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State of the Environment Monitoring Program: Waitemata, Meola Reef - 2004

July 2004

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Executive Summary

High variability is evident in both intertidal and subtidal assemblages, however the patterns that are emerging from the data create a picture of a reef highly influenced by its hydrodynamic setting. A decrease in rocky reef substrate, due to an increase in percent cover of sand plus sediment plus shell, at some subtidal sites (MSE1, MSE2, MSW2), is not influencing biota at present, but is a trend that needs to be watched in the future. Sedimentation is again highly variable, but is of finer sediments than in Long Bay and shows some trends with hydrodynamic gradients, but no temporal trends indicating a change in quantity or composition of sediments over time.

Intertidal

The numerically dominant fauna on intertidal rocky reef at Meola over the past three years have been the pacific oyster *Crassostrea gigas* and the common cats eye *Turbo smaragdus*. The size frequencies of both of these species indicate that a full range of size classes from juveniles to adults are present on the reef, suggesting that it is still able to support new recruitment. Gradients or significant differences were observed in biota both with increasing distance along the reef from the southern shore, and on the more sheltered eastern side of the reef by comparison to the western side. The density of the gastropods *T. smaragdus,* and *Melagraphia aethiops,* the anemone *Anthopleura* sp. and the chiton *Sypharochiton pelliserpentis* all increased with distance along the reef. The percentage cover of *Gelidium* sp. seaweed decreased along the reef. The densities of the horn shell *Zeacumantus lutulentus* were higher on the intertidal sites on the eastern sides of the reef (particularly at MIE1 and MIE2) by comparison to western sites. All these patterns are thought to be a reflection of biota being more numerous in their preferred habitats within gradients of hydrodynamic energy on the reef from the most sheltered sites (close to shore on the eastern side) to the most exposed (near the channel on the western side). No changes in diversity indices or multivariate statistics indicate any pulse or press impacts at this time, however, continued monitoring will be needed to confirm this impression in terms of press impacts. This reef has no immediately comparable counterparts in the Auckland region, however information from the Long Bay Waitemata sandstone reefs indicates similar percentage cover of *C. gigas* and high numbers of *Turbo smaragdus* at Meola reef by comparison.

Subtidal

The subtidal sites were numerically dominated by the large brown seaweeds of *Carpophyllum* spp. and the common cats eye *Turbo smaragdus*, as is typical of reefs in the Hauraki Gulf. The size frequencies of both of these species indicate that a full range of size classes from juveniles to adults are present on the reef, suggesting that the reef is still able to support new recruitment. Fluctuations in the densities of the most common organisms; *C. maschalocarpum, C. flexuosum, T. smaragdus* and solitary ascidians, were responsible for the majority of the differences detected between sites. *T. smaragdus* showed an increase in density at Meola reef over the last 2 years, although the cause of this is unknown and the limited data available suggests this is not a region wide pattern. *Carpophyllum* spp. plants were longer and less numerous at sites on the eastern side of the reef by comparison to the western sites. This pattern is thought to be due to the combination of high flow and shelter from the wind induced waves on the eastern side of the reef, allowing plants to grow longer and form an adult canopy on the east. The most sheltered sites MSE1, MSE2 and MSW1 showed a high and increasing percent coverage of unconsolidated substratum (fine sediments, sand or shell). This is restricting the amount of substrate for reef dwelling fauna and although it does not yet appear to be negatively affecting densities of fauna, if this trend continues then rocky substrate fauna would logically be expected to decline at some point. Meola reef subtidal sites show lower diversity, due to less rare taxa, by comparison to Long Bay sites. This relatively low diversity at Meola reef is thought to be attributable to the relative isolation, hydrodynamically active nature of the site and high turbidity due to fine sediments in the water column (as outlined in the following section).

Sediments

The sedimentation rate at Meola reef (0.04 g/cm^2/d or 147 kg/m^2/yr) is comparable to that seen at Manly, Stanmore and Waiwera sites but less than half of that at Campbells Bay, Long Bay and Torbay. However, the texture of the sediments trapped at Meola reef is finer than at the Long Bay monitoring sites (92% mud content vs. 20 to ~70% mud content respectively), translating to higher turbidity at this site (pers. obs.). Sedimentation at Meola reef appears event driven, i.e. when high sedimentation is recorded it is usually recorded at all sites on Meola reef. Greatest sedimentation of fine particles was recorded occasionally but not consistently, on the sheltered Eastern side of the reef (site MSE1).

Recommendations

1. Monitoring should be continued in order to inform management decisions and to detect any gradual or sudden changes in community structure that would signify a pulse or press impact respectively.

2. The trend of increasing percentage cover of unconsolidated sediments in some subtidal sites should be carefully watched as further increases in this must logically have an impact on rocky reef biota at these sites.

3. Sediment trapping should be continued as this has provided new information, which has proven useful in linking the biota and environment, and may provide clues as to the source of any increased sedimentation that may lead to biotic changes in the future.

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1.0 Introduction

Meola reef has documented social, historical, geological, landscape and ecological values (City Design, 2000). The central location of Meola reef to the inner Waitemata harbour, the large flux of tidal waters that pass over it and its intertidal and subtidal components make it an ideal biological candidate for "State of the Environment" monitoring. Its central location to the Auckland CBD, a large urban catchment and a variety of proposed developments lends social value to this selection. Increased sediment runoff from the land and the associated effects of sedimentation (such as abrasion and smothering), are often the first and most sustained impact of terrestrial developments upon marine communities and can have profound consequences on the arrangement and composition of reef communities (Schiel and Foster 1986). Thus a program has been initiated utilising surveys of rocky substrate benthic communities (intertidal and subtidal) and sediment collectors to detect any ecological changes and determine if these are linked to sedimentation.

Meola Reef is bordered on its landward end by the Meola reserve a site of recreational use in this highly urbanised catchment, and one of the subjects of a draft management plan for the area (City Design, 2000). The reserve has been the site of various recently completed changes (in the last 6 weeks - pers comms, ACC staff), which should improve the quality of its runoff to the Waitemata harbour (City Design, 2000). The terrestrial landfill site (in use from 1960s to 1976 and covering 11 hectares) has been capped in order to stop any chance of potentially hazardous leachates from the site. Native plantings including ngaio, cabbage tree, flax, manuka, pohutukawa, karaka, karo and karamu have been completed along the estuary edge under the leadership of Project Meola, and should improve riparian filtration of runoff. Cattle's grazing upon Meola Reef has also been halted. In addition plans exist to increase both car parking and pedestrian access, therefore ensuring its continued and perhaps increased popularity as a site for recreation.

Meola reef has been the subject of one biological study before the initiation of this monitoring programme. Auckland War Memorial Museum staff have surveyed Meola reef as part of a harbour wide study (Hayward et al., 1999) and have recognised it as "an ecosystem unique within the Waitemata harbour and probably the best sheltered harbour, hard rock, intertidal and shallow subtidal suite of habitats in the Auckland region."

A zonation pattern was documented on the reef from high tide salt marsh vegetation, descending through stunted mangrove forest, oyster-dominated intertidal reef, then Ecklonia and Carpophyllum dominated sublittoral fringe that sheltered a diverse and amazingly colourful sponge garden. One hundred and fifty five different intertidal plants and animals were recorded living on the basaltic Meola and Torpedo Bay Reefs. The presence of a sponge garden in the lower intertidal at depths shallower than expected (normally seen at water depths of 5-10m) was attributed to the high current flow and turbid water at the Meola reef mimicking conditions reminiscent of those seen at greater depths.

Monitoring of benthic biota at Meola reef has been ongoing in the intertidal from December 2000 and yearly in the subtidal from August 2001 (Ford *et al.*, 2001a, Ford *et al.*, 2001b). In these reports intertidal communities showed significantly different assemblages between communities on the East and West sides of the reef based on the abundances of some gastropod species and the anemone *Anthopleura* sp., however no seasonal pattern was apparent from bimonthly sampling over the period of a year. The sampling strategy was subsequently changed so that sampling was conducted annually. In addition, replication was increased to 30 replicates on each side of the reef (East vs. West) to detect a change of 20% in reef populations and community variables on either side of the reef. The subtidal sampling showed higher variability than the intertidal sites in terms of composition, but had a similar diversity. Subtidal sites closest to the channel, which would be expected to see higher rates of flow, saw longer stands of macroalgae (up to 3m) than sites closer to Meola reserve. Both reports recommended the use of subtidal sediment traps to try and link more closely sedimentation and biological data at Meola reef. The amount, and in most cases texture, of sediment deposited (excluding resuspension) has therefore been quantified using sediment traps approximately monthly at each of the five subtidal sites since October 2001.

Sites in the intertidal and subtidal at Meola reef were numerically dominated by a few taxa. *Turbo smaragdus* was a numerically dominant component of both the intertidal and subtidal communities. The intertidal community was also characterised by the oyster, *Crassostrea gigas,* and the subtidal community was additionally characterised by seaweeds of *Carpophyllum* sp. Size frequency histograms showed that these populations were dominated by adults but were also capable of supporting new recruits.

2.0 Methods

2.1 Intertidal Surveys

This survey aimed to record the number, size, distribution and percentage cover of all macroscopic flora and fauna (>4mm) inhabiting intertidal Meola reef. Intertidal sampling of Meola reef commenced in December 2000, and was carried out bimonthly until October 2001 (Ford *et al.*, 2001a). It was recommended in that report that there be a reduction of ~70% in sampling intensity, and also that annual sampling would be more efficient, therefore a further 2 sampling events took place in October 2002 and 2003. The sampling methods used in 2002 and 2003 were different to those used previously, being designed around the findings of a power analysis (Ford *et al.*, 2001a).

2.1.1 Site location

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

Within each site 10 permanent quadrat locations (1/4 m²) were marked on the reef at 2-3m intervals (labelled stainless steel pegs were cemented to the substrate to mark 2 corners over which the quadrat was placed). Thus 60 quadrats were surveyed overall, 30 on each side of the reef. The approximate position of each quadrat was mapped for all sites (Appendix B).

Table 1.
New site codes (this report) and their relationship to old site codes from the previous report (Ford *et al.*, 2001a).

New Site Code	Old Site Code
MIE1	4
MIE2	2
MIE3	6
MIW1	1
MIW2	3
MIW3	5

2.1.2 Survey Methodology

In each 1/4m² quadrat, organisms were identified down to the lowest practical taxonomic level. All organisms (excluding *Crassostrea gigas*, see below) were then counted and measured using vernier callipers. Measurements were always taken along the longest axis of the organism. In the case of gastropods either shell length or shell width (dependant on species shell form) were measured.

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

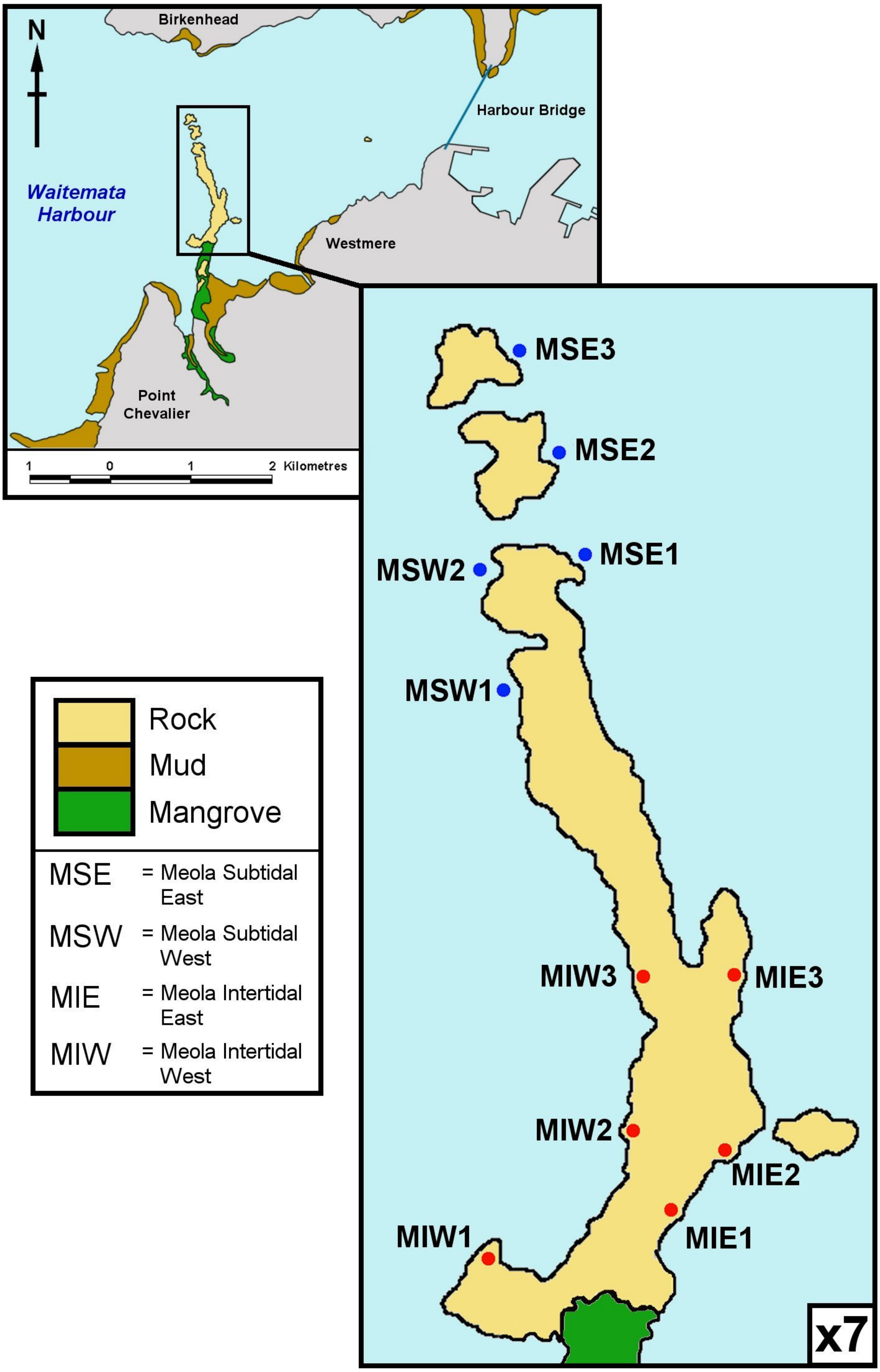

Figure 1.
Map of Meola Reef showing all intertidal and subtidal sampling sites.

Throughout all samplings on Meola reef, the Pacific oyster *Crassostrea gigas* has been the numerically dominant organism in all surveyed quadrats. To evaluate densities of oysters, each 1/4m² quadrat was divided into quarters and one quarter (1/16m²) was evaluated. Within this quarter quadrat, each individual oyster was measured to the nearest millimetre using vernier callipers.

2.1.3 Statistical analyses

Multivariate statistics were used to analyse community data. A Bray-Curtis similarity coefficient was calculated on log (x+1) transformed counts for all species at all times. This was then used to assess similarity in community structure between sites and years. The log (x+1) transformation assures both common and rare species have influence over the multivariate results (Clarke and Warwick, 1994). Multi-Dimensional Scaling (MDS) ordinations were used to provide a visual representation of the patterns between sites, between the East and West side of the reef and between years. A greater distance between points in MDS plots indicates less similarity of communities. Multivariate stress is shown on all ordinations as an indication of the accuracy of the 2-d representation of a many dimensional data cloud. Stresses less than 0.2 indicate a usable diagram, although not too much emphasis should be placed on the details of the plot if this value exceeds 0.15 (Clarke and Warwick, 1994). Non-parametric multivariate analysis of variance (NPMANOVA) (Anderson, 2001) was used to test 2002 and 2003 data for differences in SITE, E/W (East vs. West) and YEAR, and also to find any interactions between these factors. The similarity percentages (SIMPER) routine in the programme Plymouth Routines in Multivariate Ecological Research (PRIMER) was then used to determine which species were responsible for the differences seen by NPMANOVA and the density of those at each combination of site and year were plotted.

All count data was analysed for species diversity using the three diversity indices described below;

Margalef species richness (d) is calculated from d = (S-1) / *log N*.

Where S = number of species and N = total number of individuals.

Shannon Weiner Diversity is the most common diversity measure, and is calculated as follows: $H' = -\ ipi\ (log\ pi)$

Where p = proportion of the total count arising from the ith species.

Pielous evenness index is calculated from $J' = H'$(observed) / H'_{max}

Where H'_{max} = maximum possible diversity which would be achieved if all the species were equally abundant (=*log* S)

Dominant categories of cover were selected and analysed for change with SITE, YEAR, E/W (East vs. West) and all possible interactions of these factors. ANOVA on Arcsin transformed percentage data was used for this analysis. ANOVA was also used to analyse log (x+1) transformed count data for *Turbo smaragdus* and *Crassostrea gigas* (*C. gigas* count only has 20 samples, therefore count was only analysed for E/W and YEAR factors). In reporting of ANOVA results significant P values (<0.05%) are tabulated in bold font. Pairwise comparisons were completed on any significant factors found from these ANOVAs.

In agreement with the previous report (Ford *et al.*, 2001a) the Pacific oyster, *Crassostrea gigas* and the gastropod, *Turbo smaragdus* were the numerically dominant organisms surveyed on Meola reef. These two species were therefore selected in this report for the examination of population structures. Size frequency histograms were constructed for these species at each combination of site and year. Population structure was then visually examined to identify any changes with time or site.

The lack of data for the MIE3 site in 2001 in graphs is due to the design change following the Ford *et al.*, (2001a) report, which saw the addition of the MIE3 site in 2002.

2.2 Subtidal surveys

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

2.2.1 Site location

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

2.2.2 Survey Methodology

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

2.2.3 Statistical analyses

Community level analyses were undertaken using multivariate statistics in a similar way as for the intertidal surveys (section 2.1.3). Non-parametric multivariate analysis of variance (NPMANOVA) (Anderson 2001) was used to test for the effect of site, time and site by time interactions for the subtidal data. The SIMPER routine and visual examinations were then used (where applicable) to determine which taxa caused differences seen in the multivariate analysis.

Counts from the 4 most numerically dominant taxa were analysed for site, time or site by time interactions and average densities (± s.e.) per site and year were plotted where appropriate. For the examinations of population structures, two species were selected that were abundant at all sites. The species chosen for the subtidal were *Carpophyllum maschalocarpum* and the gastropod *Turbo smaragdus*. Size-frequency histograms were then constructed for these species at each combination of site and time. These plots were then visually compared in order to determine any changes in population structure over time or between sites.

Dominant categories of cover were selected and analysed for any change with site, time or site by time interactions (ANOVA on Arcsin-transformed percentage data). In reporting of ANOVA results significant P values <0.05 are tabulated in bold font.

2.3 Sedimentation measurement

2.3.1 Introduction

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

2.3.2 Sedimentation rate definition

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

2.3.3 Sediment traps and placement

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

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

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

2.3.4 Sediment processing

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

2.3.5 Statistical analyses

ANOVA were used to ascertain whether significant differences existed among the 5 sites or over time in terms of the total amounts of sediment collected or the volume of sediments <63µm.

3.0 Results

3.1 Intertidal survey

3.1.1 Community analyses

A total of thirty-six taxa were found in the intertidal quadrats from 2001 to 2003 (Appendix C).

Multi Dimensional Scaling (MDS) Ordinations are shown for all sampling years (Fig. 2) and sites over time (Fig. 3). In addition all quadrats for each site were summed and this sum was plotted on the same MDS plot to visualise the similarity or distinctness of the sites (Fig. 4). Some relationships can be seen from visual examination of these charts, especially the distinct East/West divide in 2001 (Fig.2), the divide between 2002 and 2003 data at MIE3 (Fig. 3) the relative distinctness of sites and the greater similarity of MIE3 sites to MIW sites than to MIE2 or MIE3 (Fig. 4). NPMANOVA of 2002 and 2003 count data shows significant YEAR*E/W (p=0.003) and YEAR*SITE (p=0.001) interaction factors affecting community structure. This means that East and West sites had distinct communities, (which were driven by the distinctiveness of sites MIE1 and MIE2) and these communities changed significantly between 2002 and 2003 but in different ways. Also communities were distinct at the site level over time, but the change to each sites community between 2002 and 2003 was not in any consistent direction across all the sites.

SIMPER analysis was used to determine the taxa mainly responsible for the changes detected in the NPMANOVA. Average similarity of individual sites ranged from 48% at MIE2 to 74% at MIW2. The species that were characteristic of most sites were *Turbo smaragdus*, *Sypharochiton pelliserpentis*, *Anthopleura* sp., *Melagraphia aethiops* and *Zeacumantus lutulentus* (Fig. 5). The differences that were driving any East/West differences were mainly due to high average densities of *Z. lutulentus* (30m^{-2}) and low average densities of *Anthopleura* sp. (7m^{-2}) at MIE1 and MIE2 when compared to the rest of the reef (remaining 4 sites average = *Z. lutulentus* (5m^2), *Anthopleura* sp. (24m^2)). The taxon that contributed the most to the difference seen with SITE was *T. smaragdus*. On both sides of the reef the density of this gastropod increased further out along the reef, from sites 1 through to sites 3. This pattern also occurred for *M. aethiops* on the western side, but not on the eastern side when relatively high densities are found at MIE1. Densities of *Anthopleura sp.* were also higher at the outer reef sites, with the highest density of 81m^2 found at MIW2. This pattern was also seen in *S. pelliserpentis* densities, but to a lesser degree.

Species diversity at the various sites and sampling times was also analysed using 3 measures of diversity (Fig.6). These indexes showed no significant trends in diversity over the sampling period.

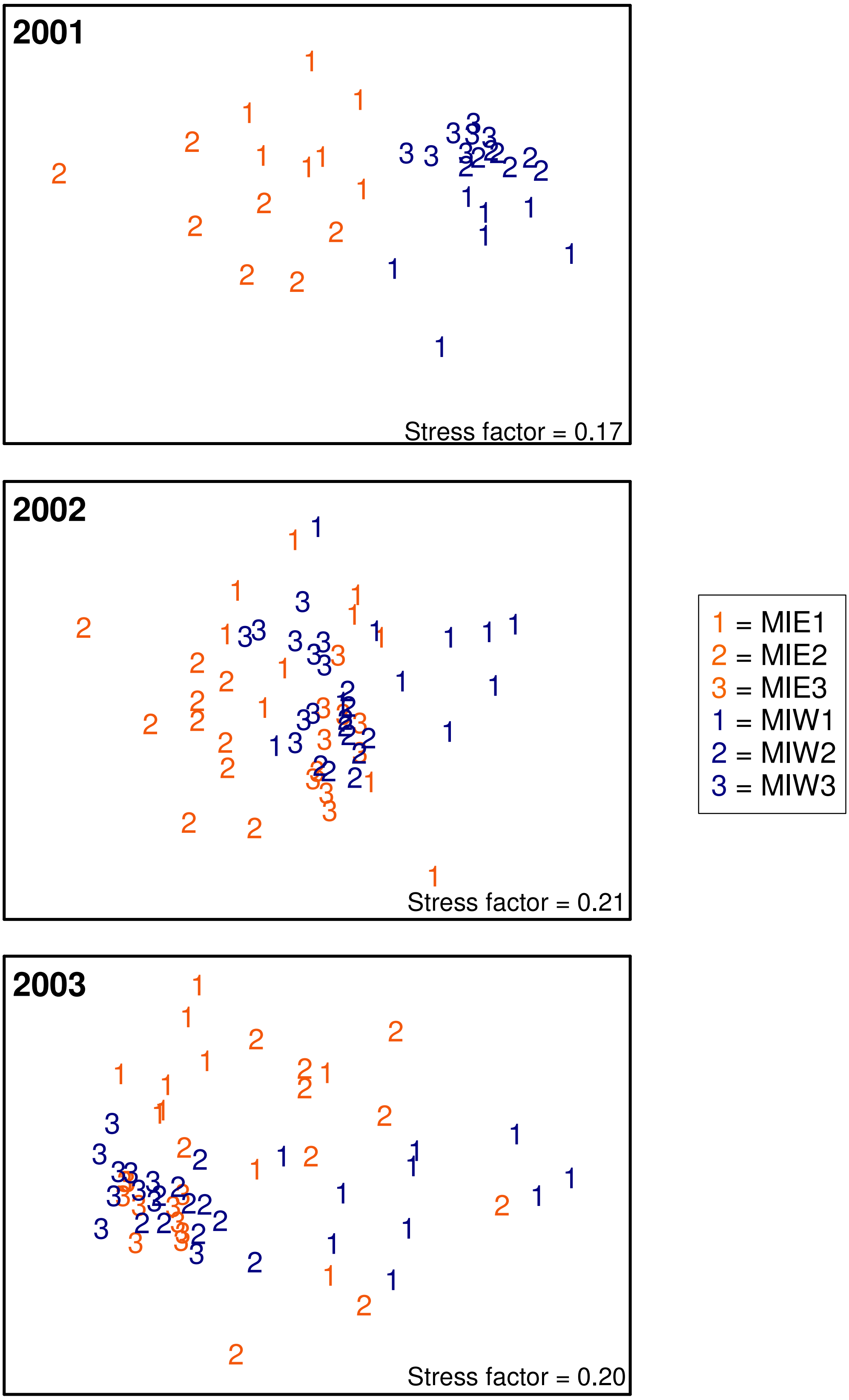

Figure 2.
Multi Dimensional Scaling (MDS) Ordination plots showing relationships between intertidal sample sites each year. Each label equates to a quadrat.

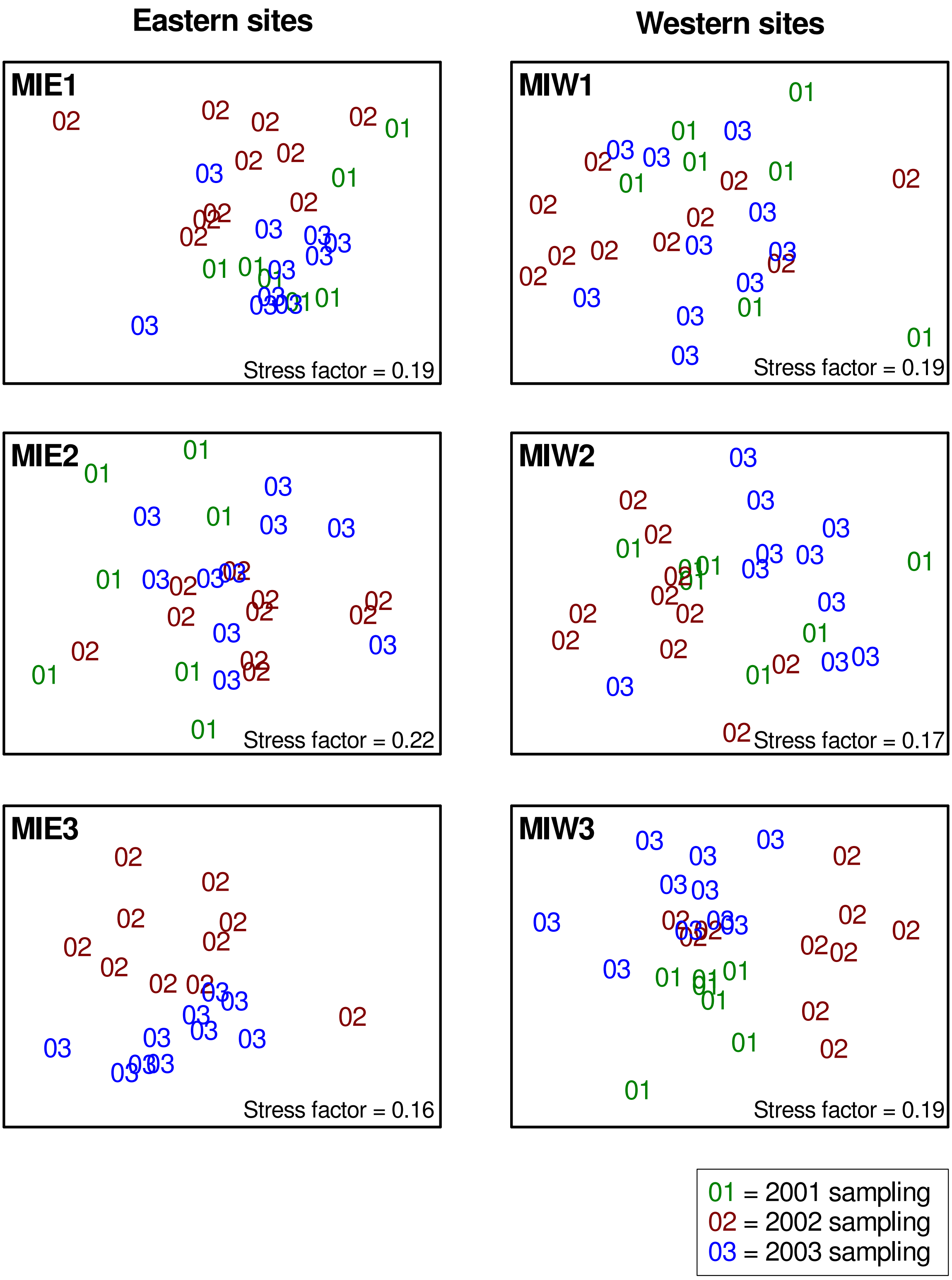

Figure 3.
Multidimensional Scaling Ordination plots showing relationships between sampling years for each intertidal site. Each label equates to one quadrat.

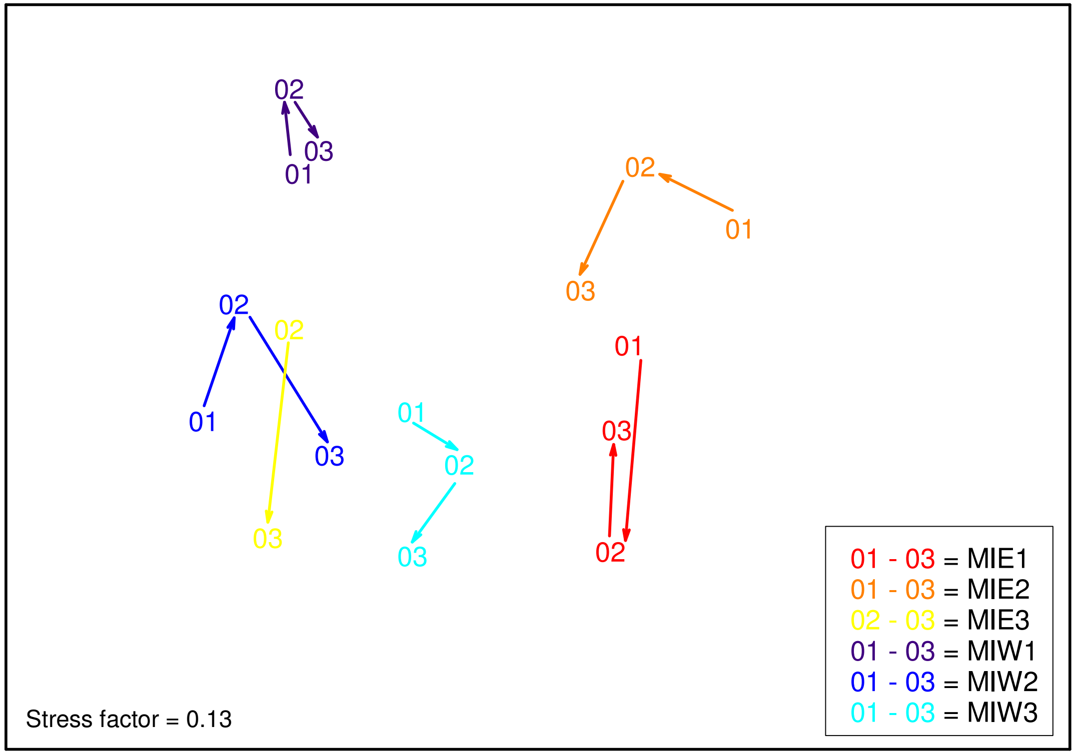

Figure 4.
Intertidal community structure changes during the time of sampling (2001 to 2003). Each label represents the sum of 10 quadrats. Note: 2001 data had less replication (n = 7) than later data therefore average count values were inserted to make the level of replication for 2001 up to 10 and make the maximal use of the existing 2002 to 2004 data.

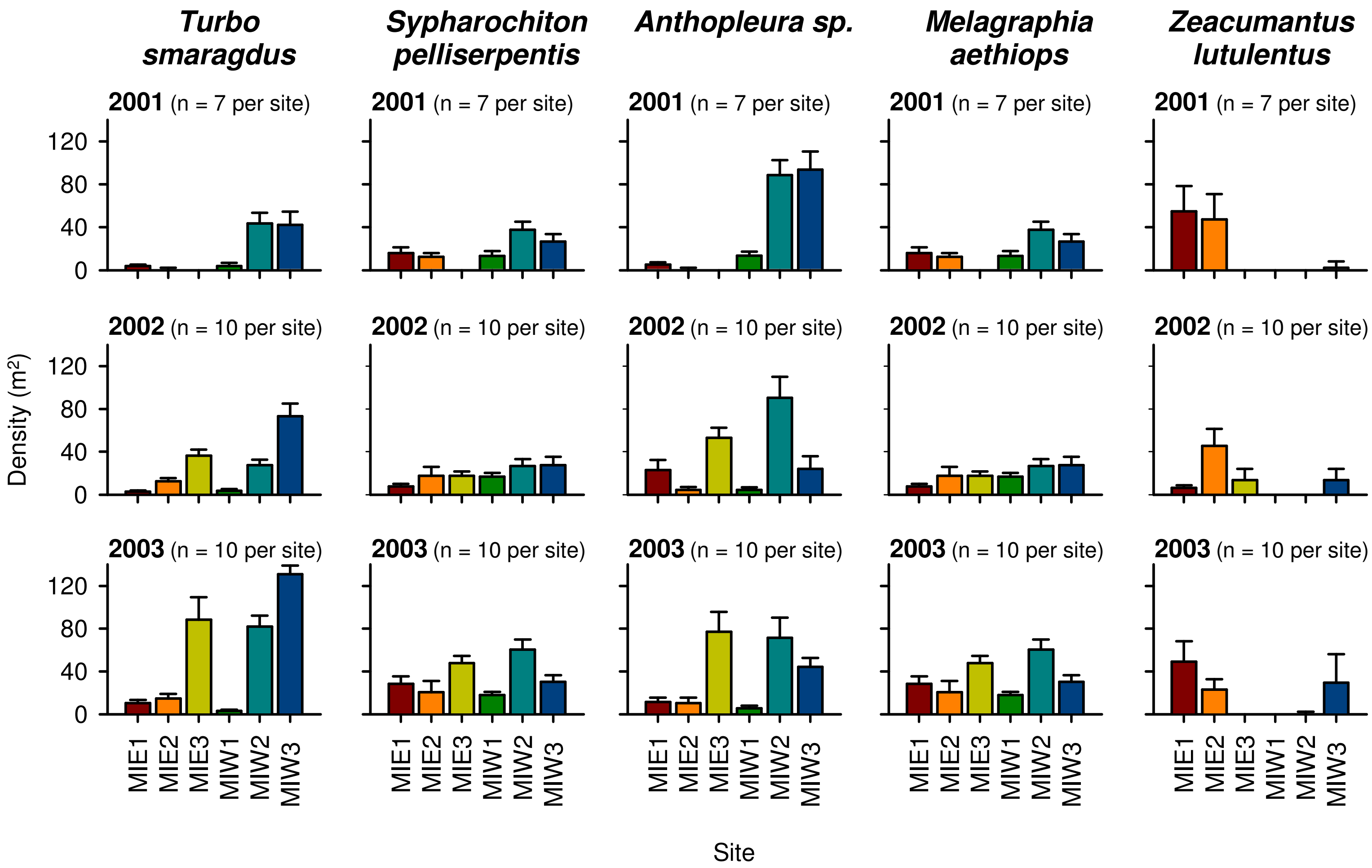

Figure 5.
Densities of *Turbo smaragdus, Sypharochiton pelliserpentis, Anthopleura* sp., *Melagraphia aethiops* and *Zeacumantus lutulentus* per m² at intertidal sites in October 2001, 2002 and 2003. Note: the lack of a bar at MIE3 in 2001 is because this site was only surveyed from 2002.

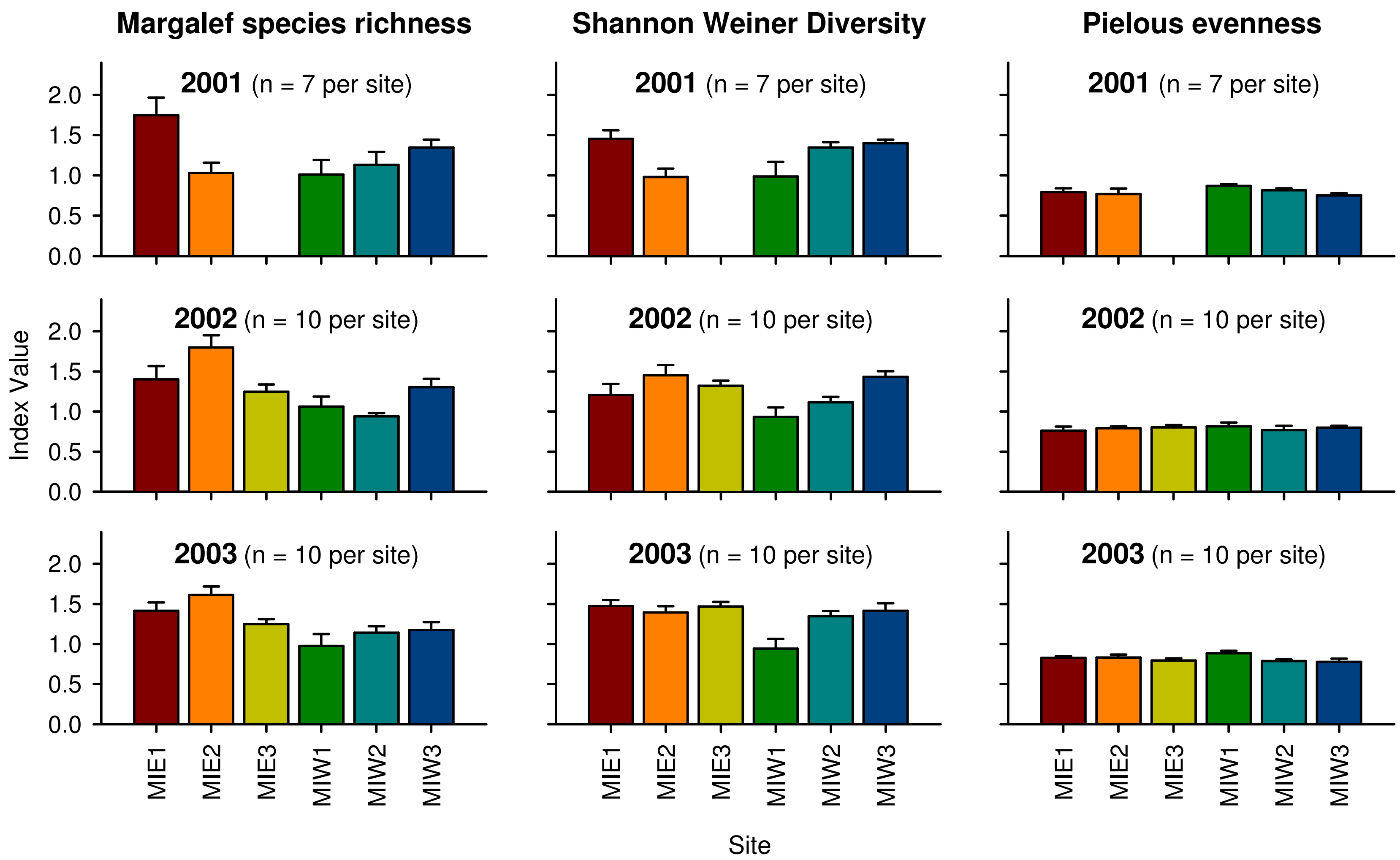

Figure 6.
Plots of diversity of species against intertidal site for October 2001, 2002 and 2003 samplings (Bars = std. Err). Note: the lack of bar at MIE3 in 2001 is because this site was only surveyed from 2002. Higher index values equate to a higher level of diversity.

3.1.2 Population analyses

The numerically dominant organism on Meola intertidal reef was the Pacific oyster, *Crassostrea gigas*, averaging 422m^{-2} ±199 s.d. over the three sampling times (October in 2001, 2002 and 2003). At sites MIE1 and MIE2, *C. gigas* densities appeared consistent over the three years (Fig.7). There were large fluctuations in oyster densities at MIW1, MIW2, MIW3 and MIE3 between 2002 and 2003 (no data for 2001 at MIE3). However, ANOVA for *C. gigas* densities in 2002 and 2003 showed no YEAR effect for this data (Table 2). The population distribution of *C. gigas* appeared normally distributed, with most individuals in the 25-35mm size range (Fig.8), although low numbers at some sites make interpretation of these data questionable. A decline in oyster densities from the size frequency data is apparent through time for most sites in Figure 8. Between 2001 and 2002 this decline is due to our methodology changing to sample less oysters, between 2002 and 2003 this change can be attributed to chance selection of quarters of quadrats within which oysters were counted, whilst densities overall remained stable (Fig. 7). For future surveys enough quadrats will be sampled at each site so that at least 100 oyster sizes are measured, to avoid this problem.

3.1.3 Percentage cover analyses

ANOVA was used to analyse data from the four main percentage cover types from 2002 and 2003 (Table 2). Bare rock cover data showed a significant E/W*SITE factor ($p=0.003$), pairwise-comparisons showed a significantly higher percentage cover of bare rock at MIW1 than the other western sites (Fig. 9). In addition, MIW1 had significantly more bare rock than MIE1 ($P<0.01$, Fig. 9). Sediment cover data analysis showed a significant E/W factor, where percentage cover of sediment on the East side of the reef was higher than that on the West ($p=0.015$, Fig. 9). Finally, *Gelidium* sp. cover was significantly lower at sites 3 (MIE3 and MIW3) when compared to the inner reef sites ($p<0.001$, Fig. 9). Percentage cover of *Crassostrea gigas* was also assessed (Fig.9). Average cover was 48.4% ± 18.4 s.d. ($n = 155$), and ranged between 32% and 62% per site for the three sampling times. An ANOVA using data from 2002 and 2003 indicates a significant E/W*SITE factor ($p=0.001$). Pairwise comparisons showed no significant difference in percentage cover between MIE3 and MIW3, but higher oyster cover was present at MIW2 when compared to MIE2 and lower cover was present at MIW1 when compared to MIE1 ($p<0.01$ for both). There was also a general trend on the reef whereby *C. gigas* cover increased further out along the reef (i.e. from sites 1 through to sites 3, particularly on the western side of the reef).

Table 2.
P values for ANOVA from Meola intertidal sites (E/W = East vs. West).

Factor	Density *Turbo smaragdus*	Density *Crassostrea gigas*	% cover *Crassostrea gigas*	% cover Bare rock	% cover Sediment	% cover *Gelidium* sp.
E/W	0.671	0.309	0.681	0.082	**0.015**	0.916
YEAR	0.374	0.128	0.876	0.243	0.346	0.292
SITE	0.553		**<0.001**	**<0.001**	0.922	**<0.001**
E/W*YEAR	0.094	0.965	0.931	0.912	0.235	0.094
E/W*SITE	0.873		**0.001**	**0.003**	0.164	0.779
YEAR*SITE	0.055		0.753	0.281	0.981	0.946
E/W*YEAR*SITE	0.1655		0.391	0.202	0.252	0.398

The gastropod, *Turbo smaragdus* was the second most abundant organism on Meola reef, averaging 34m² ± 38 s.d., ranging between 4m² and 131m² per site over the three years (Fig.10). Analysis of 2002 and 2003 count data revealed no significant factors (p>0.05, Table 2). There was however a visible trend for an increase in *T. smaragdus* densities further out the reef (Fig. 5). The almost significant year*site factor (p=0.055) for *T. smaragdus* appears to have been driven by an increase in densities at site MIE3 in 2003 relative to 2002. The population distribution of *T. smaragdus* was variable between sites and among years (Fig.10). The dominant size frequency at MIW2 in 2001 and 2003 was 15-19mm whereas in the same year at MIW3 it was 10-14mm, however, low densities of *T. smaragdus* at some sites make this size frequency data questionable, although patterns in size frequencies across years appear consistent.

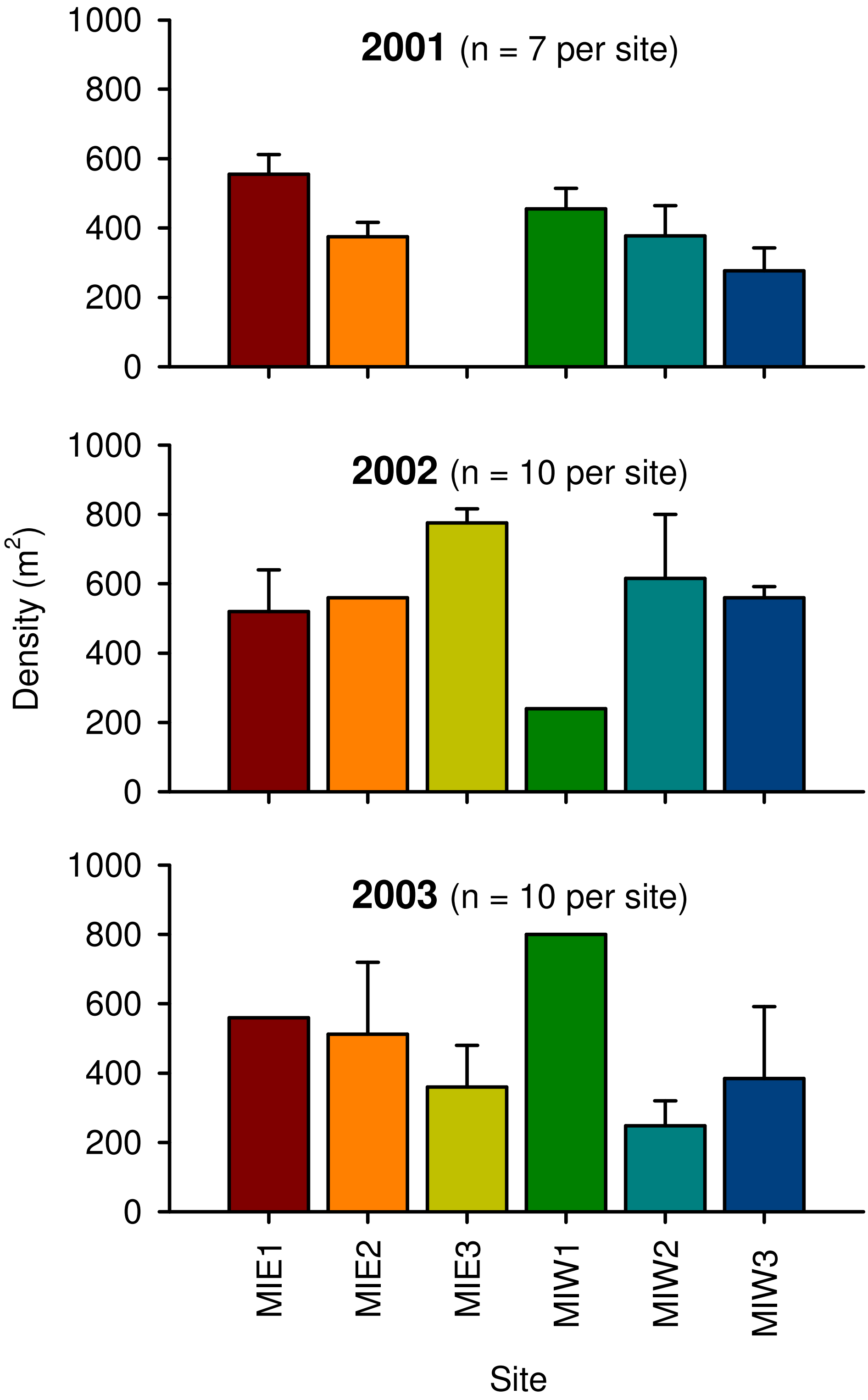

Figure 7.
Densities of *Crassostrea gigas* per m^2 at intertidal sites in October 2001, 2002 and 2003 (Bars = std. err.)
Note: the lack of a bar at MIE3 in 2001 is because this site was only surveyed from 2002.

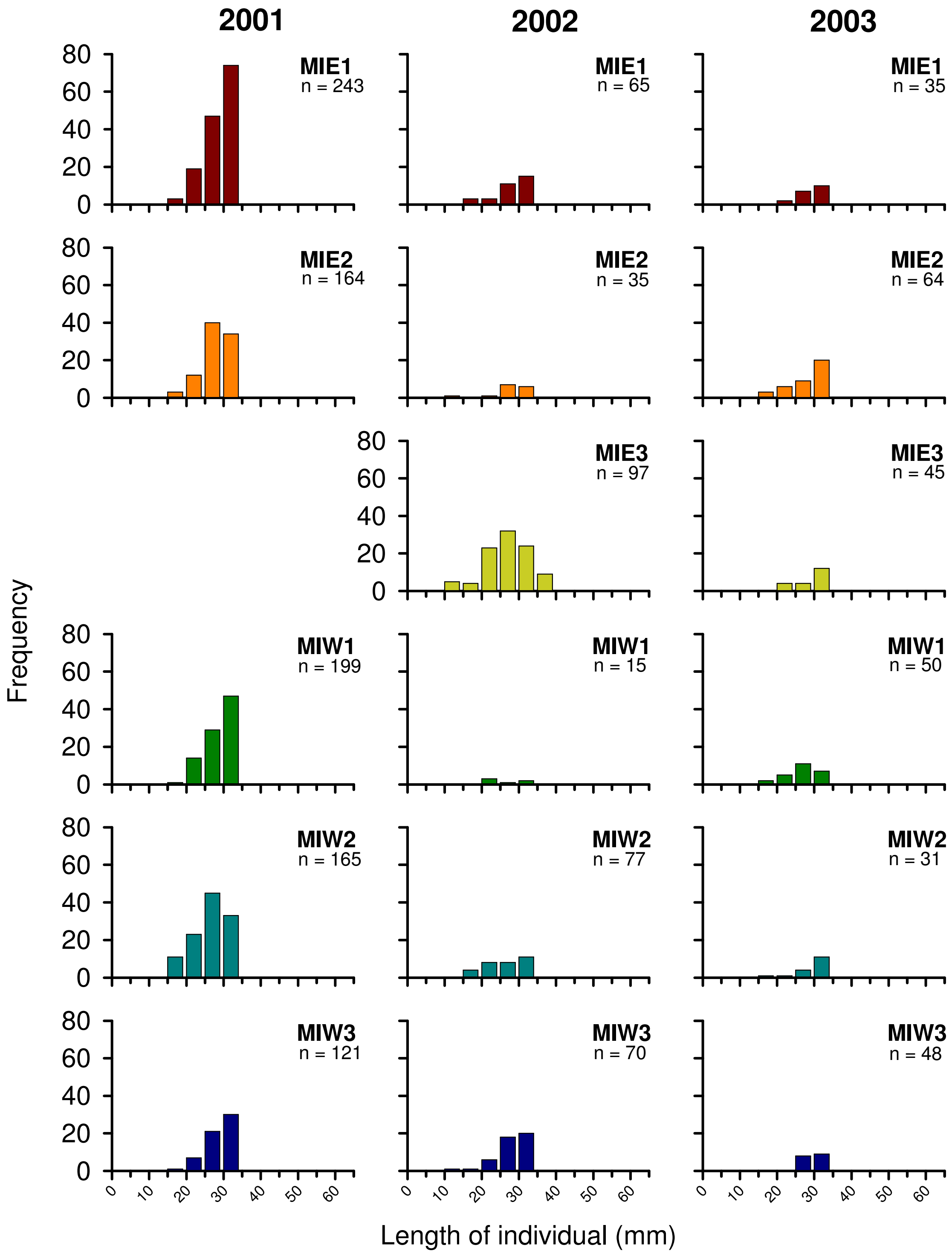

Figure 8.
Size frequency of *Crassostrea gigas* at Meola intertidal sites (pooled at the site level for each year). Note: the lack of a graph at MIE3 in 2001 is because this site was only surveyed from 2002.

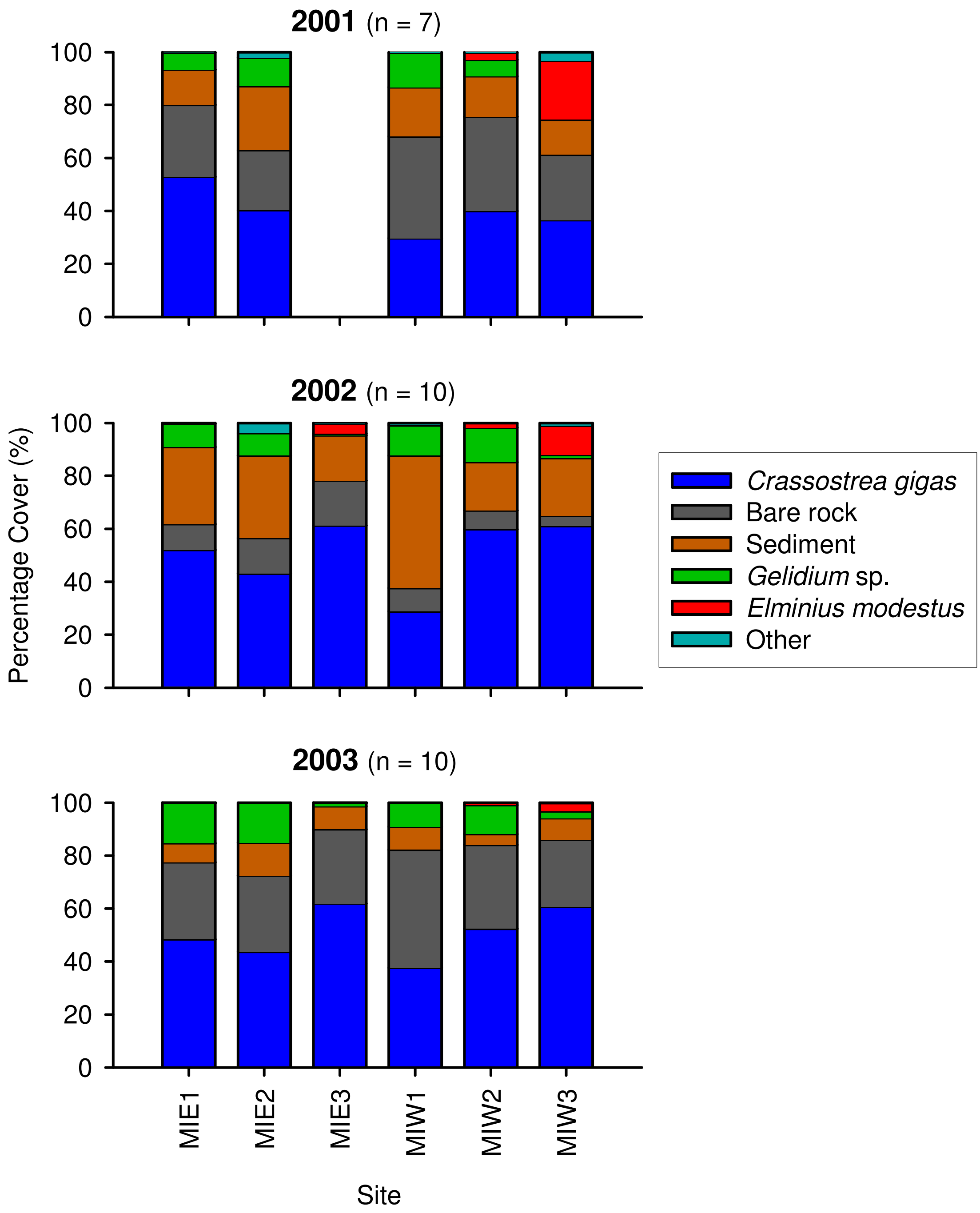

Figure 9.
Percentage cover of the six main categories of cover type at all Meola intertidal sites in October 2001, 2002 and 2003. (average std. err. = 2.652, range of std. errs. = 0 to 7.994)

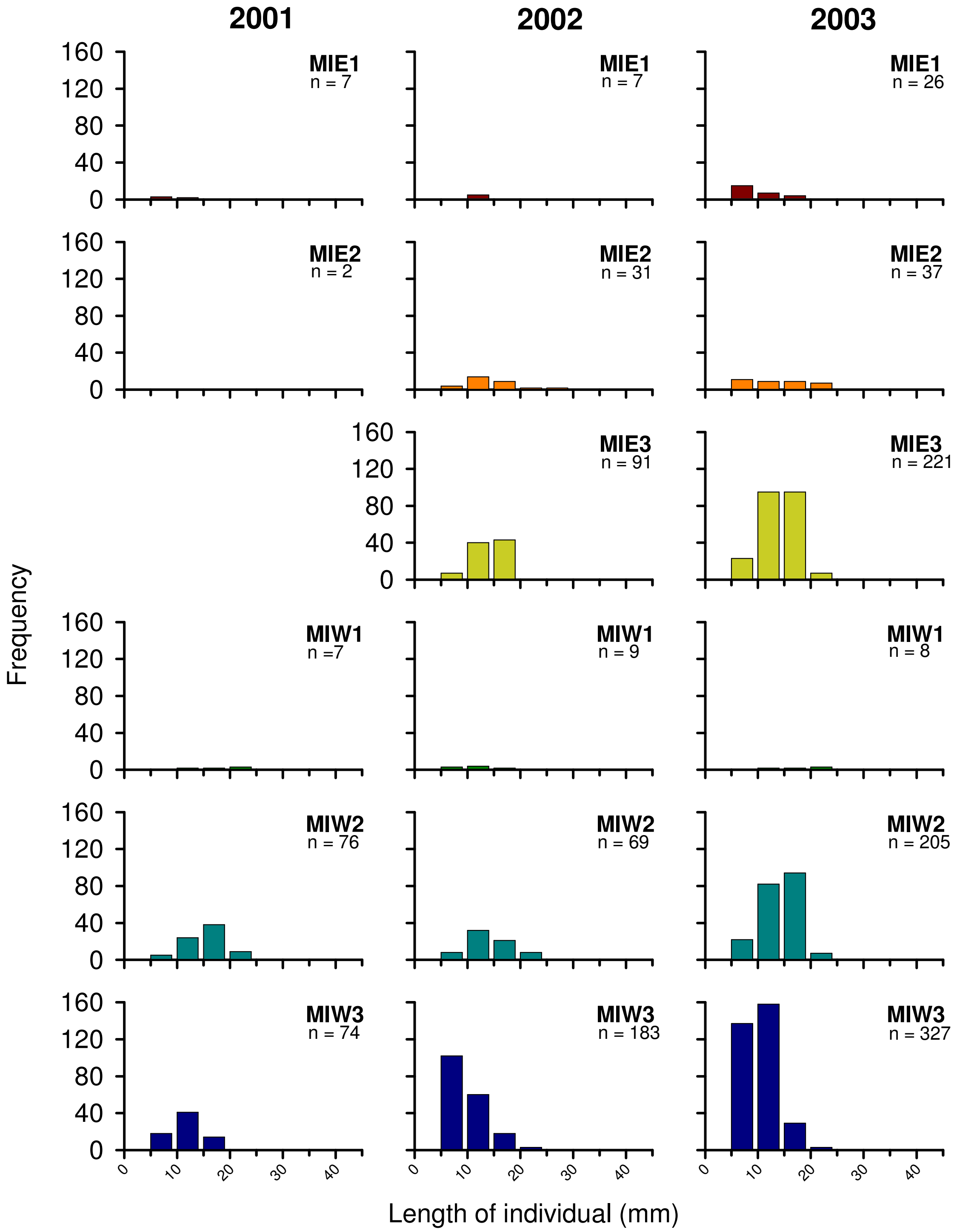

Figure 10.
Size frequency of *Turbo smaragdus* at Meola intertidal sites (pooled at the site level for each year).

3.2 Subtidal survey

3.2.1 Community analyses

Fifty-five taxa and five substrate types were found in the subtidal surveys from years 2001 to 2004 (Appendix C).

The NPMANOVA on count data showed that there was a site by year interaction (Table 3). This means that community is changing at the different sites but in not in a way that is consistent across all sites (Fig. 11). Due to problems with missing data from Year 01 data sets two options for the analysis were employed (using 4 years data, 5 replicates and using 3 years data, 7 replicates) but there were no significant differences between the results so the 4 year, 5 replicate results are shown here.

A simper analysis was then completed; changes in the densities of the most common species (*Turbo smaragdus, Carpophyllum maschalocarpum, Carpophyllum flexuosum* and Solitary ascidians) was responsible for over 50% of both the similarities within sites and the dissimilarities between sites.

Table 3.
NPMANOVA showing factors effecting community structural changes.

Factor	Meola subtidal 4year - 5reps	
	F	P
Site	4.0476	**0.001**
Year	7.1813	**0.001**
Site*Year	1.7652	**0.002**

The changes in community structure over the years are apparent in Fig. 11 and 13. Clear separation is apparent between sites MSE2 and MSE3 and the other three sites (Fig. 11). Centroid locations generally move to the left in all sites over time (Fig. 11), however with only four data points per site, it is difficult to know if this represents a pattern or just random variability. The site that shows the least change in centroid location over time is MSE2 and the site that shows the most change is site MSW2 (Fig. 11). By contrast, the most dispersion of replicates within a site is seen at site MSE2 and the least at site MSE1 (Fig. 12). High levels of variability within sites in a given year are apparent when the individual replicates are examined (Fig. 12), for example, two replicates at MSW2 in 2002 are more different to each other than any other 2 replicates at that site over all four years. Overall there is variability within and between each of the sites and years monitored, but there does not appear to be any obvious sudden or gradual changes of community structure.

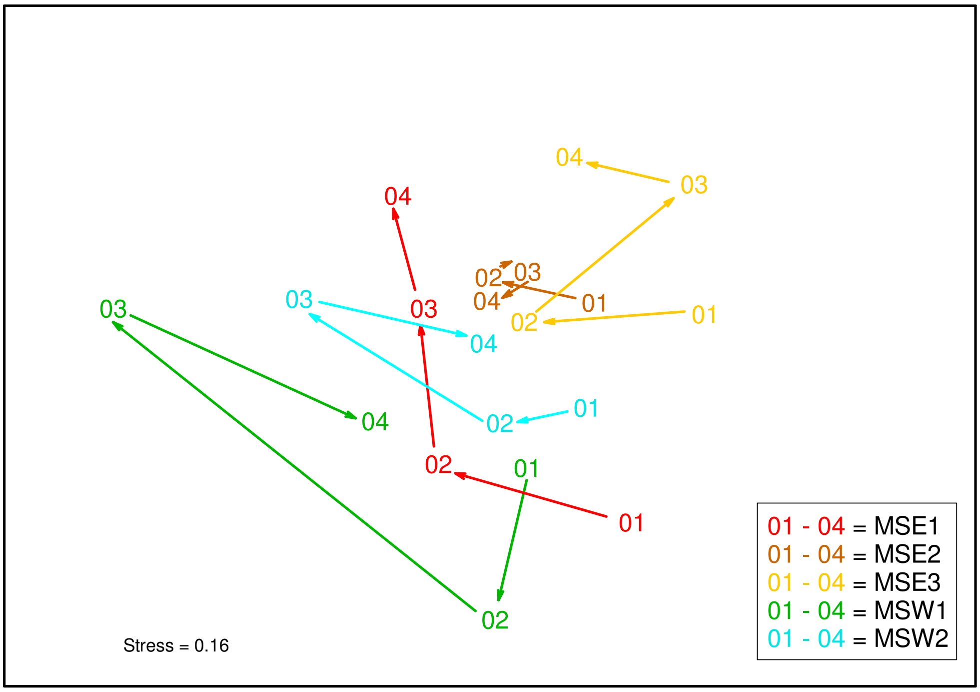

Figure 11.
Multi Dimensional Scaling (MDS) Ordination plots showing relative positions between subtidal sites in each sampling year. Each label represents the count data n= 7 quadrats per site. Note: 2001 data had less replication (n = 5-7) than later data therefore average count values were inserted to make the level of replication for 2001 up to 7 and make the maximal use of the existing 2002 to 2004 data.

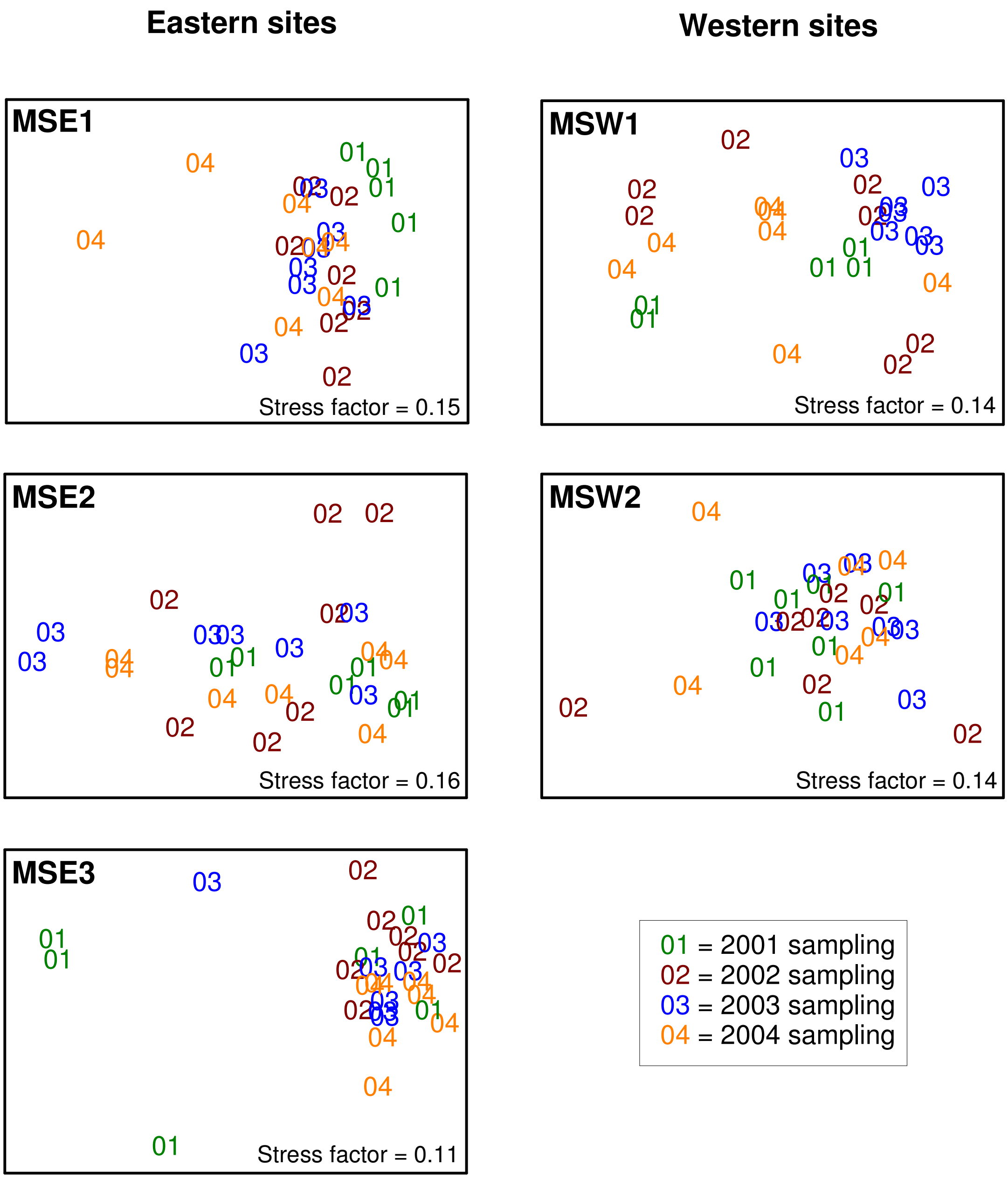

Figure 12.
Multi Dimensional Scaling (MDS) Ordination plots showing relationships between sampling years for each subtidal site. Each label equates to the count data from one quadrat.

3.2.2 Population analyses

The subtidal quadrats were dominated by the *Carpophyllum spp.* seaweed (26±3 s.e. m^{-2}) and the grazing gastropod *Turbo smaragdus* (35 ±3 s.e. m^{-2}). There were two species of *Carpophyllum* present in high numbers on the reef, *C. maschalocarpum* (16±2 s.e. m^{-2}), and *C. flexuosum* (11±2 s.e. m^{-2}).

The four most dominant species over all sampling periods (*Carpophyllum maschalocarpum, Carpophyllum flexuosum,* Solitary Ascidians and *Turbo smaragdus*) all showed a significant site by year interaction effect (Table 4). This means that the number of each species at each site changes, but not in the same way at each site over the years. Pairwise comparisons show that the first 2 years (01 and 02), and sites MSE2 and MSE3 for all the species showed the least significant differences with either site or time, respectively. In order to visually assess this variability, plots of *C. maschalocarpum* and *Turbo smaragdus* densities at each site over the years are also shown (Fig. 13, 14). Average densities were much higher for *Carpophyllum maschalocarpum* on the west when compared to the east (27±s.e. 4 on west ; 8±s.e. 2 on east). This pattern was also detected in the 2001 report (Ford *et al*, 2001b). The very low densities of *C. maschalocarpum* at site MSE3 are due to the dominance of *C. flexuosum* at this site, it shows an average density of 12 plants per m^{-2} when all four years data are considered. In addition there appears to be a trend for *T. smaragdus* densities to increase over the last three years at certain sites (MSE2, MSE3 and MSW2).

Table 4.
ANOVA results from subtidal sites using the log (x+1) transformed count data for the four most abundant species.

Factor	*Carpophyllum flexuosum*		*Carpophyllum maschalocarpum*		Solitary Ascidians		*Turbo smaragdus*	
	F	P	F	P	F	P	F	P
Site	5.72	**<0.001**	16.05	**<0.001**	1.4	0.2379	2.5	**<0.05**
Year	0.33	0.8051	3.36	0.0553	6.6	**0.0069**	3.35	0.0556
Site*Year	4.29	**<0.001**	1.87	**<0.05**	1.92	**<0.05**	2.32	**<0.05**

Population size frequency data for *C. maschalocarpum* (Fig. 15), showed in general a large cohort of small plants (50cm long) at all site in all years. The western sites had the larger number of these juvenile plants with MSW1 having the greatest number of individuals in the <50 cm size class (n = 281). MSE3 had the lowest numbers of individuals over the sampling period (n = 0 to 11). However, as previously stated *C. flexuosum* were more abundant at this site and also showed the greatest number of individuals in the < 50 cm size class (not pictured). MSE2 had the largest range of *C. maschalocarpum* plant sizes, showing individuals from 50 to 250cm in length in 2002 and 50 to 300cm in length in 2003. The size distribution for *C. maschalocarpum* the other sites over the sampling period was relatively similar, varying from 50 to 150cm in length although the numbers of individuals varied greatly (n=17 to 341).

For *Turbo smaragdus* the size range varied from 5mm to 35mm, though the extremes of this range were only noticed on very few occasions (in 2003, MSW1 had n=1, size 5mm; and in 2001, MSE1 had n=5, size 35mm). The largest cohort was seen at size 20mm for all sites during all the years (Fig. 16). MSE2 had the greatest number of individuals ranging from 92 in 2002 to 439 in 2004, with the majority being on the 20mm size class. Sites MSE1 and MSW2 had the lowest numbers of individuals, and MSE2 and MSE3 had the greatest number of individuals. In general the 20-25mm size class contained the largest number of individuals at all sites.

3.2.3 Percentage cover analyses

Percentage cover was analysed for the 5 most dominant cover types over the sampling period. In order of most to least dominant, these were Sediment, Other (a group comprised of a variety of cover types, with no singular dominant type over the period of sampling), Crustose Coralline Algae, *Ralfsia* sp., and Sand (Fig. 17).

Sediment was generally the dominant cover type through 2001 and 2002, and sand becomes more important in years 2003 and 2004, particularly on the eastern side of the reef. Crustose Coralline Algae (CCA) and *Ralfsia* sp. were present at levels between 7-29% and 2-25% respectively, but were never dominant. Shell cover generally increased over the years. The category "other" is most dominant in year 01 and gradually falls away as the other 5 groups become more dominant over time. This category has a higher percentage cover than expected (25-34%), but this is due to the occurrence of a variety of different species over the years (i.e. algae, ascidians, sponges) and cannot be assigned to just one dominant cover type.

Table 5.
ANOVA for the percentage cover types.

Factor	Sediment		Crustose coralline algae		*Ralfsia* sp.		Sand		Other	
	F	P	F	P	F	P	F	P	F	P
Site	2.28	0.0646	3.63	**0.0079**	5.41	**<0.001**	5.92	**<0.001**	2.64	**0.037**
Year	0.34	0.7935	0.2	0.8934	0.99	0.4285	0.21	0.888	0.9	0.471
Site*Year	1.4	0.1741	0.81	0.6358	1.53	0.1237	5.53	**<0.001**	1.2	0.246

Sediment cover shows no significant difference with SITE, p=0.06 (Table 5), although a strong trend of difference in percentage cover was shown whereby sites MSE2 and MSW2 showed high values for sediment cover independent of year (Fig 18). CCA has a significantly greater percentage cover at site MSW2 when compared to MSE1, over all the years, though no other significant pairwise-comparison results were detected. Site MSE1 had significantly more *Ralfsia* sp. then the rest of the sites independent of year, but no other significant pairwise-comparison results were detected. Sand percentage cover is not significantly different over the years at site MSE1 and MSE2, but at site MSE3 it was significantly greater in years 2003 and 2004 when compared to the two earlier years. The ANOVA for the 'other' category shows a significant effect of SITE, pairwise-comparisons show that site MSE1 has significantly more of its substrate covered by 'other' fauna or flora than the other sites on the eastern side (MSE2 and MSE3).

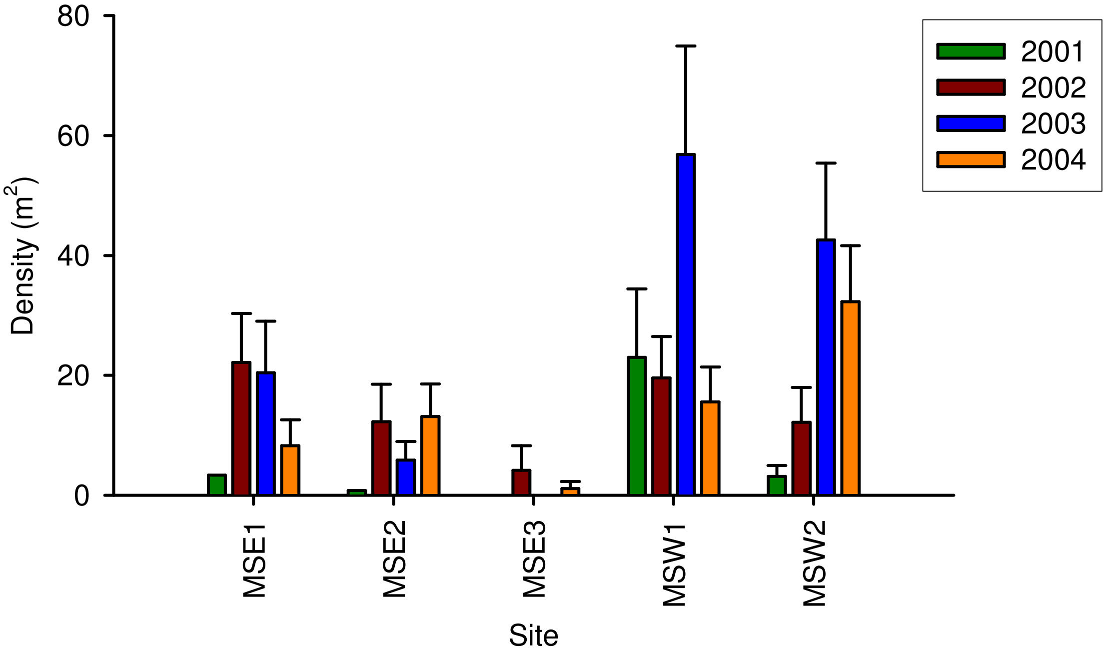

Figure 13.
Densities of *Carpophyllum maschalocarpum* per m^2 at subtidal sites from 2001 to 2004. (n = 5- 7 for all, Bars = std. err.).

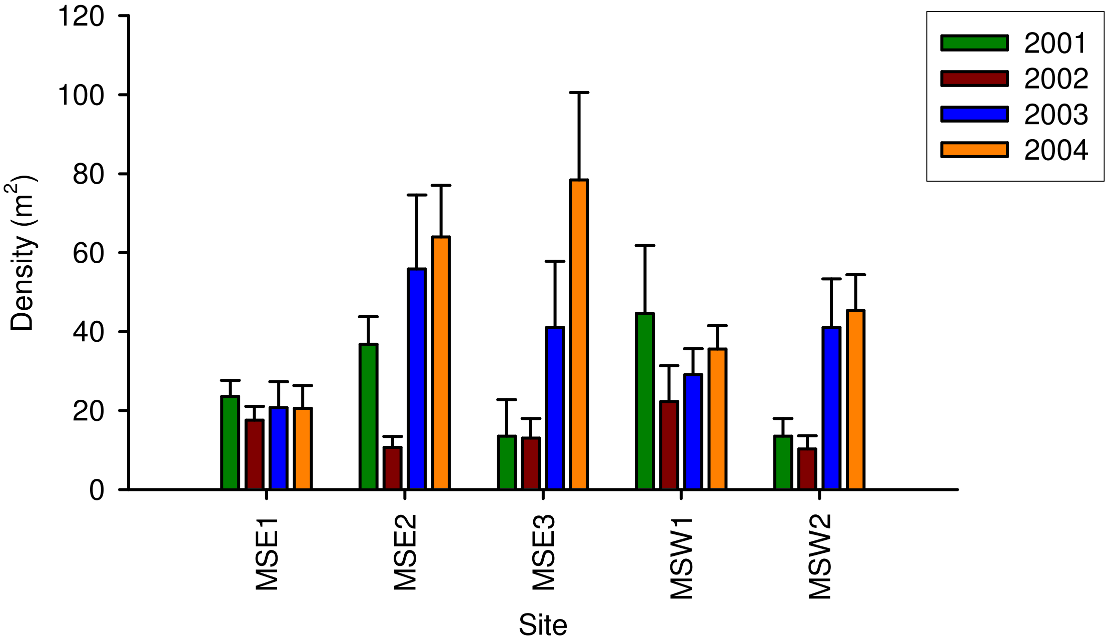

Figure 14.
Densities of *Turbo smaragdus* per m^2 at subtidal sites from 2001 to 2004. (n = 5- 7 for all, Bars = std. err.).

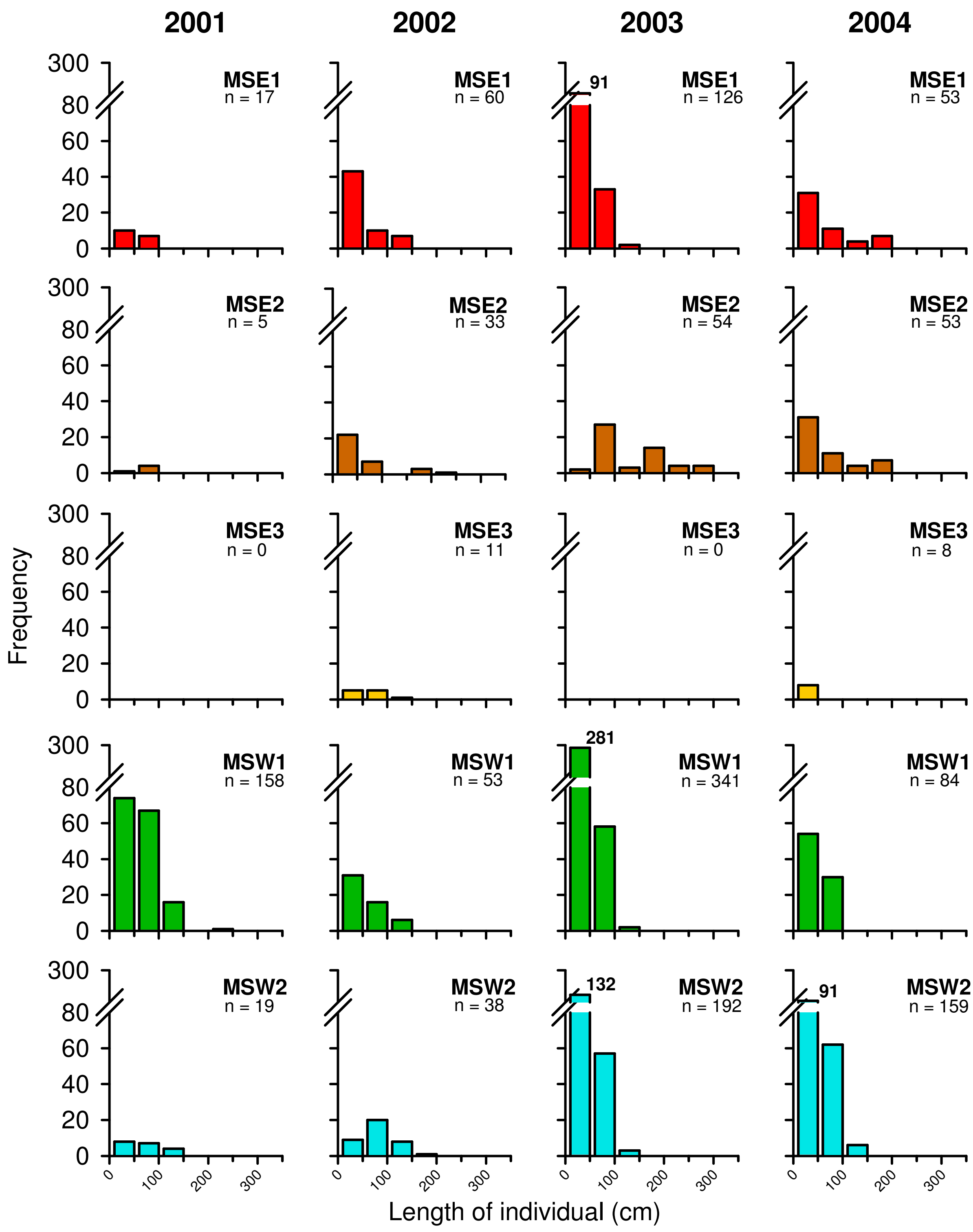

Figure 15.
Size frequency of *Carpophyllum maschalocarpum* at subtidal sites (pooled at site level for each year).

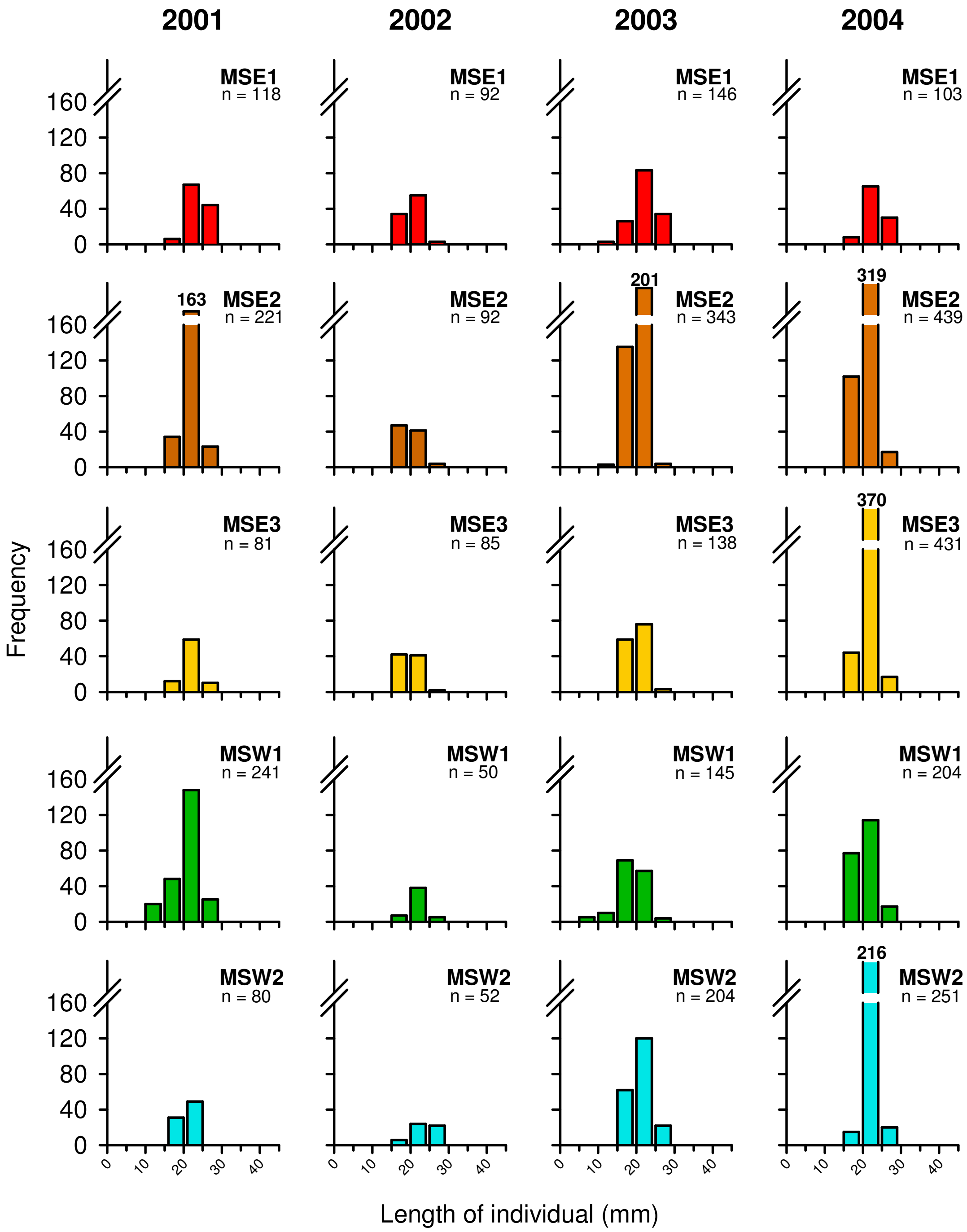

Figure 16.
Size frequency of *Turbo smaragdus* at subtidal sites (pooled at site level for each year).

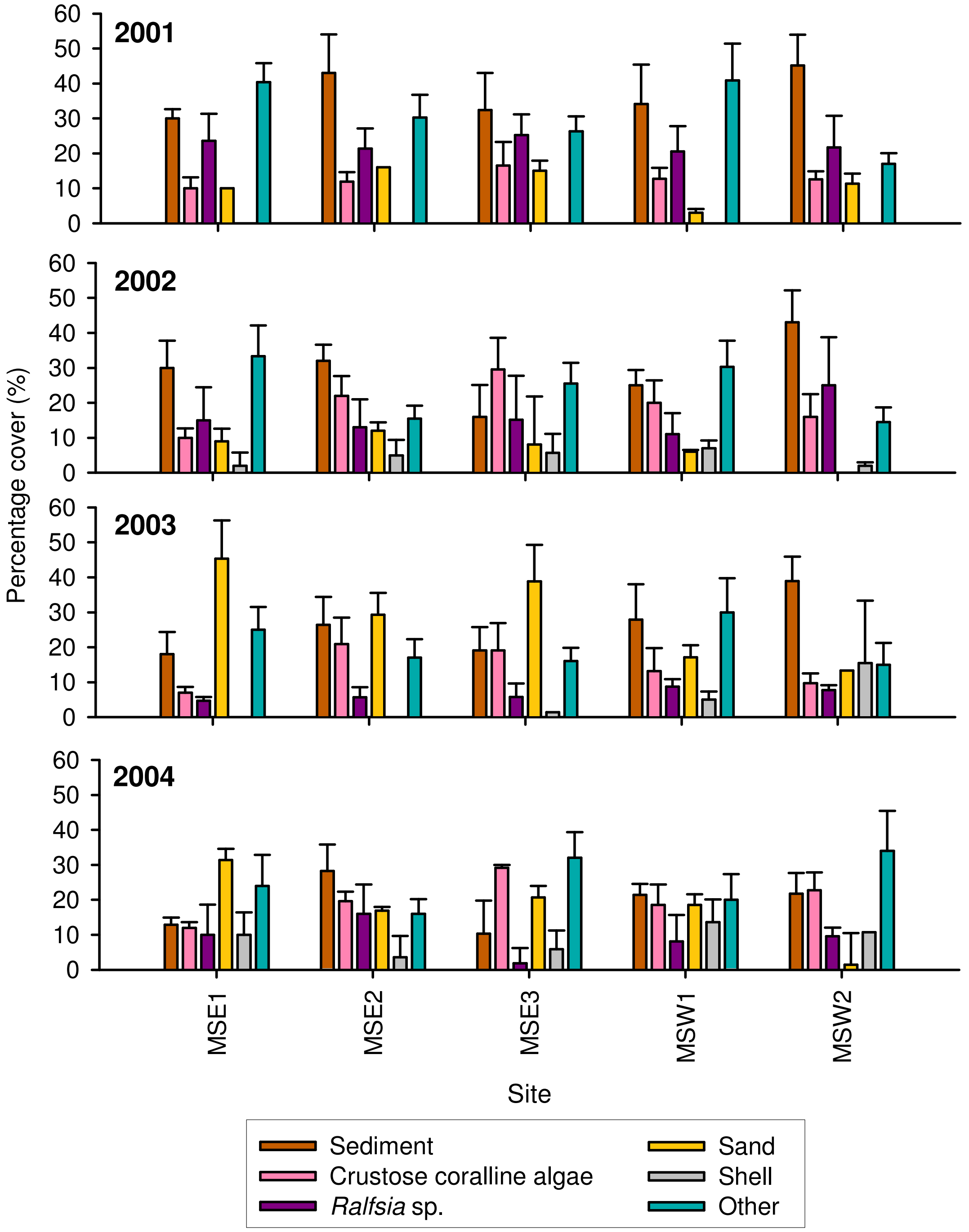

Figure 17.
Percentage cover of the six main cover types at all subtidal sites from 2001 to 2004. (n = 5- 7 for all, Bars = std. err.).

3.3 Sedimentation results

3.3.1 Sedimentation rate

Average monthly sedimentation rates for the 2001-2004 sampling period ranged between 0.0068g/day/cm^2 at MSE3 in August 2002, and 0.2517g/day/cm^2 at MSW2 in October 2001 (Fig. 18). Average sedimentation per year for Meola Reef from all data collected was 0.0403 g/cm^2/day (147 kg/m^2/yr).

Sedimentation rate showed no significant effect of either SITE or TIME (Table 6) however a strong trend was seen for sedimentation rate being influenced by TIME (p=0.09). This infers that when sedimentation rate is high it is high across the whole reef. A quick examination of the data (Fig. 18) confirms this inference (i.e. maximum sedimentation occurs at October 2001 in all sites and low sedimentation occurs at nearly all sites in July 2002 and September 2003). In order to test for cyclical patterns of sedimentation average sedimentation per time on the reef was calculated (excluding the peak in October 2001). These values were then regressed against repeating cycles of varying lengths from 3-12 months (in the form of sine functions or waves) to test for periodicity in the data. A periodicity of seven months showed the only significant regression with the average sedimentation data (P<0.01), this regression accounted for 25% of the variance in the data. When average sedimentation rates per site are examined (Fig. 19), sedimentation appears to decrease both over time and with increasing distance from the southern shore. Closer examination of the trend with time (Fig. 18) however suggests much of this decrease is driven by one peak in sedimentation in October 2001. No reason exists to suspect this sedimentation in October 2001 was not real, this was however prior to standardised grain size analysis; therefore the constituents of this peak will remain unknown. It is therefore impossible to know whether extra sedimentation at this time was due to a large amount of resuspended sediment, perhaps due to consistently windy conditions resuspending bottom sediments, or a pulse of fine sediments.

Table 6.
ANOVA on the rate of trap sedimentation and percentage composition of sediments less than 63 microns at the 5 monitored sites. Percentage composition data underwent an ArcSin transformation.

Factor	Sedimentation Rate		% of sediments <63 m		sedimentation rate of sediments <63 m	
	F	P	F	P	F	P
Site	0.76	0.55	2.39	0.06	2.54	**0.03**
Time	1.56	0.09	5.22	**0.001**	6.95	**<0.01**

3.3.2 Mud fraction

On average for all sites the percentage of particles <63μm (Fig. 20) was high (92% averaged over the whole reef) and consistent across all sites at the beginning of the analysis. This value remained steady until a dramatic drop in May 2003 at some sites, where values below 65% were reached at sites MSE2, MSW1 and MSW2 (Fig. 20). This percentage of fine particles in the sediment traps then steadily increased and became more constant. The amount of mud deposited at Meola is significantly influenced by time (p=0.001), and there is a trend for a higher percentage of fine-grained sediments to be deposited on the eastern side of the reef, particularly at site MSE1 (Fig. 21). ANOVA results show that time is highly significant and site is nearly significant in their affect upon the mud fraction (Table 6), as the percentage of fine sediments caught in the traps has generally decreased over time.

3.3.3 Sedimentation rate and mud fraction interaction

As the mud fraction calculation is based on a percentage value, to be sure fluctuations in the total sedimentation rate are not skewing the mud fraction results both factors need to be considered together. A regression analysis between sedimentation rate and %<63μm was carried out. This regression was found to be significant (R^2=0.067; p=0.009). This showed that as the rate of deposition increased, the %<63μm fraction decreased. In addition the site with the highest deposition rate (MSW1, Fig. 19) showed the lowest percentage of sediment deposition of particles less than 63 microns. Both of these relationships suggest that the mud content percentage is negatively influenced by variations in the total sedimentation rate, (i.e. as sedimentation rate increases this effectively dilutes the fine sediment content in the trap and the mud content percentage decreases). Therefore the rate of sedimentation for the mud fraction was calculated ((total sedimentation rate x percentage mud)/100) and plotted (Fig. 22). The plot shows the largest pulse of fine sediment at site MSE1 in October 2003 (0.097 g/cm^2/day), otherwise rates of deposition of mud appear highly variable. For the 12 occasions when all sediment traps were recovered the same ANOVA was run on the rate of mud deposition as for the other sediment measures. ANOVA results show a significant effect of SITE and TIME, pairwise comparisons show these differences are driven by a particularly low rate of deposition of mud in August 2003 and the higher deposition rate at MSW1 compared to MSE2 regardless of time.

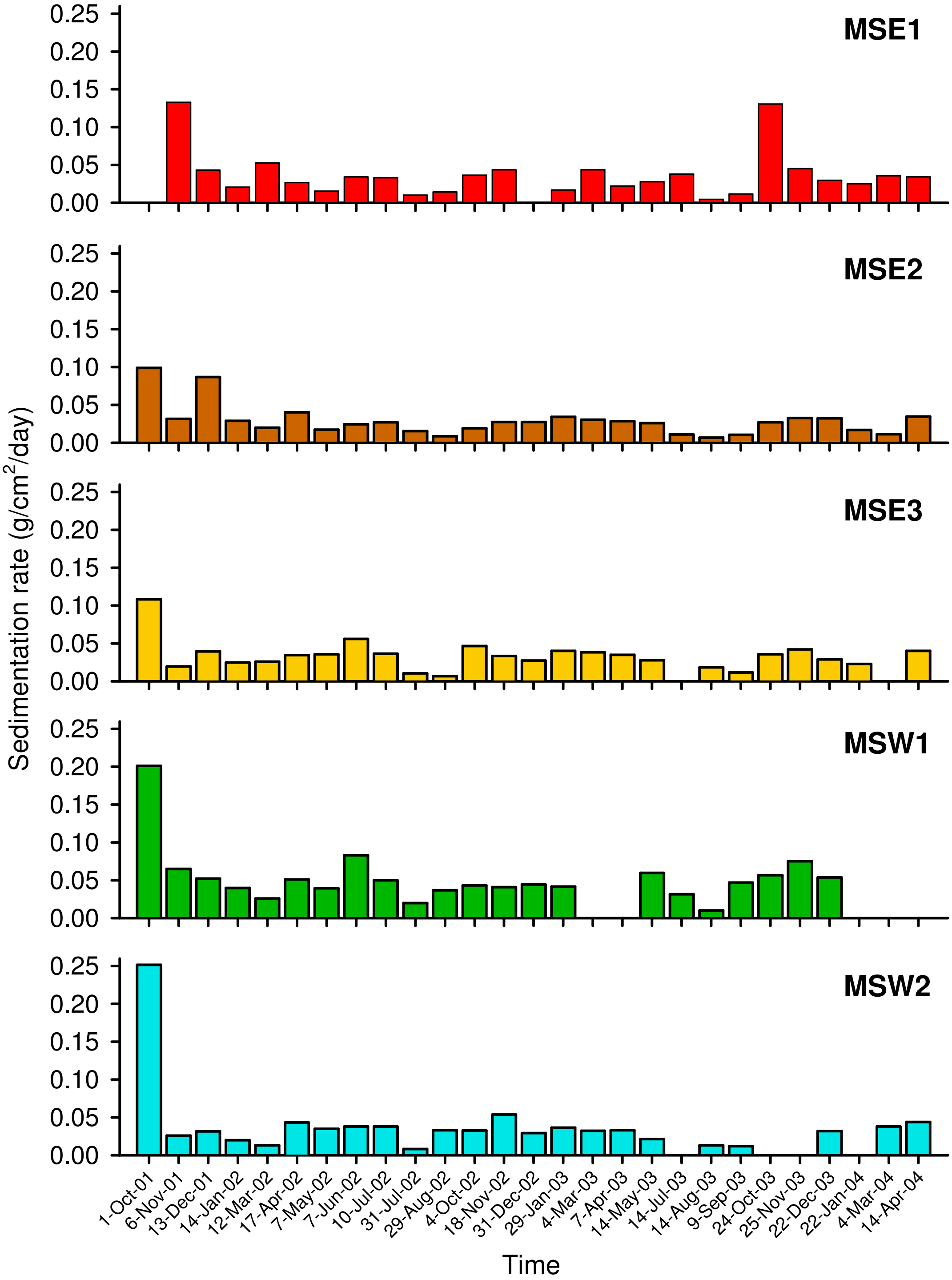

Figure 18.
Sedimentation rate at Meola subtidal sites, each bar represents one sediment trap collection at one site.

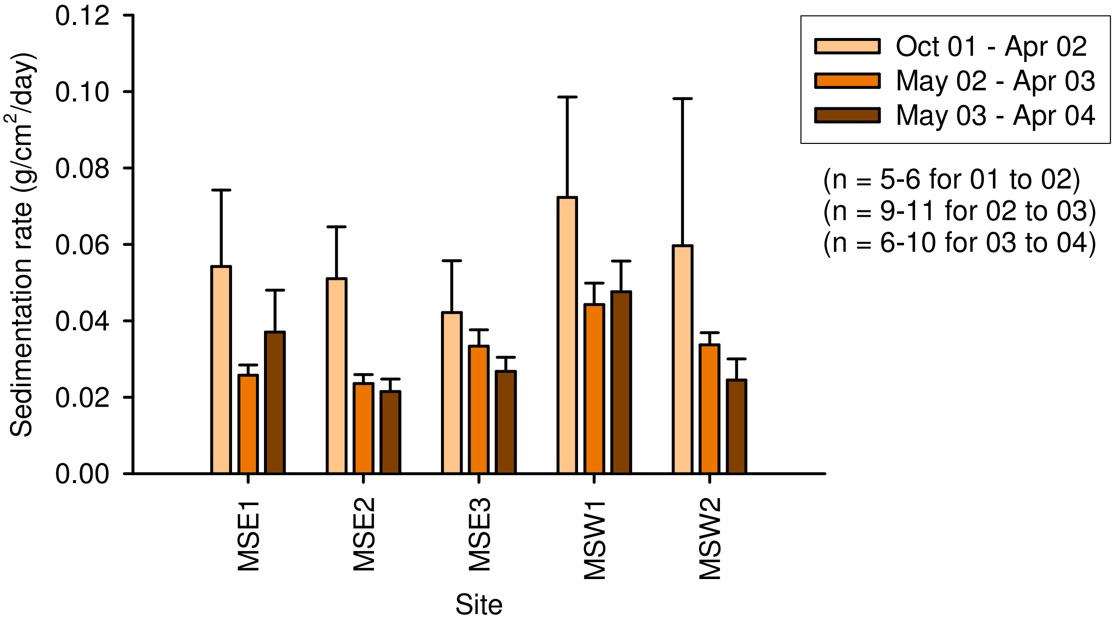

Figure 19.
Average Sedimentation rate per year at Meola subtidal sites.

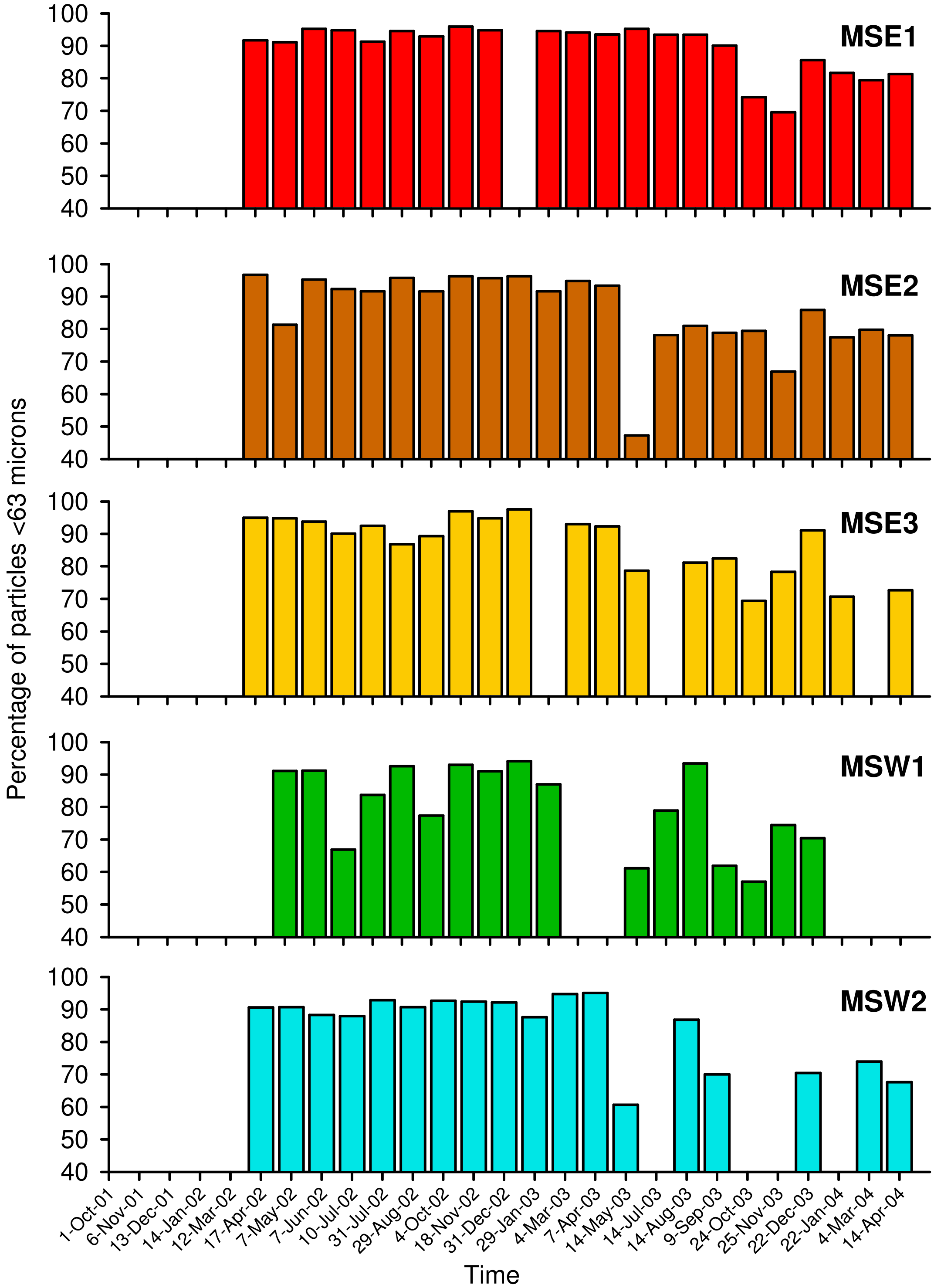

Figure 20.
Percentage of particles <63 microns caught in sediment traps at Meola subtidal sites, each bar represents one sediment trap collection at one site.

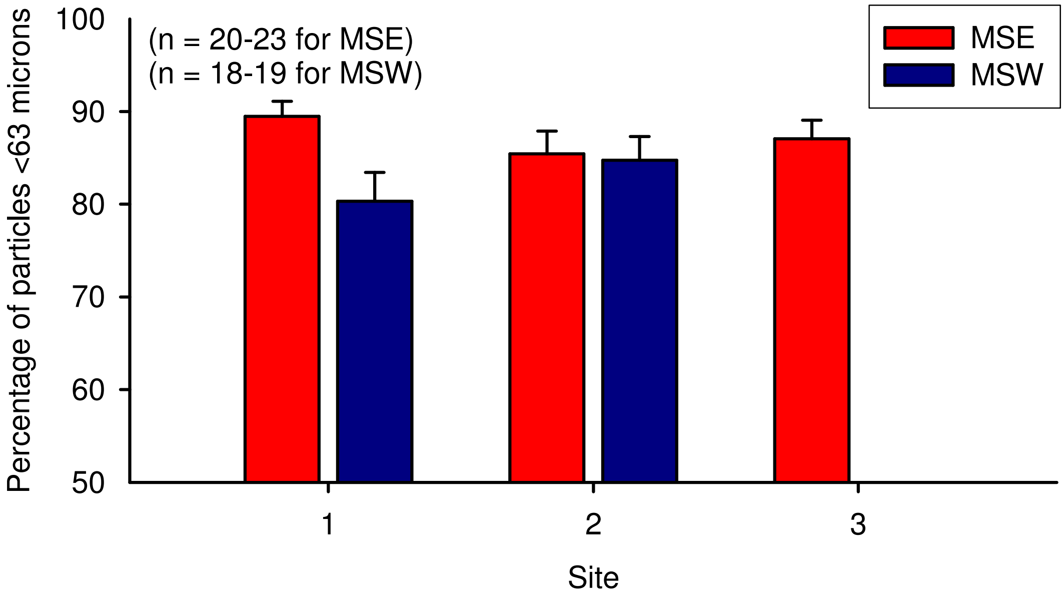

Figure 21.
Average percentage of particles <63 microns caught in sediment traps from March 2002 to April 2004.

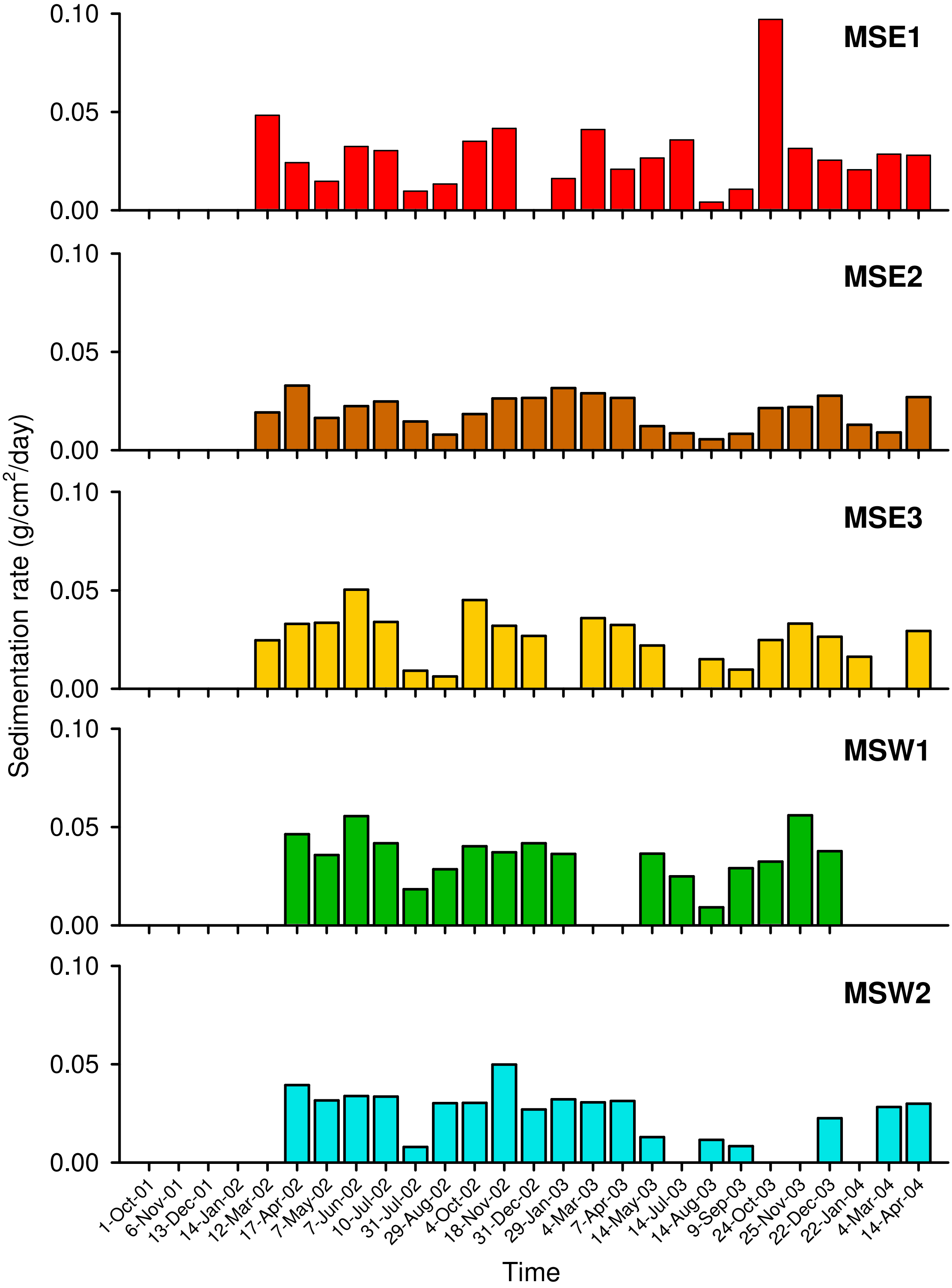

Figure 22.
Sedimentation rate of particles <63 microns at Meola subtidal sites, each bar represents one sediment trap collection at one site.

4.0 Discussion

High variability is evident in both intertidal and subtidal assemblages, however the patterns that are emerging from the data create a picture of a reef highly influenced by its hydrodynamic setting. A decrease in rocky reef substrate, due to an increase in percent cover of sand plus sediment plus shell, at some subtidal sites (MSE1, MSE2, MSW2), is not influencing biota at present, but is a trend that needs to be watched in the future. Sedimentation monitoring is again highly variable, and shows some trends with hydrodynamic gradients, but no temporal trends indicating a change in quantity or composition of sediments over time.

4.1 Intertidal biota

In the intertidal a number of trends in the densities of organisms are observed that are most probably explained by the strong gradients in hydrodynamic energy across the reef and along its length. Most of the variation observed between intertidal reef sites is due to changes in densities of *Turbo smaragdus*. There is a gradient on the reef whereby densities of this gastropod are low at the inner sites (MIE1 and MIW1), increasing with distance from the land to the outer sites (MIE3 and MIW3). Many other organisms follow the trend shown by *T. smaragdus. Melagraphia aethiops* densities on the west side of the reef increase with distance from land, and densities of *Sypharochiton pelliserpentis* and *Anthopleura* sp. are much higher on the outer reef. The cause of these increased faunal densities is probably longer immersion times and increased current at outer reef sites, which can act to increase faunal densities by at least two mechanisms. Increased current and longer immersion times can provide greater food availability for filter feeders e.g., *Anthopleura* sp. Increased current and longer immersion times can also increase microalgal biomass through increased nutrient availability further out the reef, which is then available for grazing by gastropods. In contrast the cover of *Gelidium* sp. decreases as distance increases from the Southern shore. *Gelidium* sp. prefers less exposed habitats (Adams, 1994), therefore the simplest explanation is that suitable habitat for the growth of *Gelidium* sp. gets rarer as exposure increases along the reef.

The East/West divergence in community structure is mainly due to high *Zeacumantus lutulentus* densities on the eastern side of the reef. *Z. lutulentus* prefers sheltered, organic rich shores (Morton and Miller, 1968). The dominant wind in the Auckland region is from the Southwest (Turner *et al.*, 1995) and the source of fine sediment is probably the upper harbour (to the West). These factors combined point to the eastern side of the reef being more sheltered and seeing a greater accumulation of fine particles in the lee of the reef, therefore the greater densities of *Z. lutulentus* are probably feeding on these particles.

The Pacific oyster, *Crassostrea gigas*, dominated all intertidal survey sites on Meola reef. At the more sheltered sites (MSE1 and MSE2) densities were consistent over time, but the large fluctuations in *C. gigas* densities at other sites may well be due to clumps of oysters rolling in and out of quadrats under the influence of waves or current. Percentage cover analysis suggests that patches of reef unoccupied by oysters were instead covered by bare rock or sediment, depending on the site. The highest percentage of bare rock was found at MIW1, the closest site to the land. Sediment cover was significantly higher on the more sheltered eastern side of the reef. The mechanism behind this pattern is likely to be as stated above, that the eastern side of the reef is the more sheltered side.

Neither diversity indices nor multivariate statistics give any indication of any pulse or press changes in community structure either due to loss or gain of organisms from Meola reef. The changes in intertidal community composition over time all appear to be driven by fluctuations in the density of common organisms, which reinforces this belief of no major changes on the reef. Also the presence of juveniles in the populations' size frequency histograms that were constructed (*T. smaragdus and C. gigas*) suggests the habitat is still suitable for recruitment and survival of taxa. However, it should be noted that any press effects (affecting community composition gradually over time) might not be detectable with only 4 temporal samplings.

No data exists for the Auckland region that will allow us to directly compare this intertidal reef to any other. The data available for Long Bay sites from February 2000 (Saunders and Creese, 2000) does however show some interesting comparisons with Meola reef data for common organisms. *Crassostrea gigas* was recorded as having average percentage cover of 10-70% in zones along the Torbay to Arkles Bay coast; average oyster cover at Meola reef for the 2001-2004 years was in a similar range of 29-61 % cover. *Turbo smaragdus* densities were reported as ranging from 5 to 30 per quarter m^{-2} along the Torbay to Arkles Bay coast; whilst the densities of this species are between 10 and 130 per quarter m^{-2} at Meola reef. The relatively high *T. smaragdus* densities at this site are all located at the outer reef sites (MIE3, MIW2 and MIW3) and are probably related to greater food availability due to higher flow at these sites.

4.2 Subtidal biota

The subtidal sites showed a high degree of variability, as is also seen in this habitat at Long Bay monitoring programme locations (Ford *et al.*, 2003). The biological patterns that can be distinguished from these surveys seem closely related to the hydrodynamics of the different sites on the reef. No biological changes have been detected in these surveys, however, increasing unconsolidated sediment cover (sand plus shell plus sediment) at the more sheltered sites (MSE1, MSE2 and MSW1) is a trend that merits watching in the future. It is possible that ecological changes will not result from these changes until mature plants die off, and recruitment is subsequently limited.

All the subtidal sites were dominated by the macroalgae, *Carpophyllum* spp., and the herbivorous gastropod *Turbo smaragdus*. These same two species are typical of other reefs in the Hauraki Gulf (Schiel, 1988), and in particular the sites investigated during the Long Bay monitoring program (Ford *et al.*, 2003). Fluctuations in the density of these two species are the most common cause for differences detected between sites or over years.

Carpophyllum maschalocarpum plants were longer at Meola reef (sites MSE1 and MSE2) than have been recorded at Long Bay (Ford *et al.*, 2003). This is probably due to the higher current flows making more nutrients available to the plants at Meola reef by comparison to the Long Bay sites. The reason longer plants are not seen on the western side of Meola reef may be that the subtidal algal fringe is very narrow on the west and longer plants may either a) need to be in a bed of algae to grow to this length or b) get abraded against the sharp oysters on the western side of the reef due to the action of the waves and stronger currents on this side of the reef. *C. maschalocarpum* plants are also more numerous on the western side of the reef, this is probably due to the longer plants on the eastern side forming a canopy and suppressing the growth of younger plants (probably due to lowered light levels), this may be exacerbated by the increasing sand cover on the eastern side limiting hard substrate for juveniles to settle on.

T. smaragdus densities are variable on the reef, although the data suggests an increase in *T. smaragdus* densities over the last two years at certain sites, more data will be required to determine if this is continuing. Mechanisms for this increase are not clear at this time. This increase in density does not appear to be on a regional scale, as data from the 2002 and 2003 Long Bay surveys show no clear pattern with respect to *T. smaragdus* densities (Ford *et al.*, 2003).

At the latest survey (March 2004) sites MSE1, MSE2 and MSW1 have ~54%, 49% and 54% respectively of their surface area covered by fine sediments, sand or shell. These figures generally show an increase from these three sites since 2001 (in 2001 these figures were ~31, 36 and 27% respectively). There also appears to be a switch from fine sediment to sand and shell cover at these sites, this could be due to a succession of sedimentation, whereby a thin cover of fine sediment is first covering the site, then sand and shell are subsequently covering the site. Bedload movement probably moves sand and shell at all sites on the reef but reduced resuspension at these relatively sheltered sites (MSE1, MSE2 and MSW1) is probably the reason that particles accumulate at these sites. This loss of rocky reef habitat is of concern as a thin veneer of fine sediment may affect recruitment by covering rocky reef, but may also get washed away. Sand and shell are heavier and therefore are less likely to be washed away and more likely to permanently take up space that used to be occupied by rocky reefs. Shell substrate replacing rocky reef may have a lesser impact than mud in the short term, i.e. hard substrate grazers can still utilize shells for grazing, but in the longer term shells are likely to be either eroded away in storms or not support settlement of algae for any length of time. Densities of *Carpophyllum maschalocarpum* and *Turbo smaragdus* at these sites were however within the range seen in the Long Bay study (Ford *et al.* 2003), therefore it does not appear that these sites are affected at this time by habitat loss. If this trend of increasing percent cover continues, then a lack of habitat may start to affect these faunal densities, with the most extreme scenario being a complete loss of the sublittoral algal fringe at these sites as all subtidal reef is submerged by sediments.

Meola subtidal sites had significantly ($P<0.001$) lower diversity (average number of species at Meola 2001 to 2003 = 6) than the Long Bay monitoring programme subtidal sites (average number of species at Long Bay monitoring programme sites 2001 to 2003 = 8-9). The same species dominate at both the Long Bay sites and the Meola reef sites, therefore the logical conclusion is that there are fewer rare species present at Meola reef. This impression is reinforced by the relative length of the species lists (Long Bay Monitoring programme = 69 taxa, Meola = 55 taxa). This lack of diversity at Meola reef is across taxonomic groups i.e. algae, echinoderms, gastropods and hydroids are all absent at Meola Reef by comparison to the Long Bay monitoring programme. This is probably due to a combination of the relative isolation, high load of fine sediments and fast current at Meola reef relative to the Long Bay monitoring programme sites.

4.3 Sediments

The sediment trap and percentage cover results emphasise the strong hydrodynamic forces at work at Meola reef, and the finer nature of the sediments deposited at this site by comparison to the Long Bay monitoring programme sites.

The total rate of sedimentation as measured by the sediment traps is relatively low when compared to the Long Bay sites (Meola reef average=147 $kg/m^2/yr$; Long Bay monitoring programme average=480 $kg/m^2/yr$, Ford *et al.*, 2003). Note: There was an error in the yearly sedimentation rate reported by Ford *et al.*, 2003, underestimating the value by a factor of 10, the value stated in this report is the corrected value. The sedimentation rates at Meola reef are similar to those reported from Manly, Stanmore and Waiwera (averages all less than 0.1$g/cm^2/d$), although lower by a factor of at least 2 than those recorded from the more exposed Campbells Bay, Long Bay and Torbay (Ford *et al.*, 2003a). This result was unexpected given the poor underwater visibility frequently encountered at this site by contrast to the open coast sites. However, when the less than 63 micron fraction is examined this percentage at Meola reef (92%) was far higher than seen at any of the Long Bay monitoring programme sites (averages per site/year combination range from <20 to ~ 70% (Ford *et al.*, 2003a). Therefore at Meola reef there appears to be less total sedimentation than in other surveyed sites, however more of that sedimentation is composed of fine sediments (probably from a source in the Upper harbour), which are likely to settle more slowly from the water column and hence more strongly affect visibility. Any decrease in sediment deposited in traps from May 2003 (Figure 20) has seen no corresponding change in community structure, although if increases in diversity are seen in response to this change it may take years to eventuate as new taxa gradually recruit to the sites.

Both the sedimentation rates (total and mud fraction) examined show at least a trend ($p<0.1$) for a relationship with time, and the mud component of that sedimentation (both in percentage and absolute terms) also shows a significant relationship with site. This means that sedimentation events (probably due to high rainfall events, wind driven resuspension, or a combination of both these forces) are affecting the whole reef, therefore high sedimentation will generally occur at all sites at the same time (e.g. October 2001). However, site MSE1 in particular, due to its sheltered location appears to occasionally have high sedimentation, particularly of the finer sediments, when compared to the other sites. Total sedimentation showed a significant 7 month periodicity, given that this means high sedimentation rates will be in different months each year, it will be interesting to see if this periodicity continues to be seen with future monitoring.

4.4 Recommendations

1. Monitoring should be continued in order to inform management decisions and to detect any gradual or sudden changes in community structure that would signify a pulse or press impact respectively.

2. For intertidal size frequency counts of oysters at least 100 measurements of oysters need to be taken at each site when measured in order to look for site-specific changes in oyster size frequencies.

3. The trend of increasing percentage cover of unconsolidated sediments in some subtidal sites should be carefully watched as further increases in this must logically have an impact on rocky reef biota at these sites.

4. Sediment trapping should be continued as this has provided new information, which has proven useful in linking the biota and environment, and may provide clues as to the source of any increased sedimentation that may lead to biotic changes in the future.

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6.0 Appendices

6.1 Appendix A. GPS positions

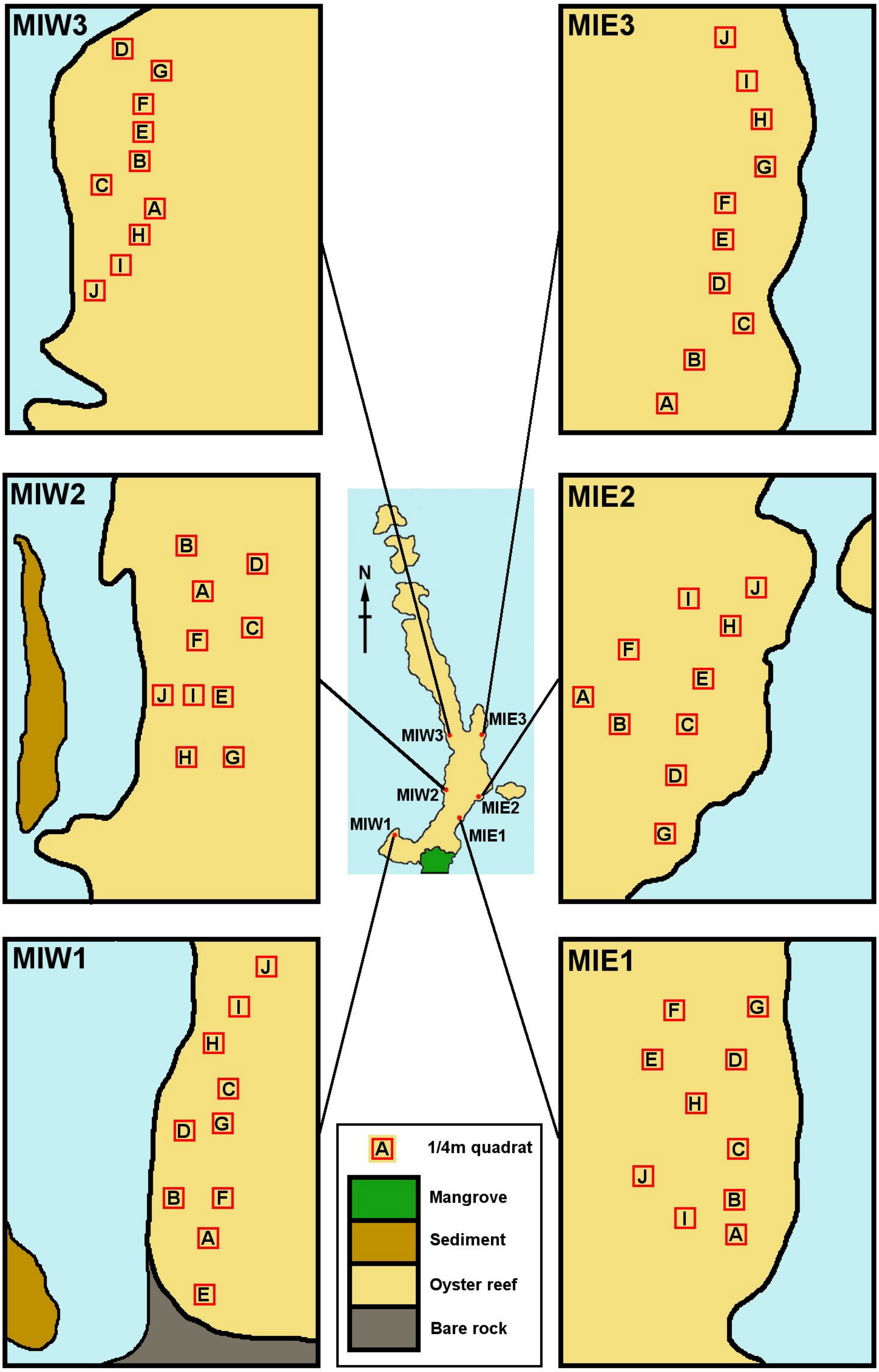
6.1.1 Meola intertidal site locations

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

6.1.2 Meola subtidal site locations

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

6.2 Appendix B. Map of intertidal sites



6.3 Appendix C. List of taxa

For both intertidal and subtidal count data

aa = very abundant (>10m^{-2})
a = abundant (1-10m^{-2})
r= rare (<1m^{-2})

For both intertidal and subtidal percent cover data

aa = very abundant (>10%)
a = abundant (1-10%)
r = rare (<1%)

6.3.1 Intertidal taxa list

Species Name	Common Name	MIE1			MIE2			MIE3		MIW1			MIW2			MIW3		
		01	02	03	01	02	03	02	03	01	02	03	01	02	03	01	02	03
Macroalgae																		
Gracilaria chilensis		r	r	r	a	a		r		r	r					a	r	
Hormosira banksii	Neptunes necklace															a	r	r
Ulva lactuca	Sea lettuce										r						r	
Encrusting algae																		
Corallina officinalis	Coralline turf		r										r			r	r	
***Gelidium* sp.**		a	a	aa	aa	a	aa	r	a	aa	aa	a	a	aa	aa	r	a	a
Bivalves																		
Austovenus stutchburyi	Cockle			r														
Crassostrea gigas	Pacific oyster	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Musculista stenhousia	Asian date mussel																	r
Nucula nitidula	Nut shell	r																
Xenostrobus pulex	Small black mussel	a	a	a	r		r		a			r	r		r	a		aa
Herbivorous Gastropods																		
Bulla quoyii	Bubble shell															r		
Diloma subrostrata	Top shell	r	r	r	a	r	a									r		
Melagraphia aethiops	Spotted top shell	a	a	aa	r	a	r	a	a	r	r	a	a	a	a	aa	aa	aa
Turbo smaragdus	Top shell	a	r	aa	r	aa	a	aa	aa	a	a	r	aa	aa	aa	aa	aa	aa
Zeacumanthus lutulentus	Horn shell	aa	a	aa	aa		a								r			a
Predatory Whelk																		
***Buccinulum* spp.**	Whelk					a												
Cominella adspersa	Speckled whelk	r				r		r	r				r	r		r		
Cominella glandiformis	Mud whelk	a		a	a	r	r	a			a			a	r		aa	r
Cominella maculosa	Spotted whelk		a														r	
Crustacea																		
Elimnus modestus	Barnacle							a	r		r		a	a	r	aa	aa	a
Helice crassa	Mud crab				a			a		r	a			a			a	
Petrolisthes elongatus	Half crab												r		r			r
Sphaeromatid Isopod						r		r									a	
Other Species																		
Acanthochiton zealandicus	Bristle chiton						r		a				r		r		r	r
Acarini	Mite	r	r		r	a		r		r						r	r	
***Anthopleura* sp.**	Anemone	a	a	a	r	r	a		aa	a		a	aa		aa	aa		aa
Crepidula monoxyla	Slipper limpet					a		a			r			r			a	
Diadumene lineata	Orange striped anemone								r									
Nerita melanotragus	Nerita			r														
Notoacmea helmsi	Keyhole limpet			r		r			r									
Onchidella nigricans	Reef slug	r		r	a	r	a		aa	a		a	a		a	a		a
Patiriella regularis	Cushion star												r					
Perinereis novaehollandiae	Green nereid								r									
Sypharochiton pelliserpentis	Snake-skin chiton	a	a	a	a	aa	a		aa	a		a	a		aa	a	a	a
Unidentified Amphipod						r												
Unidentified Polychaete						r												

6.3.2 Subtidal taxa list

	MSE1				MSE2				MSE3				MSW1				MSW2			
	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04
Macroalgae																				
Carpophyllum flexuosum	a	a	a	a	a	a	a	aa	a	a	aa	aa	a	a		a	a	a	r	a
Carpophyllum maschalocarpum	a	aa	aa	a	r	a	a	aa		a		a	aa	aa	aa	aa	a	a	aa	aa
Carpophyllum plumosum				a															r	
Cladophoropsis herpestica						r								a				r		
Codium fragile															r					
Colpomenia sinuosa		a												aa						
***Cystophora* sp.**																			r	
Ecklonia radiata	a	a	a	r	r	r	r	r	a	a	aa	a	r	a	a	a	a	a	aa	a
***Gracilaria* sp.**													r							
***Halopteris* sp.**	a												r		r					
***Hildenbrandia* sp.**	a	aa			a	a			a	a			a	a			a	a		
Hormosira banksii														a						
***Laurencia* sp**													r							
Red foliose algae			r				r								r					
Sargassum sinclairii	a	a	a	r	r	r		r	r	r	a		r	r	r	a	r	a	r	a
Encrusting algae																				
Coralline Turfing Algae	aa	a	a	r			r	r	a		a	a	aa	a	a	r			a	r
Crustose coralline algae	a	a	a	a	aa	aa	aa	aa	a	aa	aa	aa	a	aa	a	aa	aa	aa	a	aa
***Ralfsia* sp.**	aa	aa	a	a	a	a	a	aa	a	aa	a	a	a	a	a	a	a	aa	a	a
Green turf				r	a			r	a		r	a	r		r	r	a		r	a
Bivalves																				
Mytilus edulis galloprovincialis										r										
Crassostrea gigas	r													r						
Perna canaliculus				r									r	r		r				r
Herbivorous Gastropods																				
Bulla quoyii								r												
Cabestana spengleri																		r		
Cantharidus purpureus	r		r				r				r	r			r	r			r	r
Cryptoconchus porosus								r							r					
Maoricolpus roseus									r											r
Trochus viridus	r	r	r	a	a	r	a	a	a	a	a	a			r	r		r	r	a
Turbo smaragdus	aa	aa	aa	aa	aa	aa	aa	aa	a	aa	aa	aa	aa	aa	aa	aa	a	a	aa	aa
Predatory Whelk																				
***Buccinulum* sp**	r			r				r								r	r			r
Cominella adspersa	r	r						r				r		r						
Cominella virgata												r								
Haustrum haustorium																a				
Thais orbita																	r			

Subtidal taxa list continued

	MSE1				MSE2				MSE3				MSW1				MSW2			
	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04
Echinoderms																				
Coscinasterias muricata	r	r			r	r	r		r	r	r		r	r	r		r	r	r	r
Evechinus chloroticus		r				r	r	r			r	r		r						
Patiriella regularis	r	a	r	a	r	r	r	r	r	r	a	r	a	a	r	r	r	a	r	r
Stegnaster inflatus											r									
Sponges																				
***Ancorina* sp.**							r				r	r		r	r					
Cliona celata		r		r		r	r	r		a	r	r			r	r		r		r
Sponges	r	r	a		a	a	a	a	a	a	a	a	a	r	r	a	a	a	r	a
Tethya aurantium			r	r		r		r		r	a									
Tethya ingalli											r									
Other Species																				
Anemone		r				r						r			r	r				
Ascidians - colonial										r										
Ascidians - solitary	a	a	r	r	aa	a	a	a	a	a	a	a	a	a		a	a	a	r	a
Barnacles							r													
Bryozoan							r				r		r		r	r			r	
Dendrodois citrina					r			r		r					r				r	r
Eudoxochiton nobilis		r																		
Ishnochiton maorianus																		r		
Notomithrax minor																	r			
***Polymastia* sp.**															r					
Sypharochiton pelliserpentis				r																
Waltonia inconspicua										r										
Substrate																				
Bare rock			a	a			a	a			a	a	r	r	a	a			a	aa
Gravel				a				a				a			r					
Sand	r	a	aa	aa	a	a	aa	aa	a	aa	aa	aa	r	a	aa	aa	a		a	a
Sediment	aa	aa	aa	a	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
Shell	r	a		a		a	r	a	a	aa	a	a		a	a	a		a	aa	a