). The appropriate polynomial required for the spline to provide an adequately-shaped fit for each species was determined using BIC. The value at which the predicted density achieved a maximum along the gradient was identified in order to find the 'optimal' percentage cover of sediment for each taxon.

4 Intertidal Results

4.1 Characterization of the Meola Reef intertidal sites

Intertidal surveys of Meola Reef from 2001-2007 recorded 35 taxa and 12 cover types (Appendix D, Section 8.4). The substratum cover at all intertidal sites at Meola Reef was dominated by *Crassostrea*, bare rock and sediment. These cover, on average (across all sites and times), 47%, 30% and 11% of the space on the reef respectively. The monitored community was over 90% numerically dominated by six taxa: the grazing gastropods *Turbo*, *Melagraphia* and *Zeacumantus*, the grazing chiton *Sypharochiton*, the anemone *Anthopleura* and the small mussel *Xenostrobus*. With the exception of *Onchidella nigricans* (only found in sediment pockets), all monitoring species were associated with hard substratum.

The initial PERMANOVA analysis on both intertidal count and cover data suggested that generalizations about the intertidal community of Meola Reef were not possible. A significant interaction occurred between side, distance and year for the count and cover data (Table 1). This means that the temporal patterns in both counts and covers differed depending upon the side of the reef, the distance along it and the year examined.

Sites showed strong clustering over time for both the count and cover data. The amount of variance explained by the spatial factors (side and distance) in the count and cover analyses (26 and 34%, respectively, Table 1) was large compared to the temporal variability (explained by the year factor) in each of these analyses (9 and 8%, respectively, Table 1). This can be observed in the MDS plots where sites (shown as symbols) are grouped together but years (shown as numbers) are not (Figure 4, Figure 5).

The similarity of communities between sites differed depending upon the metric examined. Count data suggested that communities at sites MIE1, MIE2 and MIW1 were highly similar to each other (Figure 4). By contrast, when cover data was examined, sites MIW2, MIW3 and MIE3 showed a high level of community similarity (Figure 5). The high temporal stability and separation of community compositions on the MDS plots (Figure 4, Figure 5) suggests that it is valid to characterise each site by its fauna and cover classes.

Table 1

PERMANOVA results from analysis of the Bray-Curtis similarities of ln transformed intertidal count and cover data. %Var is the percentage of variation explained by each factor. Note: Presence/absence transformed data showed the same pattern of all factors being significant.

| Factor | df | Pseudo-F | P(perm) | perms | % Var |
|-------------------|-----|----------|---------|-------|-------|
| Count data | | | | | |
| Year (Ye) | 5 | 6.5758 | 0.001 | 998 | 8.9 |
| Side (Si) | 1 | 41.944 | 0.001 | 998 | 14.6 |
| Distance (Di) | 2 | 18.297 | 0.001 | 996 | 11.5 |
| Ye x Si | 4 | 2.0641 | 0.003 | 999 | 5.0 |
| Ye x Di | 8 | 2.0736 | 0.002 | 999 | 6.1 |
| Si x Di | 2 | 37.282 | 0.001 | 998 | 22.9 |
| Ye x Si x Di | 7 | 1.5906 | 0.013 | 997 | 6.2 |
| Res | 255 | | | | 24.9 |
| Total | 284 | | | | |
| Cover data | | | | | |
| Year (Ye) | 6 | 6.4428 | 0.001 | 999 | 7.8 |
| Side (Si) | 1 | 66.923 | 0.001 | 999 | 15.0 |
| Distance (Di) | 2 | 72.852 | 0.001 | 998 | 19.1 |
| Ye x Si | 6 | 4.0943 | 0.001 | 998 | 8.3 |
| Ye x Di | 12 | 1.9937 | 0.002 | 997 | 5.7 |
| Si x Di | 2 | 16.039 | 0.001 | 999 | 12.1 |
| Ye x Si x Di | 11 | 1.8566 | 0.007 | 999 | 7.3 |
| Res | 354 | | | | 24.7 |
| Total | 394 | | | | |

Figure 4

MDS plot of the Bray-Curtis dissimilarities of ln transformed intertidal cover data (excluding *Crassostrea gigas*). Each point is averaged of n= 5-7 quadrats, numbers indicate the year of sampling, i.e. 1= 2001, 7 = 2007. The biplot shows a unit circle (radius=1) with those substrate type correlated with an MDS axis (Pearson correlations >|0.4|).

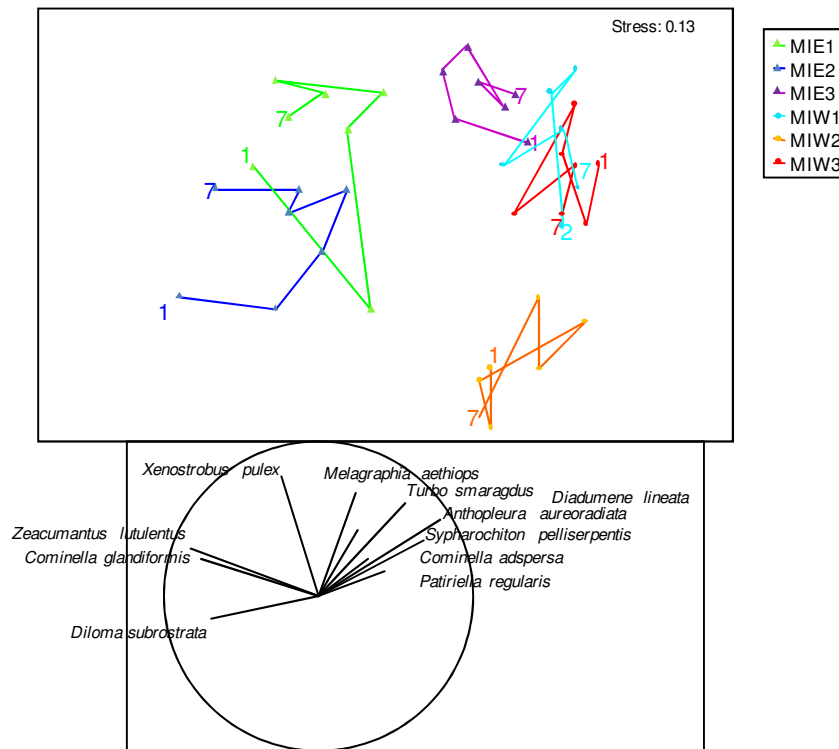
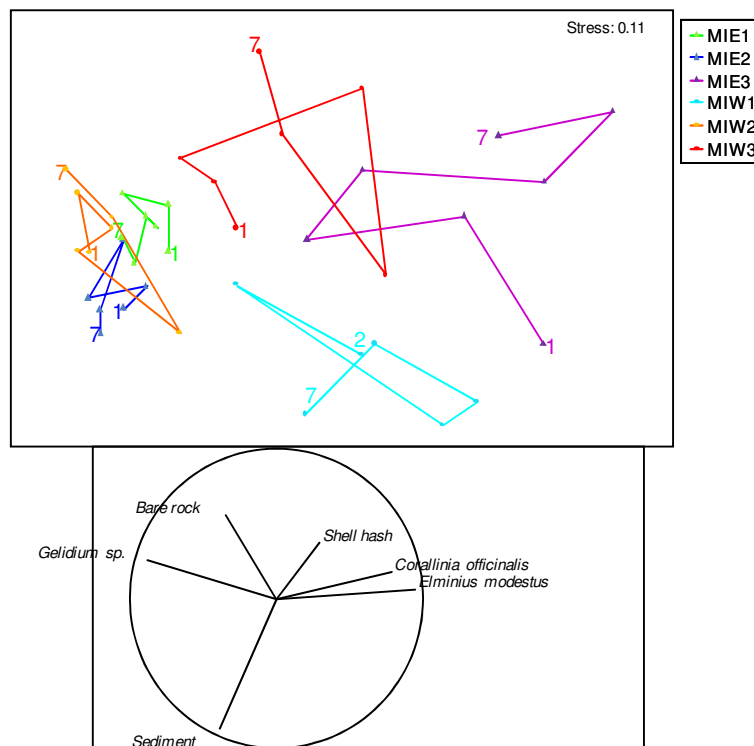


Figure 5

MDS plot of the Bray-Curtis dissimilarities of ln transformed intertidal cover data (excluding *Crassostrea gigas*). Each point is averaged of n= 5-7 quadrats, numbers indicate the year of sampling, i.e. 1= 2001, 7 = 2007. The biplot shows a unit circle (radius=1) with those substrate type correlated with an MDS axis (Pearson correlations >|0.4|).



4.1.1 Specific characteristics of each intertidal site

Specific features of each intertidal site were determined using classification trees (shown in Appendix E, Section 8.5). A summary of each tree is listed below:

- Site MIE1 was characterised by relatively high abundance of *Zeacumantus*, *Melagraphia* and a moderate cover of *Gelidium*.
- Site MIE2 was characterised by relatively low abundance of *Melagraphia*, but high abundance of *Zeacumantus* and *C. glandiformis*
- Site MIE3 was characterised by low cover of bare rock and *Gelidium*.
- Site MIW1 was characterised by relatively low total abundance, low densities of *Zeacumantus* and *Xenostrobus*
- Site MIW2 was characterised by high abundance of *Turbo* and low percentage cover of *Elminius* and sediment.
- Site MIW3 was characterised by a high abundance of *Melagraphia*. Most quadrats had a moderate cover of *Elminius* (and those quadrats with few *Elminius* had large numbers of *Turbo*).

4.2 Examination of changes over time

4.2.1 Change in community composition

The amount of community change at a site, as measured by the dispersion of count data over time, was mainly driven by changes in abundance rather than composition. The similarity measures that most stressed changes in abundance (MG_2 and Manhattan) detected a significant site effect on dispersion over time ($p = 0.014$ for both). Those measures that most stressed compositional change (MG_{10} and Jaccard's) showed no significant site effect on dispersion over time ($p = 0.073$ and 0.337 , respectively). None of the similarity measures tested showed a significant difference between the sites MIE1, MIE3 and MIW3 when pair-wise comparisons were considered. Examination of the MDS plot suggested that these sites all showed relatively high variability over time (Figure 6).

A significant site effect was usually detected when the dispersion of cover data was examined over time. Of the four similarity measures tested, only the Jaccard's measure reported a marginally non-significant difference in dispersion between sites ($p = 0.06$). All other measures showed a significant difference ($p < 0.01$). Pair-wise comparisons showed that for all similarity measures, sites MIE1 and MIE2 were the most significantly different; examination of corresponding MDS plots showed these sites to be the least variable over time (Figure 7).

When count or cover data was analysed for directional change across all sites, and across Meola Reef as a whole, only one significant change was detected (count data at MIE2, Table 2). This can be seen as a shift over time at site MIE2 upwards and to the right when viewed in the MDS plot (Figure 4). When using a presence/absence transformation, this result was marginally non-significant ($p < 0.1$), suggesting this directional change was caused more by differences in abundance rather than composition.

In general, sites MIE1, MIE3 and MIW3 were significantly more variable than sites MIE2, MIW1 and MIW2. Only count data at site MIE2 showed a directional change over time and this change appeared to be driven by changes in abundance rather than composition. Cover data showed that sites MIE1 and MIE2 are the least variable and the most significantly different in the extent of their change over time.

Table 2

Results of seriation test upon individual intertidal sites and intertidal Meola Reef as a whole. Analyses were completed using Bray-Curtis similarities of ln transformed data. Presence/absence transformed data did not show significance for this site which suggests directional change in community composition is largely driven by changes in abundance.

| Area | Cover | | Count | |
|------------|----------|-------|----------|-------|
| | <i>P</i> | Rho | <i>P</i> | Rho |
| MIE1 | 0.140 | 0.248 | 0.442 | 0.007 |
| MIE2 | 0.877 | 0.262 | 0.002* | 0.762 |
| MIE3 | 0.477 | 0.004 | 0.166 | 0.245 |
| MIW1 | 0.189 | 0.222 | 0.341 | 0.062 |
| MIW2 | 0.347 | 0.082 | 0.770 | 0.179 |
| MIW3 | 0.153 | 0.257 | 0.121 | 0.270 |
| Meola reef | 0.336 | 0.102 | 0.431 | 0.045 |

Figure 6

An example MDS plot of the intertidal count data, using MG_2 = Modified Gower base-2 dissimilarity measure (averaged using $n = 5-7$ quadrats for each point). Numbers indicate the year of sampling, i.e. 1 = 2001, 7 = 2007.

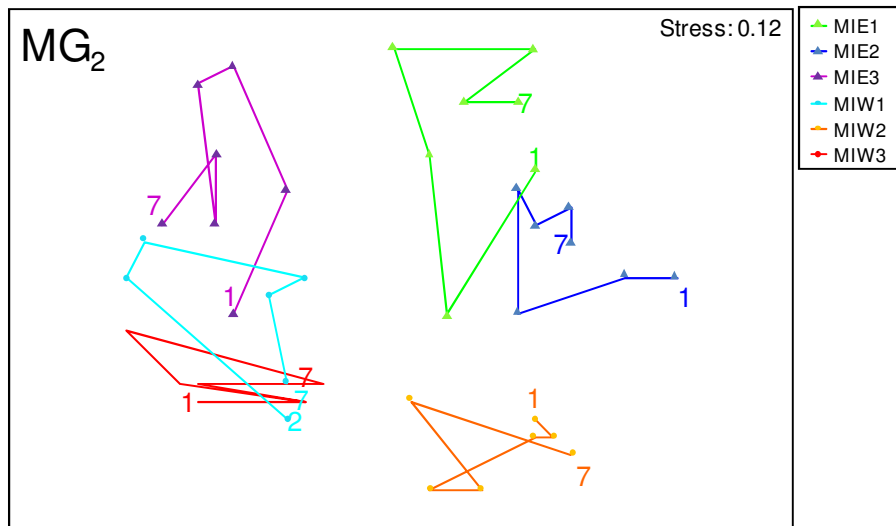
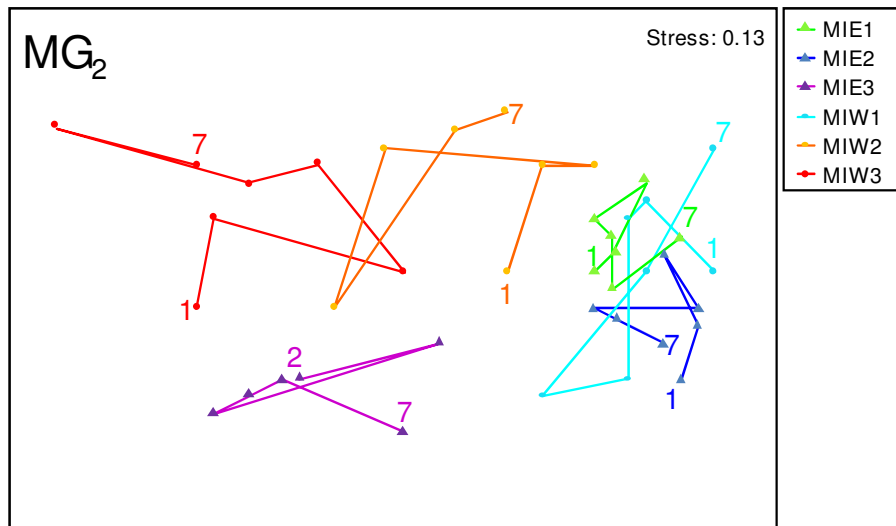


Figure 7

An example MDS plot of the intertidal cover data, using MG_2 = Modified Gower base-2 dissimilarity measure (averaged using $n = 5-7$ quadrats for each point). Numbers indicate the year of sampling, i.e. 1 = 2001, 7 = 2007.



4.2.2 Changes in size frequency distributions

The size distributions of *Crassostrea* and *Sypharochiton* showed evidence of changes over time upon ($p < 0.05$, Table 3). The change in *Crassostrea* (Table 3) can be attributed to a change in sampling methodology between 2001 and later years. More *Crassostrea* were measured in 2001 (due to the sampling method), but the size distribution of *Crassostrea* sizes has been stable. The size distribution of *Sypharochiton* was relatively unstable at one site (MIE1), however there is no clear trend in the size distributions. None of the other measured taxa exhibited any changes over time in the size frequency distribution (see Appendix F).

Table 3

PERMANOVA results examining the effect of site and time on Bray-Curtis dissimilarities of $\ln(x+1)$ transformed intertidal size frequency data. Asterisks indicate where the $\ln(x+1)$ transformed and presence/absence transformed data differ in their significance.

| Taxa | P value | |
|-------------------------------------|---------|----------|
| | Site | Time |
| <i>Crassostrea gigas</i> | 0.765 | 0.001 |
| <i>Turbo smaragdus</i> | 0.001 | 0.169 |
| <i>Melagraphia aethiops</i> | 0.001 | 0.094** |
| <i>Sypharochiton pelliserpentis</i> | 0.617 | 0.001*** |
| <i>Xenostrobus pulex</i> | 0.002 | 0.212 |

* presence/absence transformation $p = 0.057$

** presence/absence transformation $p = 0.043$

*** presence/absence transformation $p = 0.27$

4.2.3 Tracking univariate variables through time

The seven most abundant intertidal species at Meola Reef constituted 95.5% of all counted intertidal individuals⁶. Examining the temporal trends of these species should give a good representation of the major trends at Meola Reef.

The most abundant species counted at the intertidal Meola sites were:

1. *Anthopleura aureoradiata*
2. *Turbo smaragdus*
3. *Sypharochiton pelliserpentis*
4. *Xenostrobus pulex*
5. *Melagraphia aethiops*

⁶ Note: the Pacific oyster (*Crassostrea gigas*) is the dominant macrofaunal species at Meola, but abundance of this species is estimated through percentage cover rather than direct counts.

6. *Zeacumantus lutulentus*

7. *Onchidella nigricans*

Change in abundance (count data)

The results from the univariate GLMM analyses examining changes over time are summarised in Table 4 and Table 5. Confidence intervals in count variables are expressed as a percentage change in abundance per year (i.e. a multiplicative [proportional] change).

Changes in abundance over time for species above (as well as total abundance, site diversity and evenness) are shown in Figure 8 - 20. Each figure shows a left-hand lattice plot with points corresponding to quadrat abundances. A black least squares regression line and a red local regression smoother were fit to each site-panel. The right plot averages abundance across: (i) the entire reef [thick black line], (ii) each eastern site [red lines] and (iii) each western site [blue lines]. Distance along the reef is shown by the labels: 1 [southern reef] – 3 [northern reef]. Note: The right plot uses a different y-axis scale.

Figure 8

Change in total abundance of intertidal organisms in quadrats at Meola Reef. A black least squares (LS) regression line and a red local regression smoother are fitted to each site panel. The right hand graph shows the changes in site and reef averages over time (black = reef average, blue = western sites; red = eastern sites).

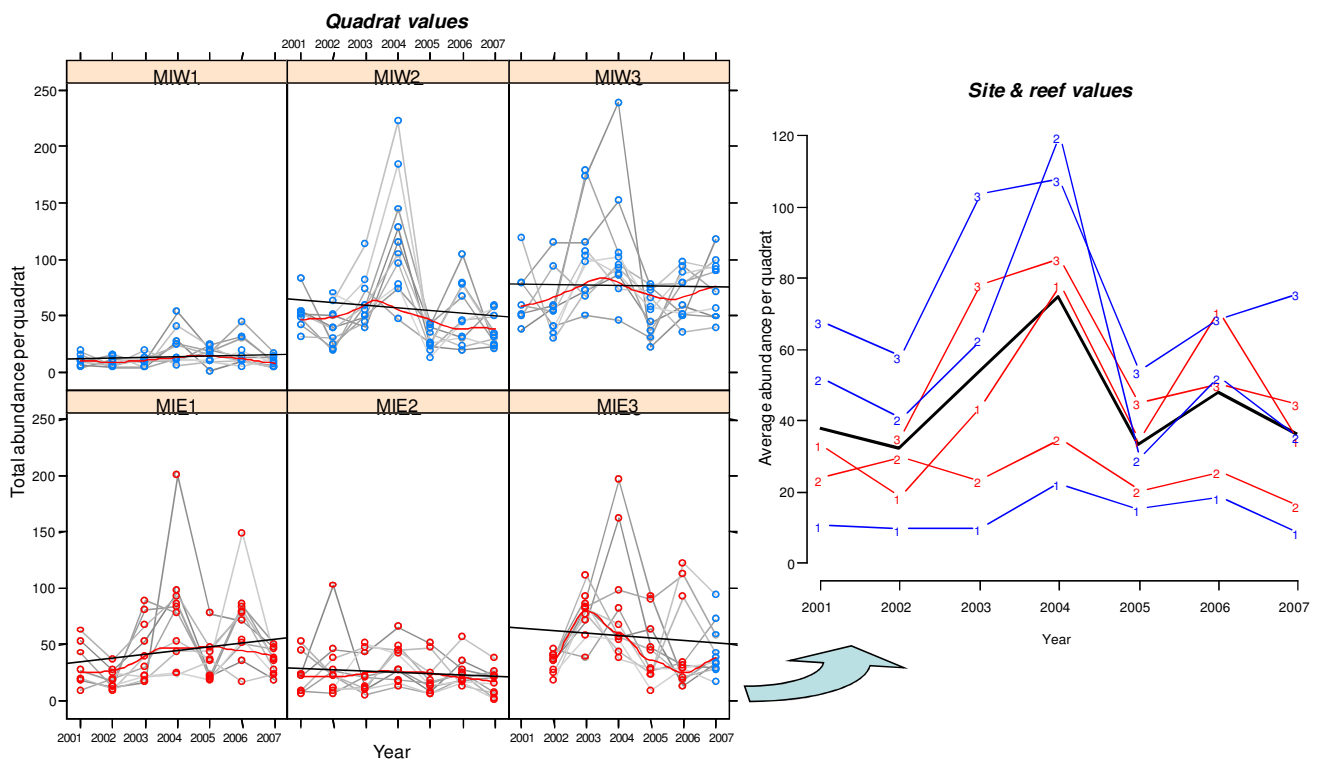


Figure 9

Site level evenness index and sampled diversity plotted vs time for count data. Coloured lines show the change in site and reef averages over time (black = reef average, blue = western sites; Red = eastern sites),

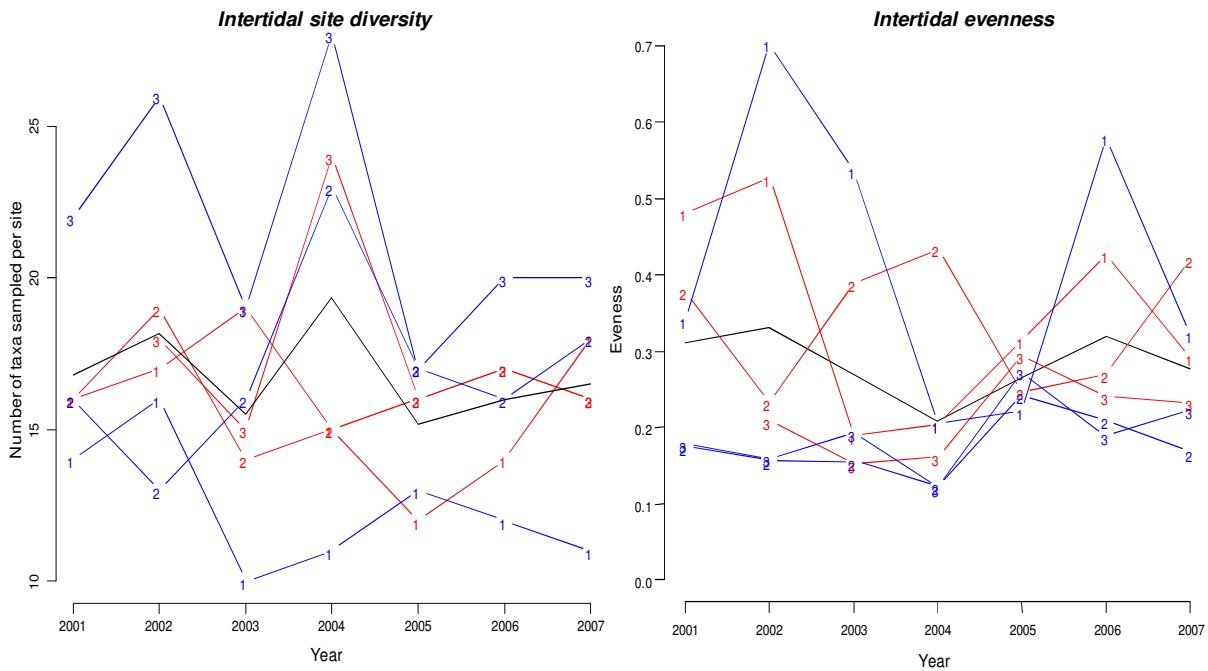


Figure 10

Anthopleura aureoradiata – figure details are explained in Figure 8.

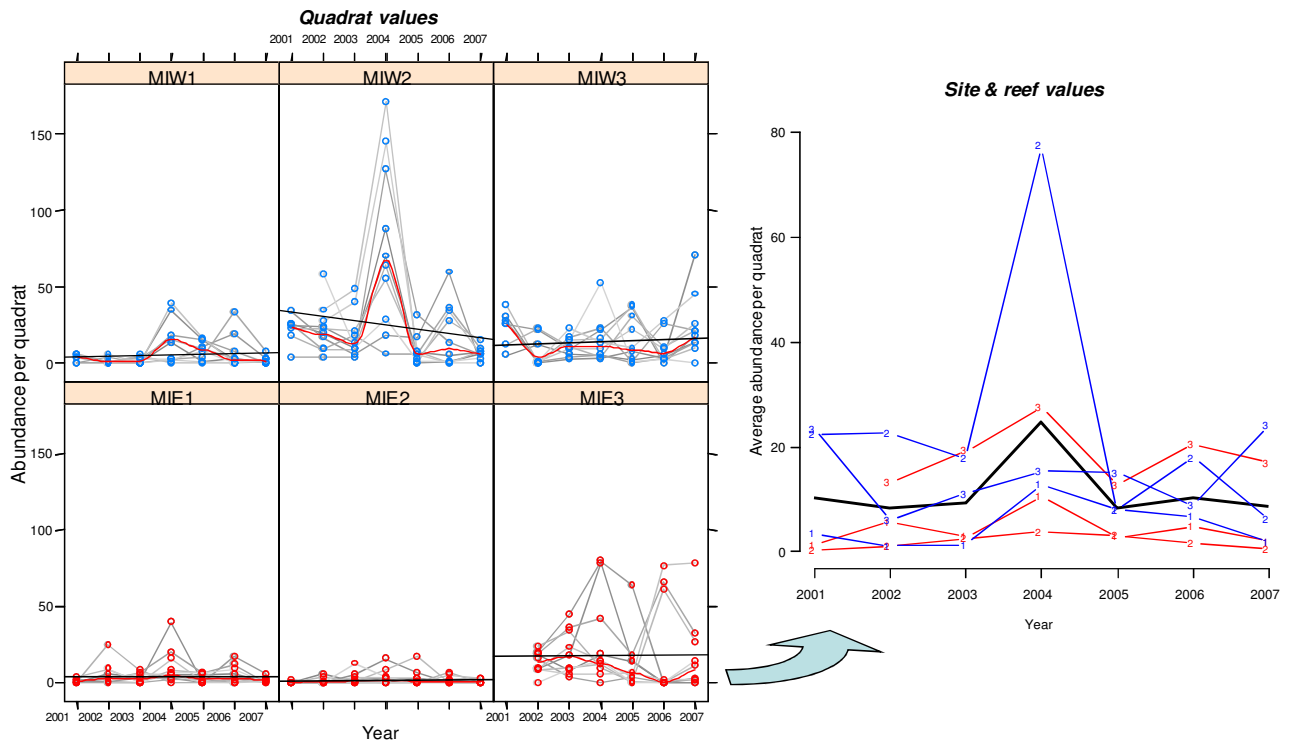


Figure 11
Turbo smaragdus – figure details are explained in Figure 8.

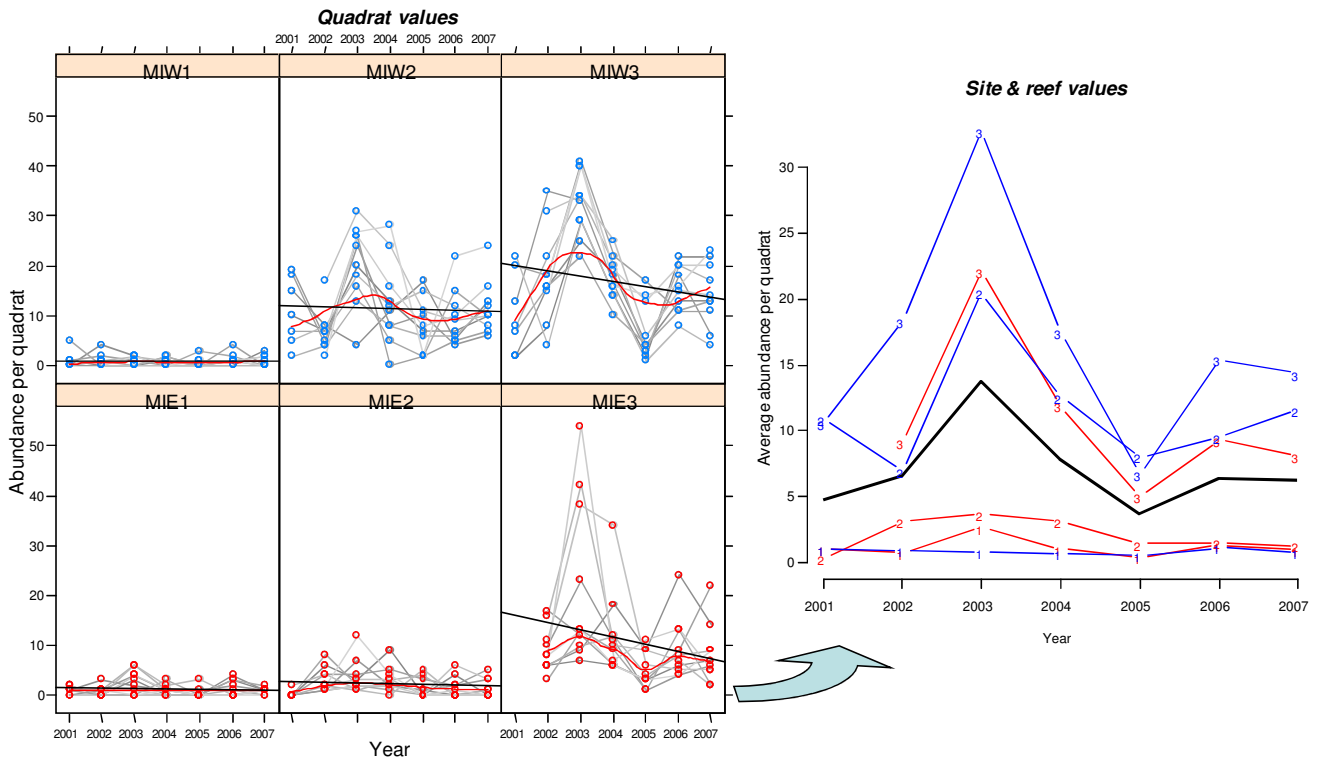


Figure 12
Sypharochiton pelliserpentis – figure details are explained in Figure 8.

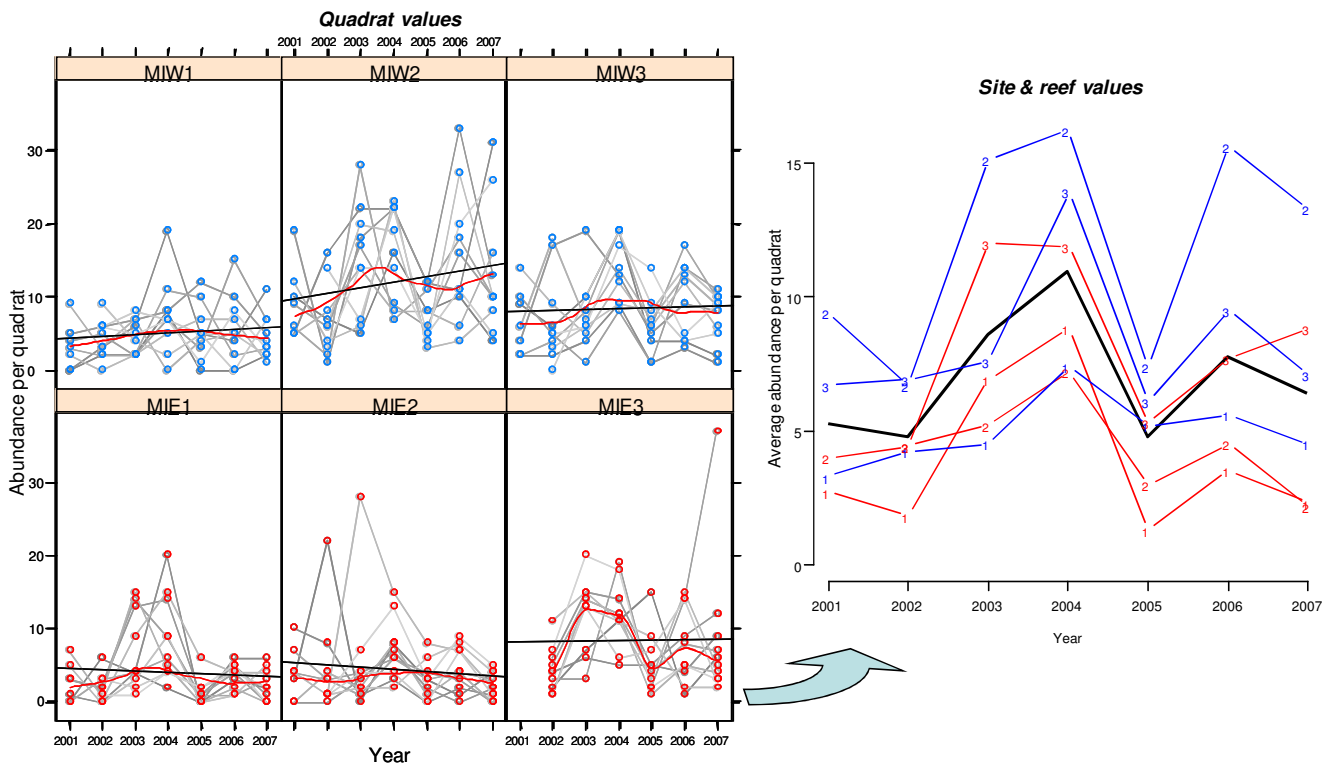


Figure 13

Xenostrobus pulex – figure details are explained in Figure 8.

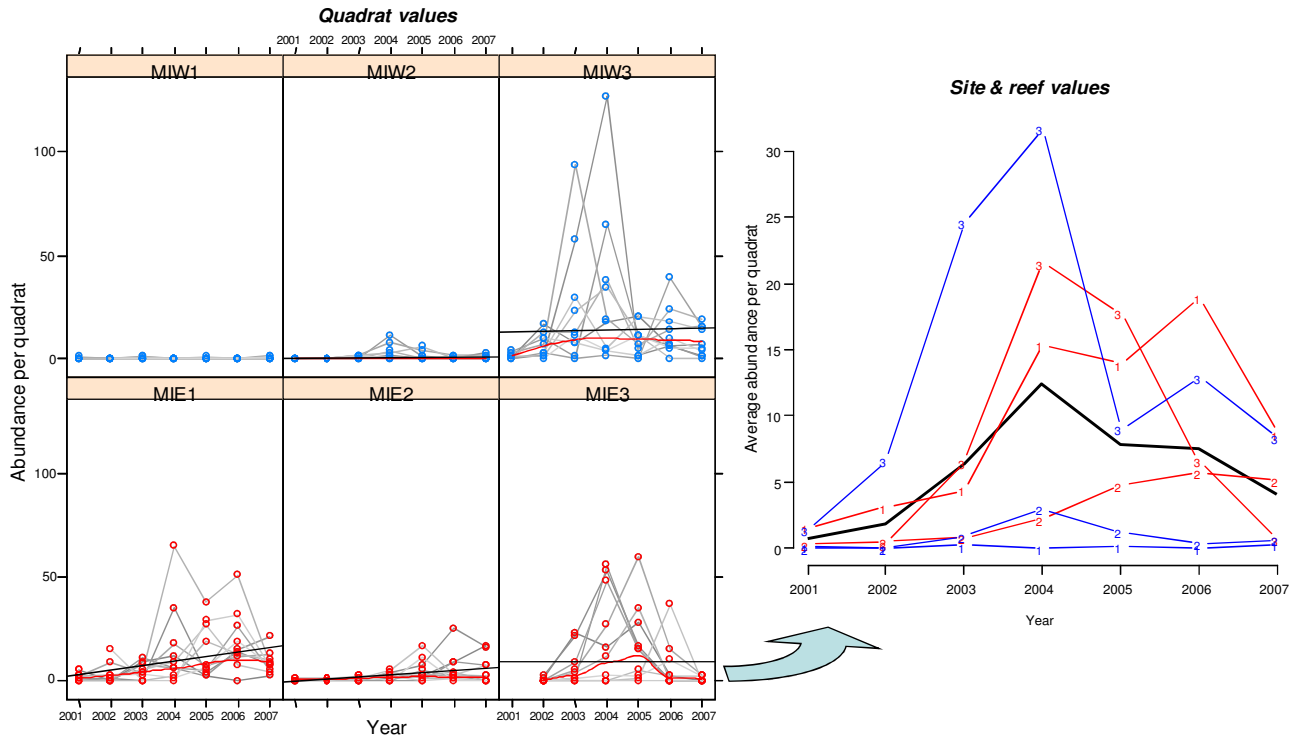


Figure 14

Melagraphia aethiops – figure details are explained in Figure 8.

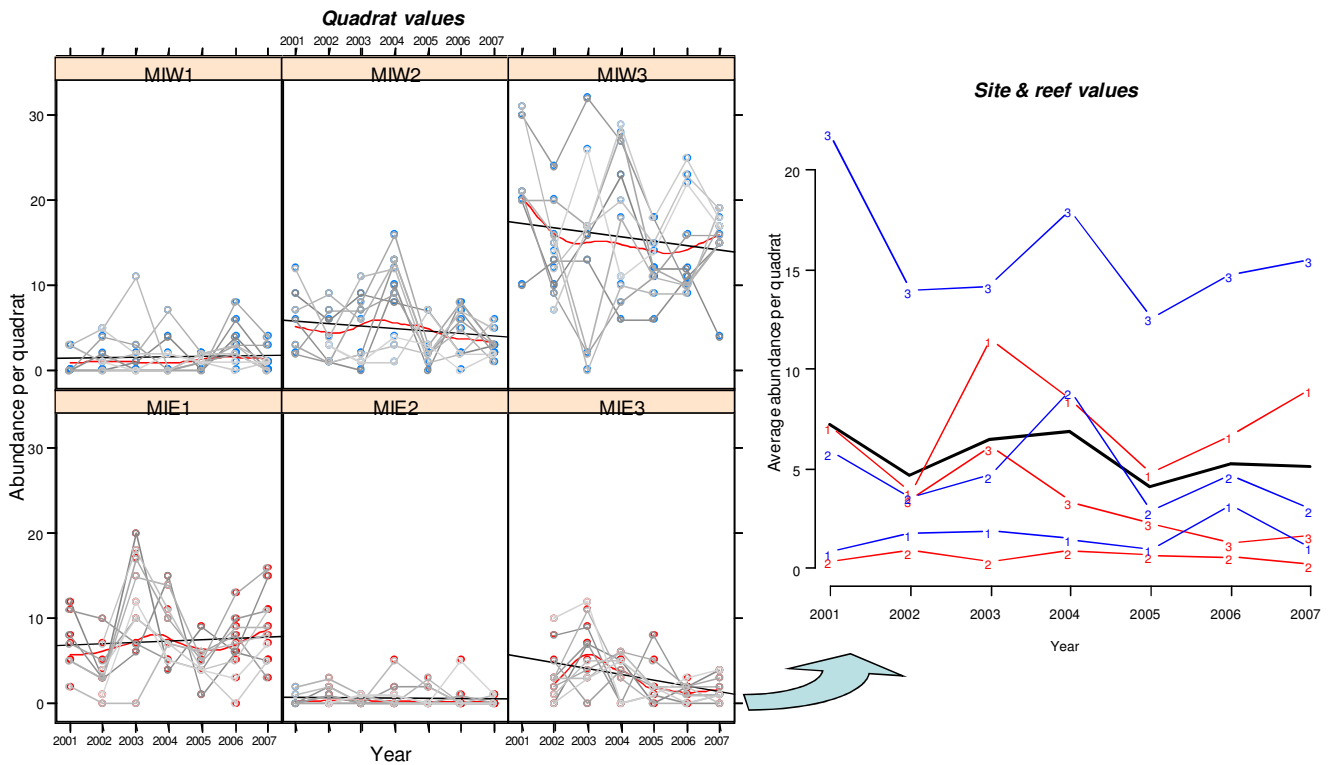


Figure 15

Zeacumantus lutulentus – figure details are explained in Figure 8.

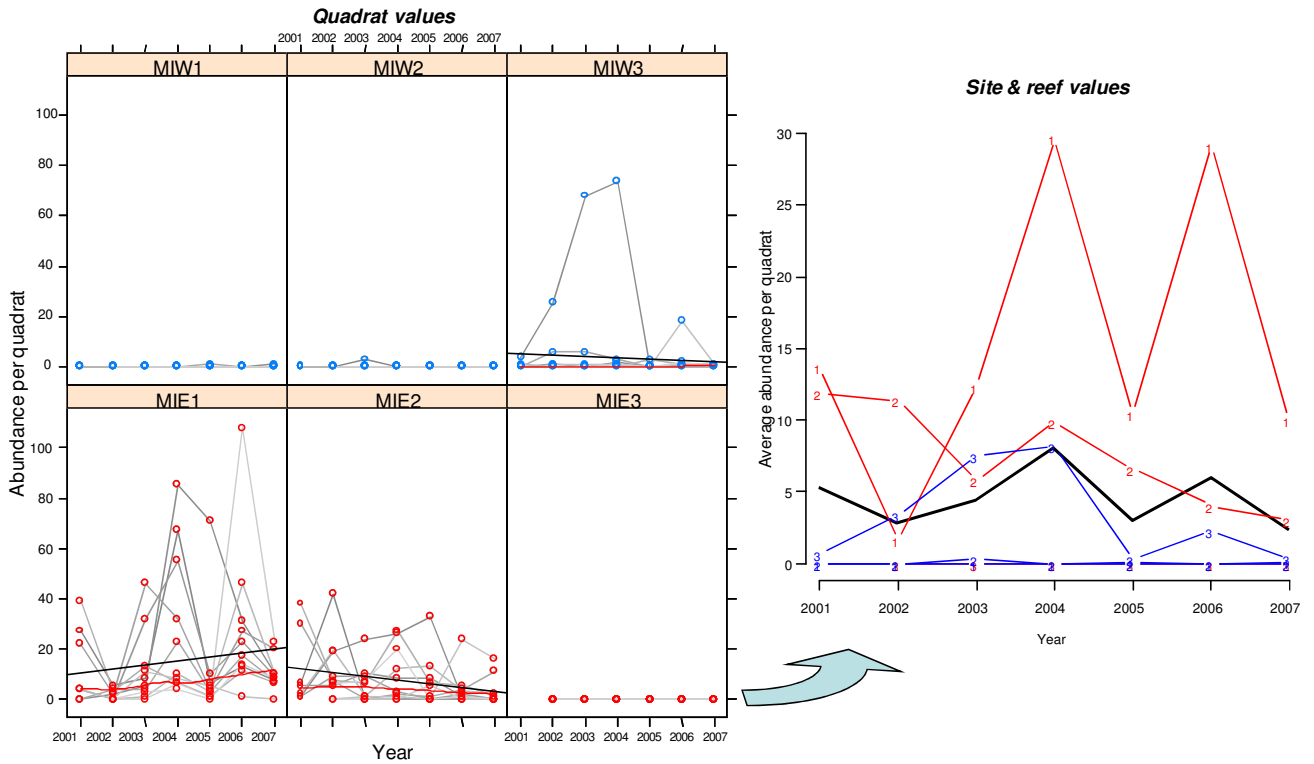


Figure 16

Onchidella nigricans – figure details are explained in Figure 8.

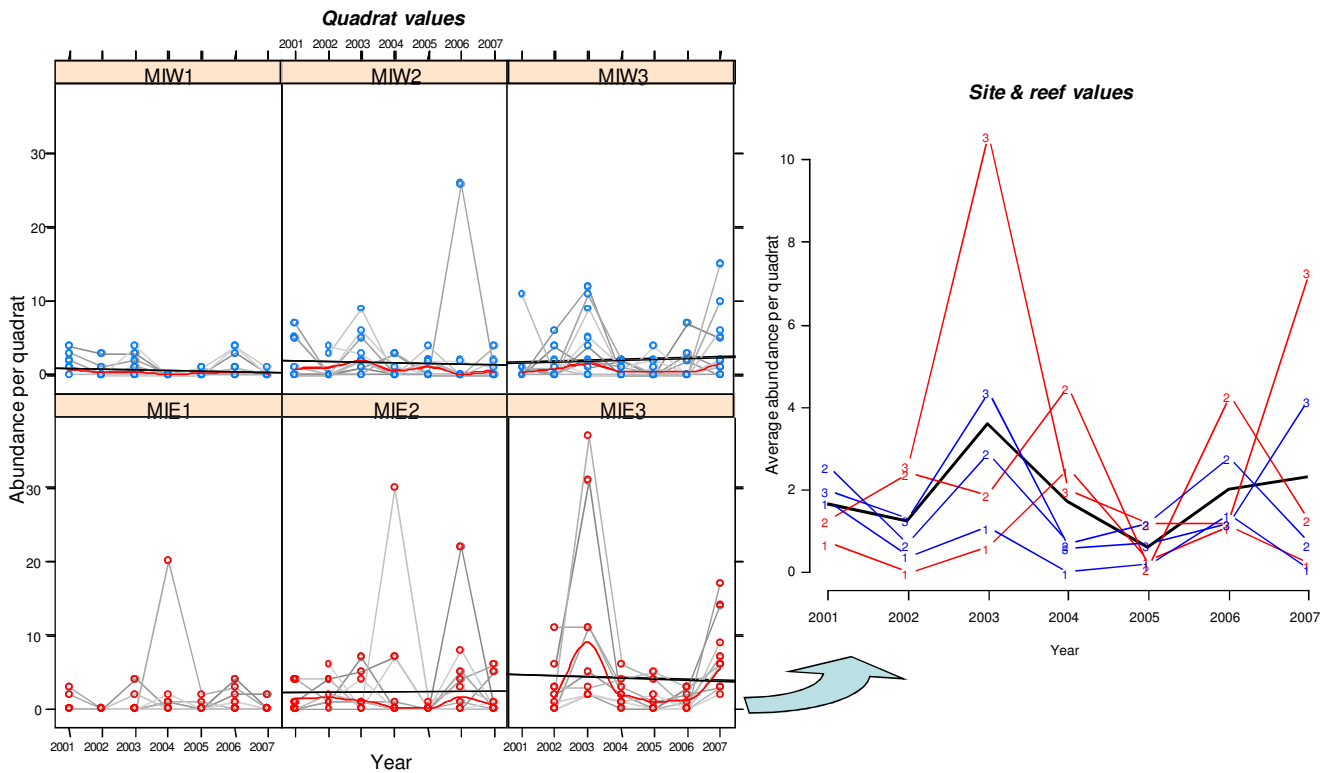


Table 4

Summary of the GLMM model results for (i) major species and (ii) univariate summary indices with intertidal count data. Significant interactions mean that effects are localised rather than reef-wide; the localised effects for those species are summarised in Table 5. Predictor variables in red show a negative relationship; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$. *st_ENSO* refers to the 'short-term ENSO' index variable.

| Species | Reef-wide significant variables | | | | | Significant interactions |
|-----------------------------------|--|---|----------------|--------------------|-------------|--|
| | Year | ENSO | st_ENSO | Distance | Side | |
| Anthopleura | | | 11 - 25% | | | |
| Turbo | -(0 - 10)% | 56 - 115% | | Sites 3 > 1 | | |
| Sypharochiton | | 11 - 29% | | | | |
| Xenostrobus | | <see Table 5 for site specific effects> | | | | Year*Side*** Year*Distance*** (Side*Distance***) |
| Melagraphia | -(0 - 29)% | | | | | |
| Zeacumantus | | | 45 - 70% | | | |
| Onchidella | | | | Sites 2 & 3 > 1 | | |
| Site Diversity⁷ | | 0.06 - 0.41 | | | | |
| Evenness (count) | | | | 1 > 2 & 3 | | |
| Total abundance | | <see Table 5 for site specific effects> | | | | Year*Side*** Year*Distance*** (Side*Distance***) |

Change in abundance (count data)

The total abundance was higher, on average, at northern sites. The only intertidal site that showed a significant linear change was site MIE1, which showed a significant increase ($p < 0.05$). The change primarily occurred from 2001-2004, and appears to have stabilised since 2004. It should also be noted that although there was no statistically linear change in site MIE3, the total abundance at this site was the lowest around 2005-2006 and has exhibited a small recovery since then.

There is no evidence of reef-wide changes over time in either diversity or evenness indices in either the count or cover intertidal data.

Anthopleura was found at a comparatively high average density (typically greater than 15 per quadrat) at sites MIW2, MIW3 and MIE3. There is no evidence of a (linear) trend in *Anthopleura* abundance over time. However, there was an obvious, but short-term, spike in its abundance at most MIW2 quadrats (no other sites showed an unusual increase).

⁷Site diversity & evenness were calculated using a GLMM with identity link and Normal errors. Listed effects for these rows are therefore additive, e.g. we estimate that Diversity has increased between 0.06 - 0.4 species /year.

Turbo was found in moderate density (typically greater than 10 per quadrat) at the most northern sites. *Turbo* exhibited a statistically significant but small decline over time across Meola (we estimate a decline in abundance of up to 10% per year across the reef). The northern sites (MIE3 and MIW3) had significantly greater abundances than the southern sites (MIE1 and MIW1) ($p < 0.01$). It should be noted that the site with the greatest abundance (MIW3) appears to have a cyclical pattern and 2006 and 2007 have shown modest increases in abundance. A longer time series is required to determine the nature of the cyclical pattern. There was no evidence of a temporal trend in *Sypharochiton* abundance at the intertidal sites in Meola Reef. Site abundance of *Sypharochiton* generally increased until 2004 and subsequently either stable or in decline.

Xenostrobus was found in moderate densities at most sites except MIW1 (where few individuals were found), and two quadrats at MIW3 had high densities (around 100/quadrat) in 2003 and 2004. There is evidence that *Xenostrobus* abundance is increasing at sites MIE1 and MIE2, which historically had very low abundance. There is considerable uncertainty in the estimates of change at both sites - we estimate the increase at site MIE1 is between 4 - 99% per year and between 26-86% per year at site MIE2. Although the abundance at MIE3 increased in density from almost zero in 2002 to more than 20 per quadrat in 2004, it has since declined at that site back to almost zero.

Melagraphia was found in moderate densities at site MIW3 (15-20 per quadrat). There is evidence that reef-wide *Melagraphia* abundance has been in decline since 2001. We estimate that its abundance is dropping by up to 29% per year. This drop was principally driven by the most northern sites (i.e. sites MIE3 and MIW3).

Zeacumantus was found in moderate-high densities (5-25 per quadrat) at the southern reef sites on the eastern sites (MIE1 and MIE2), and occasionally in one quadrat in the outer reef site at MIW3. *Zeacumantus* densities appear to be relatively stable at these sites.

Onchidella was found in modest densities at all sites (typically between 0-10 per quadrat), with quadrats at more northern sites occasionally containing more than 30 individuals. There was no evidence of a long-term linear trend in *Onchidella* abundance in any of the monitored sites (or across the reef as a whole). However, there was some evidence of a recent increase in abundance levels at site MIE3. Continued monitoring is required to determine if this increase is transitory.

Table 5

Localised effects summarizing the GLMM model results for those major species with count data. *st_ENSO* refers to the short-term ENSO index variable.

| Species | Location | Significant variables | | |
|------------------------|-------------|-----------------------|------|---------|
| | | Year | ENSO | st_ENSO |
| <i>Xenostrobus</i> | <i>MIW1</i> | | | |
| | <i>MIW2</i> | | | |
| | <i>MIW3</i> | | | 44-67% |
| | <i>MIE1</i> | 5-99% | | 11-87% |
| | <i>MIE2</i> | 26-86% | | |
| | <i>MIE3</i> | | | |
| <i>Total abundance</i> | <i>MIW1</i> | | | 7-81% |
| | <i>MIW2</i> | | | 4-72% |
| | <i>MIW3</i> | | | |
| | <i>MIE1</i> | 3-25% | | 11-87% |
| | <i>MIE2</i> | | | |
| | <i>MIE3</i> | | | |

Change in percentage cover

Changes in percentage cover over time (as well as total abundance and site evenness) are shown in Figure 17 - 24.

The results from the univariate GLMM analyses examining percentage cover changes over time are summarised in Table 6 and Table 7. Confidence intervals in cover variables are expressed as an additive change in percentage cover per year.

Figure 17

Intertidal evenness - %cover data. Coloured lines show the change in site and reef averages over time (black = reef average, blue = western sites; Red = eastern sites).

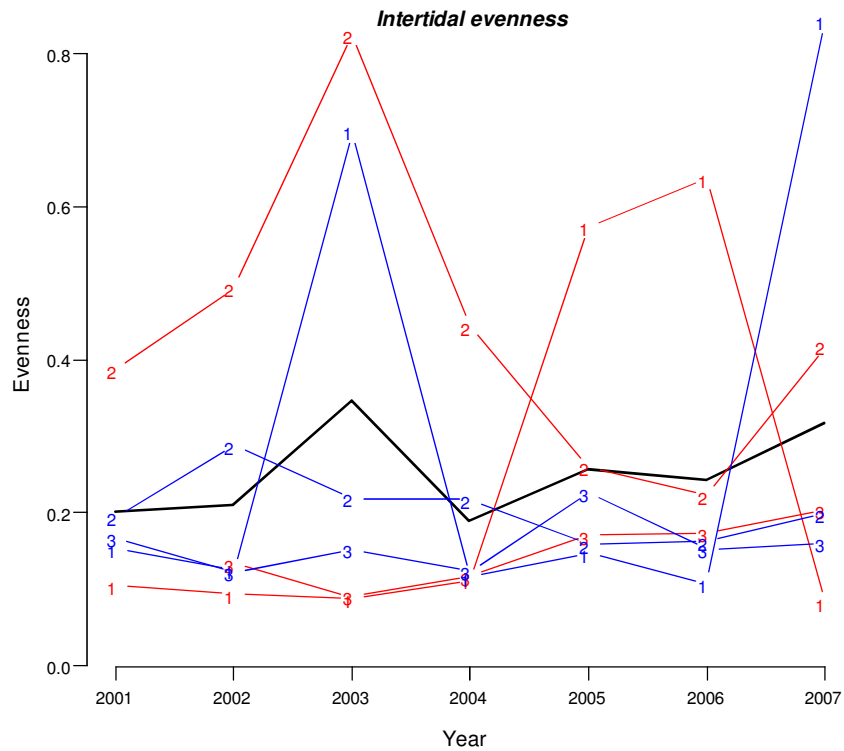


Figure 18

Percentage cover of sediment – figure details are explained in Figure 8.

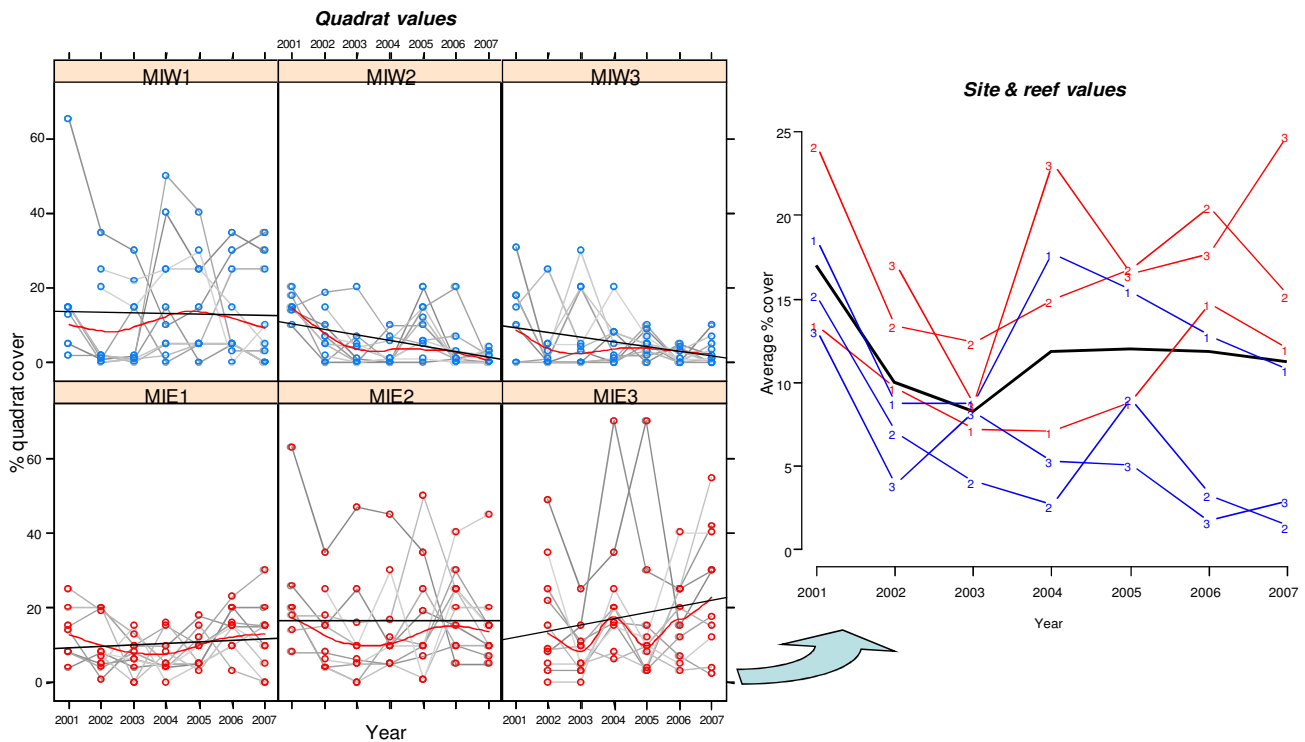


Figure 19

Percentage cover of *Crassostrea gigas* – figure details are explained in Figure 8.

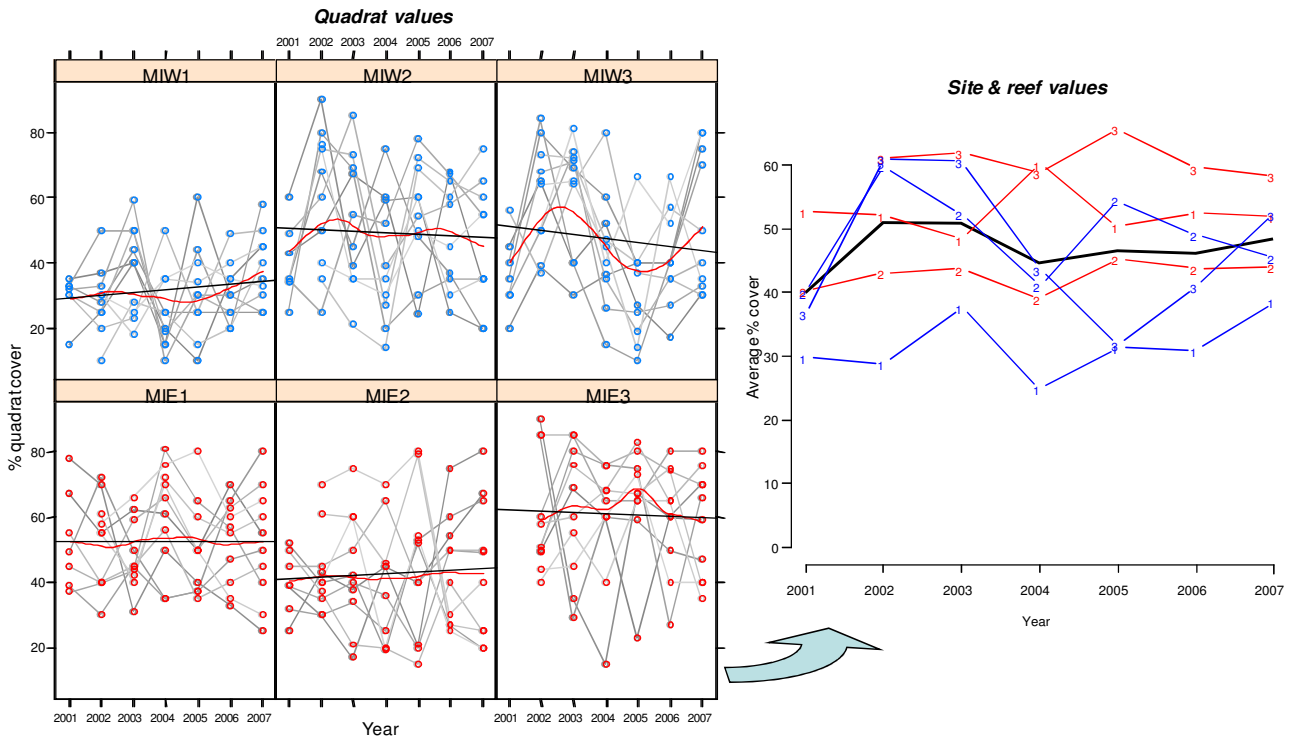


Figure 20

Percentage cover of barnacles – figure details are explained in Figure 8.

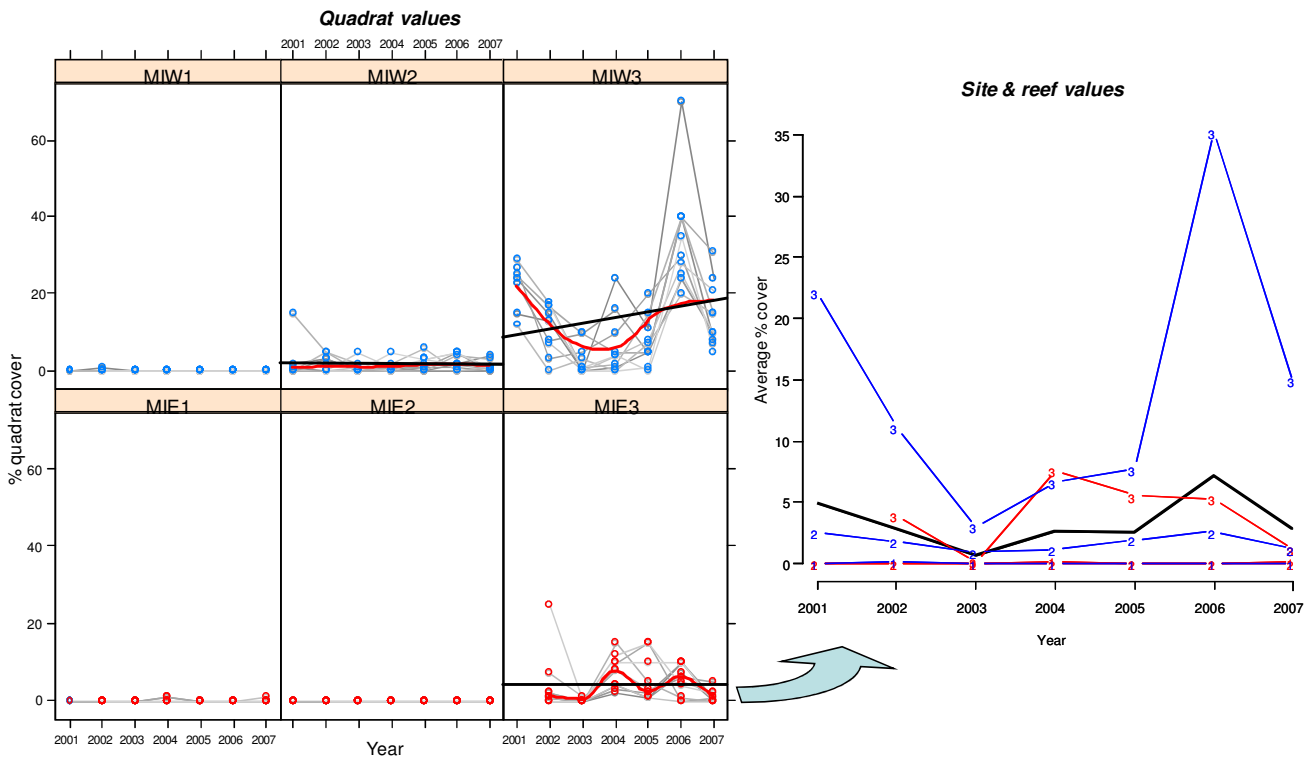


Table 6

Summary of the GLMM model results for percentage cover variables. Significant interactions mean that reef-wide effects cannot be integrated; the localised effects for those species are summarised in Table 7. Predictor variables in red show a negative relationship; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$. *st_ENSO* refers to the 'short-term ENSO' index variable.

| Variable | Reef-wide significant variables | | | | | Significant interactions |
|----------------------------------|---|------|---------|----------|------|--------------------------|
| | Year | ENSO | st_ENSO | Distance | Side | |
| %Sediment | <see Table 7 for site specific effects> | | | | | <i>Year*Side***</i> |
| %Crassostrea | | | | | | |
| %Barnacles | <see Table 7 for site specific effects> | | | | | |
| Evenness (cover data) | | | | | | |

Table 7

Localised effects summarizing the GLMM model results for those major species with percentage cover data. Predictor variables in red show a negative relationship. *st_ENSO* refers to the short-term ENSO index variable.

| Variable | Location | Significant effects | | |
|-------------------|-----------|---------------------|---------------|---------|
| | | Year | ENSO | st_ENSO |
| %Sediment | East side | | -(4.9%-18.2%) | |
| | West side | -(0.3-1.5%) | | |
| %Barnacles | MIW2 | | | |
| | MIW3 | 0-2.57% | 20%-39% | |
| | MIE3 | | | |

Cover data

There was no evidence of any change in evenness in the composition of those species measured by percentage cover.

There was strong evidence of a decline in percentage cover of sediment on the west side of (intertidal) Meola ($p=0.003$). There was some evidence that the change over time has been non-linear ($p=0.028$), but the non-linearity is small enough to be well modelled as a simple linear effect.

Crassostrea was ubiquitous at the intertidal Meola sites, and there was no evidence of any change in its percentage cover at the reef. In contrast, barnacles were only found at the more northern sites (i.e. MIW2, MIW3 and MIE3) and have increased by up to 3% per year (at these sites) since the programme's inception. Barnacles were most abundant at MIW3, and this site showed a cyclical pattern (even after accounting for ENSO). The shortness of the time series means that the apparent increase in cover may be a part of a cycle rather than a real long-term change.

4.3 Relationship between temporal change and environmental factors

4.3.1 Multivariate analyses

The count and cover data both showed a significant relationship between sediment cover and community structure (Table 8). No significant correlation was seen between the Multivariate El Niño Indices and either the count or cover data. The fact that a relationship was seen between sediment cover and ln transformed, but not presence/absence transformed data, suggests abundance rather than composition based change with changing sediment cover. The reverse case for cover variables suggests that changes in sediment cover affect the composition of other cover classes present. CAP plots for both count and cover data consistently showed relatively low levels of sediment cover at sites MIW1 and MIW2 and relatively high levels of sediment cover at sites MIE2 and MIE3 (Figure 21).

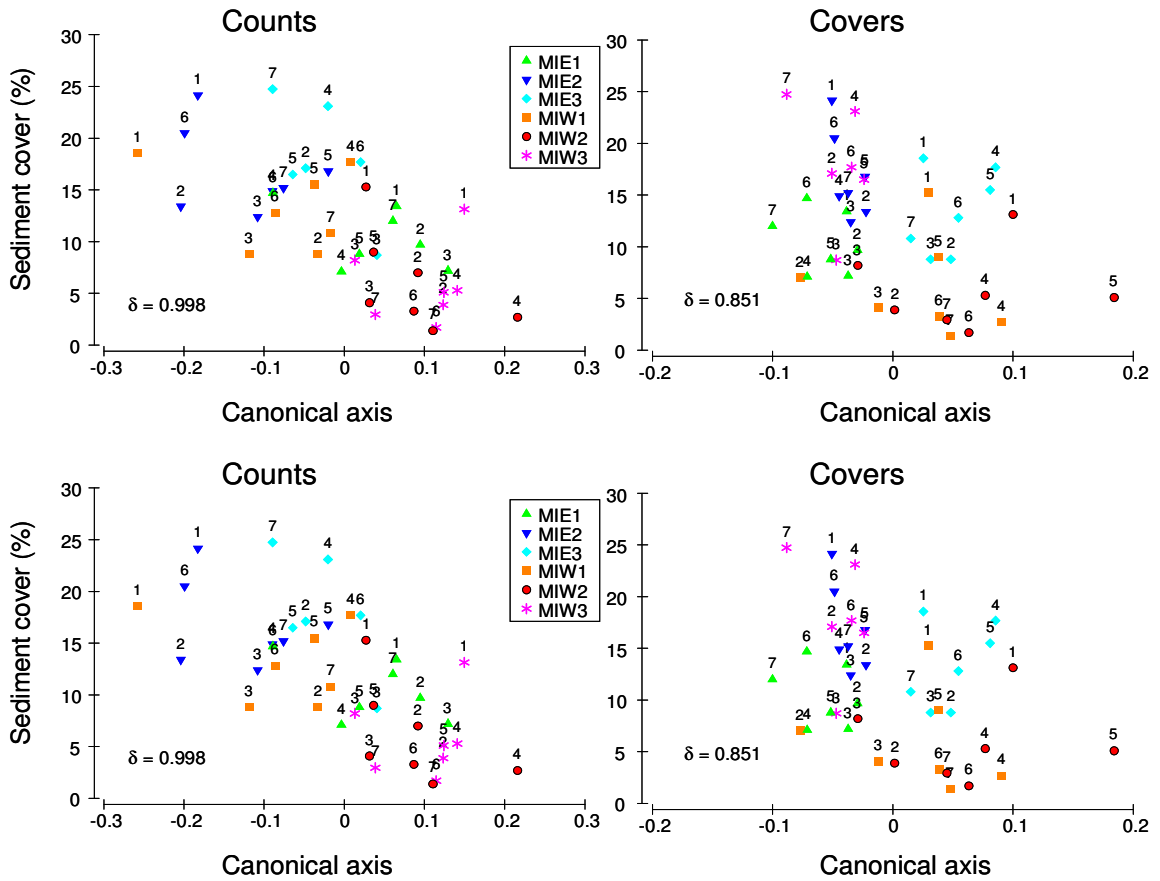
Table 8

Results of DISTLM analyses relating environmental variables to Bray-Curtis dissimilarities of intertidal count and cover data. Environmental variables used were: MEI short = calculated over the month prior to sampling, MEI medium = calculated over the year prior to sampling and % cover = the average percentage cover of sediments at each year by site combination. Note: ln = natural log (x); p/a = presence/absence.

| Response | Trans | Factor | P | % var. |
|------------|-------|-------------|-------|--------|
| Count data | ln | % sed cover | 0.028 | 6.9 |
| Count data | p/a | N/A | | |
| Count data | ln | N/A | | |
| Count data | p/a | % sed cover | 0.016 | 10.6 |

Figure 21

CAP analysis graphics showing the relationship CAP axis 1 from the Bray-Curtis dissimilarities of ln transformed raw count (excluding *Crassostrea gigas*) or cover data (excluding sediment cover) and sediment cover (all data averaged per year by site, $n = 5-7$). Symbols indicate sites and numbers indicate years.



4.3.2 Univariate analyses

4.3.2.1 Percentage cover of sediment

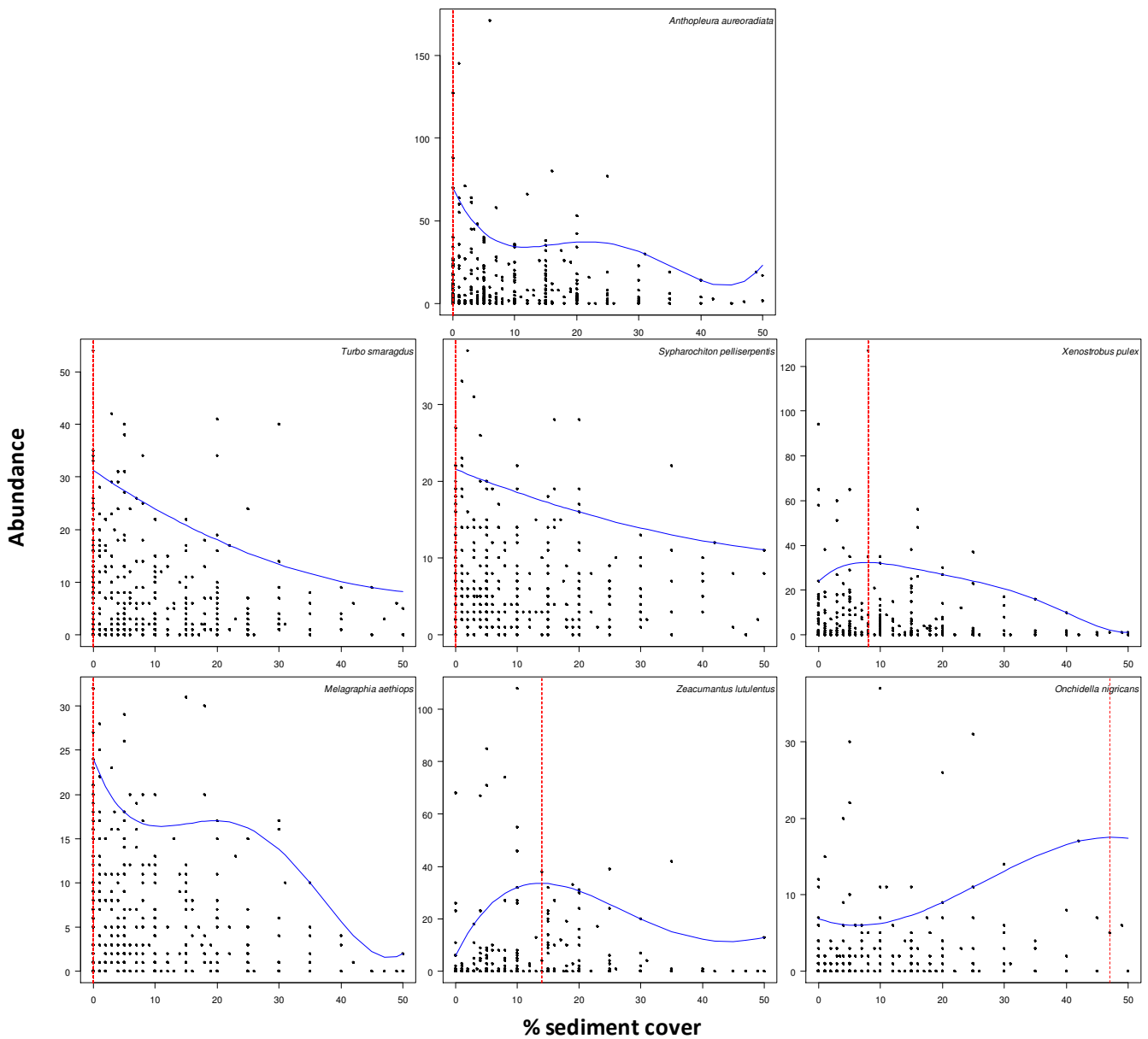
Is percentage cover of sediment in each quadrat an important variable in determining the abundance of the dominant macrofauna at Meola Reef? If so, it is important to characterise how species change along this gradient.

Scatterplots of the most prominent species show that in many cases the relationship is non-linear, and in some cases is modal rather than monotonic (e.g. *Xenostrobus*, *Zeacumantus* in Figure 22). The modal relationship motivated the use of polynomial regression splines on the 95th percentile (see Section 3.4.3.2). This type of model forms an 'envelope' that describes where the organism is likely to be found along the environmental gradient.

Although up to 70% sediment was found in some quadrats, we limited the analysis to between 0 to 50% cover because this range of values had sufficient data points to give reasonable support to any model. Relationships were one of: (i) decreasing with increasing sediment cover (*Anthopleura*, *Turbo*, *Sypharochiton*, *Melagraphia*), (ii) unimodal with a relatively broad tolerance (e.g. *Xenostrobus* and *Zeacumantus*), or (iii) increasing with increasing sediment cover (*Onchidella*).

Figure 22

Relationship between individual intertidal taxa (as indicated) and percentage sediment cover. The polynomial regression spline model for the 95th percentile is shown in blue, with the maximum from the model (interpretable as an estimated optimum for the taxon) indicated by a red line. Note: the regression-spline fit only used percentage sediment cover values $\leq 50\%$, only three quadrats had observations $>50\%$.



4.3.2.2 ENSO effects

There is evidence that ENSO influences the abundance of some intertidal organisms and sediment cover at Meola (see Table 4). For example, Figure 23 (graph A) shows the predicted values for barnacles at site MIW3 from a model that uses only ENSO and a linear trend as the explanatory variables,

$$\text{i.e. } E(\text{Barnacle abundance at MIW3}) \sim b_0 + b_1(\text{Year}) + b_2(\text{ENSO})$$

Similarly, There is also strong evidence that ENSO has affected the percentage sediment cover on the east side of Meola ($p < 0.001$),

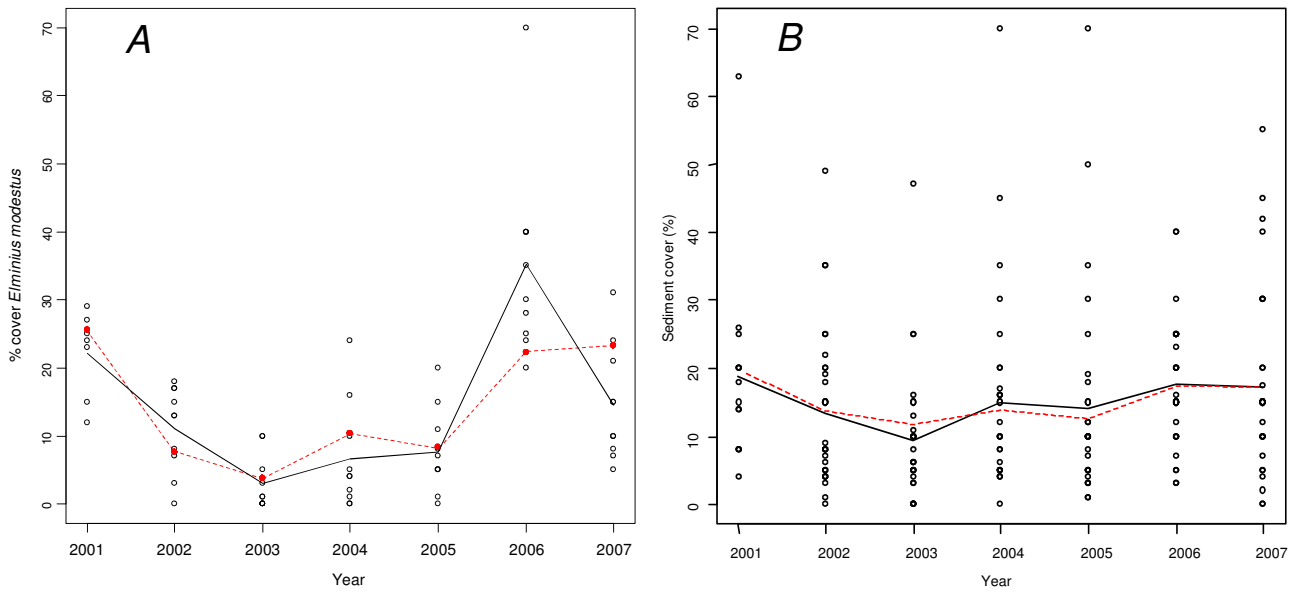
$$\text{i.e. } E(\% \text{Sediment cover on the East side of Meola}) \sim b_0 + b_1(\text{ENSO}) .$$

Although the model tracks the average value of these variables relatively well, we advise caution when considering the current model's future predictive power. They are, after all, models that are only based on a time series of seven points. Any short time series may, by chance, be well approximated by a polynomial-type variable (such as ENSO). A longer time series (or at the least, a time series with many more measured points) is required before the real predictive power of ENSO will become more apparent.

We estimate that a unit increase in the short-term MEI (i.e. over the three months prior to sampling) increases the total abundance at sites MIW1, MIW2 and MIE1 by between 4 – 87%. There is also evidence that a short-term increase in MEI appears to correlate with reef-wide increases in *Anthopleura* and *Zeacumantus* as well as an increase in *Xenostrobus* at MIE2 and MIW3.

Figure 23

Some examples of using ENSO to predict percentage cover (graph A: barnacles at site MIW3, graph B: sediment on the eastern side of Meola Reef). Points indicate the sample quadrat values; solid black lines track the actual average yearly value of the data and the dashed red line shows the predicted value. In graph A, the explanatory variables of the model were ENSO and a linear trend; graph B used only ENSO as an explanatory variable.



5 Subtidal Results

5.1 Characterisation of the subtidal Meola Reef sites

Subtidal surveys of Meola Reef from 2001 to 2008 have recorded 43 taxa and 46 cover types (Appendix G, Section 8.7). The reef is visually dominated by canopy forming brown algae (predominantly *Carpophyllum flexuosum*, *Carpophyllum maschalocarpum* and *Ecklonia*). Underneath or adjacent to this canopy the substrate always consisted of >60% unconsolidated substrates (sand, mud, shell and gravel), crustose algae and coralline turfing algae. The remaining substrate was dominated by bare rock, sponges and solitary ascidians. The gastropod, *Turbo*, is the most numerous monitored organism on the reef. *Turbo* lives on the kelp and seafloor and comprises 97% of the gastropods and 76% of all measured fauna on the reef.

The initial PERMANOVA on both subtidal count and cover data suggested that generalisations about the subtidal communities of Meola Reef are not possible. A significant interaction occurred between side, distance and year for count data (Table 9). This means that for count data the temporal patterns differed depending upon both the side and the distance along the reef. Cover data showed significant two-way interactions between (i) side and year, and (ii) side and distance (Table 9). This means that the change in substrate cover over time and the effect of distance on substrate cover both depended on which side of the reef was examined.

The subtidal data showed more temporal and less spatial structuring than the intertidal data. The subtidal data showed a relatively large proportion of variance explained by the year factor (13-14%), relatively small amounts of variance explained by spatial factors and a relatively large proportion of unexplained variance (58-64%, Table 9). The relative strengths of these effects can be observed in the MDS plot of year by site centroids (Figure 24). The year effect can be seen, for example, by the location of all the 2008 samples in the top half of the plot and the 2004 samples in the bottom half of the plot. The relatively weak spatial effects can be seen by the large spread of sites in this diagram in contrast to those in Figure 4 and Figure 5. The MDS of cover data is harder to interpret as the three dimensional representation must be used; similar patterns are however evident in this diagram, e.g., 2003 samples seem tightly grouped while samples from the same site seem relatively widespread (Figure 25).

Characterising individual sites or years from the subtidal in terms of count or cover data is difficult. The only pattern obvious from examination of the count or cover variables was that bare rock was largely absent as a cover class in 2001, 2002 and 2008. The significant interactions involving the year factor for both count and cover variables (Table 9) in combination with the temporal variability seen in the MDS plots suggest that temporal patterns need to be examined at the individual site level.

Table 9

PERMANOVA results from analysis of the Bray-Curtis similarities of ln transformed subtidal count and cover data. %Var is the percentage of variation explained by each factor. Note: the same analysis on presence/absence transformed data showed a significant Si x Di effect ($p = 0.001$). Otherwise, results were equivalent.

| Factor | df | Pseudo-F | P(perms) | perms | % Var |
|-------------------|-----|----------|----------|-------|-------|
| Count data | | | | | |
| Year (Ye) | 7 | 9.5401 | 0.001 | 999 | 14.29 |
| Side (Si) | 1 | 21.211 | 0.001 | 999 | 4.54 |
| Distance (Di) | 2 | 5.1727 | 0.001 | 999 | 2.21 |
| Ye x Si | 7 | 4.2868 | 0.001 | 998 | 6.42 |
| Ye x Di | 14 | 2.5243 | 0.001 | 998 | 7.56 |
| Si x Di | 2 | 3.4702 | 0.001 | 997 | 1.49 |
| Ye x Si x Di | 13 | 1.3437 | 0.031 | 999 | 3.74 |
| Res | 275 | | | | 58.85 |
| Total | 321 | | | | |
| Count data | | | | | |
| Year (Ye) | 7 | 8.0355 | 0.001 | 997 | 13 |
| Side (Si) | 1 | 11.322 | 0.001 | 997 | 3 |
| Distance (Di) | 2 | 6.6256 | 0.001 | 999 | 3 |
| Ye x Si | 7 | 3.2796 | 0.001 | 997 | 5 |
| Ye x Di | 14 | 1.6928 | 0.001 | 998 | 5 |
| Si x Di | 2 | 1.6745 | 0.089 | 999 | 1 |
| Ye x Si x Di | 13 | 1.1987 | 0.126 | 998 | 4 |
| Res | 277 | | | | 64 |
| Total | 323 | | | | |

Figure 24

MDS plot of the subtidal count data, using Bray-Curtis dissimilarity on ln-transformed subtidal count data (averaged using $n = 5-7$ quadrats for each point). Numbers indicate the year of sampling, i.e. 1 = 2001, 8 = 2008. The biplot shows a unit circle (radius=1) with those taxa correlated with an MDS axis (Pearson correlations $>|0.5|$).

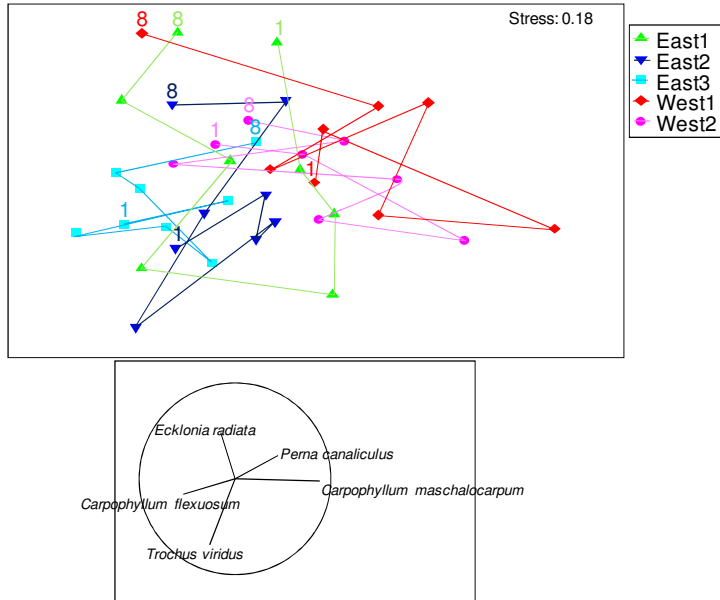
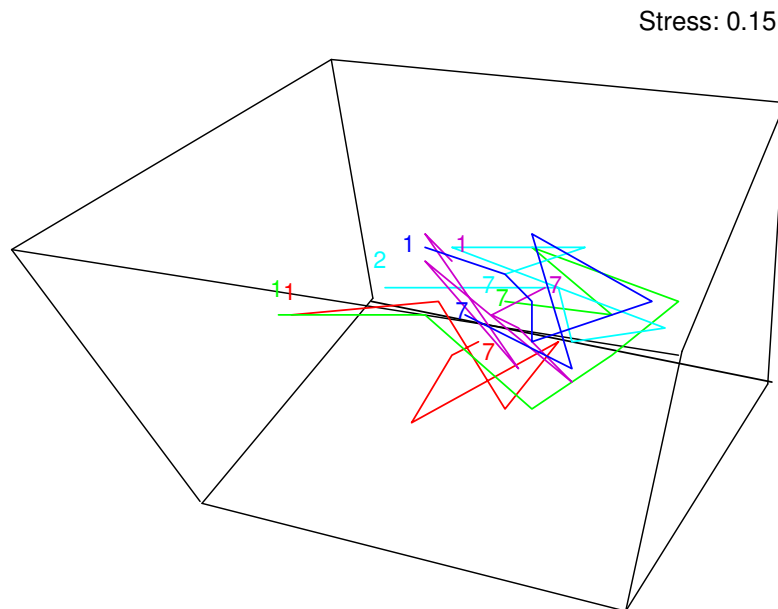


Figure 25

Three dimensional MDS plot of Bray-Curtis dissimilarities of ln transformed subtidal cover data. Numbers indicate year of sampling, i.e. 1=2001, 7= 2007, symbols indicate sites.(averaged using $n = 5-7$ for each point).



5.2 Examination of changes over time

5.2.1 Change in community composition

Dispersion of community composition did not differ significantly among sites over time for either the count or the cover data; this result was consistent independent of the similarity measure used (Table 10). This can be viewed graphically in Appendix H (Section 8.8) where the amount of dispersion of a site over time appears similar throughout the MDS plots.

Table 10

PERMDISP results investigating the effect of site upon multivariate dispersion

| Similarity measure | Cover <i>P</i> | Count <i>P</i> |
|------------------------------|-------------------|-------------------|
| Jaccard's | 0.54 | 0.81 |
| Manhattan | 0.22 | 0.49 |
| Modified Gower ₂ | 0.38 | 0.83 |
| Modified Gower ₁₀ | 0.88 | 0.58 |

Significant directional change was detected in the subtidal percent covers from Meola Reef at sites MSE1 and MSW1 (Table 11). The fact that these significant differences were not present under a presence/absence transformation suggests that these changes were driven by changes in relative abundances rather than composition. MDS plots of the year by site centroids do not, however, suggest directional change (Figure 24). Similarly, when the whole reef was examined marginally, non-significant results were seen for seriation for count and cover data (Table 11); yet MDS plots either did not suggest any directional change, or are dominated by one outlier in the case of the cover data (Appendix H Section 8.8).

In summary, there is no convincing evidence that individual subtidal sites are changing differently over time or that individual sites, or the reef as a whole, is changing linearly over time.

Table 11

Results of seriation test upon individual subtidal sites and subtidal Meola Reef as a whole. Analyses were completed using Bray-Curtis similarities of ln transformed data. * Presence/absence transformed data differed in their detection of significant differences ($p < 0.05$) for these results.

| Area | Cover | | Count | |
|------------|--------|--------|-------|--------|
| | P | Rho | P | Rho |
| MSE1 | 0.035* | 0.373 | 0.054 | 0.34 |
| MSE2 | 0.076 | 0.297 | 0.239 | 0.134 |
| MSE3 | 0.366 | 0.067 | 0.115 | 0.235 |
| MSW1 | 0.01* | 0.416 | 0.649 | -0.086 |
| MSW2 | 0.618 | -0.075 | 0.804 | 0.169 |
| Meola Reef | 0.066* | 0.312 | 0.071 | 0.292 |

5.2.2 Changes in size frequency distributions

There is evidence that the size distribution of algae *C. flexuosum* and *Ecklonia* and the gastropod *Turbo* have changed over time (Table 12). For *C. flexuosum* there was no significant difference in the size distribution between sites. Examination of yearly histograms showed that the changes in *C. flexuosum* were due to an influx of juveniles in 2003 at one site (MSE3) in conjunction with a lack of individuals at the western side. In addition, an unusually large number of large *C. flexuosum* plants were sampled in 2005. (Appendix F, Section 8.6).

The size frequency distributions of *Ecklonia* stipes have been unstable over time – but no clear directional change is evident. However, in 2008, unusually large numbers of small *Ecklonia* were found on the south-eastern sites (MSE1 and MSE2).

The size frequency distribution of *Turbo* significantly differed over time and between sites. These showed no consistent direction in size frequency change over time (Appendix F, Section 8.6). Although there has been little change in the sizes of *Turbo*, the population numbers increased between 2003 and 2005.

Table 12

PERMANOVA results examining the effect of site and time on Bray-Curtis dissimilarities of $\ln(x+1)$ transformed subtidal size frequency data. Asterisks indicate where the $\ln(x+1)$ transformed and presence/absence transformed data differ in their significance.

| Taxa | P value | |
|------------------------------------|---------------------|----------|
| | Site | Time |
| <i>Carpophyllum maschalocarpum</i> | 0.152 | 0.352 |
| <i>Carpophyllum flexuosum</i> | 0.117 | 0.017* |
| <i>Ecklonia radiata</i> | 0.015** | 0.002*** |
| <i>Turbo smaragdus</i> | 0.023* ⁴ | 0.002 |

*presence/absence transformation $P = 0.070$

**presence/absence transformation $P = 0.090$

***presence/absence transformation $P = 0.073$

*⁴presence/absence transformation $P = 0.077$

5.2.3 Tracking univariate variables through time

The five most abundant species counted at the subtidal Meola sites (constituting 92% of the total abundance) were:

1. *Turbo smaragdus*
2. *Carpophyllum maschalocarpum*
3. *Carpophyllum flexuosum*
4. Solitary ascidians
5. *Ecklonia radiata*

Table 13 and Table 14 show trends of over time for the major subtidal macro-biota and summary indices.

Note: Unless stated otherwise, confidence intervals in count variables are expressed as a percentage change in abundance per year (i.e. a multiplicative [proportional] change).

Table 13

Summary of the GLMM model results for the major counted species and univariate summary indices. Significant interactions mean that reef-wide effects are not sensible. Effects in red show a negative relationship; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$. *st_ENSO* refers to the 'short-term ENSO' index variable.

| <i>Species</i> | <i>Reef-wide significant effects</i> | | | | | <i>Significant interactions</i> |
|-----------------------------|--------------------------------------|---|----------------|-------------|---------------------------|---------------------------------|
| | <i>Year</i> | <i>ENSO</i> | <i>st_ENSO</i> | <i>Side</i> | <i>log(mid trap rate)</i> | |
| <i>Turbo</i> | Quadratic | -(9-16)% | | | | -(19-31)% |
| <i>C. maschalocarpum</i> | | | 206 - 224% | | | |
| <i>C. flexuosum</i> | | | 21-45% | | | -(16-37)% |
| Solitary ascidians | Quadratic | 19-42% | | | | -(25-55)% |
| <i>E. radiata</i> | | | -(14-44)% | | | |
| Total abundance | | | 45-60% | | | -(14-27)% |
| log(Algal biomass) | | <see Table 14 for Side specific results> | | | | Year*Side*** |
| Site diversity ⁸ | 0.03- 0.237 | 0.04-0.67 | | | | |
| Evenness | | | | | | |

Table 14

Summary of the GLMM model results for algal biomass.

| | <i>Location</i> | <i>Significant effects</i> | | | |
|--------------------|-----------------|----------------------------|-------------|----------------|-----------------------|
| | | <i>Year</i> | <i>ENSO</i> | <i>st_ENSO</i> | <i>log(trap rate)</i> |
| log(Algal biomass) | East | -(8-28)% | 11-73% | | -(30-83)% |
| | West | | | | |

⁸Site diversity, evenness and algal biomass were calculated using a GLMM with identity link and Normal errors. Listed effects for these rows are therefore additive, e.g. we estimate that diversity has increased between 0.03 – 0.24 species /year.

5.2.3.1 Changes in indices over time

Figure 29 show the change in total abundance, algal biomass, site diversity and evenness (count and cover) for the subtidal data.

Salient points are summarized below:

- There was no evidence that total abundance has changed over time.
- We estimate that, on the east side of Meola, algal biomass decreased by between 8 -28% per year (there was no evidence of a change on the west side).
- There was evidence of a small increase in subtidal site diversity (between 0 to 2 species over eight years).
- There was no evidence of any unidirectional change in subtidal evenness at Meola Reef.

Figure 26

Average change in total abundance (i.e. total number of organisms) for each site (standard error bars are shown). The top right graph shows the change in total abundance averaged across the entire reef (solid black line).

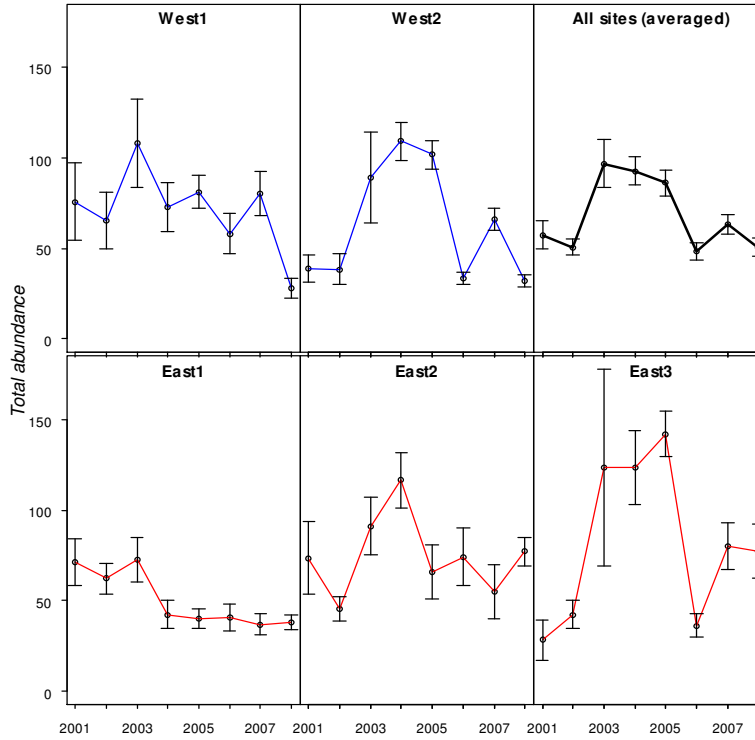


Figure 27

Change in algal biomass over time – see Figure 26 for a more detailed caption description.

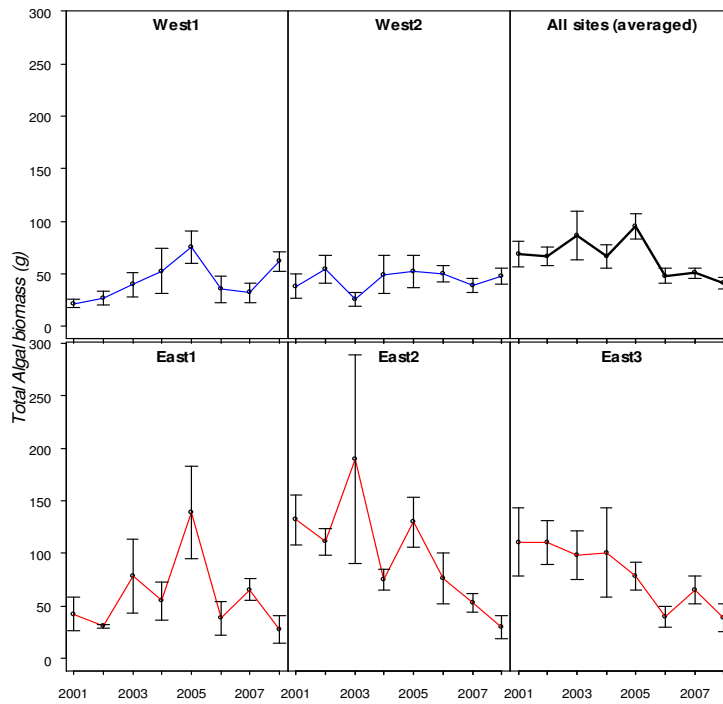


Figure 28

Change in subtidal diversity over time. Red lines indicate eastern sites, blue lines indicate western sites and numbers indicate their distance along the reef (1 = southernmost, 3 = northernmost site).

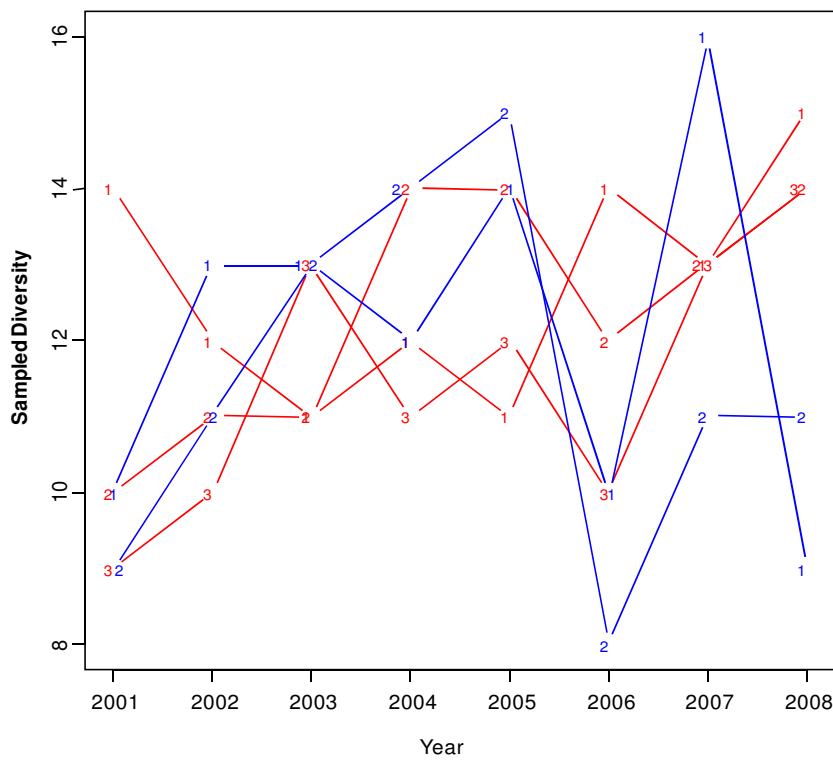
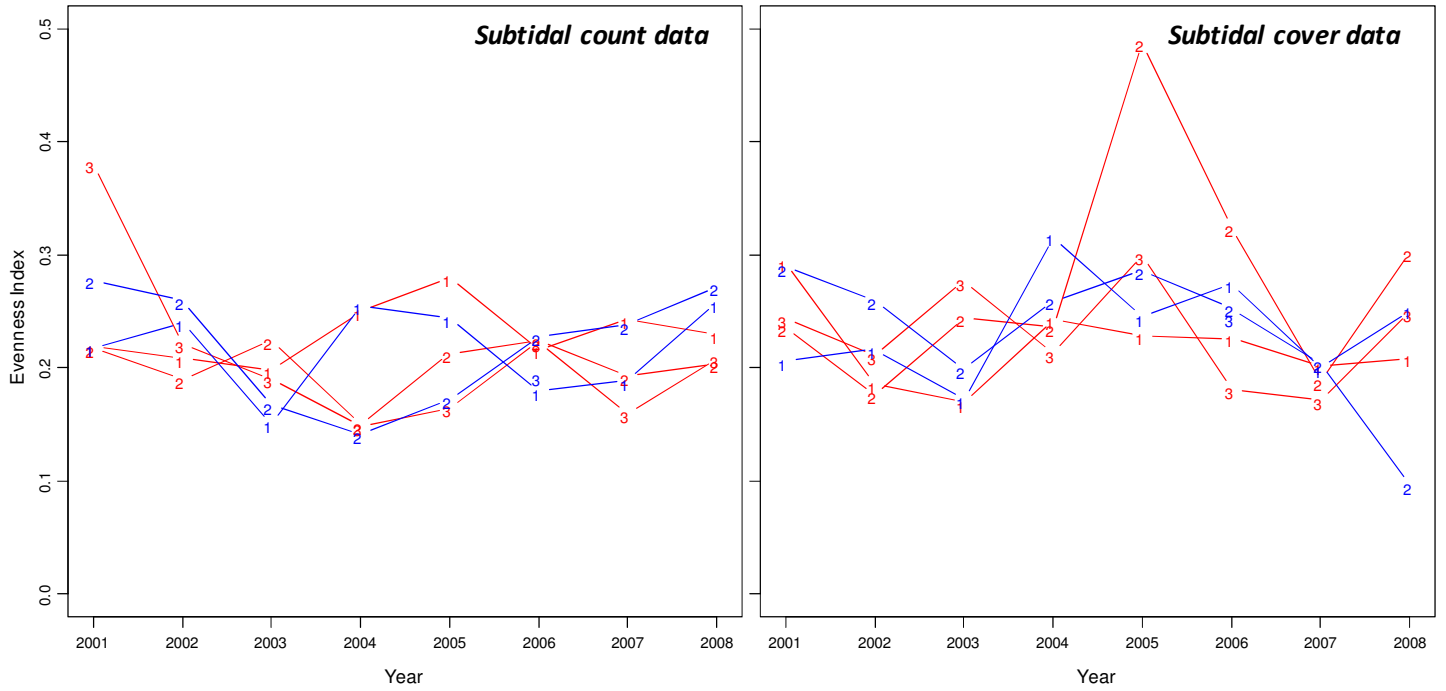


Figure 29

Change in subtidal evenness over time. Red lines indicate eastern sites, blue lines indicate western sites and numbers indicate their distance along the reef (1 = most southern, 3 = most northern site).



5.2.3.2 Changes in macrobiotic abundances

Non-linear changes in abundance

The abundance of *Turbo* and solitary ascidians changed in a non-linear manner (Table 13). Figure 30 shows the approximate change in time of *Turbo* abundance (after accounting for ENSO effects). There is clear non-linearity in the time series [which was modelled by a quadratic,

$$\text{i.e. } E[\log(\textit{Turbo} \textit{ abundance})] \sim b_0 + b_1(\textit{Year}) + b_2(\textit{Year}^2) + b_3(\textit{ENSO})].$$

Turbo abundance appeared to peak in 2004, and has since stabilised at a lower level. The change was more marked at the western sites, with recent recovery in abundance at the eastern sites (Figure 32).

In contrast, the population of solitary ascidians at all sites may be increasing again (Figure 31) after a decline in the eastern sites in 2001 (Figure 33).

Figure 30

Change in time (on the log scale) of *Turbo*. The solid line estimates the change over time (surrounding dashed lines showing the 95% CI [determined by bootstrapping]).

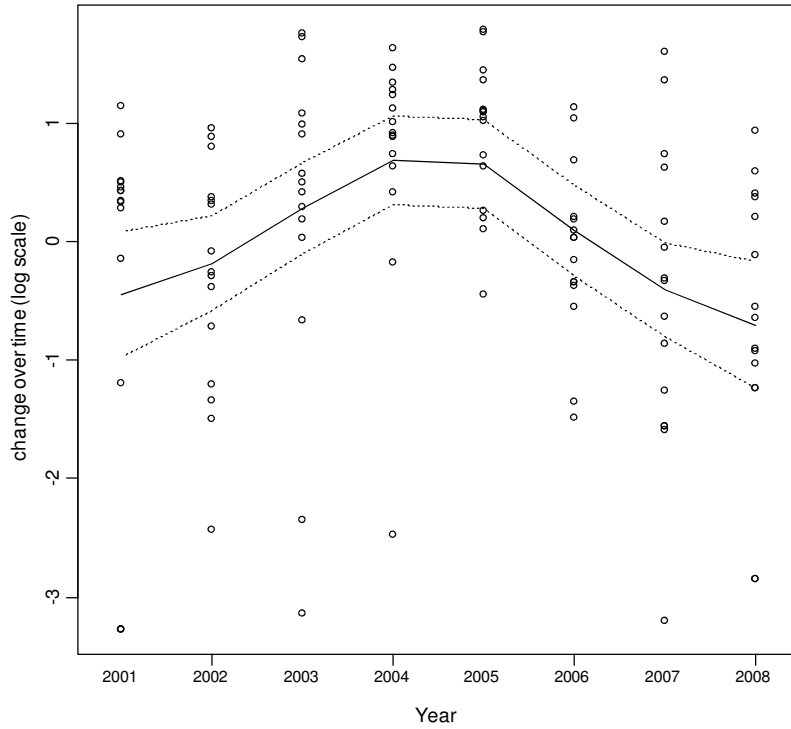


Figure 31

Change in time (on the log scale) of solitary ascidians (after accounting for the effect of ENSO). The solid line estimates the change over time (surrounding dashed lines show the 95% CI [determined by bootstrapping]).

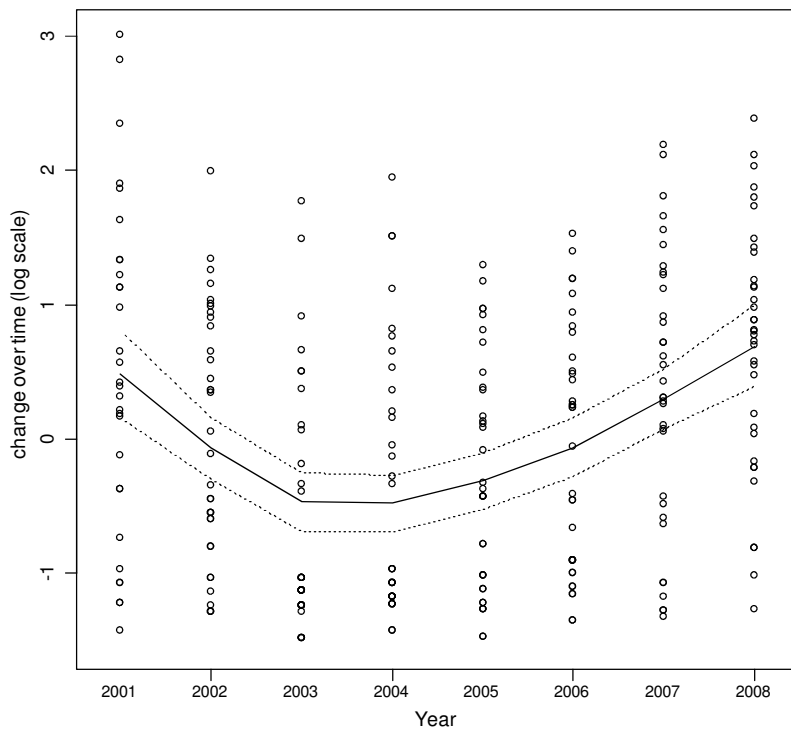


Figure 32

Change in *Turbo* abundance over time – see Figure 26 for a more detailed caption description.

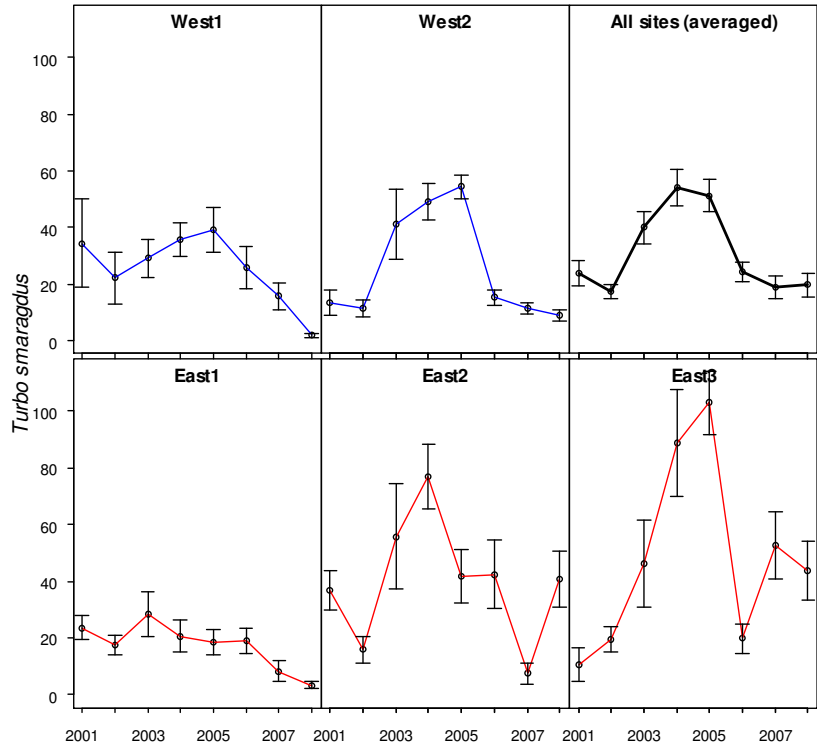
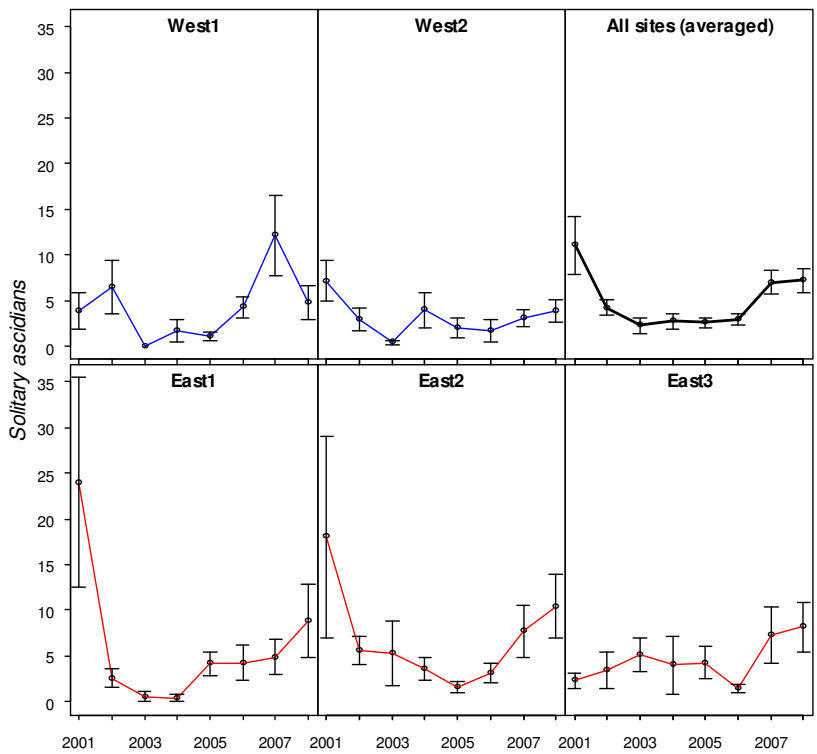


Figure 33

Change in solitary ascidians abundance over time – see Figure 26 for a more detailed caption description.



Changes in algal abundance

Salient points are summarized below:

- There is no evidence of a trend in the abundance of *C. maschalocarpum* (Figure 34) or *C. flexuosum*. However, there was a large, transitory spike in the abundance *C. flexuosum* in 2003 at one site (Figure 35, East3). The increase in abundance was caused by an influx of juveniles (<20 cm long) – see Appendix F, Section 8.6.7.
- *Ecklonia* abundance has been increasing since 2005. Changes have been principally due to the large increase in numbers in 2008 at the eastern sites (Figure 36, East1 and East2), although the western sites also show modest increases.

Figure 34

Change in *Carpophyllum maschalocarpum* abundance over time – see Figure 26 for a more detailed caption description.

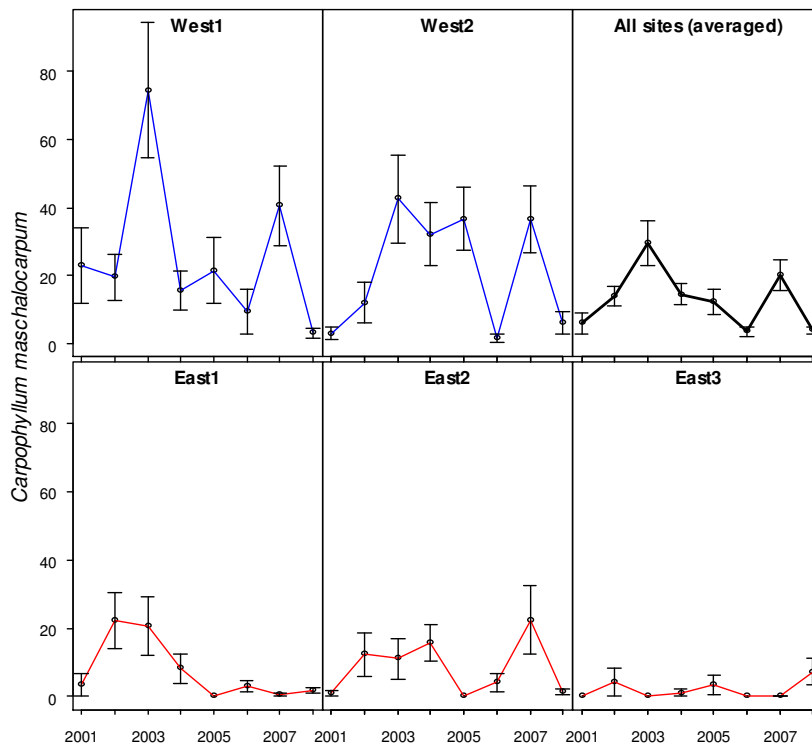


Figure 35

Change in *Carpophyllum flexuosum* abundance over time – see Figure 26 for a more detailed caption description.

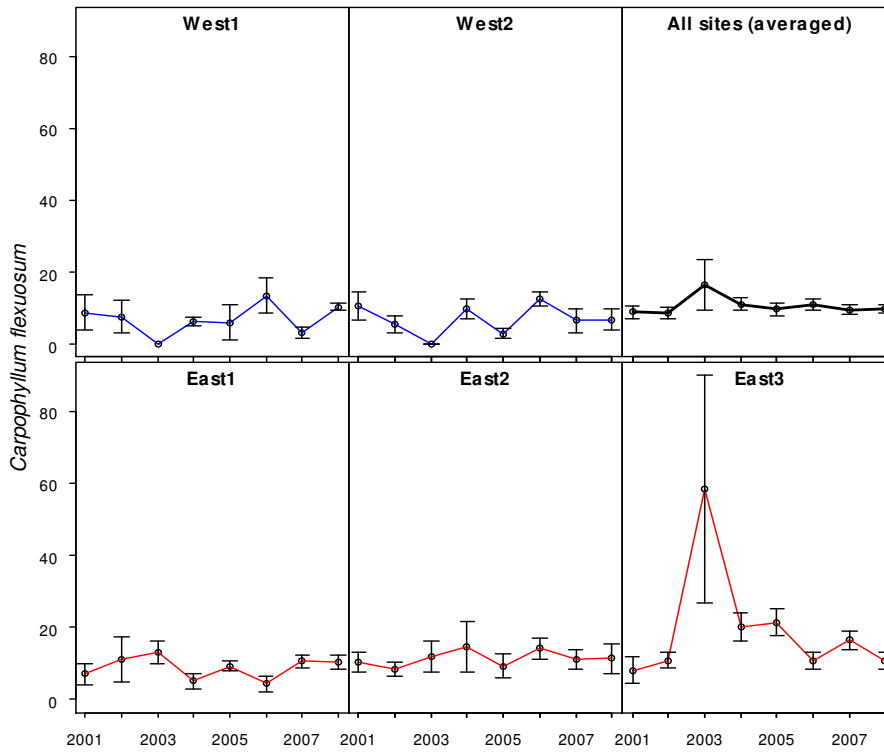
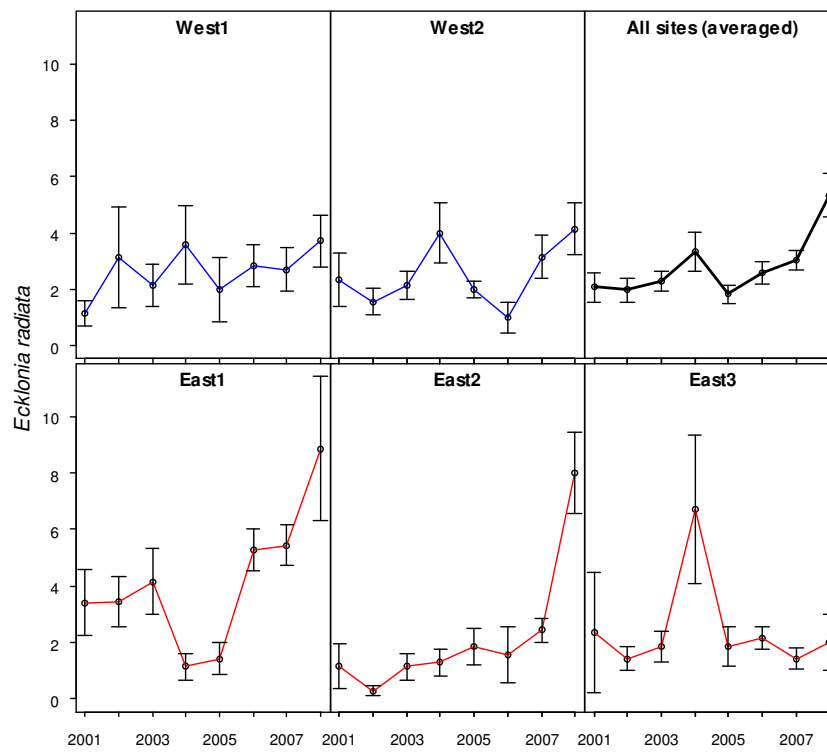


Figure 36

Change in *Ecklonia radiata* abundance over time – see Figure 26 for a more detailed caption description.



5.3 Relationship between temporal change and environmental factors

5.3.1 Multivariate analyses

When the entire data set was considered, MEI measures were usually correlated with patterns in count or cover data. However, this pattern was not seen when the reduced data set (see Section 3.4.3.1) was examined (Table 15).

Table 15

Results of DISTLM analyses relating environmental variables to Bray-Curtis dissimilarities of subtidal count and cover data. Environmental variables used were: the MEI calculated across the whole region as both a short (calculated from the month prior to sampling) and medium (calculated from the year prior to sampling) range term. Environmental variables used at the site by year level were % cover (= the average percentage cover of sediments at each year by site combination), the average trap rate, average percentage of fines in the trap and the average weight of fines in the trap. These variables were all calculated as both short and medium range measures (as outlined for the MEI). p/a = presence/absence. Two sets of data were used: all biological data (n = 40 sites) regressed against the three environmental variables where a complete data set was available (MEI medium and short and % cover) and a subset of the sites (n = 29) regressed against all environmental variables.

| <i>All data</i> | | | | |
|-----------------|--------------|---------------|----------|---------------|
| Response | Trans | Factor | P | % Var. |
| Count data | In | MEI mid | 0.002 | 0.113 |
| Count data | p/a | MEI mid | 0.012 | 0.066 |
| | | MEI short | 0.008 | 0.129 |
| Cover data | In | MEI mid | 0.001 | 0.106 |
| | | MEI short | 0.001 | 0.198 |
| | | % cover | 0.010 | 0.252 |
| Cover data | p/a | % cover | 0.006 | 0.080 |

| <i>A subset of the data regressed against all factors</i> | | | | |
|---|--------------|---------------|----------|---------------|
| Response | Trans | Factor | P | % Var. |
| Count data | In | trap rate mid | 0.019 | 0.091 |
| Count data | p/a | % cover | 0.116 | 0.061 |
| Cover data | In | % cover | 0.001 | 0.136 |
| Cover data | p/a | % cover | 0.029 | 0.077 |
| | | trap rate mid | 0.052 | 0.143 |

The changes in model structure between the two data sets suggest that the correlations seen with the full data set were driven by strong correlations between community structure and MEI measures in 2001 and 2002 (which were excluded from the reduced analysis). Unsurprisingly, the percentage cover of sediments played an important role in determining community composition, particularly of cover types (excluding sediment itself). The only other variable significantly correlated with community composition was the medium-term trap rate, suggesting that the amount of sediment settling from the water column at a site can influence community composition. Notably, none of these models explain more than 25% of the variance in the community composition. Therefore, although correlations exist between the factors quantifying climate and sediment deposition at this site, there is much variance in community composition that remains unexplained. These correlations were further investigated in the univariate analyses.

5.3.2 Univariate analyses

5.3.2.1 ENSO effects

There is evidence that all five major subtidal taxa appear to be affected by ENSO in some manner (see Table 13). We estimate that total abundance increases by 45-60% with each unit increase in the short-term ENSO, i.e. total abundance appears to be higher during El Niño years. This relationship between total abundance and short-term ENSO appears to be mainly driven by the large increase in *C. maschalocarpum* (206-224%) for each unit increase in short-term ENSO. We estimate that *C. flexuosum* also increases in El Niño years (by 21-45% for each unit increase in short-term ENSO). Similarly, there is evidence that a unit increase in medium-term ENSO is correlated with an increase of 19-42% in the population of solitary ascidians. There is evidence that medium-term ENSO affects algal biomass on the east side of Meola. We estimate that the average algal biomass on the east side increases by 11-73% per unit increase in medium-term ENSO. There is no evidence that ENSO affects algal biomass on the west side of the reef.

In contrast, there is evidence that *Ecklonia* decreases by 14-44% given a unit increase in short-term ENSO. A decrease in the abundance of the subtidal *Turbo* population was also found in El Niño years (a decrease of 9-16% per unit increase in medium-term ENSO) (this contrasted to the intertidal *Turbo* population, which appeared to increase in El Niño years).

There is evidence that ENSO affects the trap rate. We estimate that a unit increase in MEI decreases the trap rate by up to 28%.

5.3.2.2 Trapped sediment rate

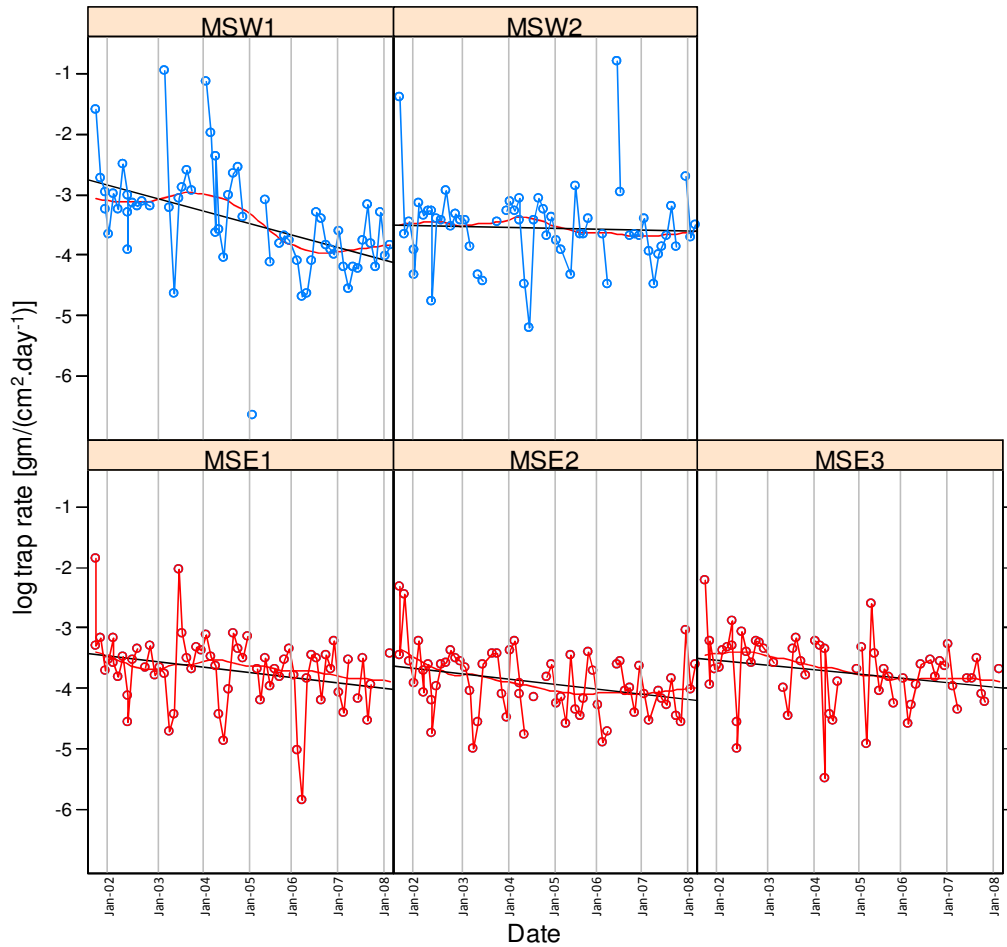
There has been a decline in the rate of sediment trapped at Meola Reef over time, although a few unusual rates did occur on the west side (see Figure 37). We estimate that the trapping rate has declined by 0-1.5% per month.

There is evidence that an increase in trapped sediment negatively affects total abundance. We estimate that a unit increase in log (medium-term trap rate) decreases the total abundance by 14-27%. Such an increase in the trap rate would also lead to decreases in: the sub-tidal *Turbo* population (19 -31%), *C. flexuosum* (16-37%), and solitary ascidians (14 -27%).

The effect of the trap rate on algal biomass depended on the side of the reef. Although there is no evidence that the trap rate affects algal biomass on the west side of the reef, we estimate that as the (log) trap rate increases by one unit on the east side, the algal biomass decreases by between 30 - 83%.

Figure 37

Scatter plot showing the change in log (trapped sediment trap rate) over time.

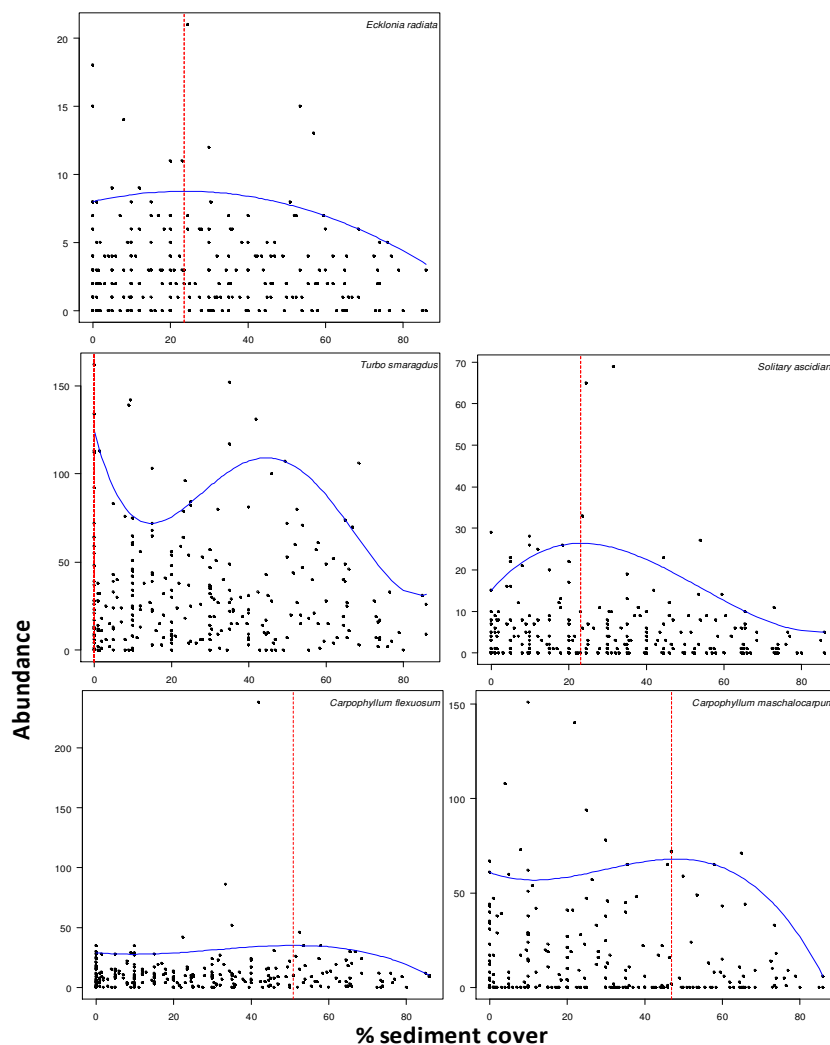


5.3.2.3 Percentage cover of sediment

The percentage sediment cover had a smaller effect on the distribution of major subtidal taxa than on the intertidal assemblage. The 95th percentile of abundance for the major kelp species (*C. maschalocarpum*, *C. flexuosum* and *Ecklonia*) showed only a minor modal response and a broad tolerance to sediment cover (Figure 38). Similarly, *Turbo* showed a bi-modal response to the sediment gradient, and the same broad tolerance zone. Solitary ascidian abundance showed a unimodal response peaking at around 25% sediment cover.

Figure 38

Relationship between individual subtidal taxa (as indicated) and percentage sediment cover. The polynomial regression spline model for the 95th percentile is shown in blue, with the maximum from the model (interpretable as an estimated optimum for the taxon) indicated by a red line. Note: the regression-spline fit only used values of percentage sediment cover $\leq 50\%$.



6 Discussion

6.1 Characterisation of sites at Meola Reef

Spatial patterns in assemblages were present at Meola Reef, but these were more marked in the intertidal area than the subtidal.

6.1.1 Intertidal sites

Intertidal sites were distinguished from each other by changes in both count and cover variables. For example, site MIE1 was characterised by relatively high abundance of *Zeacumantus* and *Melagraphia*, and high percentage cover of *Gelidium* relative to other sites (see Section 4.1 for a full listing of characteristic site taxa).

The compositional differences of the site assemblages make sense when considering the interaction between the physical locale and the biology of the organisms. For instance, the most even communities were found closest to the southern shore (Table 6). This probably reflects the mixture of soft-sediment species (*Zeacumantus*, *Diloma* and *C. glandiformis*) and hard substrate taxa present at these sites. By contrast, sites further from the southern shore were dominated by *Anthopleura*, *Turbo*, *Sypharochiton* and *Melagraphia*, species more typical of intertidal rocky reef habitats (Morton and Miller, 1968). The southern communities, that were the most sheltered from the dominant south-westerly winds (sites MIE1 and MIE2) (Hessell 1988), should also be the most wave-sheltered. These sites were characterised by the soft-sediment grazers *Zeacumantus*, *Diloma* and the scavenging whelk *C. glandiformis*, species that are most common on sheltered mudflats (Morton and Miller, 1968). The high densities of these mudflat species on Meola Reef are probably from their spread via the sediments overlying the rocky reef onto this relatively sheltered part of the reef. High cover of *Gelidium* was also seen close to the shore (MIE1, MIE2 and MIW1). It is likely that the habitat becomes too exposed for this alga as distance from the shore increases, as its distribution is confined to cracks and fissures on very exposed rocks (Adams 1994).

A significant increase in *Turbo* abundance was seen on the northern sites of the more exposed, west side of Meola Reef. *Turbo* is a deposit feeder that feeds on detritus, microalgae and bacteria (Alfaro et al 2007). It is known to be better adapted to the sublittoral fringe than the intertidal zone (Walsby 1977, Creese 1988); therefore, its increasing density at the northern sites is likely to be due to the position of these sites further down the intertidal zone. Certain other species also attain their highest densities at sites 2 and 3, further north. The filter feeding anemones (*Anthopleura* and *Diadumene*) and barnacles are likely to be increasing in response to increasing water depth and flow, which will increase the amount of food available.

6.1.2 Subtidal sites

No consistent patterns were visible at any site in terms of either subtidal count or cover data. All sites were numerically dominated by brown algae, *Turbo* and solitary ascidians. In terms of cover, the dominant classes were unconsolidated substrates (sand, gravel, shell or sediment), coralline turf and bare rock.

Size frequency data were not explicitly examined in terms of characterising sites and little data exists on expected size frequency changes for these taxa over such small spatial scales. A cursory investigation, however, reveals that our measurements agree with the few established patterns. Generally, the size of *Turbo* should increase with depth (Walsby 1977), and *C. flexuosum* at sheltered locations exhibited a 'long, bushy' growth form (Cole et al 2001). The average size of *Turbo* at Meola Reef in the intertidal (13 mm) was smaller than that in the subtidal (18 mm). Additionally, *C. flexuosum* plants were up to 4.4 m in length at Meola Reef with an average length of 75 cm, in the expected long bushy morphology.

6.2 Assessment of change over time

Due to the short time series of this data, any significant results detected in this section should be interpreted cautiously. Annual sampling means that the intertidal and subtidal time series contain only seven and eight different time points respectively; as a consequence, the chances of detecting a spurious correlation are high. For example, previously published time series analyses looking for biological effects of ENSO have used at least a decade worth of data (Dayton and Tegner 1984, Strub et al 1985). However, although the parameter estimates quantifying the effect of ENSO may not be robust (the confidence intervals around the parameters were typically quite wide), the inclusion of ENSO as a parameter in the univariate models helped to remove cyclicity in the data, thereby aiding in the identification of linear trends over time. Moreover, with continued sampling should give greater precision and accuracy when determining the effects of long-term climate changes on the biota.

6.2.1 Intertidal change

Intertidal sites closest to the southern shore (MIE1, MIE2, MIW1 and MIW2) generally showed the highest temporal stability in terms of both count and cover measures.

Intertidal site diversity appeared to increase with El Niño conditions; this increase is, however, only on the scale of a maximum \pm of 0.3 species per site. The ENSO cycle is important to New Zealand's climate but only explains ~25% of the year-to-year variance in rainfall and temperature (Mullan 1996).

The intertidal population of two gastropods, *Melagraphia* and *Turbo*, decreased in abundance over time. However, the rate of decline for both species was small. With *Turbo*, there was evidence of a cyclical change over time (even after correcting for ENSO effects), so a longer time series is required to determine if the reef-wide decline in abundance is part of a cyclic pattern. No clear, directional changes in size frequency distributions were found in any of the measured intertidal invertebrates.

Site specific correlations were also seen between some intertidal fauna and indices (*Xenostrobus*, *Elminius* and total abundance) and the ENSO. If correct, these correlations are likely to reflect differential wave action on the reef over time that could dislodge animals or remove sediment differentially between sites or sides of the reef.

6.2.2 Subtidal change

For the subtidal communities, there is no convincing evidence that any individual subtidal site communities or the reef as a whole is changing over time. The abundance of the macroalgae at Meola Reef (*C. maschalocarpum*, *C. flexuosum*) have all been relatively stable, and the numerically dominant invertebrate, *Turbo*, has exhibited a stable, if cyclical, distribution of abundance.

Although algal biomass on the west side of Meola Reef (where the algal bed is narrow) has been stable, the extensive *C. flexuosum* beds (the dominant contributor to algal biomass at Meola) on the eastern side of the reef peaked in 2005, a year when a number of unusually large individuals were surveyed at one site (MSE1). It is likely that algal biomass on the west side of the reef is limited by abrasion of *C. flexuosum* on oysters, as the algal band is directly adjacent to the intertidal in many places. Therefore, extremely long individuals are not found here. On the east side, however, if conditions are favourable, the more extensive beds can support much longer individuals (greater than 4 m, Appendix F, Section 8.6.7), which dominate the biomass.

The changes in biomass were correlated with ENSO and the trap sedimentation rate. Positive and negative correlations were observed between the short-term measures of ENSO and densities of the algae. The numbers of both *C. maschalocarpum* and *C. flexuosum* increased and the numbers of *Ecklonia* decreased. Unfortunately, simple correlations between water temperature and algal recruitment or growth are difficult to make due to the interaction of other factors such as light and nutrients, e.g., the optimum algal growth conditions for *Ecklonia* are best described in terms of light, nutrients and temperature (13-16°C, where the average daily quantum dose of light exceeds 200 E.cm⁻² and when there is high nutrient availability (Taylor 1981).

Moreover, although the climactic processes that cause changes in algal beds are either (i) direct (i.e. physical dislodgement or individual mortality) or (ii) indirect (i.e. growth, recruitment inhibition/facilitation); it is known that these factors depend on various dynamics within the algal communities. For example, algal canopies are known to inhibit algal recruitment, probably via limiting both space and light (Schiel 1988). Therefore gaps in the canopy are an important opportunity for changes in algal composition. Recruitment to these gaps is likely to be influenced by spore availability,

sediment cover, herbivory and competition amongst spores (Schiel 1988, Schiel et al 2006). In the shallow, turbid environment of the Waitemata Harbour, factors such as pre and post-settlement survival are likely to play an important role in determining algal composition.

Although individuals of *C. flexuosum* may be long, the attachment to their holdfast is relatively weak (pers. comm. J. Walker), and those plants of the eastern side of the reef that become dislodged are likely to entangle and dislodge other plants. Such a process has been recorded from other algal forests (Dayton et al 1984, Dayton, 1985, Sharp 1989).

Size frequency distributions of the *C. flexuosum* were significantly different between some years. However, these differences were found to reflect either a temporary influx of juveniles at a single site in a single year (site MSE3 in 2003), rather than any sustained, reef-wide population change over time. Similarly the other macroalgae exhibiting change in its size distribution was *Ecklonia* - again no clear directional change in the size distribution is evident. However, *Ecklonia* abundance has increased in recent years (particularly at the south-eastern sites) and unusually large numbers of small *Ecklonia* were found on the south-eastern sites (MSE1 and MSE2) in 2008. Future surveys are needed to determine if this change is a temporary or cyclical one.

The abundances of both *Turbo* and solitary ascidians appeared to change significantly depending on ENSO, but this may be due to contrasting mechanisms. The decrease in subtidal *Turbo* abundances during El Niño years contrasts with the results for the intertidal population, which increased during El Niño years (Section 6.2.1). This difference between the intertidal and subtidal supports the mechanism of movement as being responsible for this pattern. For example, if subtidal and intertidal *Turbo* can be considered one population, then weather conditions that lead to dislodgement from the intertidal increase densities in the subtidal, or conditions conducive to upwards migration lead to increases in density in the intertidal and decreases in the subtidal population. In contrast, ascidians are sedentary, and therefore a reproductive response is the only way they could be responding positively to ENSO. Solitary ascidians can grow 40% in volume over 80 days from a length of 0.5 to 1.5 cm (Robbins 1985), so it is feasible that new recruits are growing to a detectable size in response to good conditions (relevant longevity and reproductive information could not be located for this taxon).

A small linear increase in site diversity was seen over time - that equates to an increase of approximately 1 taxon per site over the 7 years of the subtidal monitoring period. Given the invasion of four recorded taxa in the subtidal zone over the monitoring period (Section 6.3.1)⁹, two of which are relatively common (*Tethya* and *Cliona*), this trend could be easily explained by invasive organisms.

⁹ *Charybdis* was only sighted and *Diadumene* was only recorded intertidally.

6.3 Comparison of communities at Meola Reef to those at Long Bay

Meola Reef is unique in the Auckland Region, so direct quantitative comparisons are not realistic, especially for the intertidal community. However, qualitative comparisons can be made between the subtidal community surveyed at Meola Reef by the MRMP and the subtidal community surveyed at Long Bay by the LBMMP. Probable reasons for the differences between time series changes for the different reefs should firstly be recognised.

1. Meola Reef exists in more turbid and wave-sheltered waters than the Long Bay reefs, but it is also more influenced by currents. Therefore a higher average density of *C. flexuosum* and *Turbo* at Meola Reef compared to that seen in the LBMMP is expected, as these taxa favour more sheltered conditions (Morton and Miller 1968, Walker 1999, Shears and Babcock 2004).
2. *Carpophyllum maschalocarpum* and *C. flexuosum* populations have been comparatively stable at Meola Reef compared. In contrast the LBMMP has shown a decline in *C. maschalocarpum* and a corresponding increase in *C. flexuosum*. Although the mechanisms behind the changes in the LBMMP are unknown, changes seem likely to be dependent upon recruitment competition after some sort of community disruption (e.g. storm events). As notes in (1) above, Meola Reef is more sheltered than the LBMMP, so it may not have been impacted by any storm events that have altered the LBMMP reefs.
3. Meola Reef supports a less diverse community than that seen in the LBMMP. The species list for count data at Long Bay contains 69 taxa and the same list for Meola Reef contains only 43 taxa. This lower diversity at Meola Reef is to be expected, because the reef is smaller and more isolated than the LBMMP reefs, and therefore the chances of encountering rare species are lower.
4. Some species commonly found in the LBMMP are virtually absent at Meola Reef. In the LBMMP, *C. plumosum*, *Zonaria turneriana* and the gastropod *Cookia sulcata* attain average densities of approximately 7, 19 and 0.5 per quadrat, respectively. At Meola Reef, only a few individuals of *C. plumosum* have been found and *Cookia* and *Zonaria* have only ever been found once each. *C. plumosum* has a preference for sheltered areas (this species is absent on the West Coast of the North Island and in Cook Strait (Morton and Miller, 1968). The absence of *C. plumosum* from the relatively current-exposed Meola Reef is therefore not surprising. Not enough is known about the ecology of *Cookia* or *Zonaria* to ascertain whether increased current, increased turbidity or reproductive isolation are the likely cause of their near absence at Meola Reef.

Meola Reef showed a generally stable community over time. Other than the macroalgal changes mentioned in (2) above, the LBMMP community also showed some fluctuations in relatively rare species, i.e. increasing average abundances of *Coscinasterias muricata*, solitary ascidians, *Buccinum lineum* and *Cystophora sp.* and decreasing average abundances of *C. virgata*, *Dicathais orbita* and *Sargassum sinclairii*

(Anderson et al 2005). A similar increase over time at Meola Reef was observed for counts of solitary ascidians (with the exclusion of high counts in 2001) and a decrease was also observed for counts of *Sargassum*. *Coscinasterias* showed a decrease at Meola Reef over the same period that it was increasing at the LBMMP. However, *Buccinulum* has had very stable abundance over time at Meola Reef which contrasts with the results for the LBMMP, where counts of *Buccinulum* have been increasing. Only three individuals of the gastropods *C. virgata* and *Dicathais orbita* have ever been found at Meola Reef (and none of the algae *Cystophora spp.*) therefore these taxa were not compared. These data suggest that the processes that are causing changes over time in the LBMMP are probably not impacting all the species at Meola Reef in the same way.¹⁰

6.3.1 Interpretation of community shifts

Sedimentation is measured at Meola Reef both using percentage cover and sediment traps.¹¹ Intertidal sediment cover on the west side of the reef was linearly decreasing and on the east side of the reef it was negatively correlated with the ENSO cycle. This ENSO correlation means less sediment cover on the eastern side of the reef when there are more winds from the west and south and cooler temperatures (i.e. El Niño years) (Mullan 1996). Sedimentation into traps (as measured by the medium trap rate) linearly decreased over time but also showed some evidence of a negative relationship with the previous month's value for ENSO. These trap values contained 58-62 different time points (depending on the site); therefore this pattern is more robust than the biological relationships we observed with ENSO. The ENSO correlation is somewhat counter to that expected, i.e. with increased wave action and colder water temperatures, less sediment settled. This could be because either less rain in El Niño conditions generates less sediment runoff, or more hydrodynamically active conditions keep sediment in suspension.

On average, the trap rate on the western side is higher. This may be caused by the long fetch with this dominant wind direction. This fetch may allow sediment to be resuspended from the shallow bed or kept in suspension until it reaches the western side of Meola Reef. This sediment might then preferentially settle on the western side at low tide due to the barrier that Meola Reef forms across the harbour. The effect of surrounding land and harbour influences may also be important in influencing sediment loading on Meola – there are a number of tributaries to the west that discharge in to the upper Waitemata harbour (e.g. Te Atatu and Greenhithe).

We have compared these sedimentation measures to measures of faunal diversity, abundance, evenness, composition and important individual taxa. Spline curves have been used to show population level responses to percentage sediment cover (which were clearly non-linear). A generalised linear mixed modelling approach was used to relate the most useful component of the trap information (average trap rate per site

¹⁰ Note: ENSO effects have not yet been examined in the LBMMP so these cannot be compared

¹¹ Sediment traps were only employed in the subtidal.

over the year preceding sampling) to individual taxa densities after any accounting for trends or ENSO effects.

As the amount of trapped sediment increases, declines are seen in total densities and densities of solitary ascidians, *C. flexuosum* and *Turbo*; this is the same general pattern observed in the spline curves examining abundance vs. percentage sediment cover gradient (see Section 4.3.2.1 and Section 5.3.2.3). This suggests that the present rates of sediment flux (as measured by trap rates) influence the densities of some species, in addition to the influence of current sediment cover on the substrate. Alternately, the sediment trap deposition rate may be a good proxy for year round sediment cover, because the annual sediment cover measure may be influenced by the weather conditions immediately preceding sampling. Several mechanisms associated with sedimentation could be responsible for the measured declines in abundance:

1. Feeding could be inhibited, which could in extreme cases lead to mortality. For example, growth of the filter feeding solitary ascidians has been seen to decline with increasing sediment concentration in the water (Robbins 1985).
2. Alternatively, recruitment may be affected, as some hard-substrate species will not recruit to sediment-covered reef, e.g. the algae *Sargassum* on coral reefs (Fabricius and De'ath 2001). The longevity of species such as *Turbo* and the relatively stable size structure of these populations suggest that adult populations are probably remaining relatively unchanged. Juveniles are usually more susceptible to sediment impacts, e.g. the juvenile sea urchin *Evechinus chloroticus* (Walker 2007). It is likely that the declines in solitary ascidians, *C. flexuosum* and *Turbo* are, therefore, due to poor recruitment events in high sediment deposition periods, rather than declines in adult populations.

The relationship between sediment cover and population densities (see Figure 16 and 47) is useful for predicting what changes may occur in community composition as sediment cover increases. Of the major intertidal and subtidal populations tested, only *Onchidella* increased with increasing sediment cover. *Onchidella* was the only monitored organism solely found on sediment substrate at Meola Reef (pers. obs.) All other intertidal species show a decline in abundance with increasing sediment cover - even *Zeacumantus*, which is often described as a soft-shore species (Morton and Miller 1968), exhibited a unimodal response to sediment cover. This suggests that increasing sediment cover is likely to result in a decline in the intertidal species presently inhabiting Meola Reef.

In general, the major subtidal macrofauna and flora showed a greater tolerance to sediment cover than the major intertidal species. Notably, the subtidal *Turbo* population showed a considerably wider range of tolerance to sediment cover than its intertidal counterpart. This pattern is expected, as algae, can provide extra substrate and a refuge from the impacts of sediment deposition on the seabed. Therefore, as long as algal cover is retained, sediment impacts are likely to be less marked in the subtidal than in the intertidal for grazing gastropods.

Toxic urban pollutants were not measured on a scale or at locations that are compatible for analysis with the MRMP data. If ecologically significant declines or increases in taxa were seen we could attempt to correlate harbour-wide pollutant patterns with known susceptibilities or life histories of the affected taxa. As these declines were not seen, this was not investigated further.

Six taxa of invasive species have previously been identified at Meola Reef. In addition, in 2007 the crab *Charybdis*, and in 2008 the tunicate *Styela clava*, were identified at Meola Reef in low numbers. Of the eight invasive taxa identified, *Crassostrea* continues to be numerically and structurally dominant in the intertidal, as it has been since the inception of the MRMP (Ford et al 2006). There is no mention of *Crassostrea* at Meola Reef in Morton and Miller (1968), but by 1983 it was widespread there (Dromgoole and Foster 1983). *Cliona* and *Tethya* have been recorded in the subtidal areas with low percentage covers (averages of 0.477 and 0.139% cover, respectively, Appendix E, Section 8.4.3) every year from 2002. *Diadumene* has been present consistently since 2004. *Chaetopterus* was only recorded in two subtidal quadrats in 2005. Thus far, none of these invasive organisms have shown an ecologically concerning pattern of increasing density or percentage cover over the monitored period. Interestingly, the oyster bed provides a structural matrix that probably shelters a higher diversity than the bare rock, or possibly even the worm reefs that preceded it (Morton and Miller 1968), as habitat heterogeneity is known to promote diversity (Tokeshi 1999). Therefore, the loss of this particular invasive organism would probably result in additional diversity losses, at least in the short-term until other biological reefs develop.

6.4 Recommendations

1. This monitoring programme should be continued in its present form. The time series is becoming sufficiently long to attempt correlating important inter-annual climatic phenomena with biological patterns. However, the correlations shown thus far (with ENSO) are not robust, due to the current short time span of the monitoring programme. A longer time series of data is needed so that any decline or improvement in this SOE monitoring site can be placed in an appropriate temporal context.
2. We have found very few trends in the MRMP. These include (i) a general decrease in sediment trap rate, (ii) a decrease in the gastropod, *Melagraphia* and (iii) a decrease in algal biomass on the eastern side of the reef. Although the change in *Melagraphia* has been relatively small (and most sites have shown an increase in the 2007 survey), the decrease in algal biomass is cause for some concern and should be examined carefully in the future.

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8 Appendices

8.1 Appendix A. GPS positions

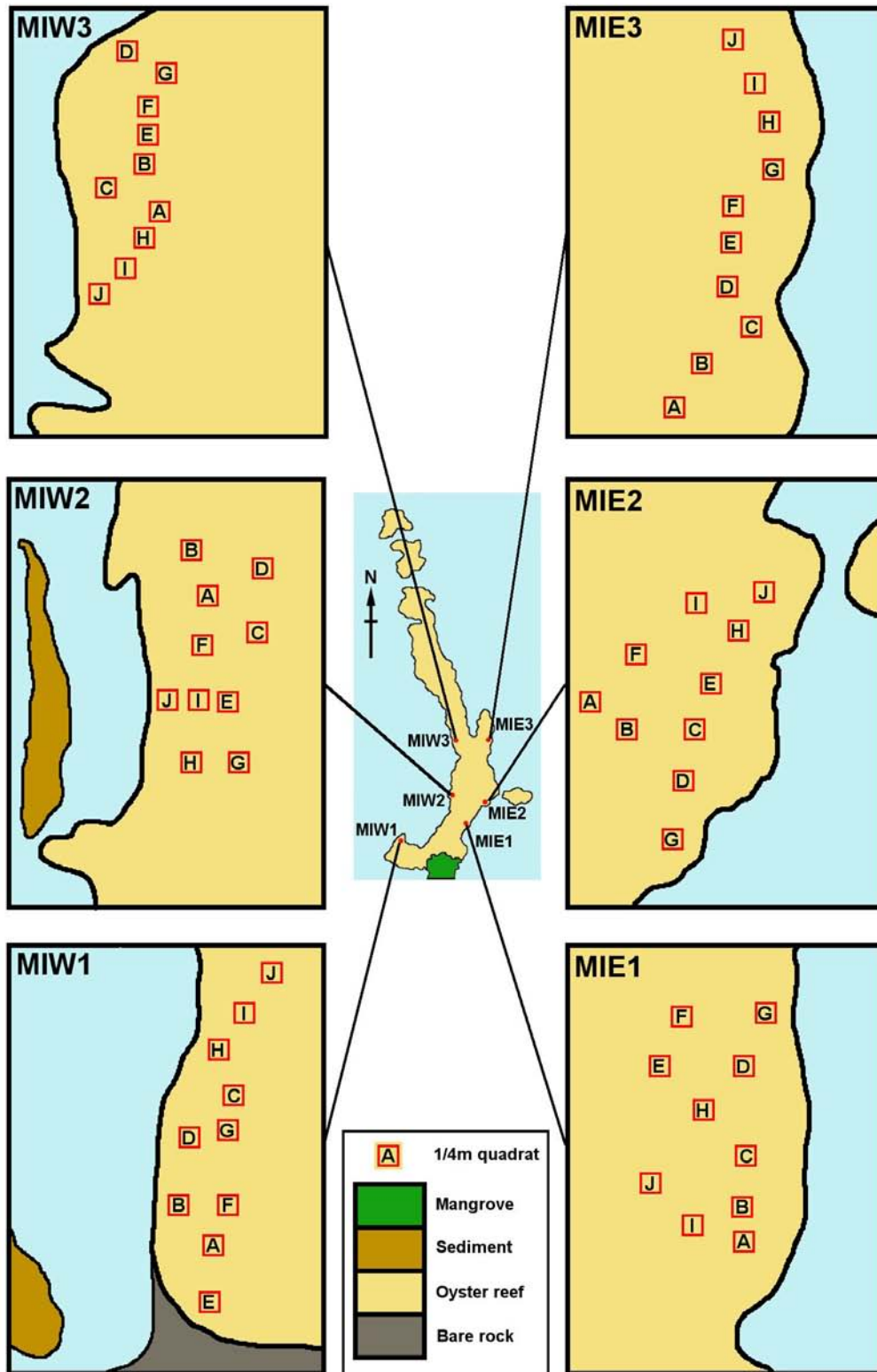
8.1.1 Meola intertidal site locations

| Site | Height above MLWS (m) | | Side of reef |
|-------------|-----------------------|-------------------------------|--------------|
| MIE1 | 1.78-2.04 | S 36° 50.74' E 174° 42.70' | East |
| MIE2 | 1.44-1.97 | S 36° 50.71' E 174° 42.71' | East |
| MIE3 | 1.40-1.93 | S 36° 50.65' E 174° 42.77' | East |
| MIW1 | 1.40-1.93 | S 36° 50.78' E 174° 42.62' | West |
| MIW2 | 0.59-1.21 | S 36° 50.71' E 174° 42.69' | West |
| MIW3 | 1.08-1.28 | S 36° 50.65' E 174° 42.72' | West |

8.1.2 Meola subtidal site locations

| Site | Height below MLWS (m) | | Side of reef |
|-------------|-----------------------|---------------------------------|--------------|
| MSE1 | 1.00-2.00 | S 36° 50.176' E 174° 42.599' | East |
| MSE2 | 1.00-2.00 | S 36° 50.095' E 174° 42.569' | East |
| MSE3 | 1.00-2.00 | S 36° 50.045' E 174° 42.544' | East |
| MSW1 | 1.00-2.00 | S 36° 50.249' E 174° 42.559' | West |
| MSW2 | 1.00-2.00 | S 36° 50.190' E 174° 42.553' | West |

8.2 Appendix B. Map of intertidal sites



8.3 Appendix C. 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 – Akaike’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 – Canonical 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.

Dispersion – Measures the spread of samples, in this document at a site over time. More dispersed communities will change more over time than less dispersed communities.

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 – Non-metric 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.

8.4 Appendix D. Taxa lists

All covers or densities are stated as average values per quadrat across the entire data set.

8.4.1 Intertidal cover

| Name | Group | Cover |
|-------------------------------|--------------|--------------|
| <i>Crassostrea gigas</i> | Bivalve | 47.209 |
| Bare rock | Substrate | 30.746 |
| Sediment | Substrate | 11.362 |
| <i>Gelidium</i> sp. | Red algae | 6.432 |
| Barnacles | Crustacean | 3.262 |
| <i>Gracilaria chilensis</i> | Red algae | 0.567 |
| Shell hash | Substrate | 0.233 |
| <i>Corallinia officinalis</i> | Red algae | 0.130 |
| <i>Hormosira banksii</i> | Brown algae | 0.033 |
| <i>Ulva lactuca</i> | Green algae | 0.018 |
| <i>Carpophyllum</i> sp. | Brown algae | 0.005 |
| <i>Ralfsia</i> sp. | Red algae | 0.003 |

8.4.2 Intertidal count

| Name | Group | Density |
|-------------------------------------|-------------------|---------|
| <i>Anthopleura auroeradiata</i> . | Anemone | 11.377 |
| <i>Turbo smaragdus</i> | Gastropod | 7.132 |
| <i>Sypharochiton pelliserpentis</i> | Chiton | 6.995 |
| <i>Xenostrobus pulex</i> | Bivalve | 6.051 |
| <i>Melagraphia aethiops</i> | Gastropod | 5.547 |
| <i>Zeacumantus lutulentus</i> | Gastropod | 4.423 |
| <i>Onchidella nigricans</i> | Pulmonate slug | 1.886 |
| <i>Cominella glandiformis</i> | Gastropod | 0.559 |
| <i>Diadumene lineata</i> | Anemone | 0.463 |
| Acari | Mite | 0.291 |
| <i>Diloma subrostrata</i> | Gastropod | 0.289 |
| <i>Cominella maculosa</i> | Gastropod | 0.091 |
| <i>Cominella adspersa</i> | Gastropod | 0.089 |
| <i>Acanthochiton zealandicus</i> | Chiton | 0.061 |
| <i>Notoacmea helmsi</i> | Limpet | 0.025 |
| <i>Patiriella regularis</i> | Echinoderm | 0.020 |
| <i>Petrolisthes elongatus</i> | Crab | 0.020 |
| <i>Buccinulum lineum</i> | Gastropod | 0.018 |
| <i>Cominella virgata</i> | Gastropod | 0.015 |
| <i>Helice crassa</i> | Crab | 0.013 |
| Unidentified Polychaete | Polychaete | 0.013 |
| <i>Musculista senhousia</i> | Bivalve | 0.010 |
| <i>Austovenus stutchburyi</i> | Bivalve | 0.008 |
| <i>Limaria sp.</i> | Bivalve | 0.008 |
| <i>Perinereis novaehollandiae</i> | Polychaete | 0.008 |
| Solitary ascidian | Ascidian | 0.008 |
| <i>Nucula nitidula</i> | Bivalve | 0.005 |
| Tunicate | Tunicates | 0.005 |
| <i>Bulla sp.</i> | Gastropod | 0.003 |
| <i>Crepidula monoxyla</i> | Gastropod | 0.003 |
| <i>Modiolarca impacta</i> | Bivalve | 0.003 |
| <i>Nerita melanotragus</i> | Gastropod | 0.003 |
| Sphaeromatid Isopod | Isopod | 0.003 |
| Unidentified Amphipod | Amphipod | 0.003 |
| <i>Zegalerus tenuis</i> | Gastropod | 0.003 |

8.4.3 Subtidal cover

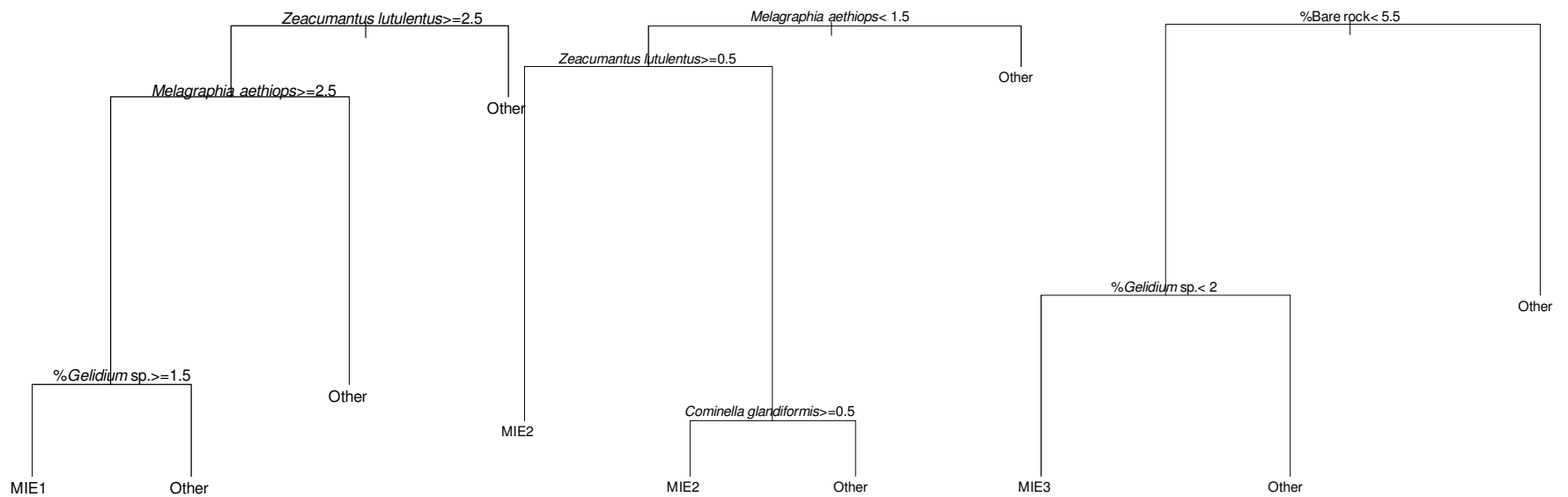
| Name | Group | Cover |
|---|--------------|--------------|
| Sediment | Substrate | 27.529 |
| Crustose coralline algae | Red algae | 16.005 |
| Sand | Substrate | 14.656 |
| Ralfsia | Red Algae | 14.185 |
| Shell | Substrate | 7.711 |
| Coralline Turfing Algae | Red Algae | 4.301 |
| Bare rock | Substrate | 3.245 |
| Sponges | Sponge | 3.173 |
| <i>Carpophyllum maschalocarpum</i> | Brown algae | 1.535 |
| Green turf | Green algae | 1.502 |
| <i>Carpophyllum flexuosum</i> | Brown algae | 1.495 |
| <i>Ecklonia radiata</i> | Brown alge | 1.137 |
| Solitary ascidians | Ascidian | 0.623 |
| Gravel | Substrate | 0.557 |
| <i>Cliona celata</i> | Sponge | 0.477 |
| <i>Crassostrea gigas</i> | Bivalves | 0.424 |
| Bryozoan | Bryozoan | 0.329 |
| Red foliose algae | Red Algae | 0.162 |
| <i>Sargassum sinclairii</i> | Brown algae | 0.139 |
| <i>Tethya burtoni</i> | Sponge | 0.139 |
| Ancorina sp. | Sponge | 0.099 |
| <i>Perna canaliculus</i> | Bivalve | 0.085 |
| Hydroids | Hydroids | 0.080 |
| <i>Colpomenia sinuosa</i> | Brown algae | 0.052 |
| <i>Halopteris</i> sp. | Brown algae | 0.051 |
| Anemone | Anemone | 0.046 |
| <i>Polymastia</i> sp. | Sponge | 0.035 |
| <i>Hormosira banksii</i> | Brown algae | 0.034 |
| <i>Waltonia inconspicua</i> | Brachiopod | 0.028 |
| Green filamentous algae | Green algae | 0.022 |
| Phorbasidae | Sponge | 0.015 |
| <i>Aptos aptos</i> | Sponge | 0.014 |
| Codium (globular) | Green algae | 0.011 |
| Brown turfing scum | Brown algae | 0.009 |
| Barnacles | Crustacean | 0.008 |
| <i>Carpophyllum plumosum</i> | Brown algae | 0.006 |
| <i>Codium fragile</i> | Green algae | 0.006 |
| Colonial ascidians | Ascidian | 0.006 |
| <i>Chaetopterus</i> sp. | Polychaete | 0.003 |
| Red turfing algae | Red Algae | 0.003 |
| <i>Tethya ingalli</i> | Sponge | 0.003 |
| <i>Cystophora</i> sp. | Brown algae | 0.002 |
| <i>Glossophora kunthii</i> | Brown algae | 0.002 |
| <i>Mytilus edulis galloprovincialis</i> | Bivalve | 0.002 |
| <i>Styela clava</i> | Tunicate | 0.002 |
| <i>Zonaria turneriana</i> | Brown algae | 0.002 |

8.4.4 Subtidal count

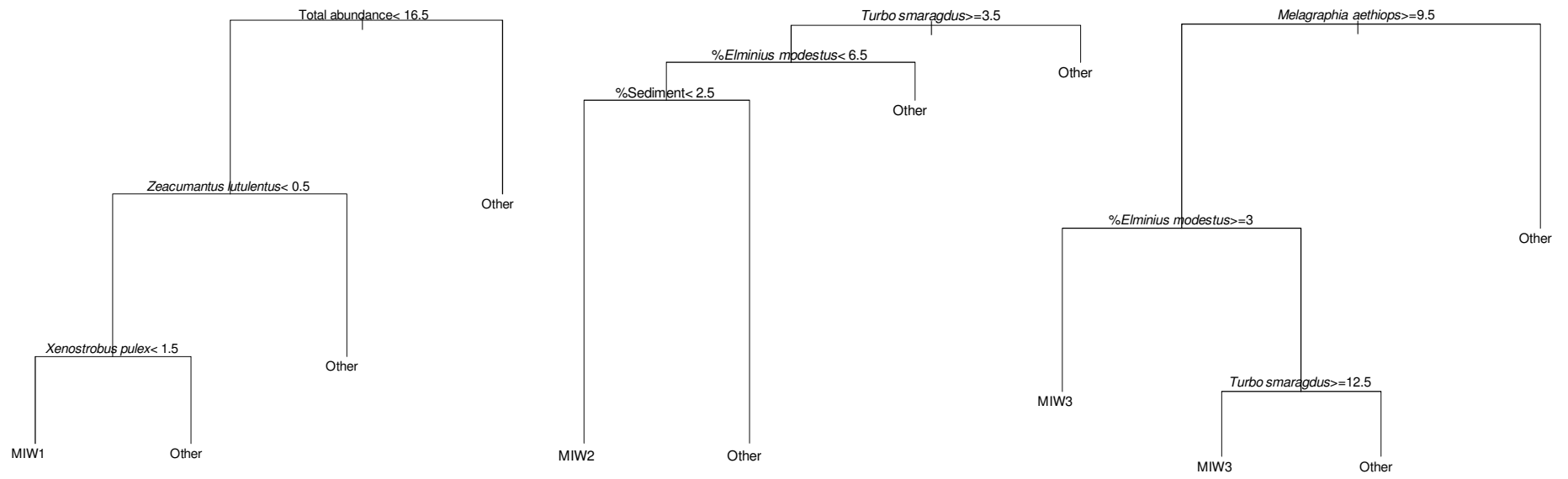
| Name | Group | Density |
|-------------------------------------|--------------|----------------|
| <i>Turbo smaragdus</i> | Gastropod | 33.315 |
| <i>Carpophyllum maschalocarpum</i> | Brown algae | 13.370 |
| <i>Carpophyllum flexuosum</i> | Brown algae | 10.231 |
| Solitary ascidians | Ascidian | 5.117 |
| <i>Ecklonia radiata</i> | Brown algae | 3.022 |
| <i>Patiriella regularis</i> | Echinoderm | 1.000 |
| <i>Trochus viridus</i> | Gastropod | 0.929 |
| <i>Crassostrea gigas</i> | Bivalves | 0.910 |
| <i>Tethya burtoni</i> | Sponge | 0.846 |
| <i>Sargassum sinclairii</i> | Brown algae | 0.787 |
| <i>Coscinasterias muricata</i> . | Echinoderm | 0.389 |
| <i>Perna canaliculus</i> | Bivalve | 0.361 |
| <i>Hormosira banksii</i> | Brown algae | 0.302 |
| <i>Halopteris</i> sp | Brown algae | 0.179 |
| <i>Cryptoconchus porosus</i> | Gastropods | 0.142 |
| <i>Aptos aptos</i> | Sponge | 0.120 |
| <i>Evechinus chloroticus</i> | Echinoderm | 0.083 |
| <i>Cominella adspersa</i> | Gastropod | 0.077 |
| <i>Cantharidus purpureus</i> | Gastropod | 0.071 |
| Chiton | Chiton | 0.068 |
| <i>Carpophyllum plumosum</i> | Brown algae | 0.065 |
| <i>Buccinulum lineum</i> | Gastropod | 0.056 |
| <i>Dendrodoris citrina</i> | Nudibranch | 0.043 |
| Red foliose algae | Red Algae | 0.043 |
| <i>Codium fragile</i> | Green algae | 0.012 |
| <i>Cominella virgata</i> | Gastropod | 0.009 |
| <i>Maoricolpus roseus</i> | Gastropod | 0.009 |
| <i>Styela clava</i> | Tunicate | 0.009 |
| <i>Sypharochiton pelliserpentis</i> | Chiton | 0.009 |
| <i>Dicathais orbita</i> | Gastropod | 0.009 |
| <i>Bulla quoyii</i> | Gastropod | 0.006 |
| <i>Cabestana spengleri</i> | Gastropod | 0.006 |
| <i>Penion sulcatus</i> | Gastropod | 0.006 |
| <i>Tethya ingalli</i> | Sponge | 0.006 |
| Anemone | Anemone | 0.003 |
| <i>Cominella maculosa</i> | Gastropod | 0.003 |
| <i>Cookia sulcata</i> | Gastropod | 0.003 |
| <i>Cystophora</i> sp | Brown algae | 0.003 |
| <i>Glossophora kunthii</i> | Brown algae | 0.003 |
| <i>Haustrum haustorium</i> | Gastropod | 0.003 |
| Opisthobranch | Gastropod | 0.003 |
| <i>Stegnaster inflatus</i> | Echinoderm | 0.003 |
| <i>Zonaria turneriana</i> | Brown algae | 0.003 |

8.5 Appendix E: Classification and Regression Trees

8.5.1 Intertidal Eastern sites

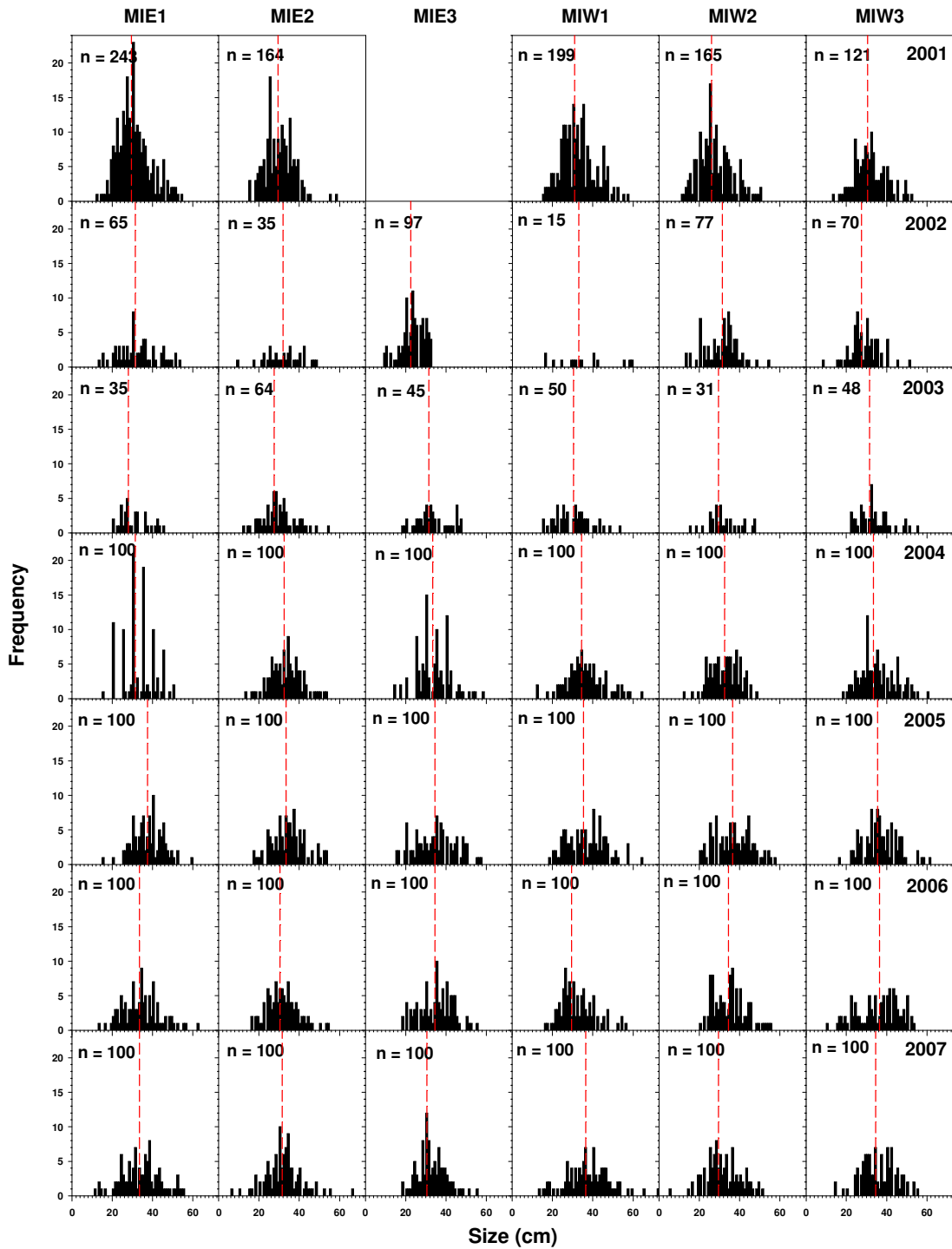


8.5.2 Intertidal Western sites

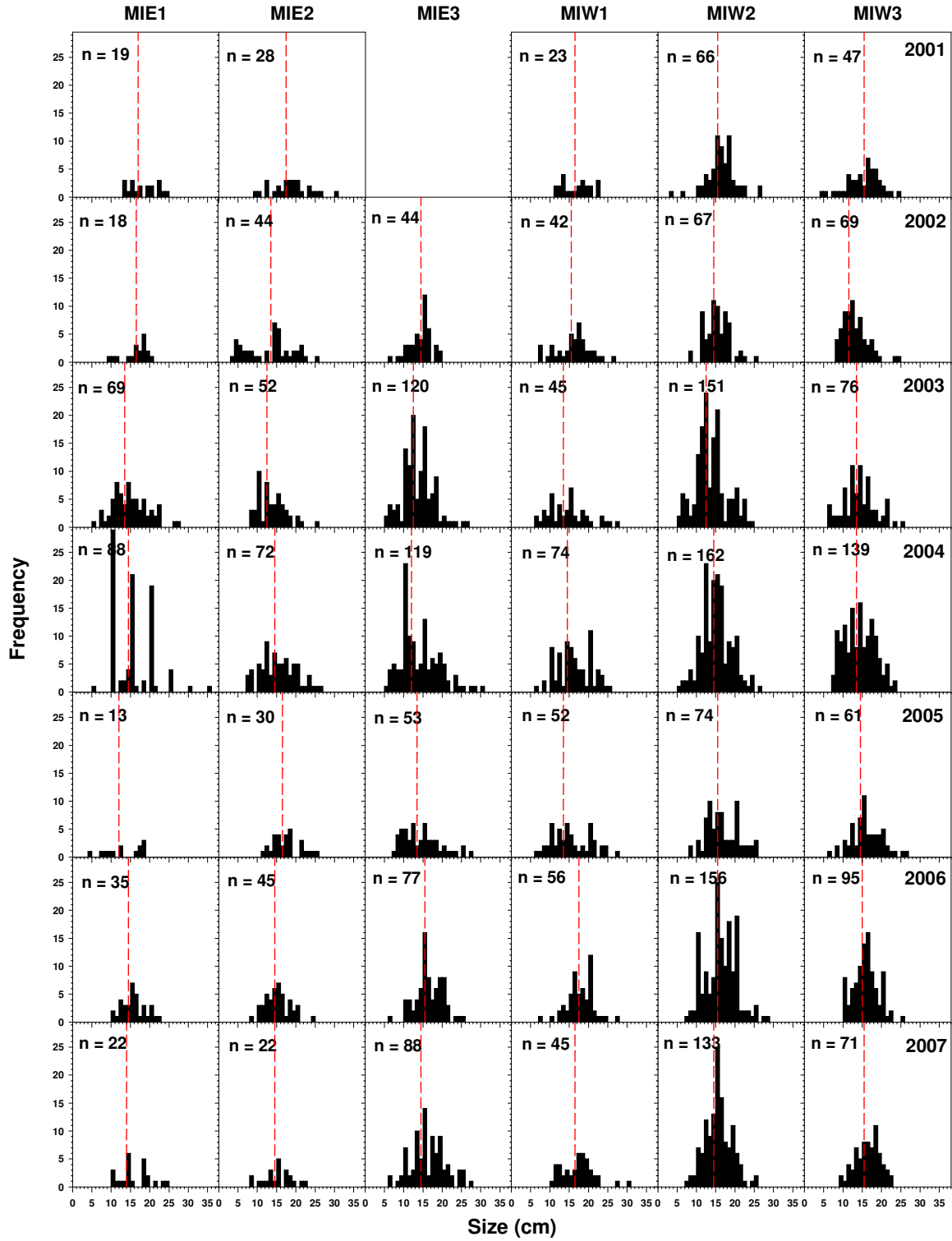


8.6 Appendix F. Size frequency histograms

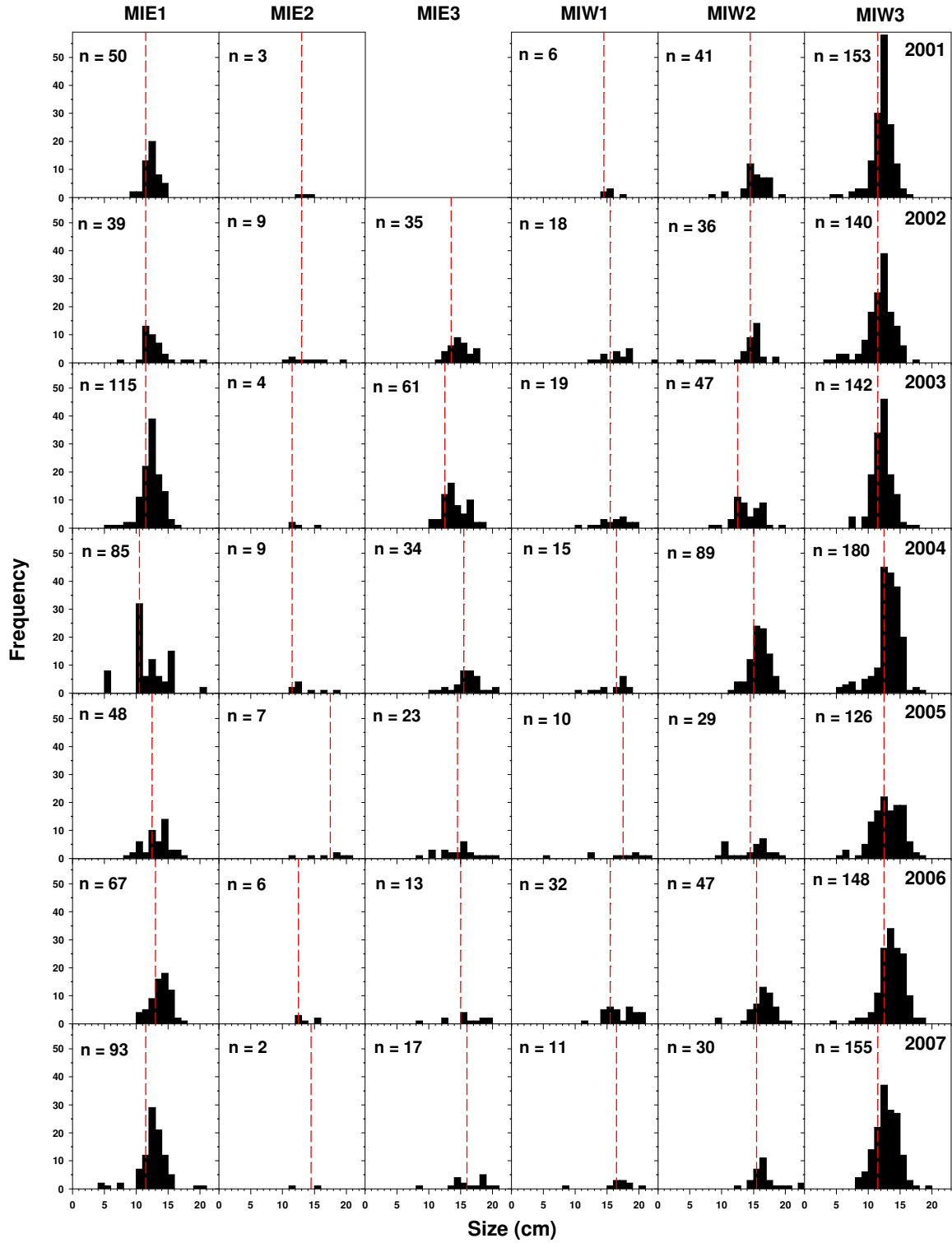
8.6.1 *Crassostrea gigas* (Intertidal)



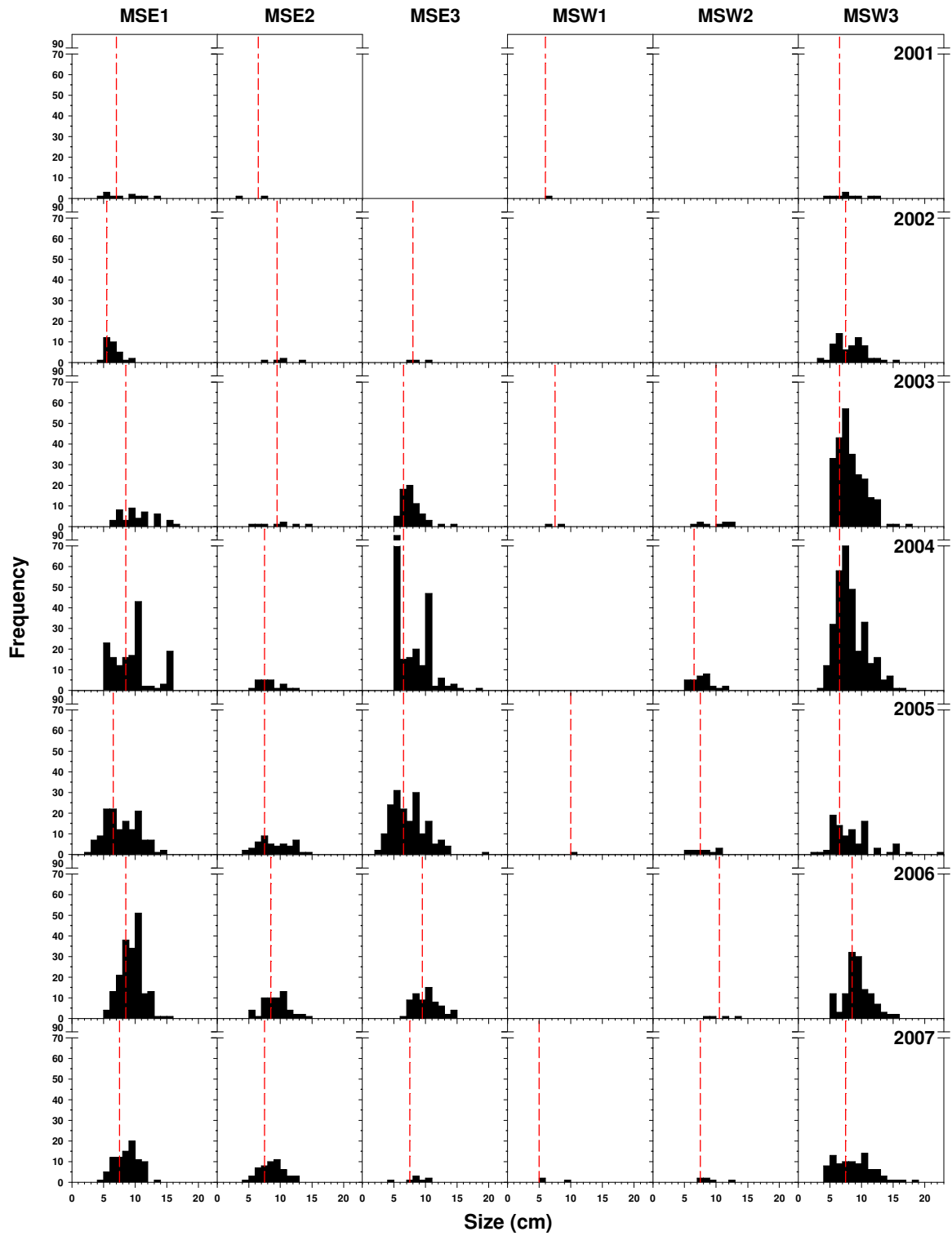
8.6.2 *Sypharochiton pelliserpentis* (Intertidal)



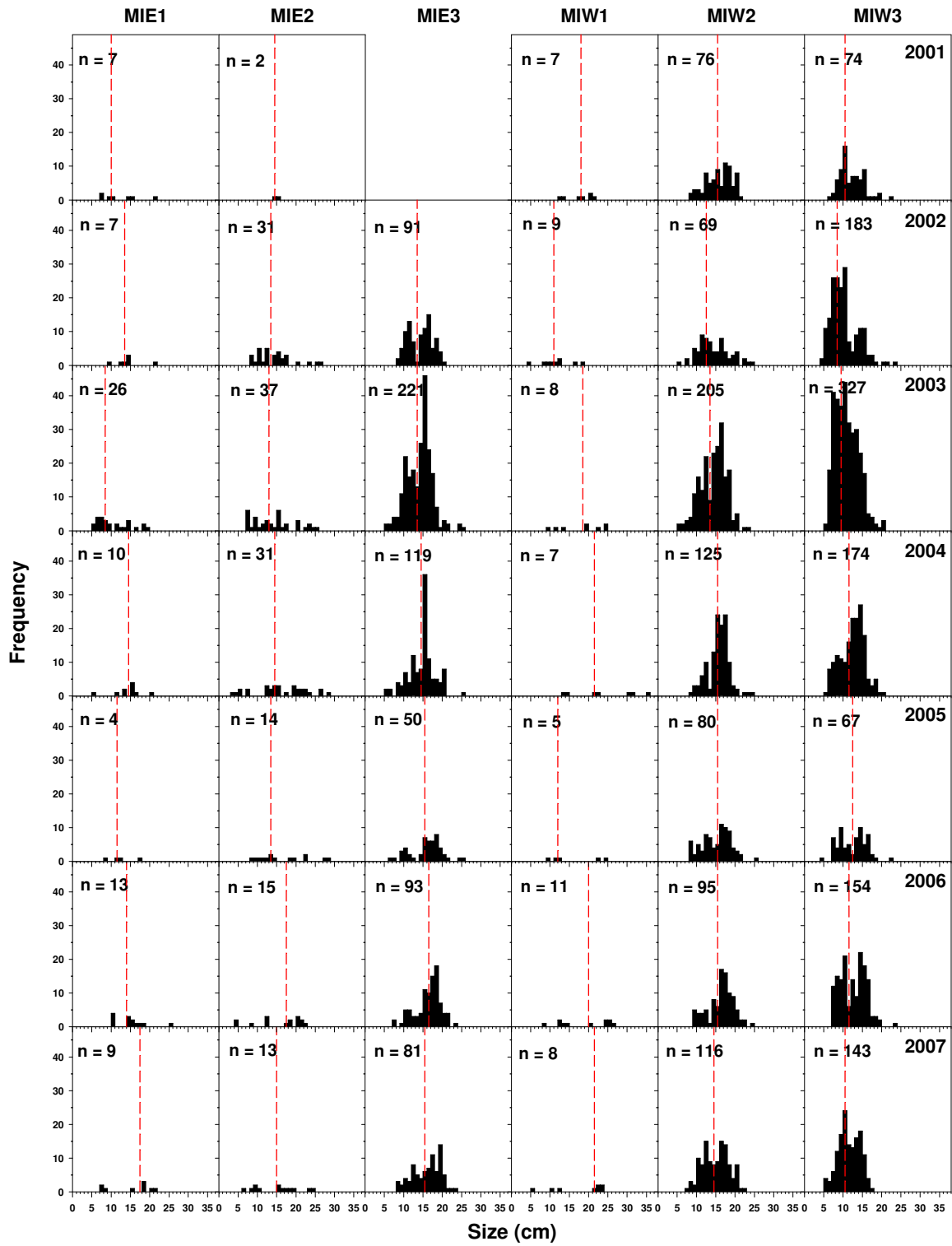
8.6.3 *Melagraphia aethiops* (Intertidal)



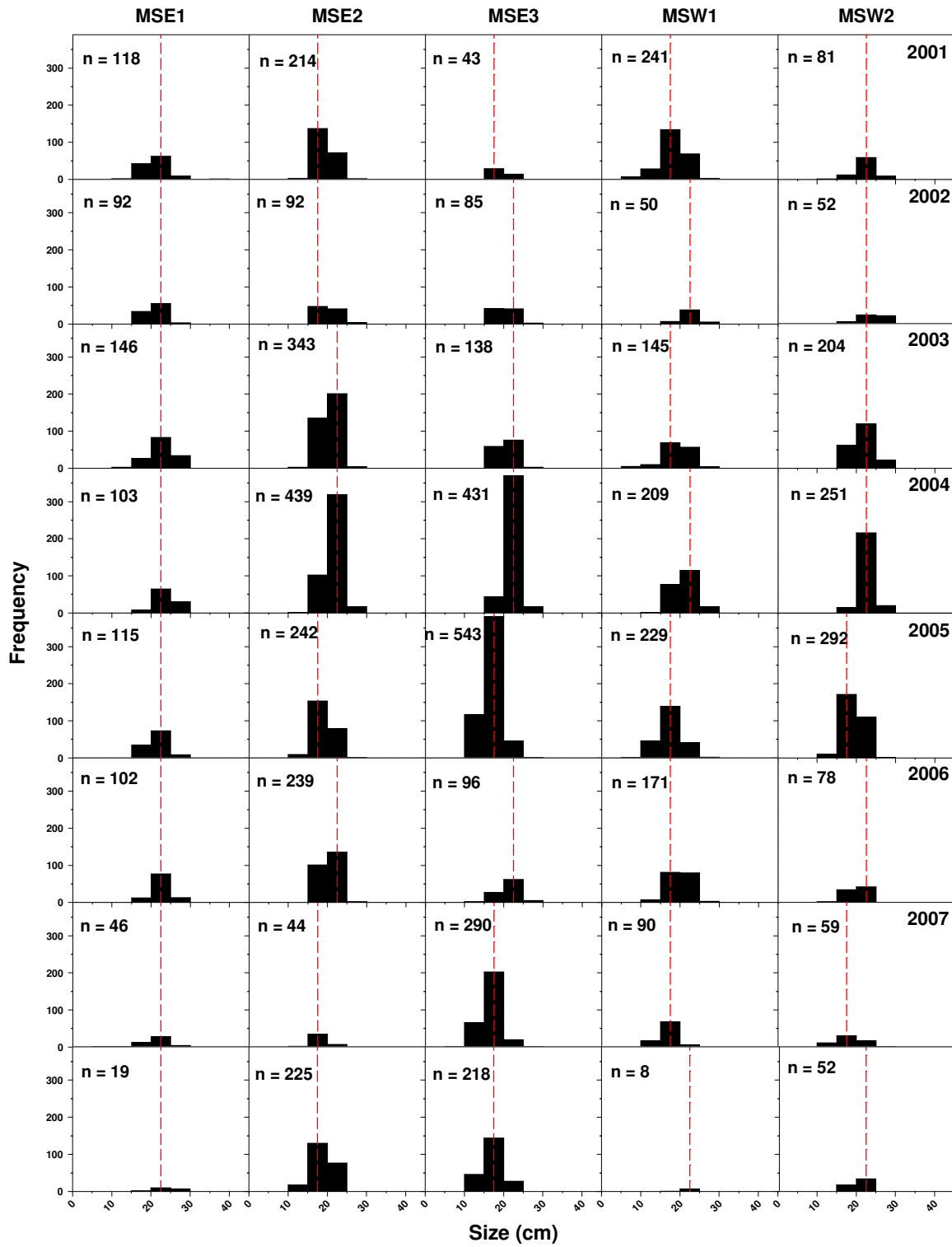
8.6.4 *Xenostrobus pulex*



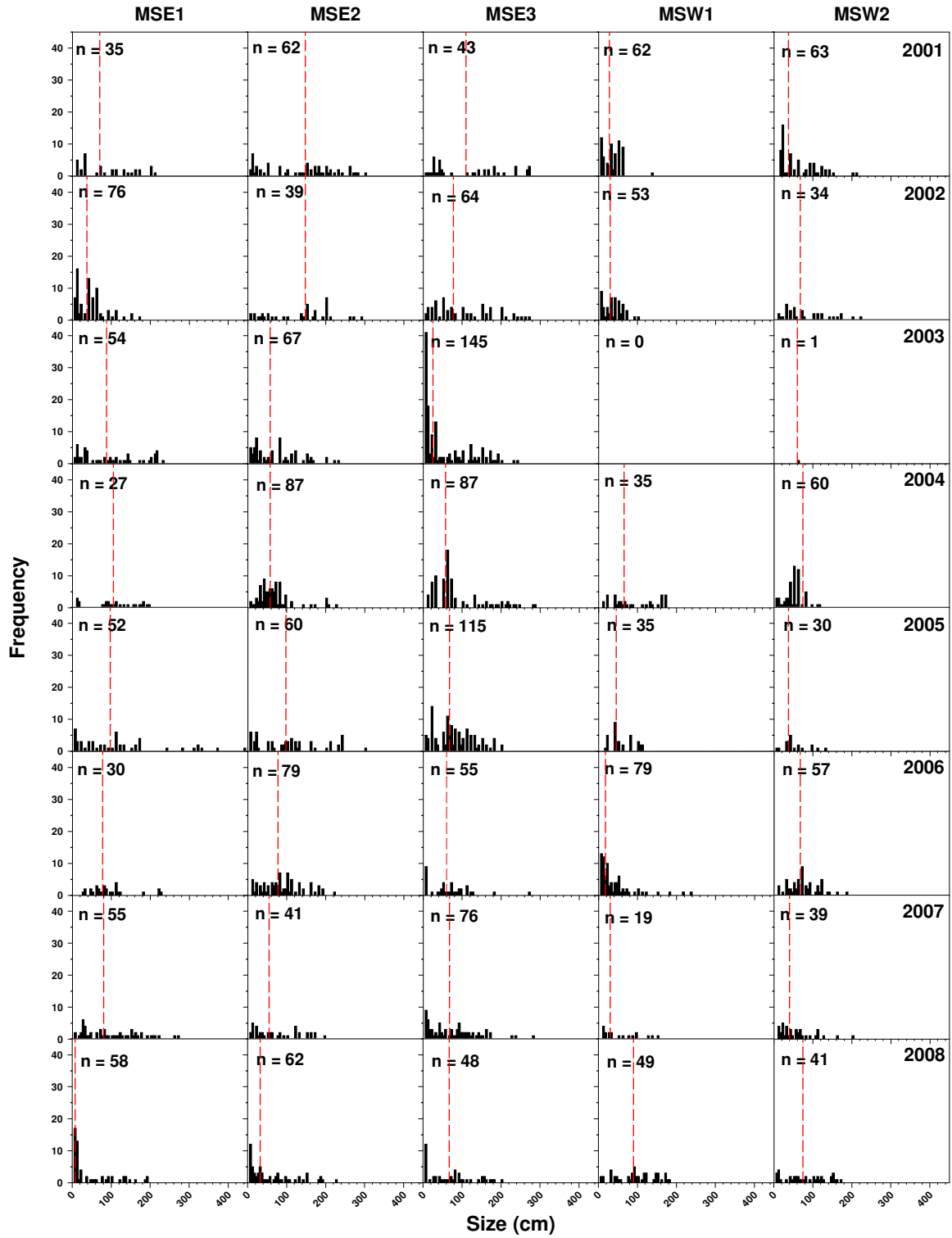
8.6.5 *Turbo smaragdus* (Intertidal)



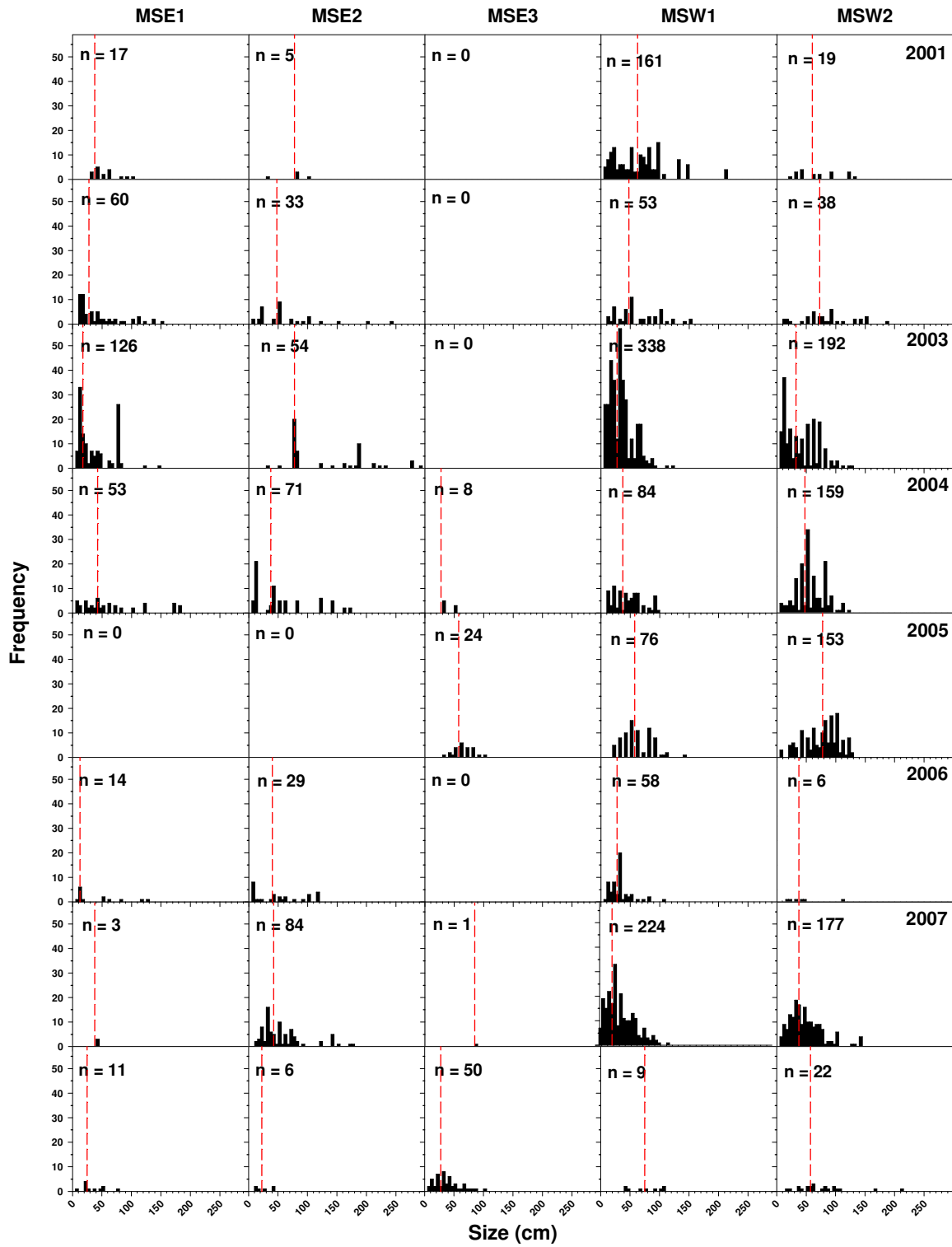
8.6.6 *Turbo smaragdus* (subtidal)



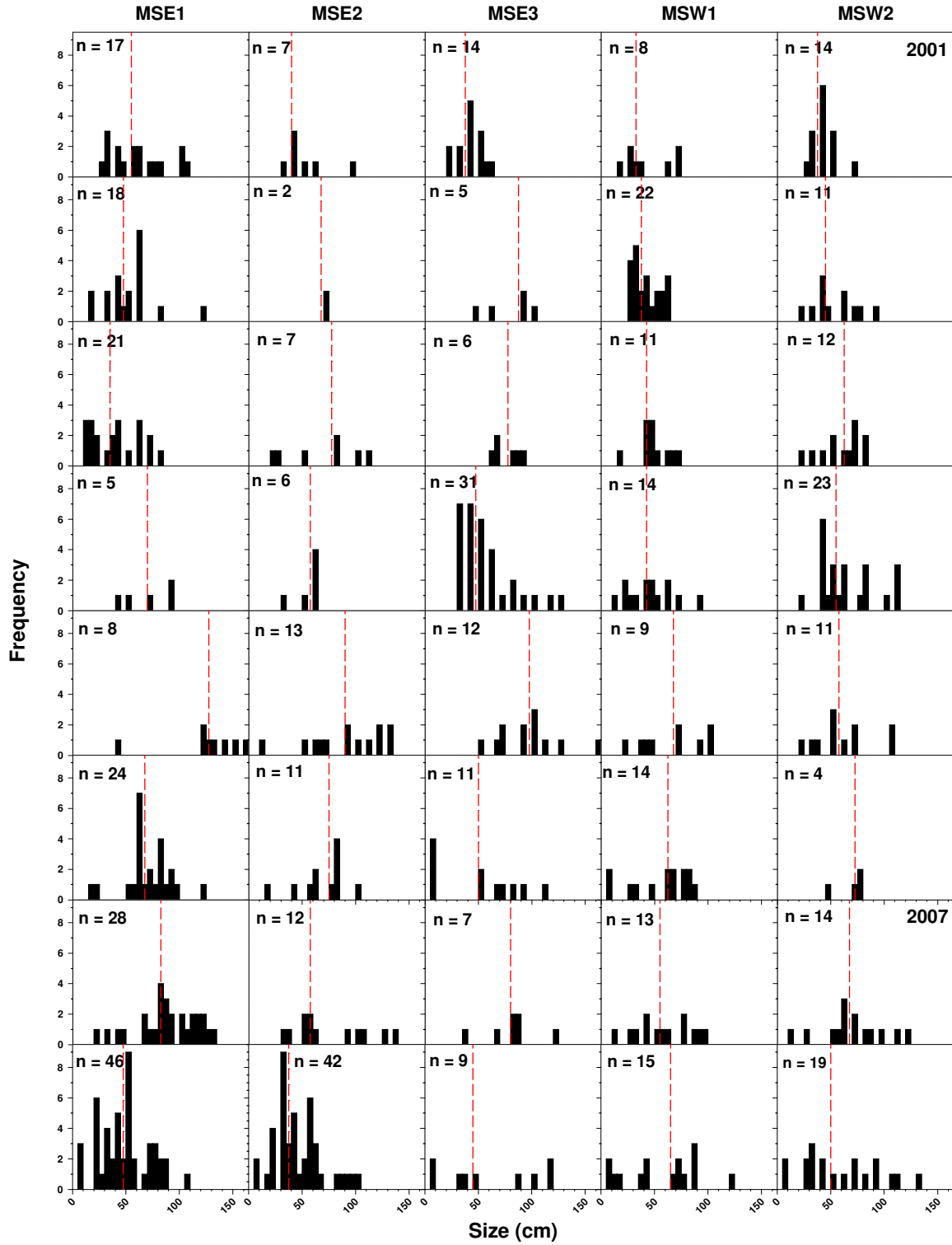
8.6.7 *Carpophyllum flexuosum* (Subtidal)



8.6.8 *Carpophyllum maschalocarpum* (Subtidal)



8.6.9 *Ecklonia radiata*



8.7 Appendix G. Chronological synopsis of sampling methodology

8.7.1 Intertidal Reef Monitoring

8.7.1.1 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 greater than 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 C). 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 (Figure 1); these were relocated using Global Positioning System (GPS) coordinates and site view photographs. Within each site, seven permanent quadrats (1/4 sq m²) 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) was 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 aforementioned 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 categorised 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.

8.7.1.2 2002-2003 (Ford et al 2004)

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

Sixty samples were taken on the reef (30 samples on each side of the reef, east and west, ten samples at each of three sites) to incorporate the important variability in this habitat. This number of quadrats was a result of one new site being added (to balance the design regarding sides of the reef) and the number of quadrats was increased from seven to ten 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 was decreased, given the consistency of the population structure of this organism. Each individual oyster was measured within a quarter of each $\frac{1}{4}$ m² 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).

8.7.1.3 2004-2007 (Ford et al 2006, 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 less than 100 oysters were measured within each site, more oysters within quadrats were measured until 100 oysters were measured at each site.¹² All other methods remained identical to those stated in the 2004 report (Ford et al 2004).

8.7.2 Subtidal reef monitoring

8.7.2.1 2001 (Ford et al 2001a)

Previous studies of sheltered shallow subtidal reef assemblages 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 those used in the LBMMP (Anderson et al 2005).

¹² 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.

The five sites were distributed between the east and west facing sides of Meola Reef (Figure 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 2 m depth below MLWS. Coordinates for each site were initially recorded by GPS. Sediment collectors were deployed at each site. Surface buoys (~10 cm by 5 cm) 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 20 m of the sediment collectors. In five of these quadrats all macroalgae and invertebrates greater than 4 cm and 4 mm, 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 two of the seven 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 5 cm. For the laminarian kelp, *Ecklonia radiata*, this included both the stipe length and the total length. The longest axis of solitary macro invertebrates was also measured to the nearest 5mm. Mobile organisms (e.g. crabs) were not enumerated.¹³

8.7.2.2 2002-2008 (Ford et al 2004, Ford et al 2006, Current Report)

Each year in late summer the same five sites were re-surveyed using the same methodology.

8.7.3 Sediment collection and total sedimentation rate calculation

8.7.3.1 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 with a heavy steel base. The inner 'trap' was made from PVC pipe, 37 mm in diameter and 500 mm 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 resuspension of the trapped material (Knauer and Asper, 1989). This first pipe (the trap) was then inserted into a metal pipe (the trap holder), 40 mm in diameter and 400 mm in length, which had been welded to a large, heavy, steel base. This construction ensured the 'trap' had a stable platform and anchor, decreasing the chance of its movement through wave or tidal action.

¹³ 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

All collectors were placed on the subtidal reef in areas surrounded by macroalgae. All traps were oriented vertically and placed at least 1 m 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), and then oven-dried at 65-80°C for 24 hours. The filter and contents were then weighed to determine total dry weight, which was then converted into a daily rate of sedimentation 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. The total trapped sedimentation rate is therefore comparable from 2001 until the present day.

8.7.4 Sediment textural analysis

8.7.4.1 **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 LBMMP 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.

8.7.4.2 **2002 – March 2003 (Ford, 2003)**

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.

8.7.4.3 2003– 2008 (Ford et al 2004, 2006, 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, 2003, 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:

- Hydrogen peroxide treatment (6-30%) until frothing ceases
- Bulking, homogenisation and sub-sampling
- 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.

According to {Ford, 2003 #3}, 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 of up to 60 grams of each individual dried sediment sample was then taken. Samples were thoroughly mixed beforehand to ensure 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.

8.7.5 Summary of methodology for sediment textural processing

8.7.5.1 2001 (Walker, 2001)

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

8.7.5.2 2002-May 2003 (Ford, 2003)

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.

8.7.5.3 April 2003 -2008 (Ford et al 2004, 2006, Current report)

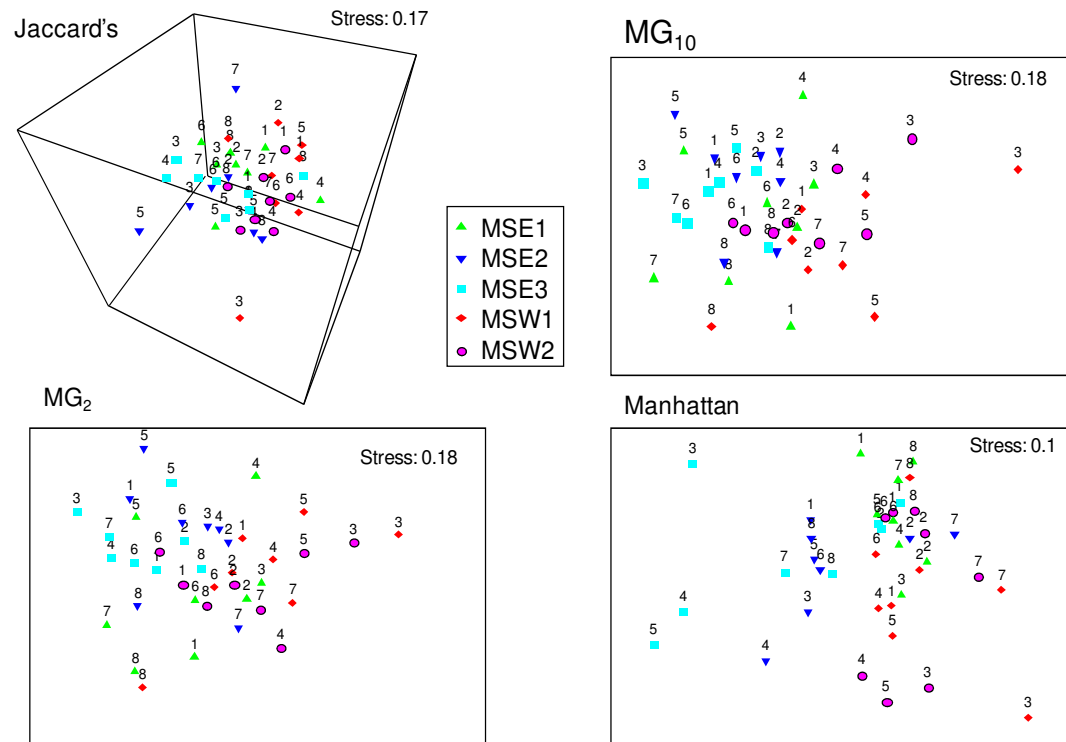
Sediments from each trap were pre-treated with hydrogen peroxide (to remove organics) and Calgon (to prevent clumping) prior to laser analysis. The percentage of sediment <63µm was determined by analysing the entire sample using a Malvern particle analyser.

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

8.8 Appendix H. Plots of dispersion

8.8.1 MDS plots of average subtidal count data (in 2 or 3 dimensions)

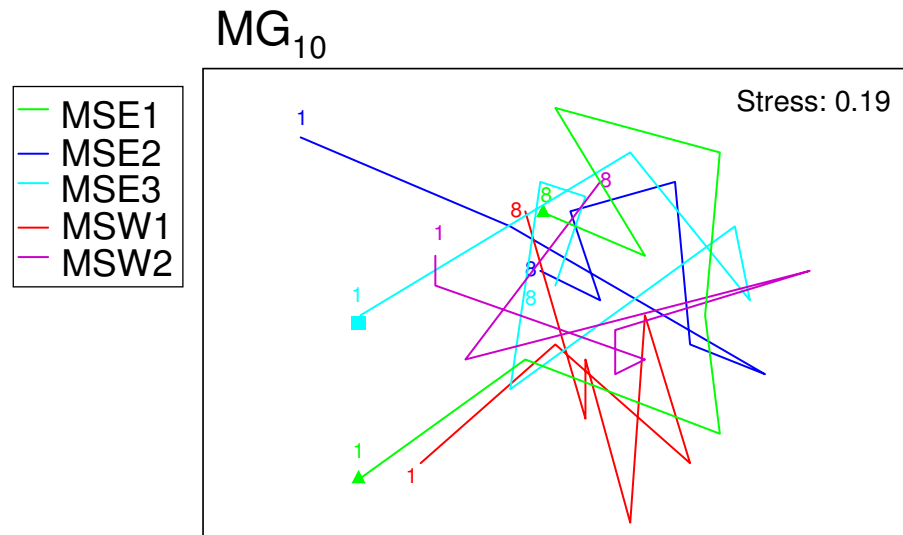
Plots are shown when averaged by year and site following the application of different similarity measures for the PERMDISP analysis. MG = Modified Gower. N = 5-7 for each point, 1 = 2001, 8 = 2008. An example plot is shown.



Appendix H Continued...

8.8.2 MDS plots of average subtidal cover data (in 2 or 3 dimensions)

Plots are shown following the application of different similarity measures for the PERMDISP analysis when averaged by year and site. MG = Modified Gower. N = 5-7 for each point. An example plot is shown.



8.9 Appendix I. MDS plots of average subtidal reef composition over time

Plots are based on Bray-Curtis similarities from ln transformed count and cover data. n= 30 to 35 for each year

