



# Long Bay Marine Monitoring Programme Report: 2005

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## 2 EXECUTIVE SUMMARY

The Long Bay Marine Monitoring Programme was initiated in 1998 with the objective of detecting and documenting the impact of urban development on the intertidal and subtidal marine environments of Long Bay. In 1999 the programme was extended to other coastal areas in order to place any patterns observed at Long Bay into a regional context. The communities in each of two essential habitats have been monitored: intertidal beaches and shallow subtidal rocky reefs. In addition to Long Bay itself, the additional beaches monitored are Mairangi, Torbay and Browns Bay, while additional subtidal bays monitored cover a larger spatial range and include Waiwera, Stanmore, Little Manly, Torbay and Campbells Bay. Of special concern are potential impacts of increased sedimentation with changes in land-use through time. Therefore, sediment traps deployed at each of the subtidal sites are also monitored to provide an indication of changes in water-borne sediment characteristics as development proceeds. This report presents the findings of monitoring carried out at these locations between September 2003 and March 2005. It also describes observed patterns and trends in communities over the past seven years, from 1999 to 2005.

### 2.1 Intertidal beach communities

The intertidal beach community at Long Bay is clearly distinguishable from other beaches. In addition, these assemblages have been quite consistent, showing little change through time. Long Bay has lower total abundances and diversity compared to other beaches. It also has higher relative abundances of amphipods (crustaceans) at its northern end and higher relative abundances of polychaetes (worms) in the mid-shore at its southern end, compared to other beaches. Differences among the beaches are likely to be caused by differences in their physical features and beach morphology. There is no current evidence to suggest that there have been any specific impacts of urbanisation at Long Bay over the past seven years.

We consider that likely sources of impacts on beach fauna with increased urbanisation may include increased stormwater outflows, with potential increases in freshwater, contaminants, such as heavy metals, and/or effluent. To aid in the ongoing interpretation of patterns in intertidal beach fauna and to provide better information regarding probable causal links, we recommend that a number of additional factors be considered as part of this monitoring programme, including measures of stormwater and wastewater inputs and various land-use variables, such as the number of new dwellings, industrial sites, etc. in the catchment areas associated with each beach.

## 2.2 Subtidal rocky reef communities

There is a strong north-south gradient in subtidal community structure, which has become more pronounced in recent years (2004-2005). The communities at Long Bay fall within this gradient and are broadly similar to those found at other bays (Torbay and Campbells) in the inner Hauraki Gulf. The existing north-south gradient in community structure is correlated with increases in the average trap rate of sediments and increased variability in trap rate at southern sites. The southern bays showed biological patterns consistent with documented patterns for shallow reef areas having reduced wave-action and greater sediment loads and turbidity, including greater abundances of the brown alga *Carpophyllum maschalocarpum*, the herbivorous gastropod *Turbo smaragdus* and the predatory whelk *Cominella virgata* compared to the northern bays.

There have been significant changes in community structure through time (since 1999, but especially in the last three years) for all bays. These changes have been most pronounced at the two northern bays (Waiwera and Stanmore) and consisted primarily in a shift in the dominant species of brown alga, from *Carpophyllum maschalocarpum* to *C. flexuosum*, and overall increases in the abundances of several species, including sea cucumbers (*Stichopus mollis*), sea stars (*Patiriella regularis*), sponges (*Tethya aurantium*) and herbivorous gastropods (*Cookia sulcata*, *Maoricolpus roseus* and *Cantharidus purpureus*). Changes through time in assemblages across all bays were strongly correlated with decreases over the past seven years in the proportion of fine sediments (< 63µm) obtained in traps across the entire region. This observed trend of a decrease in the proportion of fine sediments is the opposite of what would be expected to occur under the scenario of increased terrestrial runoff from urbanization and land works. However, small but consistent increases of some species at the northern sites clearly warrants further monitoring to see if the divergence between north and south continues through time, particularly as development proceeds.

There is currently little or no evidence to suggest that Long Bay has been impacted in any significant or negative way over the past seven years. These subtidal communities have remained relatively stable and minor temporal trends observed there have also been observed at other monitored bays as part of general regional trends. Importantly, the results obtained indicate that this monitoring programme is sensitive and has the power to detect relevant changes in community structure through time across the entire region, and at particular bays, even within the current pre-development phase. We recommend that ongoing monitoring also include consideration of long-term climate variables, such as sea surface temperature, as well as more specific information on changes in land-use and catchment development as it proceeds. This will provide a clearer context for interpreting patterns so that the weight of evidence concerning impacts and potential causative factors can be assessed.

## 3 INTRODUCTION

### 3.1 Background

Sedimentation has been identified internationally as an increasing and widespread problem for a range of habitats (Airoldi 2003). Sedimentation and infilling of estuaries are natural processes, however the rate of these processes is being considerably accelerated by human activities on land (Thrush et al. 2004). Human activities on land currently represent the main cause of historically recent changes in sediment delivery to coastal zones (GESAMP 1990). Increased amounts of sediments may lead to smothering of benthic communities and may have both lethal and sublethal effects on organisms in shallow coastal habitats (Roper et al. 1988, Creese and Cole 1995, Snelder and Trueman 1995, Creese and Kingsford 1998, Morrisey et al. 2003). Organisms inhabiting coastal areas may be affected in a number of ways, from physical smothering of the sediment surface causing anoxia (Norkko et al. 2002), to the accumulation of toxins associated with sediment (Snelder and Trueman 1995). Changes in sediment grain size may also affect rates of faunal movement and the sediment biogeochemistry (Rhoads and Young 1970), may enhance turbidity with implications for suspension feeders (e.g., clogging of gills, etc.), and potentially alter food quality (Ellis et al. 2002). In New Zealand, the effects of sedimentation on soft-sediment macrofaunal communities have received considerable attention and much of this research is summarised in an Auckland Regional Council report by Gibbs and Hewitt (2004).

While harbours and estuaries are typically the first receiving environments for increased sediment deposition, some of this sediment will ultimately be delivered to the wider coastal environment where it may be deposited on subtidal reefs. Increased sedimentation on subtidal reefs may smother or scour adult and juvenile stages of organisms and prevent settlement of propagules (see review in Airoldi 2003 and references therein).

Sedimentation may play an important structuring role in subtidal algal communities on temperate rocky reefs (Schiel and Foster 1986, Schaffer and Parks 1994, Dayton 1995, Airoldi and Cinelli 1997, Airoldi and Virgilio 1998, Irving and Connell 2002a, b, Airoldi 2003). In general, algal diversity is reduced (Gorostiaga et al. 1998) and there is a loss of canopy-forming seaweeds at sites with high sediment loads (Airoldi 2003).

Long Bay is 20 minutes' drive north of Auckland's CBD and is situated immediately to the south of the Whangaparaoa Peninsula and north of the residential areas of the North Shore and East Coast Bays. Forming the northern boundary of Long Bay is the Okura River and to the east are the islands of the inner Hauraki Gulf and Coromandel Peninsula. The Long Bay Marine Reserve was established in 1995 and extends 926 metres offshore, stretching from Toroa Point in the south, to the Okura Estuary in the north (Honeywill et al. 2002). Long Bay

has a diverse array of habitat types, including sandy beaches, intertidal reefs, shallow subtidal reefs, deeper soft-bottom areas and muddy estuarine habitats, making it a representative sub-sample of the habitat types in the greater Hauraki Gulf area (Walker et. al. 2001).

The Long Bay catchment has been re-zoned to be within metropolitan urban limits (Auckland Regional Growth Forum 1999). This re-zoning allows for urban development along the cliff tops above the beach and along the streams, in particular Awaruku stream. Monitoring was initiated due to concerns over terrestrial sediment entering the Long Bay marine environment during or after heavy rain events via either Awaruku (at the southern end of the beach) or Vaughans (at the northern end) streams as well as via the Okura and Weiti estuaries. The Long Bay Marine Monitoring Programme was initiated in 1998 with the objective of detecting and documenting the impact of urban development on the intertidal and subtidal marine environments of Long Bay. In 1999, the programme was extended to other coastal areas around Long Bay in order to place any patterns observed at Long Bay into a regional context. It was envisaged that if Long Bay were to be impacted by urbanisation, the scale of the impact could be gauged against recordings from the other bays. These other bays would either act as control sites, or could be used to assess the spread of disturbance, over various distances away from Long Bay.

The Long Bay Marine Monitoring Programme has been developed over eight years and monitors intertidal macrofauna on beaches and subtidal reef macroinvertebrates and macroalgae. The monitoring programme provides data on individual species abundance as well as community structure. As part of the subtidal monitoring programme, sediment levels in the area are also quantified. This report presents the findings of monitoring carried out between September 2003 and March 2005. In addition, this report provides detailed analysis of trends in macrofaunal and macroalgal communities from 1999 to 2005. The present report concentrates on two major areas of the marine environment: firstly, the macrofaunal communities of intertidal beaches in the area and secondly, the community structure and levels of sediment present in the water column above the subtidal rocky reefs in Long Bay Marine Reserve and surrounding bays.

### 3.2 Intertidal monitoring

Intertidal soft-sediment marine habitats have been monitored at Long Bay since 1998 and at three other nearby beaches, Mairangi, Browns Bay and Torbay since 1999. This report presents spatial and temporal variations in macrofaunal communities at these beaches. Long Bay was additionally divided in two to analyse differences between its northern and southern ends, as Long Bay is considerably longer than the other beaches and potentially receives different inputs from the two streams in the catchment, Awaruku to the south and Vaughans to the north. Long Bay is considered a non-depositional environment and is

subject to wave and tidal action (Walker et al. 2000). Against this background of a dynamic beach environment, it is unlikely that any increased inputs of fine sediment during development of the catchment will accumulate on the beach in the same way as it may in sheltered estuaries and bays. Therefore it is unlikely that changes in sediment grain size would be detected through time. Nevertheless there may well be impacts from pulse inputs of sediment as well as chronic inputs of other urban effluent that could lead to degradation of marine habitats. Such periodic or pulse events may be equally stressful for organisms inhabiting the beach as constant or press events. It is likely that as urban development of the catchment progresses the frequency and intensity of these pulse events will increase. The monitoring of beaches in the Long Bay Marine Monitoring Programme is designed to detect any sustained changes in the macrofaunal community through time, over and above natural variation that occurs in such a dynamic environment. Monitoring is carried out twice a year, in spring (September) and autumn (March) in order to account for seasonal fluctuations in macrofaunal abundance and diversity.

### 3.3 Subtidal monitoring

Subtidal communities of rocky reefs have been monitored at Long Bay since 1998 and at five other nearby bays (Campbells, Torbay, Little Manly, Stanmore and Waiwera) since 1999. These bays represent an overall gradient of distance from Auckland's CBD and thus in degree of urbanisation of catchments. Monitoring is carried out on an annual basis. Long Bay was surveyed in each of four seasons in 1998 and systematic seasonal variation in benthic populations was pronounced only in *Carpophyllum maschalocarpum*. These results suggested that annual monitoring was adequate for assessing subtidal reef communities at Long Bay. Subtidal monitoring focuses on reef-associated macroinvertebrates, macroalgae and substrate cover, which includes encrusting algae and invertebrates.

As part of the subtidal monitoring programme, sediment levels have been monitored at Long Bay and surrounding areas since 1999 to assess the types and quantities of sediment mobilised in the water column over monitored reefs. Sediment levels have been quantified using sediment traps, which measure total trapped sediment over a given period of time as well as the percentage of trapped fine sediment. In addition, percentage cover of the reef by sediment was also estimated. Cylindrical traps have been widely used to trap both sediment and larvae in marine systems (see Butman et al. 1986). Sediment traps provide a measure of sediment flux over short time periods (days to months) but may be strongly influenced by wave action and sediment accumulated in traps may be comprised largely of resuspended rather than just newly deposited sediment (Kozerski 1994, J. Walker pers. comm.). Estimates of percent cover have also commonly been used (Gorostiaga et al. 1998, Thomas and Ridd 2004) and may provide a more static estimate of the amount of sediment covering the reef (J. Walker pers. comm.).

The Long Bay Marine Monitoring Programme continues to establish a pre-development baseline of the biological communities and sediment levels typical of the coastlines surrounding Long Bay. Such baseline data can then be used to detect any changes to the coastal environment in the long term that may be attributable to urbanisation. The Long Bay Marine Monitoring Programme provides a unique opportunity to document changes in biotic communities as urban development proceeds and to use this knowledge base to improve predictions regarding likely impacts of urban development in other coastal areas.

## 4 METHODS

### 4.1 Intertidal beach assemblages

#### 4.1.1 Sampling methods

Sampling of intertidal beach fauna was done in each of two seasons: spring (September) and autumn (March) at each of four beaches: Long Bay (L), Torbay (T), Browns Bay (B) and Mairangi Bay (M). The locations of these beaches are shown on the map in Fig. 1. In addition, Long Bay is longer than the other beaches and earlier studies determined a difference in assemblage structure between the northern and the southern parts of the beach (Ford et al. 2003a). Therefore, Long Bay has been split into two sections, north (LN) and south (LS), for purposes of analysis. On each beach, a number of transects ( $n = 6$  from T, B and M and  $n = 5$  from each of LN and LS) were established from the foot of the dunes to the mark of Mean Low Water Springs (MLWS). The GPS coordinates for the start of each transect at each beach are given in Appendix A.

Two stations were sampled along each transect: mid-shore and low-shore (~60-70 m and ~85-110 m from the top of the beach, respectively). Within each of these stations, two cores (measuring 13 cm in diameter and 15 cm deep) were taken, and each one was sieved through a 0.5 mm mesh. The retained material was preserved in 10% formalin and 0.05g/l Rose Bengal and taken to the lab for identification. Macrobenthic organisms were counted and identified to the lowest practical taxonomic level. Bivalves of the species *Paphies australis* were classified into three different size classes: < 4 mm, 4-15 mm or > 15 mm. It is acknowledged that this species (the pipi) is difficult to distinguish from the species *Paphies subtriangulata* (the tuatua) when small in size. Therefore, bivalves counted as *Paphies* < 4 mm may include members from both of these species.

Faunal sampling of beach sediments was initiated in Long Bay in February 1998 (Babcock et al. 1998), and the other three beaches were included in the sampling programme from September 1999 (Babcock et al. 1999). However, numerous fundamental changes in sampling methodology have occurred since then, making long-term analyses difficult. Important details and the rationale for changes in the sampling protocol for these beaches through time are provided in Appendix B. In particular, note that prior to September 2001, a different size and shape of sampling unit was used (i.e., quadrats measuring 200 cm<sup>2</sup> × 10 cm deep), and all counts of organisms were done in the field. In addition, prior to September 2002, a 1 mm sieve, rather than a 0.5 mm sieve, was used. Therefore, we considered that only the data from September 2002 onwards should be used in quantitative statistical analyses. This includes 6 times of sampling (two seasons in each of 3 years): September '02, March '03, September '03, March '04, September '04 and March '05.

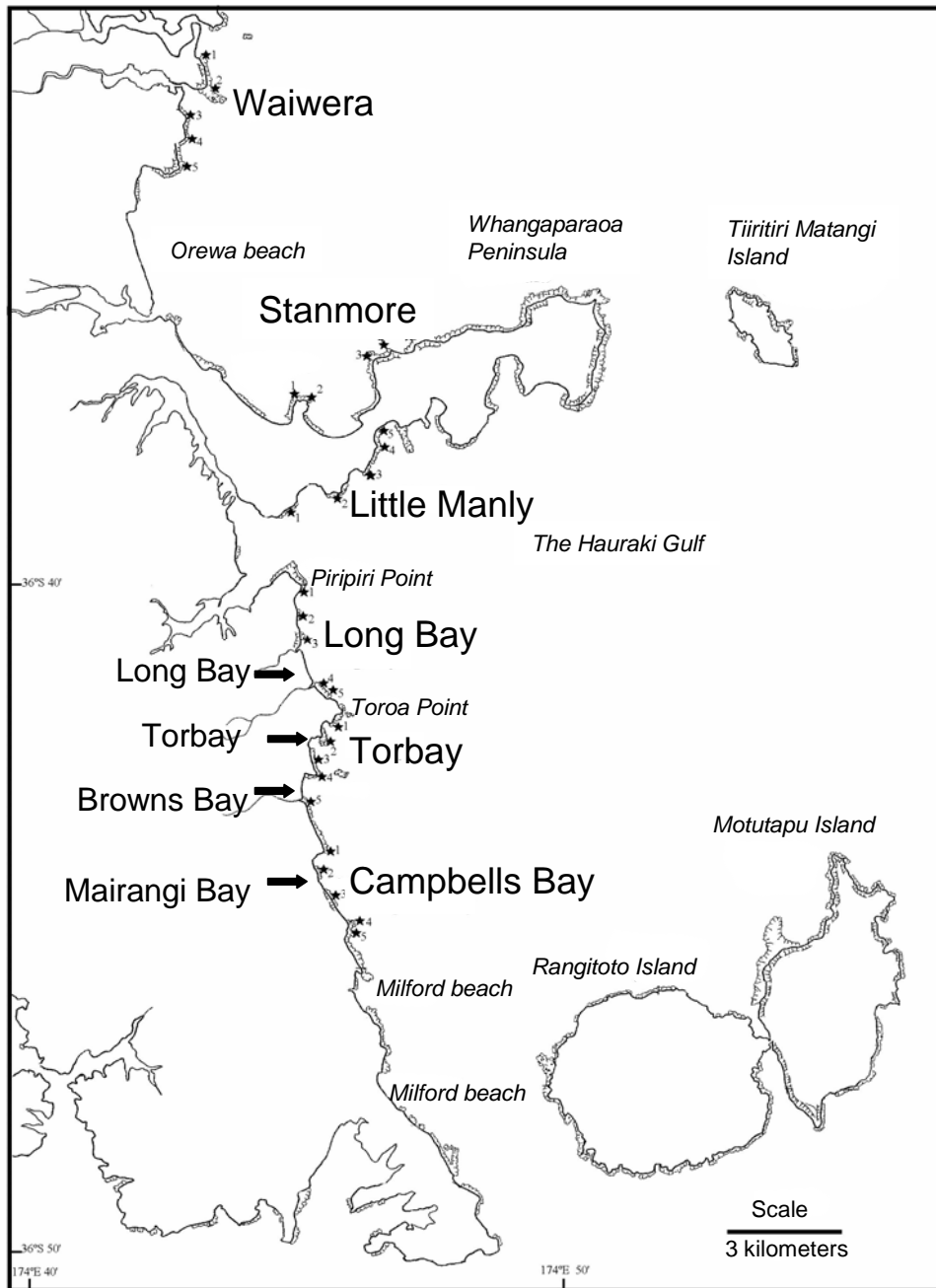


Fig. 1. Map showing location of study sites. Plain font indicates study sites and italics indicate place names of note. Arrows and names on land indicate intertidal sampling sites, stars and names on the water indicate subtidal sampling sites.

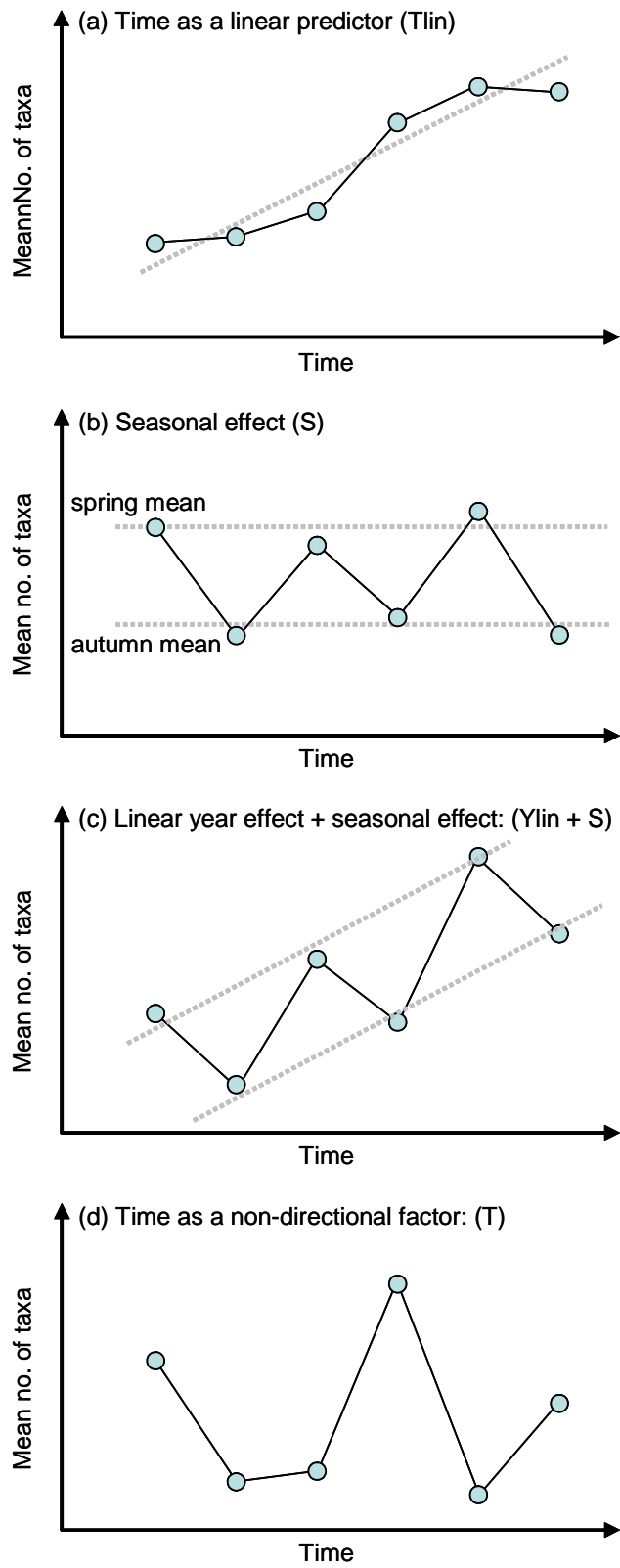


Fig. 2. Patterns for various hypothetical models for a single response variable through time.

It was possible to construct means and standard errors for longer time series for some variables by standardising for the size and number of sampling units at each time point. This was done for *Paphies* of each size class, for the total number of *Paphies*, the total number of amphipods and the total number of isopods. The latter two variables were also adjusted by reference to the report of Lohrer et al. (2002), which indicated that the change from 1.0 mm to 0.5 mm mesh size would result in an approximate doubling of the number of crustacean individuals. These longer time series have been constructed using approximately biannual data from February 1998 and are presented visually in graphical form in Appendix C. However, they should be interpreted with caution and no formal analyses of these data are warranted due to the essential incommensurability in sampling methods through time (Appendix B).

#### 4.1.2 Models and hypotheses

Interest fundamentally lies in determining answers to the following questions:

1. Are there differences among the beaches in terms of the abundance and diversity of fauna they contain? If so, how may we characterize these individual beaches? In particular, what (if anything) distinguishes Long Bay from the other beaches?
2. Are there changes in the faunal assemblages at each of the beaches through time? If so, are these (i) random changes, (ii) seasonal effects or (iii) are they due to significant increases or decreases in particular taxa (or in total abundance or diversity) through time?

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

For example, suppose we wish to model the average number of taxa per transect recorded from a given beach. If the plot of the mean per unit time looked like that in Fig. 2a, one might consider fitting a linear model, with time as a linear predictor variable. Now, suppose there was some clear seasonal effect, with larger means recorded in the spring (September) compared to the autumn (March). In that case, one might fit a model of the seasonal effect, as shown in Fig. 2b. Next, consider that there are increases (or decreases) from year to year, with the seasonal effect superimposed on this. In that case, one would fit a linear predictor for years, with the added seasonal effect (Fig. 2c). If the mean number of taxa were just bouncing around randomly, however, then the best model would be to

simply fit time as a non-directional factor, with a different mean for each time point (Fig. 2d).

We therefore have outlined several different ways that temporal variation in the data can be modeled: with time overall as either a factor (T) or as a linear predictor (T<sub>lin</sub>), with years either as a factor (Y) or as a linear predictor (Y<sub>lin</sub>), and the latter two can either include or exclude an additional seasonal effect (S).

In terms of spatial variation, we are fundamentally interested in the factor of beaches (B). Transects will be considered as replicates in all analyses, providing estimates of error variation. In addition, we wish to consider the contrast between Long Bay (LS and LN) versus the other beaches (T, B, M). The contrast between these two groups of beaches shall be denoted "LvO", for "Long Bay versus the others".

Now, the spatial and temporal components of each model can interact with one another. For example, in a model of the mean number of taxa, if the temporal effects are different at different beaches, we would expect there to be an interaction between T and B, which is denoted by T×B. A model with time (as a factor), beach and their interaction would be denoted by T + B + T×B. A shorthand way which we shall use to write this full model (the two main effects and their interaction) is T\*B. When the estimates from the model are exactly equal to the mean within each time-by-beach combination, we refer to this as a fully saturated model. Such a model is not very useful for making predictions, because it simply indicates that at every beach and at every time, something specific happens that can't be predicted from anything else. Note that the models T\*B and Y\*S\*B are essentially equivalent ways of expressing a completely saturated model for this design.

The important point here is to work out which model is "best" for a given set of data and, by virtue of this, to answer the questions posed above regarding competing hypotheses. Specifically, for each response variable of interest, we fit each of the models shown in Table 1. The interpretation of each model (i.e. its associated underlying hypothesis) is also given in the Table. Of greatest interest was to see if any of the response variables had a best model fit which included the components of either T<sub>lin</sub> or Y<sub>lin</sub>, which would indicate consistent increases or decreases through time, and also any which included the component of LvO, which would indicate a difference between Long Bay and the other beaches. On the other hand, variables with a best model fit of either T\*B or Y\*S\*B generally provide no cause for concern from a monitoring perspective, because this indicates simply that the variable of interest is varying in a non-directional manner in space and time.

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

**Table 1.** Models investigated for the analysis of intertidal beach data. B = beaches, Lv0 = the contrast of Long Bay (north and south) versus the other beaches, T = time as a factor with 6 levels, Tlin = time as a quantitative linear predictor value from 1 to 6, Y = year as a factor with 3 levels, Ylin = year as a quantitative linear predictor value from 1 to 3, S = season as a factor with two levels: September (spring) and March (autumn). The asterisk is used to indicate the complete model with all main effects and interactions in each case. For example, T\*B indicates the model: T + B + T×B.

	Model	Interpretation (underlying hypothesis)
1	T*B	Non-directional variation through time and among different beaches
2	Tlin*B	Increases or decreases through time and variation among beaches
3	T*Lv0	Non-directional variation through time and a difference between Long Bay and the other beaches
4	Tlin*Lv0	Increases or decreases through time and a difference between Long Bay and the other beaches
5	Y*S*B	Non-directional variation from year to year, seasonal effects, and variation among beaches
6	Y*S*Lv0	Non-directional variation from year to year, seasonal effects, and a difference between Long Bay and the other beaches
7	Ylin*S*B	Increases or decreases through time (years), seasonal effects, and variation among beaches
8	Ylin*S*Lv0	Increases or decreases through time (years), seasonal effects, and a difference between Long Bay and the other beaches

#### 4.1.3 Univariate analyses

Several individual univariate variables were analysed according to the models in Table 1. These were: the total number of taxa, the total number of individuals, the total number of polychaetes, the total number of amphipods, and (separately) each of the ten most abundant taxa recorded over the whole data set. All models were done separately for the mid-shore and the low shore. In addition, to visualise patterns for each variable, plots were produced of the mean ( $\pm 1$  standard error) for each beach through time, separately for the mid-shore and low-shore.

Counts of abundances of organisms are not well modeled using traditional linear models (with normal errors) for several reasons. First, organisms tend to multiply and divide, rather than to add and subtract. Therefore, rather than fitting a linear (additive) model directly, it is generally more appropriate to model the data on the log scale, making it multiplicative on the original scale. Second, organisms occur in discrete counts, rather than being continuous. Although the Poisson distribution is generally used to model random counts,

this distribution has a variance equal to its mean (i.e.  $E(Y) = \text{var}(Y) = \mu$ ). In contrast, organisms tend not to occur randomly, but instead tend to be highly aggregated, or *overdispersed*. This is generally caused by there being a great deal of zeros and quite a few counts that are extremely large. A consequence of this is that the variance, although a function of the mean, is generally much larger than the mean (e.g., Taylor 1966). The negative binomial distribution is a much better option here, where the variance is a function of both the mean and a dispersion parameter theta,  $\theta$ , as follows:  $E(Y) = \mu$ ,  $\text{var}(Y) = \mu + \mu^2/\theta$ . The negative binomial distribution is given by:

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

We analysed each univariate variable according to each of the models in Table 1 with a negative binomial generalized linear model (GLM, McCullagh and Nelder 1989) having a log link function, using the R computer program (R Development Core Team 2005). The link function determines the relationship between the variable and the linear model; in this case:

$$\log(\mu) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

where  $X_1, X_2, \dots$  are the terms in the linear model and  $\beta_0, \beta_1, \beta_2, \dots$  are the parameters associated with each term. The procedure (called "glm.nb" in the MASS library in R) uses an alternating iterative process for estimating the unknown parameters  $\mu$  (a function of the  $\beta$ 's) and  $\theta$  (Venables and Ripley 2002).

The only variable which was analysed using a different approach from this was the total number of species. This variable does not demonstrate overdispersion or a mean-variance relationship and was therefore analysed using a traditional linear model with normal (Gaussian) errors.

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

The model with the best fit (lowest BIC value) from Table 1 was then further scrutinized for a more parsimonious model by calculating BIC values for all subsets of the model. Thus, for

example, if Tlin\*B (which is Tlin + B + TlinxB) was found to be the best model from Table 1, we then examined each of the following subset models as well: (i) Tlin, (ii) B, (iii) Tlin+B.

#### 4.1.4 Multivariate analyses

Multivariate analyses combine information across all taxa and analyse patterns of change for the entire faunal assemblage simultaneously. Due to the complexities of analysing multivariate data for unbalanced designs, we focused here only on the first four models outlined in Table 1. We used permutational multivariate analysis of variance (PERMANOVA, Anderson 2001, McArdle and Anderson 2001) to analyse the multivariate data according to each of models 1-4. In order to compare the models, a "pseudo" BIC method was used. The BIC in the case of a normal (Gaussian) linear model for one variable can be written as:  $BIC = N \times \ln(RSS / N) + (\ln(N) \times p)$ , where  $N$  is the total number of observations,  $p$  is the number of parameters and  $RSS$  is the residual sum of squares. We simply substituted  $RSS$  with the residual sum of squares calculated from PERMANOVA to obtain a straightforward multivariate analogue to the BIC. The analyses were done on the basis of the Bray-Curtis dissimilarity measure (Bray and Curtis 1957) on fourth-root transformed abundance data, in order to balance the relative importance of abundant versus rarer species in the analysis (Clarke 1993). As for the univariate data, separate analyses were done for the mid-shore and low-shore communities.

Multivariate data were extremely variable at the scale of individual transects. Thus, to visualize patterns, non-metric multi-dimensional scaling (MDS, Kruskal and Wish 1978) ordinations were done on centroids (averages) for each time-by-beach combination. To ensure that centroids were calculated in Bray-Curtis (as opposed to Euclidean) space, the centroids were calculated as averages of principal coordinate (PCO, Gower 1966) axes obtained from the full Bray-Curtis dissimilarity matrix. The distance matrix among these PCO centroids was then input to the MDS algorithm in the PRIMER (v. 5) computer package (Clarke and Gorley 2001). Individual permutation tests for differences among beaches and among times were done using analysis of similarities (ANOSIM Clarke 1993) with 9999 permutations.

It was also of interest to examine and characterise compositional differences in communities from different beaches. For the most recent time of sampling (March 2005), the proportional abundances of each of several major taxonomic groups were calculated for each transect (separately for the mid-shore and low-shore). The average proportional abundance of each group was then plotted for each beach for visual quantitative comparison.

## 4.2 Subtidal assemblages

### 4.2.1 Sampling methods

#### 4.2.1.1 Biota

Sampling of subtidal assemblages has been done annually in February/March from 1999 onwards at each of five sites within each of six bays (from north to south): Waiwera (W), Stanmore (S), Little Manly (M), Long Bay (L), Torbay (T) and Campbells Bay (C). The locations of each site are shown in Fig. 1 and their GPS coordinates are given in Appendix D. The sites are all situated on rocky subtidal reefs dominated by macroalgae at depths of less than 4 m (Chart Datum). At each site,  $n = 7$  replicate quadrats measuring 1 m  $\times$  1 m were placed haphazardly at each site within 20 m of site markers. In each quadrat, individual species of macroalgae and macroinvertebrates ( $> 5$  mm) were counted and identified to the lowest practicable level (generally to species). Highly mobile organisms such as crabs were not included in counts. In addition, the percentage cover of the substratum made up of different components (such as turfing algae, large brown algae, encrusting coralline algae, bare rock, sediment, sponges, etc.) was estimated visually. Percentage cover was estimated for the smallest components first, using a 10 cm  $\times$  10 cm area as 1 % cover, until only one cover type remained. This was then allocated the remainder to a total of 100%. When uneven topography made the surface area under the quadrat greater than 100 cm  $\times$  100 cm, then an area larger than 10 cm  $\times$  10 cm was used to estimate 1% cover. For example, if an overhang meant there was an extra area of approximately 50% under the quadrat, then an area of 15 cm  $\times$  10 cm was used to estimate 1% cover. In five of the seven quadrats, the size of each individual was measured, to the nearest 5 cm (using a tape measure) for macroalgae and to the nearest 5 mm (using a ruled bar) for macroinvertebrates. Although sampling at Long Bay originated in 1998 (Babcock et al. 1998), methodology has been consistent only since 1999. Details of changes to sampling methodology through time are documented in Appendix B.

#### 4.2.1.2 Sediments

An important goal of the Long Bay Marine Monitoring Programme is to attempt to relate any potential changes in assemblages over time to changes in sedimentation regime. Direct measures of sedimentation are extremely difficult and costly to obtain, due to the natural movement of marine and terrestrially-derived sediments, resuspension with currents and wave action, etc. A proxy measure of sediment fluxes is provided to some extent by sediment traps. Sediment traps were deployed at each of the 30 sites (5 sites  $\times$  6 bays) which were designed to retain sediment deposited from the water column and to avoid potential resuspension (see Walker et al. 2001 and Ford et al. 2003a for details).

Sediment in traps were collected approximately monthly, however, there were often problems retrieving samples due to bad weather or loss of traps from public interference. Thus, the number of sampling times of traps per year from each site is highly variable (from  $n = 1-10$ ) as is the length of time that traps were left between sampling times. After collection, the contents of traps were filtered through a  $1.2 \mu\text{m}$  filter, oven dried at  $65-80^\circ\text{C}$  for 24 hours, then weighed. Values for the rate of sediment accumulation in each trap at each successful time of sampling were calculated in grams per  $\text{cm}^2$  per day. At each site, these values were then averaged for each year prior to sampling of the biota. This variable is referred to as the "average trap rate". Also calculated was the standard deviation of the values across each yearly period: "SD(trap rate)". Not only is the average trap rate of interest, the variability in trapping rate of sediments is also potentially an indicator for differences in overall sedimentation regime.

The grain size characteristics of sediments in traps are also of interest. It is expected that increases in sedimentation due to changes in land-use would result in increases in the rate of fine sediments deposited (i.e., mud  $< 63 \mu\text{m}$  in diameter). The proportion of the volume of sediments obtained in each trap that is  $< 63 \mu\text{m}$  in diameter has been measured since 2001, using a Galai laser particle analyser. From 2003 onwards, each sample was also pre-treated to remove organics according to the recommendations and methods provided in Ford et al. (2003b). Note that data from 2001 onwards can be used for statistical analyses, as the relationship between values obtained with versus without pre-treatment are very highly correlated (see Appendix B and further details in Ford et al. 2003b). Thus, the additional variables of interest here are: (i) the proportion of trapped sediments  $< 63 \mu\text{m}$  and (ii) the trap rate for fine sediments only (= proportion  $< 63 \mu\text{m} \times$  total trap rate). These variables were also averaged across each year prior to biotic sampling for each site. In addition, the percentage cover of sediment on the reef, estimated visually in each quadrat as part of the biotic sampling, was also analysed.

#### 4.2.2 Models and hypotheses

The models and hypotheses associated with the subtidal datasets are similar to those for intertidal beaches in several ways, but there are important differences. Interest fundamentally lies in determining answers to the following questions:

1. Are there differences among the bays in terms of the abundance and diversity of flora and fauna they contain? If so, how may we characterise individual bays? Is Long Bay distinguishable from the other bays? Is there a north-south gradient in the distribution of subtidal organisms (i.e. as one goes further into the Hauraki Gulf)?
2. Are there changes in the assemblages at any of the bays (or across all bays) through time? If so, are these random changes or are they due to significant

increases or decreases in particular taxa (or in total abundance or diversity) through time?

3. What are the spatial and temporal patterns in the sediment trap data? Is there any evidence for changes in sedimentation regime through time along this coastline? Is there a relationship between spatial or temporal patterns in the biota and patterns in sediment trap data?

Biotic and sediment trap data were investigated according to the models given in Table 2. These differ from the models investigated for intertidal data, because they do not include a seasonal component (as only annual data are available), but they do include a term for Bays as either a factor (B), or as a linear predictor (B<sub>lin</sub>). The latter is a series of integers from 1 to 6 indicating the bays' positions along a gradient from north to south. Previous studies have indicated that water clarity and sediment inputs increase with increasing distance from the opening of the Hauraki Gulf, affecting subtidal communities (Paul 1968, Grace 1983, Walker 1999).

#### 4.2.3 Univariate analyses

Several individual univariate variables were analysed according to the models in Table 2. These were: the total number of taxa, the total number of individuals, and (separately) the counts of each of the fifteen most abundant taxa recorded over the whole data set. To visualise patterns for each variable, plots were produced of the mean ( $\pm 1$  standard error) for each bay through time. Individual sediment variables were also analysed using univariate models, including (i) average trap rate, (ii) SD(trap rate), (iii) proportion < 63 mm, (iv) average trap rate of < 63 mm and (v) percentage cover of sediment in quadrats.

**Table 2.** Models investigated for the analysis of subtidal rocky shore data. B = bays as a factor with 6 levels, B<sub>lin</sub> = bays along a north-south gradient, Lv0 = the contrast of Long Bay versus the other bays, Y = year as a factor with 7 levels, Y<sub>lin</sub> = year as a quantitative linear predictor value from 1 to 7. The asterisk is used to indicate the complete model with all main effects and interactions in each case, as in Table 1.

	Model	Interpretation (underlying hypothesis)
1	Y*B	Non-directional variation through time and among different bays
2	Y <sub>lin</sub> *B	Increases or decreases through time and variation among bays
3	Y *B <sub>lin</sub>	Non-directional variation through time and a north-south gradient in bay effects
4	Y <sub>lin</sub> *B <sub>lin</sub>	Increases or decreases through time and a north-south gradient in bay effects
5	Y*Lv0	Non-directional variation through time and a difference between Long Bay and the other
6	Y <sub>lin</sub> *Lv0	Increases or decreases through time and a difference between Long Bay and the other bays

Modelling was done using the general approach outlined for the intertidal data, with one important difference. For intertidal data, transects were the lowest-level replicates for analysis. However, for the subtidal experimental design, we have the random effect of five sites within each bay, and quadrats are the lowest-level replicates. This leads to the need for a mixed model, involving fixed effects (as given in Table 2) and, in each case, the additional random factor of "Sites".

We analysed each univariate variable according to each of the models in Table 2 and included a random site effect with a negative binomial generalized linear mixed model (GLMM, Booth et al. 2003) having a log link function. This was achieved using a special library "glmmADMB", written by Skaug and Fournier (2004), which links the R computer program (R Development Core Team 2005) to an automatic differentiation model builder – random effects (ADMB-RE) program. The library is available from:

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

The total number of species, which conformed to traditional assumptions, was analysed using a linear mixed-effects model with normal errors (obtained by using the function "lme" in the "nlme" library in R). The percentage cover of sediment per quadrat was also analysed in this way. Other sediment variables were analysed using traditional linear models as well, but there was no random effect of sites for these, as data were obtained at the site level. The average trap rate and the trap rate for fine sediments were both log-transformed and SD(trap rate) was square-root transformed before analysis to conform with the assumptions of normality and homogeneity.

The models in Table 2 and all possible subsets of them were evaluated for each variable and the best model fit in each case was chosen using the BIC criterion.

#### 4.2.4 Multivariate analyses

As for the intertidal datasets, PERMANOVA was used to analyse the subtidal multivariate data according to each of models 1-6 shown in Table 2 and a pseudo BIC criterion was used to provide a rank of best fit. This was done separately for the count data and for the percentage cover data. Analyses were done on distances among site centroids (from  $n = 7$  quadrats) of principal coordinates based on Bray-Curtis dissimilarities of fourth-root transformed data.

To visualize large-scale patterns, non-metric MDS plots (one for counts and one for percentage cover) were done on centroids for each year-by-bay combination. The centroids were calculated as averages (from 5 sites) of principal coordinate axes from the Bray-Curtis dissimilarity matrices among sites. In addition, separate MDS plots were done using data at the site level examining: (a) patterns through time for each bay and (b) patterns across bays in each year. Individual ANOSIM tests (9999 permutations) were also done examining the effects of years for each bay and the effects of bays for each year. In addition, the

hypothesis of a gradient through time (a multivariate pattern of seriation in years) was investigated for each bay with a Mantel test (Mantel 1967) using Spearman's rank correlation ( $\rho$ ) available in the RELATE routine in PRIMER (Clarke and Gorley 2001). The hypothesis of a spatial gradient (a multivariate pattern of seriation from north to south) was also investigated for each year using this routine. All analyses were done separately for counts and percentage cover data.

The above analyses indicated that seriation in time and space was apparent (see results section 3.2.1). To further clarify these trends, canonical analyses of principal coordinates (CAP, Anderson and Willis 2003) were done on count data (at the level of whole bays) relating biota to (i) seriation in time (Ylin) and (ii) seriation in space from north to south (Blin). A plot of these two canonical axes against one another provided a visual ordination of these effects. Individual species having strong rank correlations with these canonical axes were identified and, along with the univariate analyses described above, provided insights into the components of the biota most indicative of these trends.

Finally, it was of interest to determine if either directional changes in assemblage structure through time (Ylin) or along the north-south gradient in space (Blin) were related to sediment variables. These potential relationships were examined graphically and by calculating Spearman's rank correlation ( $\rho$ ) between each sediment variable and each of the canonical variables.

## 5 RESULTS

### 5.1 Intertidal beach assemblages

#### 5.1.1 Patterns in whole assemblages

A total of 62 taxa were included in analyses. Although the taxonomic identification of organisms in samples has improved for this monitoring programme through time, the 62 taxa used here for multivariate analyses were those that were distinct and identifiable as and from September 2002.

Comparison of the 4 candidate models using PERMANOVA revealed that, for mid-shore assemblages, the Tlin\*LvO model resulted in the best fit for these assemblages (Table 3a). For the low-shore assemblages, the most parsimonious model was T\*LvO (Table 3b). These results suggest that the intertidal beach assemblages at Long Bay are distinct from the other beach assemblages for the low-shore and for the mid-shore. Furthermore, it indicates that directional changes through time are apparent for the mid-shore assemblages.

**Table 3.** Comparison of 4 models for multivariate assemblages from each of the mid-shore and low-shore of intertidal beaches, using PERMANOVA and a pseudo-multivariate BIC criterion.  $F$ = the  $F$ -ratio for the analysis of the full model,  $RSS$ = the residual sum of squares from the full PERMANOVA model,  $p$ = the number of parameters in the full model and  $BIC = N \times \ln(RSS/M) + (2 \times p)$ . Analyses were based on the Bray-Curtis dissimilarity measure and 4<sup>th</sup>-root transformed abundances of 62 taxa. The best (most parsimonious) model has the lowest BIC; models are presented in increasing order of BIC value.

	Model	F	RSS	p	BIC
(a) Mid-shore					
4	Tlin*LvO	4.49	486154	3	1354
2	Tlin*B	4.65	415907	9	1359
3	T*LvO	4.59	397522	11	1362
1	T*B	4.28	277069	29	1393
(b) Low-shore					
3	T*LvO	6.05	337046	11	1334
4	Tlin*LvO	5.34	438105	3	1337
2	Tlin*B	4.89	376107	9	1342
1	T*B	5.13	231328	29	1363

In contrast with these results, the non-metric MDS plot for mid-shore assemblages indicated that there were no clear directional temporal trends. There was no obvious pattern of sequential change (i.e. the numbers 1-6 did not order themselves sequentially) on the plot, either within beaches or across all beaches (Fig. 3). This pattern was supported by the results of the ANOSIM test, which, although it detected a significant time effect, pair-wise comparisons among the different times were inconclusive, with no single time period clearly distinguishable from the others (Table 4a). For low-shore assemblages, however, there was a clear pattern of difference between assemblages sampled at time 1 (September '02) and those sampled at other times (Fig. 3), which was statistically significant (Table 4b). However, no other time points differed significantly from one another (Table 4b).

**Table 4.** Summary of ANOSIM results examining effects of time (1-6, from Sep '02 through until Mar '05) and beaches (LN = Long Bay North, LS = Long Bay South, T = Torbay, B = Browns Bay and M = Mairangi Bay) for multivariate assemblages from each of the mid-shore and low-shore of intertidal beaches. Analyses were done on distances among centroids from principal coordinates (obtained using Bray-Curtis and 4<sup>th</sup>-root transformed abundances) and tests were done using 9999 permutations.

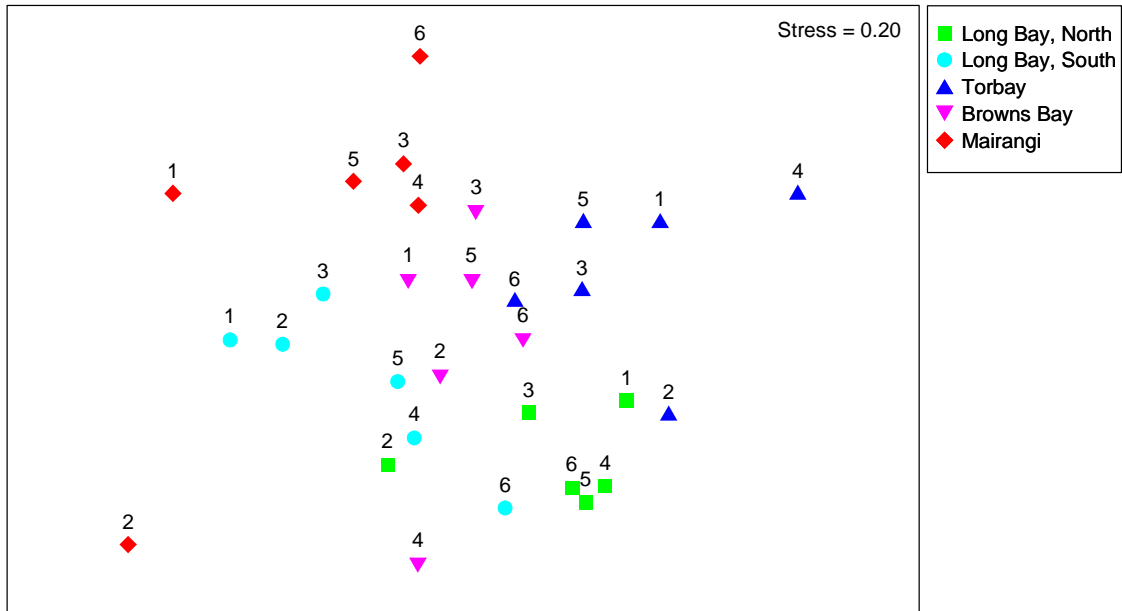
	R	P	Pair-wise tests
(a) Mid-shore			
Beach	0.424	0.0001	All $P < 0.035$
Time	0.234	0.0009	No consistent differences
(b) Low-shore			
Beach	0.418	0.0001	All $P < 0.002$ , except LN=LS, LS=M
Time	0.393	0.0001	1 {2, 3, 4, 5, 6}

Despite the lack of any clear temporal trends, strong spatial patterns were apparent on the MDS plots (Fig. 3) and in the ANOSIM results, with larger overall R statistics and significant differences detected among all beaches for the mid-shore (Table 4). For the low-shore, there was no significant difference detected between the north and south sections of Long Bay, nor between Long Bay South and Mairangi, although the latter result may largely have been caused by greater within-group variation for Mairangi caused by earlier sampling dates (1 and 2) being quite dissimilar from those taken later (Fig. 3).

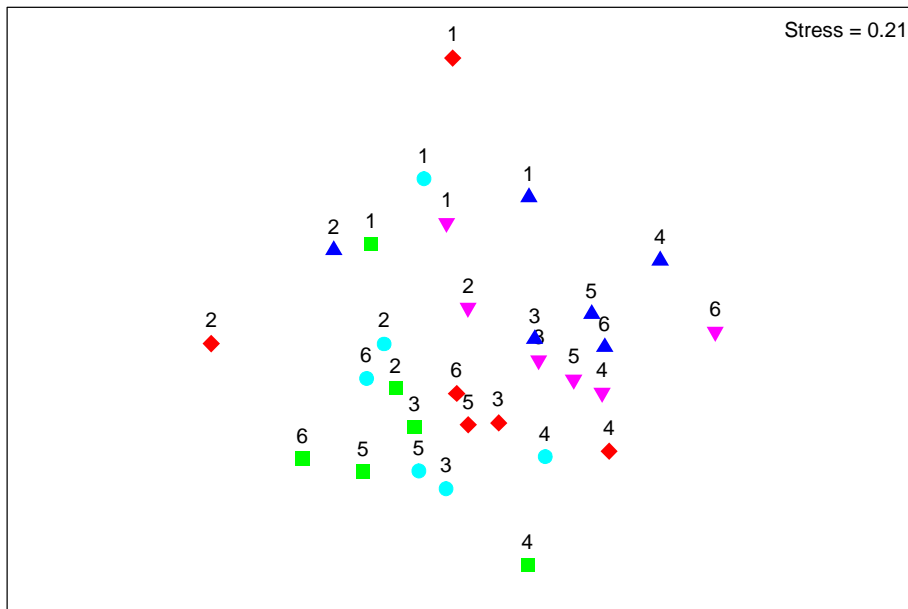
Several clear differences in community composition characterised the different beaches. For mid-shore assemblages, Long Bay North had large proportional abundances of amphipods and bivalves and Long Bay South had high dominance by bivalves (Fig. 4). Torbay, Browns Bay and Mairangi showed a bit more even distribution across the groups with greater contributions from polychaetes, isopods and other crustaceans. Cumaceans

and polychaetes were dominant at Mairangi, while bivalves and polychaetes were more prominent at Torbay and Browns Bay.

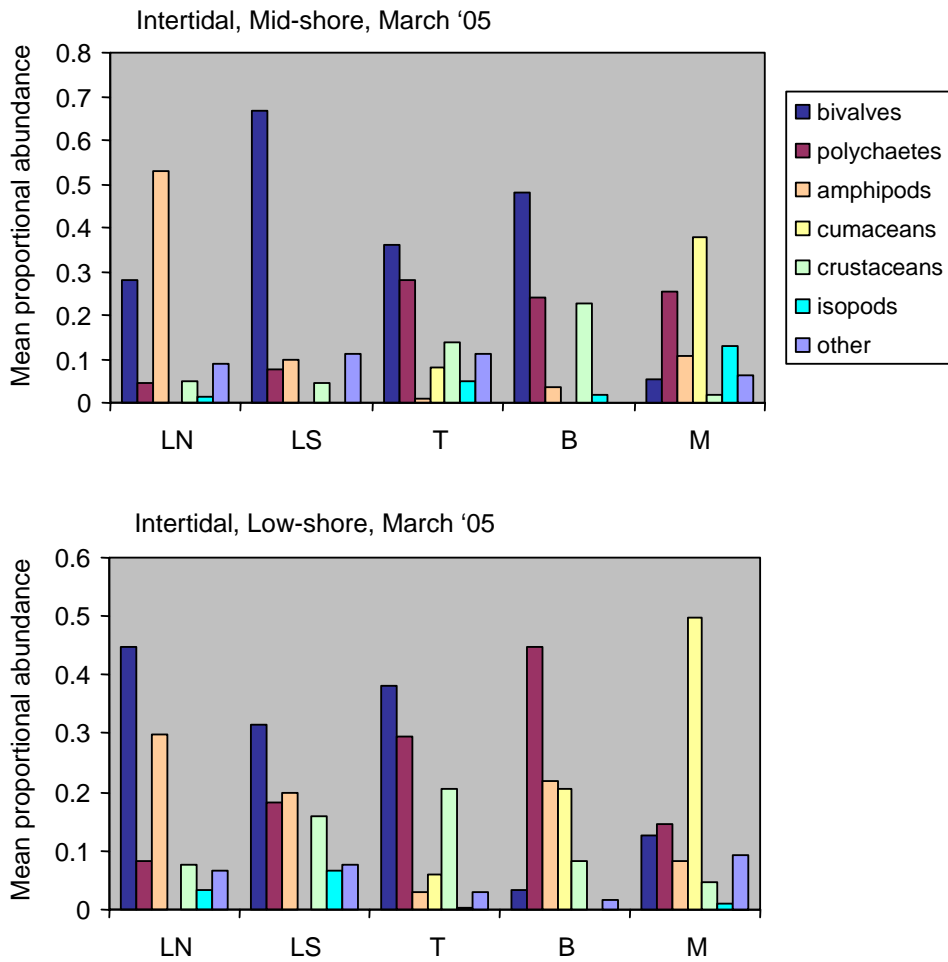
### Intertidal beaches, Mid-shore



### Intertidal beaches, Low-shore



**Fig. 3.** Non-metric MDS plots of centroids (from principal coordinates using Bray-Curtis dissimilarities of 4<sup>th</sup>-root transformed abundances) of intertidal mid-shore and low-shore beach assemblages at each of 5 sites, with the time series indicated using integers: 1 = Sep '02, 2 = Mar '03, 3 = Sep '03, 4 = Mar '04, 5 = Sep '04, 6 = Mar '05.



**Fig. 4.** Mean proportional abundances for March 2005 of each of several major taxonomic groups at each beach (LN = Long Bay North, LS = Long Bay South, T=Torbay, B = Browns Bay and M = Mairangi). Note that the general category "crustaceans" includes all crustaceans other than amphipods, isopods and cumaceans, which are already listed as separate categories.

Profiles of general assemblage structure were more similar for Long Bay North and South for the low-shore assemblages. Torbay had greater proportional abundances of polychaetes and crustaceans in the low-shore, while Browns Bay was dominated by polychaetes and Mairangi was dominated by cumaceans (Fig. 4).

### 5.1.2 Patterns in diversity, individual taxa and groups

The best model fit (on the basis of the BIC criterion) for each of the ten most abundant individual taxa and also for the total number of individuals, total number of taxa, total number of polychaetes and total number of amphipods are shown in Table 5. The ones of greatest interest are those which have shown either  $T_{lin}$  or  $Y_{lin}$  as a component in their best model, as these indicate trends (either increases or decreases) through time. As another general note, the value of the dispersion parameter ( $\theta$ ) varied between 0.08 and 2.9, and the model deviance was generally near to or less than the residual degrees of freedom, indicating that the negative binomial models were reasonable for these data.

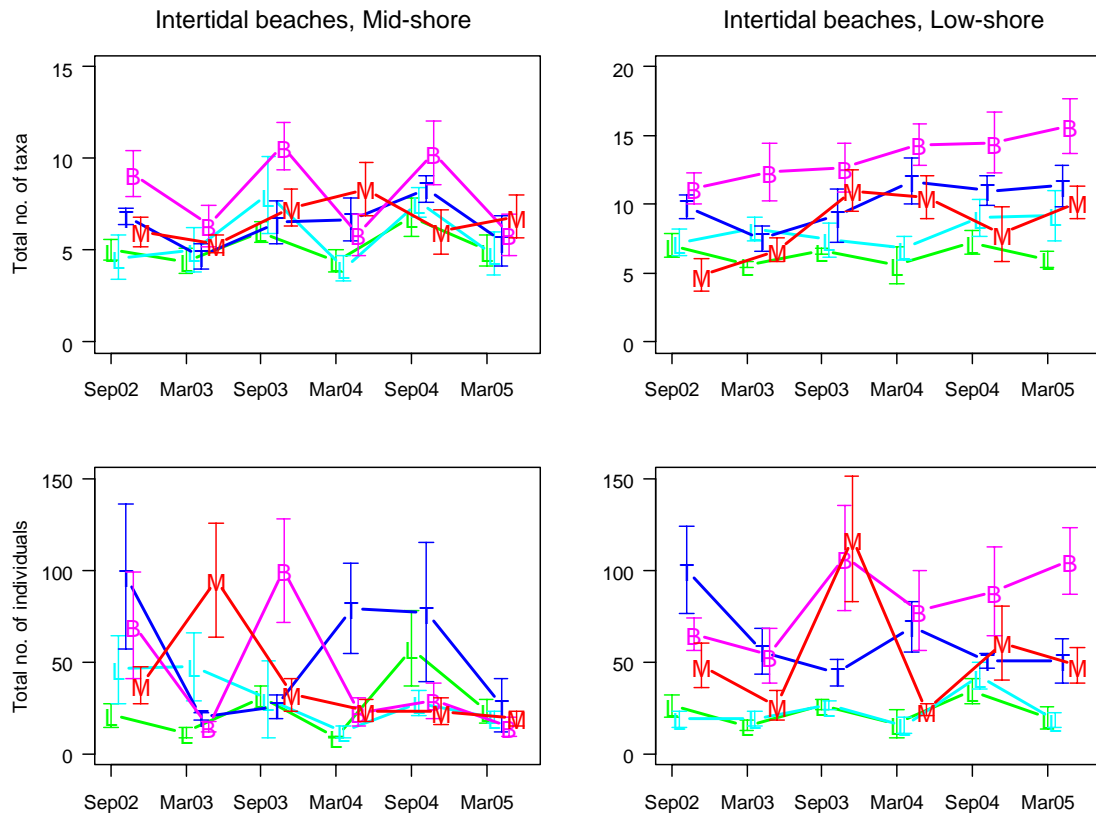
#### 5.1.2.1 Differences among beaches

There were significant differences among the bays in almost all analyses done (Table 5). Many of these differences were due to Long Bay (either north or south or both) showing significant differences from other locations. For example, in mid-shore and in low-shore assemblages, there were generally greater average numbers of taxa at Browns Bay and lower average numbers of taxa at Long Bay than at the other locations (Fig. 5). Patterns in the total number of individuals were somewhat erratic for mid-shore assemblages. However, for low-shore assemblages, there were clearly greater numbers of individuals at Torbay, Browns Bay and Mairangi than at Long Bay North or South (Fig. 5).

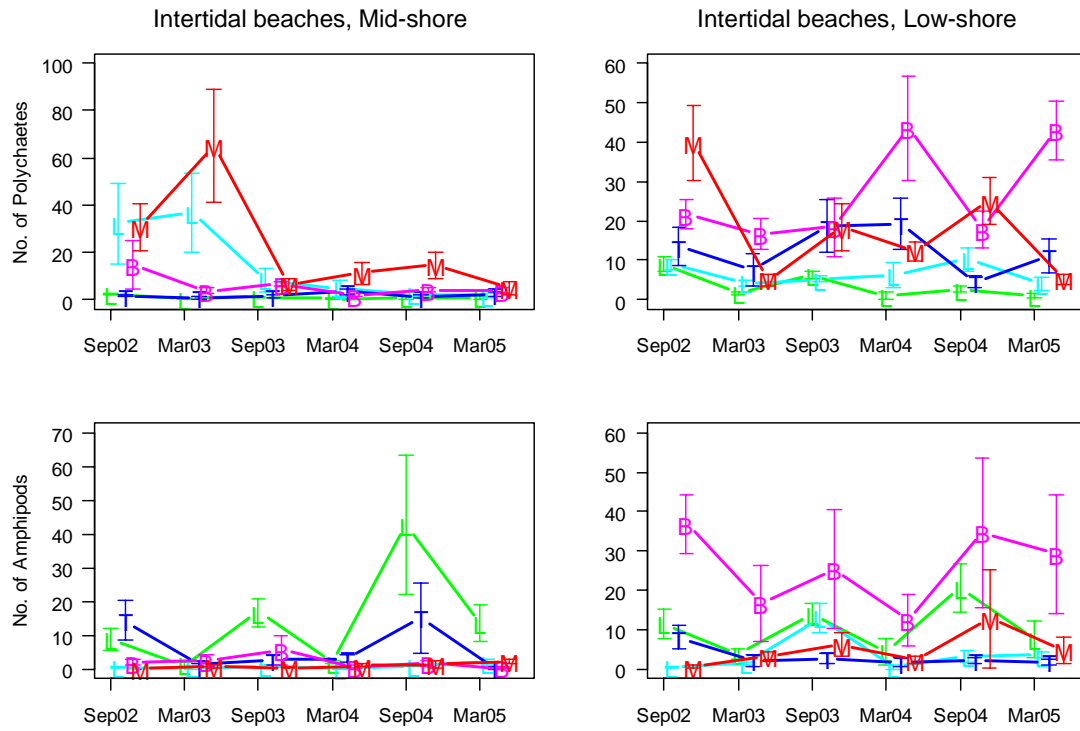
There were greater average abundances of polychaetes observed at Browns Bay, Mairangi and Torbay than at Long Bay North or South for the low-shore (Table 5, Fig. 6). In the mid-shore, however, the total number of polychaetes has been greatest on average at Long Bay South and Mairangi. Spatial differences among beaches were also apparent in the total number of amphipods. In the low-shore, there were greater average abundances of amphipods at Browns Bay, followed by Long Bay North and then Mairangi, with very few recorded from either of the other beaches (Table 5, Fig. 6). In the mid-shore, greater average abundances of amphipods were obtained from Long Bay North than from any of the other beaches.

Results for the pipi (*Paphies australis*) are shown graphically for each of three variables: *Paphies* juveniles (< 4 mm), adult *Paphies australis* (> 4 mm) and the total number of *Paphies* (their sum), although only the total number was analysed statistically. Average abundances of *Paphies* per transect in either the low-shore or mid-shore never rose above 20 at any beach other than Torbay (Fig. 7). There were clearly a great deal more pipis at

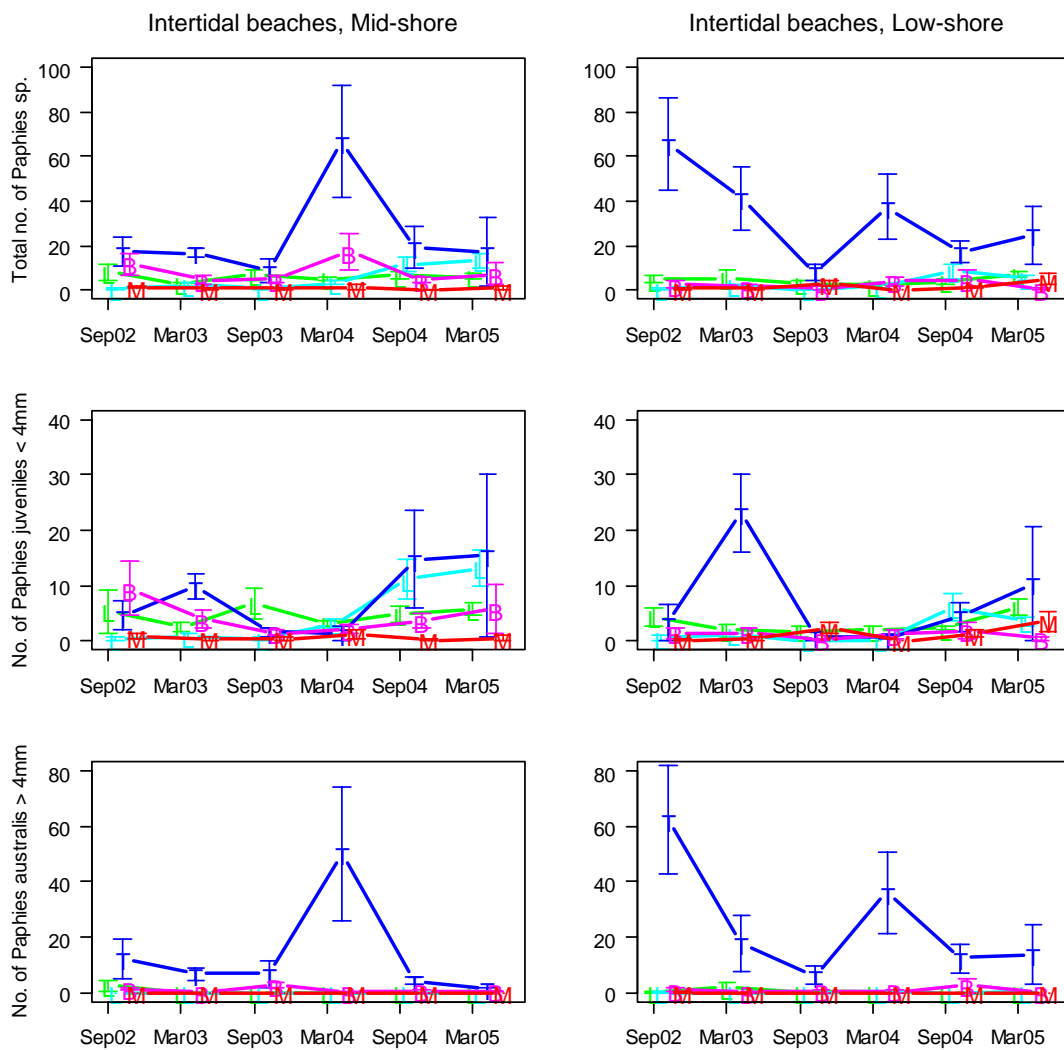
Torbay on average than at any other beach sampled. In addition, there was no clear connection between the abundances of juveniles and the abundances of adults at any given time (Fig. 7).



**Fig. 5.** Mean  $\pm$  1SE total no. of taxa and total no. of individuals in each of the low-shore and mid-shore for intertidal beaches. L (green) = Long Bay North, L (cyan) = Long Bay South, T (blue) = Torbay, B (magenta) = Browns Bay and M (red) = Mairangi. Sample sizes were  $n = 5$  transects for Long Bay and  $n = 6$  elsewhere.



**Fig. 6.** Mean  $\pm$  1SE total no. of polychaetes and total no. of amphipods in each of the low-shore and mid-shore for intertidal beaches. L (green) = Long Bay North, L (cyan) = Long Bay South, T (blue) = Torbay, B (magenta) = Browns Bay and M (red) = Mairangi. Sample sizes were  $n = 5$  transects for Long Bay and  $n = 6$  elsewhere.



**Fig. 7.** Mean  $\pm$  1SE abundance of *Paphies* sp. in total and in each of two size classes in each of the low-shore and mid-shore for intertidal beaches. L (green) = Long Bay North, L (cyan) = Long Bay South, T (blue) = Torbay, B (magenta) = Browns Bay and M (red) = Mairangi. Sample sizes were  $n = 5$  transects for Long Bay and  $n = 6$  elsewhere.

**Table 5.** Results of negative binomial GLMs for several individual response variables at each of the mid-shore (m) and low-shore (l) on intertidal beaches. The best model in each case is shown, along with the number of parameters ( $\rho$ ), degrees of freedom of the residual (*dfres*), deviance (*dev*), estimate of the dispersion parameter ( $\theta$ ) and the information criterion (*BIC*). The total number of taxa was analysed using a traditional linear model with normal errors, instead of the negative binomial. Note: T\*B and Y\*S\*B are identical, fully saturated models which identify the means for all beach and time combinations uniquely.

Variable	Model equation	$\rho$	dfres	dev	$\theta$	BIC
Total taxa (m)	S+B	5	162	1147.94	-	835.49
Total taxa (l)	Ylin+B	5	162	1808.52	-	911.85
Total individuals (m)	Ylin+S	2	165	187.68	1.212	1572.49
Total individuals (l)	S+B	5	162	175.57	2.892	1575.67
Total polychaetes (m)	Tlin*B	9	158	173.65	1.109	938.52
Total polychaetes (l)	Ylin+S+B+Ylin×S+S×B	11	156	180.16	1.899	1176.00
Total amphipods (m)	Ylin+S+B+Ylin×B+S×B	14	153	165.58	0.900	746.99
Total amphipods (l)	S+B	5	162	186.01	0.563	1008.47
Paphies (m)	Tlin*B	9	158	173.37	1.035	922.80
Paphies (l)	Y+B	6	161	175.70	0.643	853.67
Copepods (m)	S+Lv0 +S×Lv0	3	164	91.14	0.248	445.74
Copepods (l)	Y+S+B+Y×S	9	158	86.08	0.292	420.07
Waitangi (m)	Ylin+S+B+Ylin×B	10	157	159.98	0.954	609.53
Waitangi (l)	S+B	5	162	170.05	0.421	833.00
Colurostylis (m)	Tlin*B	9	158	111.09	0.320	463.21
Colurostylis (l)	Tlin*Lv0	3	164	165.07	0.441	743.55
Hesionidae (m)	Y+B	6	161	109.72	0.245	518.95
Hesionidae (l)	Ylin+B	5	162	117.48	0.239	503.66
Amphipod.ne (m)	S	1	166	26.13	0.076	84.95
Amphipod.ne (l)	B	4	163	65.36	0.184	324.20
Nematodes (m)	Lv0	1	166	129.91	0.297	487.10
Nematodes (l)	Ylin+S+B+Ylin×S	7	160	134.13	0.348	557.79
Ostracods (m)	Ylin+S	2	165	86.18	0.365	312.38
Ostracods (l)	Y+B	6	161	131.01	0.606	519.69
Scolecopsis (m)	Y+S	3	164	99.16	0.383	329.90
Scolecopsis (l)	Y+S+B+Y×S	9	158	111.19	0.693	495.74
Magelona (m)	Tlin*Lv0	3	164	65.40	0.308	189.21
Magelona (l)	Y+S+B+Y×S	9	158	163.66	1.095	638.83

The best model fit for copepods included the term Lv0, and it was clear that there were greater average abundances of copepods at Torbay, Browns Bay and Mairangi than at Long

Bay (Appendix E1). In contrast, greater average abundances of the amphipod *Waitangi sp.* have been recorded from Long Bay North than from any of the other beaches (Appendix E1). Patterns in the abundances of the cumacean *Colurostylis sp.* have been largely erratic, although their numbers tend to be lower on average at Long Bay than at the other beaches (Appendix E1).

Although polychaetes of the family Hesionidae were once abundant at Long Bay South, Browns Bay and Mairangi (September 2002), relatively few have been recorded since that time (Appendix E2). The unidentified amphipod referred to as "no eye" (Amphipod.ne in Table 5) occurred almost exclusively in the low-shore at Browns Bay (Appendix E2). Average abundances of Nematodes have been fairly erratic, although greater numbers tend to be encountered at Long Bay South than elsewhere and very few have ever been recorded from Torbay (Appendix E2).

In low-shore assemblages, there were greater average abundances of Ostracods at Torbay and Browns Bay than elsewhere (Appendix E3). The polychaetes *Scolelepis sp.* and *Magelona dakini* have both shown fairly erratic spatio-temporal patterns of abundance, although greater average abundances of *Magelona* occurred at Browns Bay than at the other beaches in the most recent sampling (Appendix E3).

#### 5.1.2.2 Temporal changes

The total number of taxa demonstrated a trend of increasing diversity through time in low-shore assemblages (Ylin) (Table 5, Figs. 5, 6). For mid-shore assemblages, no trend was detected, but there was a very clear seasonal effect (S), with greater diversity in the spring (September) than in the autumn (March) across all bays. The total abundance of individuals showed yearly decreases across all bays (Ylin), as well as a seasonal effect (with higher numbers in spring) for mid-shore assemblages (Table 5, Fig. 5). In contrast, there were no linear trends detected in this variable for the low-shore assemblages, although the seasonal effect of generally greater average abundances in spring was still clear.

For the total number of polychaetes, decreasing abundances were detected through time for mid-shore assemblages at Long Bay South, Browns Bay and Mairangi, although no consistent temporal patterns across bays were apparent in the low-shore (Fig. 6, Table 5). In the low-shore and in the mid-shore, there was a clear seasonal effect on the average abundance of amphipods, with greater average abundances recorded in spring than in autumn (Fig. 6, Table 5). In the mid-shore, there was also a pattern of increases in the average abundance of amphipods each year at Long Bay North.

In the low-shore environment, yearly differences in the abundances of *Paphies* were not directional through time (Table 5, Fig. 7). In the mid-shore, however, modeling suggested there have been increases in average abundances of *Paphies* at Torbay and at Long Bay South, with little or no changes at the other beaches (Table 5), although this model does

not appear to be terribly convincing by reference to the fairly erratic mean values through time shown in Fig. 7.

The greatest average abundance of copepods was observed in September 2003, with very few having been recorded from any location since then (Appendix E1). Temporal patterns for the amphipod *Waitangi sp.* include a clear seasonal pattern, with greater abundances on average in spring than in autumn for both the low-shore and the mid-shore. There have also been increases through time (Ylin) in the abundances of *Waitangi sp.* at Long Bay North in the mid-shore (Table 5, Appendix E1). The cumacean *Colurostylis sp.* demonstrated a pattern of increasing average abundance through time at Torbay, Browns Bay and Mairangi, but decreases through time at Long Bay North and South (Table 5, Appendix E1).

The average abundance of Hesionidae has decreased through time in both the mid-shore and low-shore assemblages (Table 5, Appendix E2). In contrast, the unidentified amphipod “no eye” has increased through time (that is, where it occurs at Browns Bay), and also shows a clear seasonal pattern of greater numbers in spring (Appendix E2). For Nematodes, neither trends nor seasonal effects are apparent (Table 5, Appendix E2).

The average abundance of Ostracods increased significantly from year to year across all bays in the low-shore and in the mid-shore (Table 5, Appendix E3). Although no clear temporal trends were detected for the polychaete *Scolelepis sp.*, the polychaete *Magelona dakini* showed a significant pattern of increases through time at Torbay, Browns Bay and Mairangi, but decreases through time at Long Bay North and South for mid-shore assemblages (Table 5, Appendix E3).

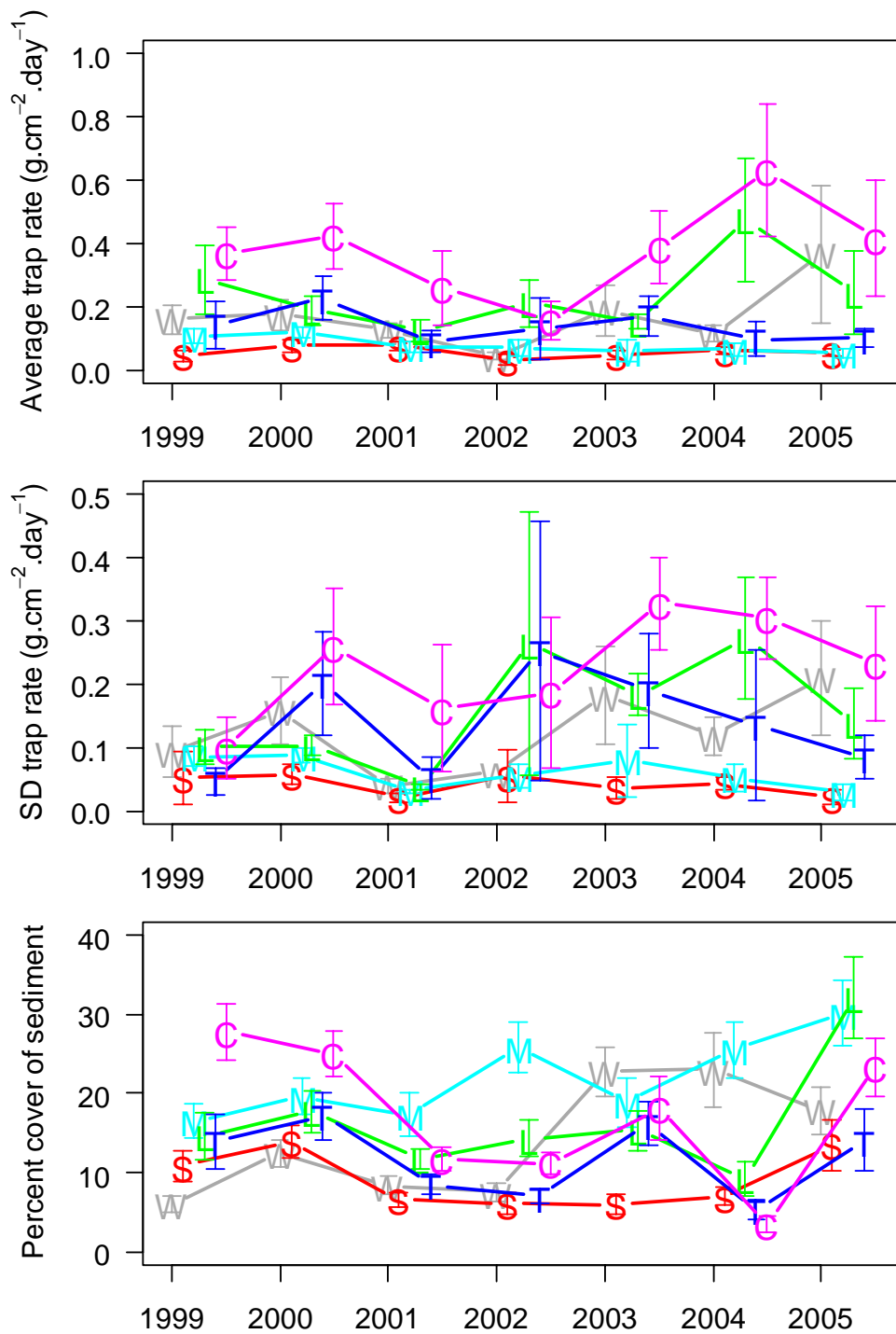
## 5.2 Subtidal assemblages

### 5.2.1 Patterns in sediment variables

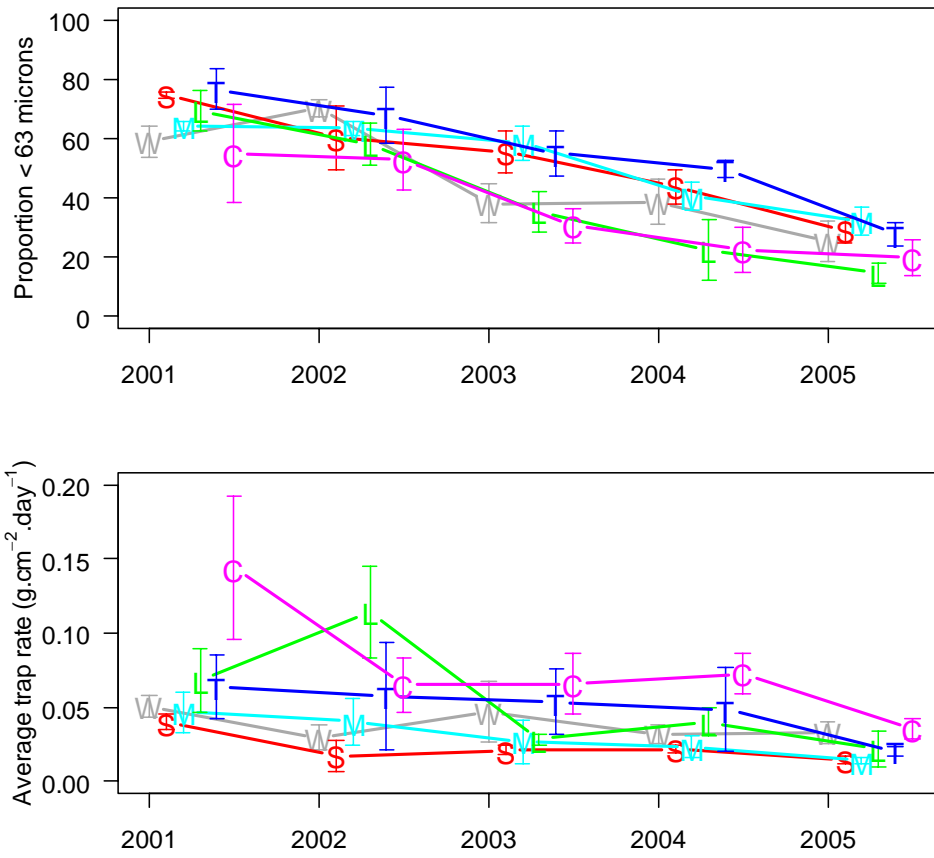
There were significant differences among the bays in the average rate of sediment accumulation in traps (Table 6, Fig. 8). This was fairly consistent through time, as the best model fit for this variable (on the basis of the BIC criterion) did not include any temporal component (Table 6). The greatest average trap rates were observed at Campbells Bay and Long Bay (Fig. 8). Tukey’s HSD pair-wise comparisons among the bays for this variable revealed a gradient, as follows:  $S < M < T < W < L < C$ , with adjacent bays in this sequence not being significantly different from one another, but other differences being statistically significant. Variability in sediment trap rate ( $SD(\text{trap rate})$ ) demonstrated a pattern that mirrored that seen for the average trap rate, showing the same ordered sequence of differences among bays (Table 6, Fig. 8). This pattern was also consistent through time. The estimated percentage cover of sediment varied from year to year and from bay to bay and did not show any clear trends (Table 6, Fig. 8). At the most recent

census (2005), Long Bay and Little Manly showed the greatest average percentage cover of sediment, while Torbay and Stanmore showed the lowest (Fig. 8).

In contrast, the proportion of trapped sediments < 63  $\mu\text{m}$  decreased significantly through time (Table 6, Fig. 9). Significant differences among the bays were also detected, with greater proportions of fine sediments seen at Torbay, followed by Little Manly, Stanmore and Waiwera, with Campbells and Long Bay having the smallest proportions of fine sediments in traps (Table 6, Fig. 9). The average trap rate for fine sediments has also therefore decreased through time, with the greatest trap rate of fine sediments seen at Campbells, Torbay and Long Bay, and the smallest average values of this variable at Waiwera, Stanmore and Little Manly (Table 6, Fig. 9).



**Fig. 8.** Mean  $\pm$  1SE average trap rate, SD(trap rate) and percentage cover of sediments at monitored subtidal sites. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes varied from  $n = 3-5$  sites at each location per year for trap rates, while the sample size for percentage cover was  $n = 35$  (5 sites  $\times$  7 quadrats).



**Fig. 9.** Mean  $\pm$  1SE proportion of trapped sediment < 63 $\mu$ m and average trap rate for fine sediments (< 63  $\mu$ m) at monitored subtidal sites. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes varied from  $n = 3$ -5 sites at each location per year.

**Table 6.** Results of linear models for sediment variables. The best model in each case is shown, along with the number of parameters ( $p$ ), degrees of freedom of the residual ( $df_{res}$ ), log of the likelihood (logL), and the information criterion ( $BIC$ ). The average trap rate (overall) and the average trap rate of sediments  $< 63 \mu\text{m}$  were both log-transformed before analysis, while  $SD(\text{trap rate})$  was square-root transformed.

Variable	Model equation	$p$	$df_{res}$	logL	BIC
Average trap rate	B	6	192	-254.39	545.80
$SD(\text{trap rate})$	B	6	192	77.65	-119.19
Proportion $< 63 \mu\text{m}$	$Y_{lin} + B$	7	127	-538.90	1116.98
Average trap rate of $< 63 \mu\text{m}$	$Y_{lin} + B$	7	127	-133.89	306.96
Percentage cover of sediment	$Y*B$	43	1427	-6006.05	12332.63

**Table 7.** Comparison of 6 models for multivariate subtidal assemblages on the basis of either (a) count data (63 variables) or (b) percentage cover data (47 variables), using PERMANOVA and a pseudo-multivariate BIC criterion.  $F$  = the  $F$ -ratio for the analysis of the full model,  $RSS$  = the residual sum of squares from the full PERMANOVA model,  $p$  = the number of parameters in the full model and  $BIC = N \times \ln(RSS/M) + (2 \times p)$ . Analyses were based on the Bray-Curtis dissimilarity measure and 4<sup>th</sup>-root transformed abundances. The best (most parsimonious) model has the lowest BIC; models are presented in increasing order of BIC value.

	Model	$F$	$RSS$	$p$	BIC
(a) Count data					
4	$Y_{lin}*B_{lin}$	14.53	124999	3	1358
2	$Y_{lin}*B$	5.37	116644	11	1386
6	$Y_{lin}*Lv0$	3.25	144618	3	1388
3	$Y*B_{lin}$	4.42	117111	13	1398
5	$Y*Lv0$	4.10	119093	13	1401
1	$Y*B$	3.43	82444	41	1474
(b) Cover data					
4	$Y_{lin}*B_{lin}$	15.41	96691	3	1304
5	$Y*Lv0$	6.45	82906	13	1325
2	$Y_{lin}*B$	4.12	96322	11	1346
6	$Y_{lin}*Lv0$	3.25	144618	3	1388
3	$Y*B_{lin}$	4.42	117111	13	1398
1	$Y*B$	4.31	57716	41	1399

## 5.2.2 Patterns in whole assemblages

Count data included 63 variables, and percentage cover data included 47 variables. Analyses using PERMANOVA and a pseudo BIC criterion indicated that the most parsimonious model for these assemblages, on the basis of either count or percentage cover data, was Ylin\*Blin (Table 7). This suggests that there is seriation through time (i.e. directional changes), and also that there is a north-south gradient in subtidal assemblage structure. Patterns on two-factor MDS plots supported these models: numbers (representing years) tended to be ordered from smallest to largest, moving from left to right across the diagrams (Fig. 10). Ordering of assemblages from north to south (from top to bottom in the MDS plots) was more apparent for percentage cover data than for count data, however (Fig. 10).

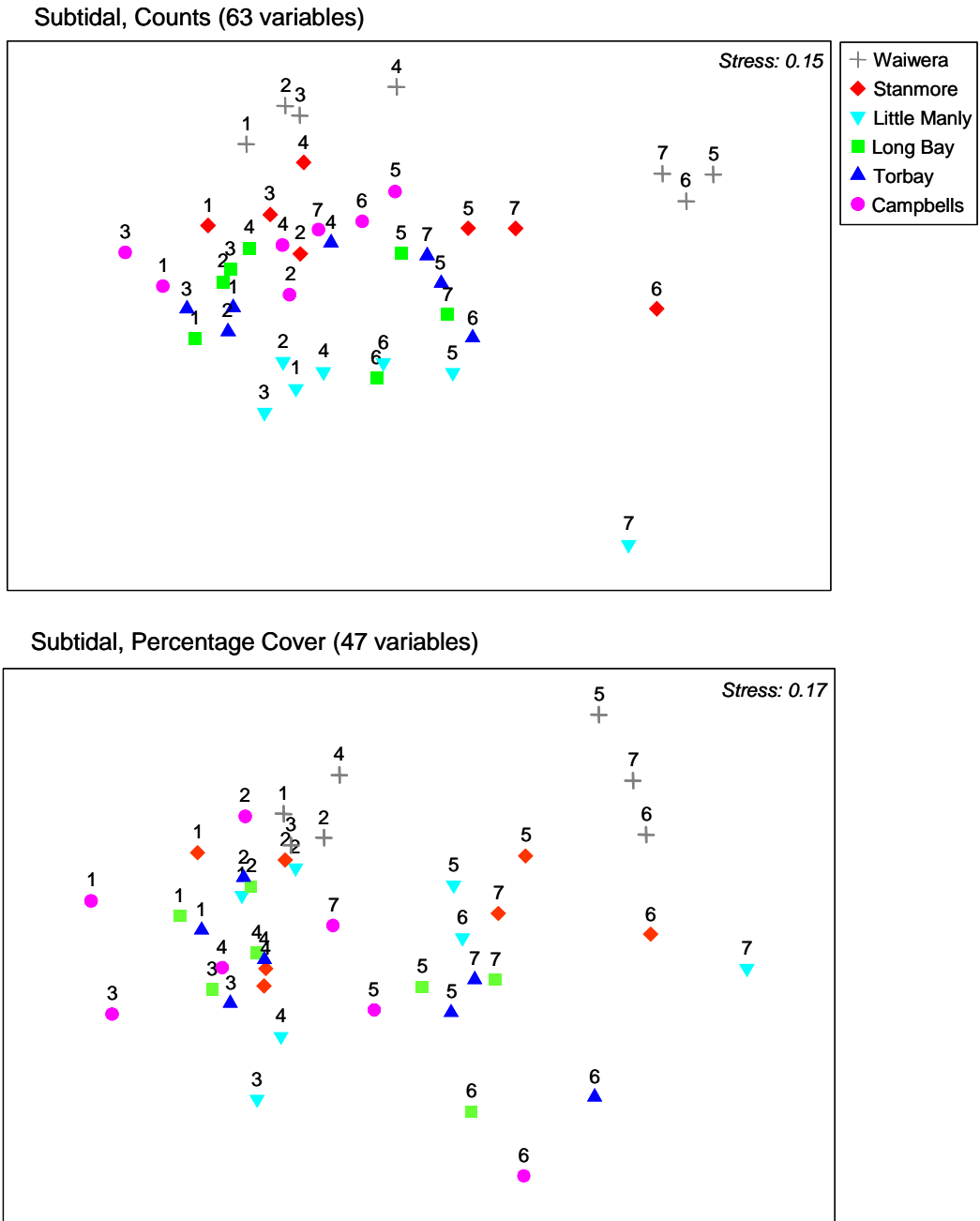
Furthermore, the Ylin×Blin interaction term was (in both cases) statistically significant ( $P < 0.0001$ ), suggesting that the degree of temporal seriation varied across bays and/or that the strength of the north-south gradient varied through time. Separate individual analyses and MDS plots of the count data showed that differences in assemblage structure among bays and also the strength of the north-south gradient has generally increased through time, becoming most pronounced in 2004 and 2005 (Fig. 11, Table 8). In addition, separate analyses also showed that differences among years and also the strength of the directional changes through time generally increased from south to north, being most pronounced at Waiwera and at Stanmore (Fig. 12, Table 9). These patterns were also clearly apparent in the percentage cover data; in fact, they were even stronger (see tables of results in Appendix F; MDS plots not included here).

**Table 8.** ANOSIM  $R$ -statistic and test for Bay effects and Mantel test for seriation from north to south (using Spearman's  $\rho$ ), done separately for each year on the count data from subtidal assemblages.

Year	Bay effects		Seriation	
	R	P		P
1999	0.145	0.0160	0.157	0.0058
2000	0.068	0.1080	0.045	0.2189
2001	0.211	0.0020	0.092	0.0666
2002	0.282	0.0001	0.133	0.0225
2003	0.212	0.0004	0.199	0.0021
2004	0.495	0.0001	0.366	0.0001
2005	0.441	0.0001	0.275	0.0030

**Table 9.** ANOSIM  $R$ -statistic and test for Year effects and Mantel test for seriation through time (using Spearman's  $\rho$ ), done separately for each Bay (listed from south to north) on the count data from subtidal assemblages.

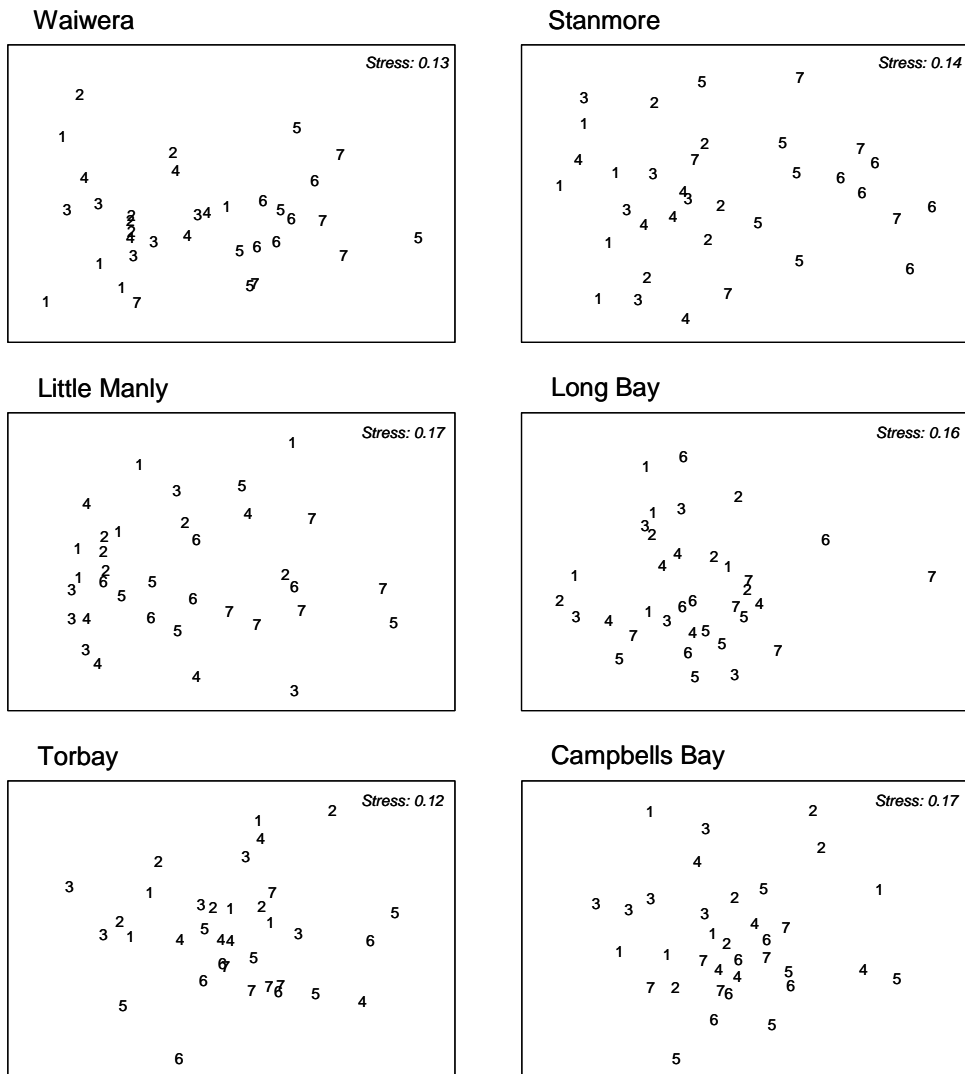
Bay	Year effects		Seriation	
	R	P		P
Campbells	0.266	0.0001	0.179	0.002
Torbay	0.086	0.0690	0.138	0.009
Long Bay	0.160	0.0070	0.249	0.001
Little Manly	0.171	0.0100	0.221	0.002
Stanmore	0.476	0.0001	0.491	0.001
Waiwera	0.401	0.0001	0.514	0.001



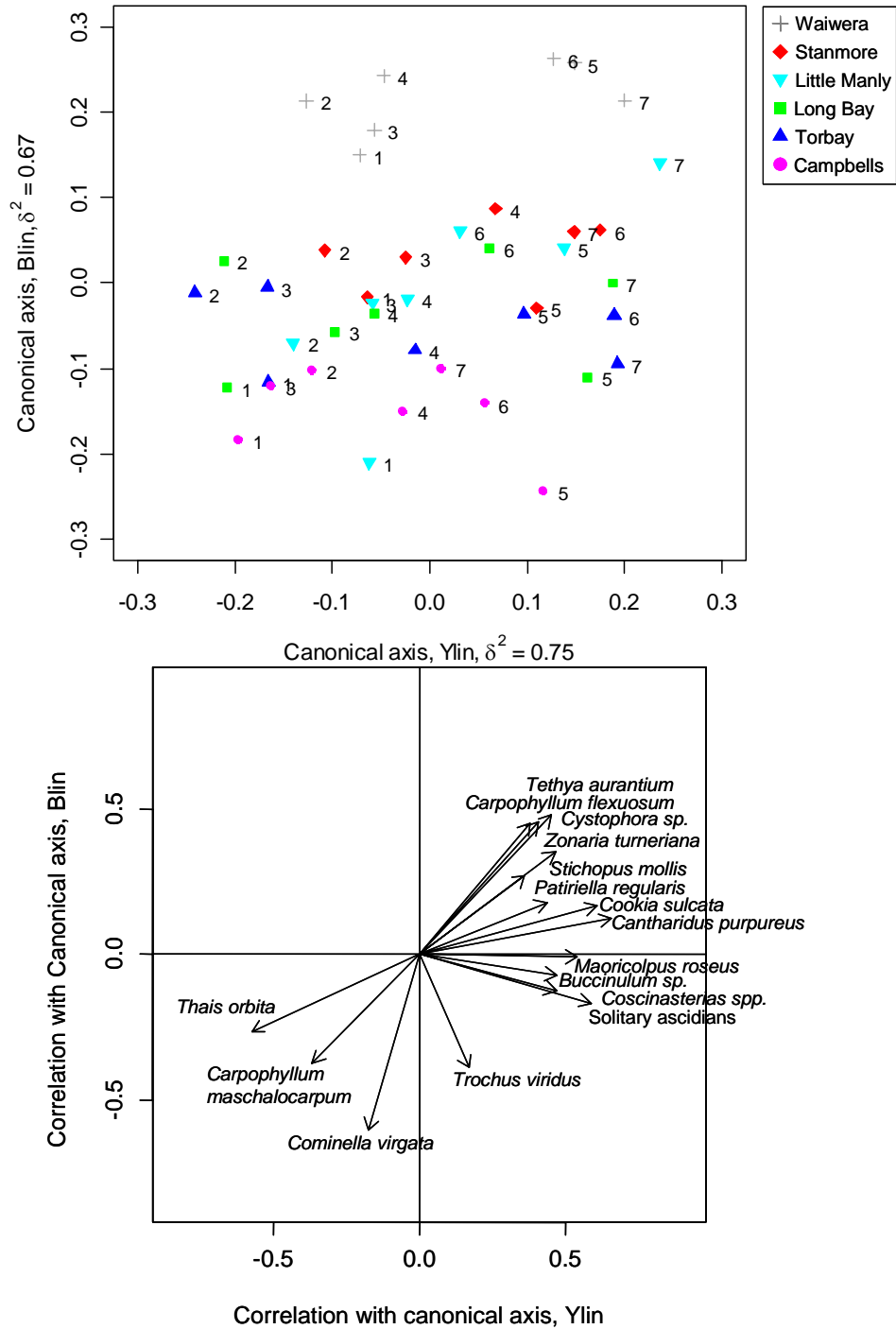
**Fig. 10.** Non-metric MDS plots of assemblages on the basis of counts (top) and percentage cover (bottom) at each of 6 bays, with the time series indicated using integers: 1 = 1999, 2 = 2000, 3 = 2001, 4 = 2002, 5 = 2003, 6 = 2004, 7 = 2005. Each point is a centroid of  $n = 5$  sites  $\times$  7 quadrats, calculated from principal coordinates using Bray-Curtis dissimilarities and a 4<sup>th</sup>-root transformation.



**Fig. 11.** Non-metric MDS plots showing bay effects within each year for subtidal count data: W = Waiwera, S = Stanmore, M = Little Manly, L = Long Bay, T = Torbay and C = Campbells Bay. Each point is a centroid of  $n = 7$  quadrats, calculated from principal coordinates using Bray-Curtis dissimilarities and a 4<sup>th</sup>-root transformation.



**Fig. 12.** Non-metric MDS plots of subtidal count data showing changes through time in each bay: 1 = 1999, 2 = 2000, 3 = 2001, 4 = 2002, 5 = 2003, 6 = 2004 and 7 = 2005. Each point is a centroid of  $n = 7$  quadrats, calculated from principal coordinates using Bray-Curtis dissimilarities and a 4<sup>th</sup>-root transformation.



**Fig. 13.** Plot of the CAP axis relating biotic count data to seriation from north to south (Blin) versus the CAP axis relating biotic count data to seriation through time (Ylin). Numbers 1-7 refer to years, as in Fig. 12. Shown below this plot is the strength and direction of Spearman rank correlations of individual species with each of the CAP axes, using arrows.

Thus, subtidal rocky reef assemblages at Waiwera and Stanmore appear to have changed significantly and directionally through time, which has in turn resulted in an increase in the north-south gradient in assemblage structure apparent in the most recent surveys of 2004 and 2005.

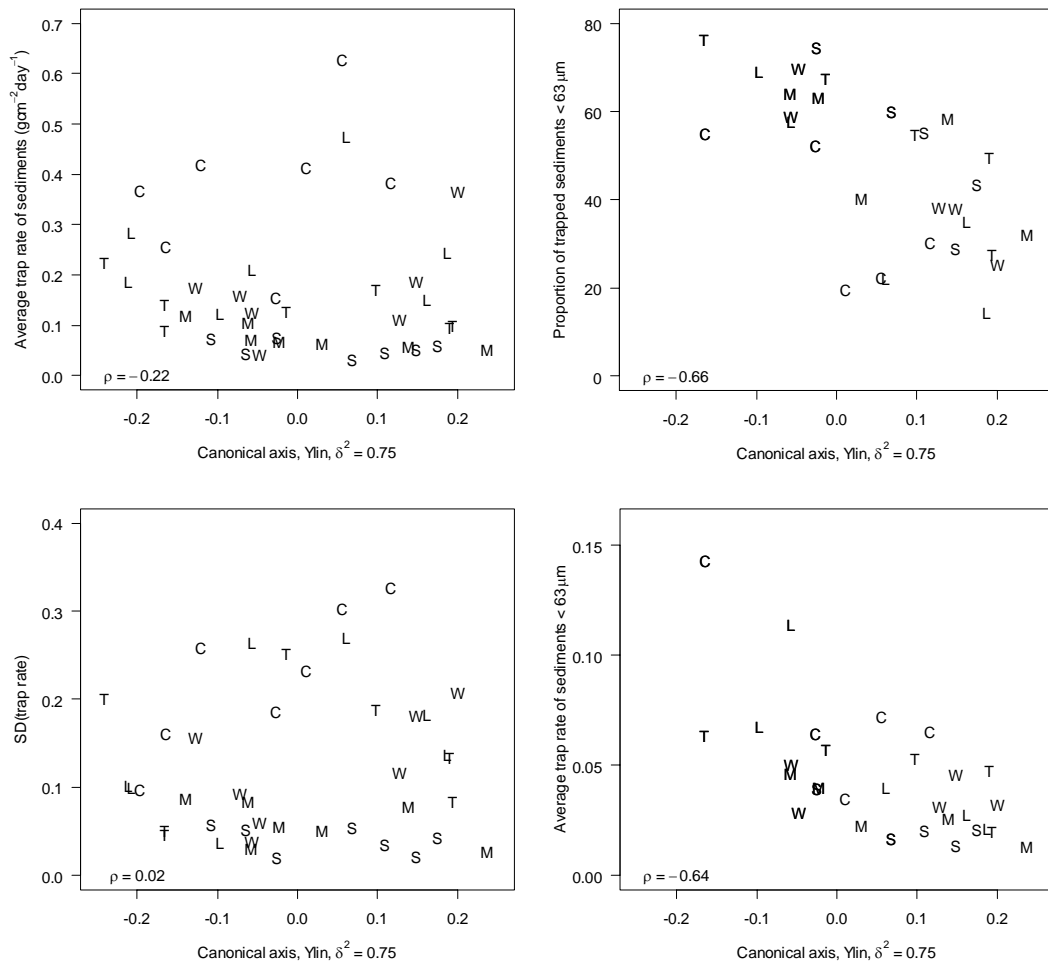
Constrained (CAP) ordinations, where the assemblages were ordered along each of the Ylin and Blin gradients directly were also done in order to elucidate the particular species responsible for these patterns. Essentially, each constrained ordination seeks the axis through the multivariate cloud of points which has the highest correlation with a chosen gradient, and orders (projects) the observations accordingly along that axis. These analyses were done on count data (Bray-Curtis, fourth-root transformed) on the basis of  $m = 5$  principal coordinate axes in each case. The squared canonical correlations ( $\delta^2$ ) were quite high, with  $\delta^2 = 0.75$  for Ylin and  $\delta^2 = 0.67$  for Blin (Fig. 13). The greatest change in assemblage structure through time was observed between 2002 and 2003 (i.e., the assemblages from time periods numbered 1-4 are on the left of the diagram and those from time periods 5-7 are on the right). Also, assemblages from Waiwera (at the top of the diagram) are clearly quite distinct from the other assemblages, and the north-south gradient is more clearly seen here (Fig. 13) than in the unconstrained MDS plot of Fig. 10.

Species having a strong relationship with these axes were obtained by calculating the Spearman rank correlations between each species variable and each of axis 1 ( $\rho_1$ ) and axis 2 ( $\rho_2$ ). Only species having strong correlations (with arrows having a length of  $\ell > 0.5$ , where  $\ell = \sqrt{\rho_1^2 + \rho_2^2}$ ) were included in the plot in Fig. 13. Changes associated with the northern bays (particularly Waiwera) through time include increases in the average abundances of the brown algae *Carpophyllum flexuosum*, *Cystophora sp.* and *Zonaria turneriana*, of the encrusting sponge *Tethya aurantium*, of the echinoderms *Stichopus mollis* and *Patiriella regularis*, and of the herbivorous gastropods *Cookia sulcata*, *Maoricolpus roseus* and *Cantharidus purpureus*. This has occurred with concomitant decreases in the average abundances of predatory gastropods *Thais orbita* and *Cominella virgata* and of the brown alga *Carpophyllum maschalocarpum* (Fig. 13). Patterns in mean abundance for those species which are highlighted here but were not abundant enough to be included in explicit univariate models (analysed in section 3.2.4 below) are shown in Appendices G1 and G2.

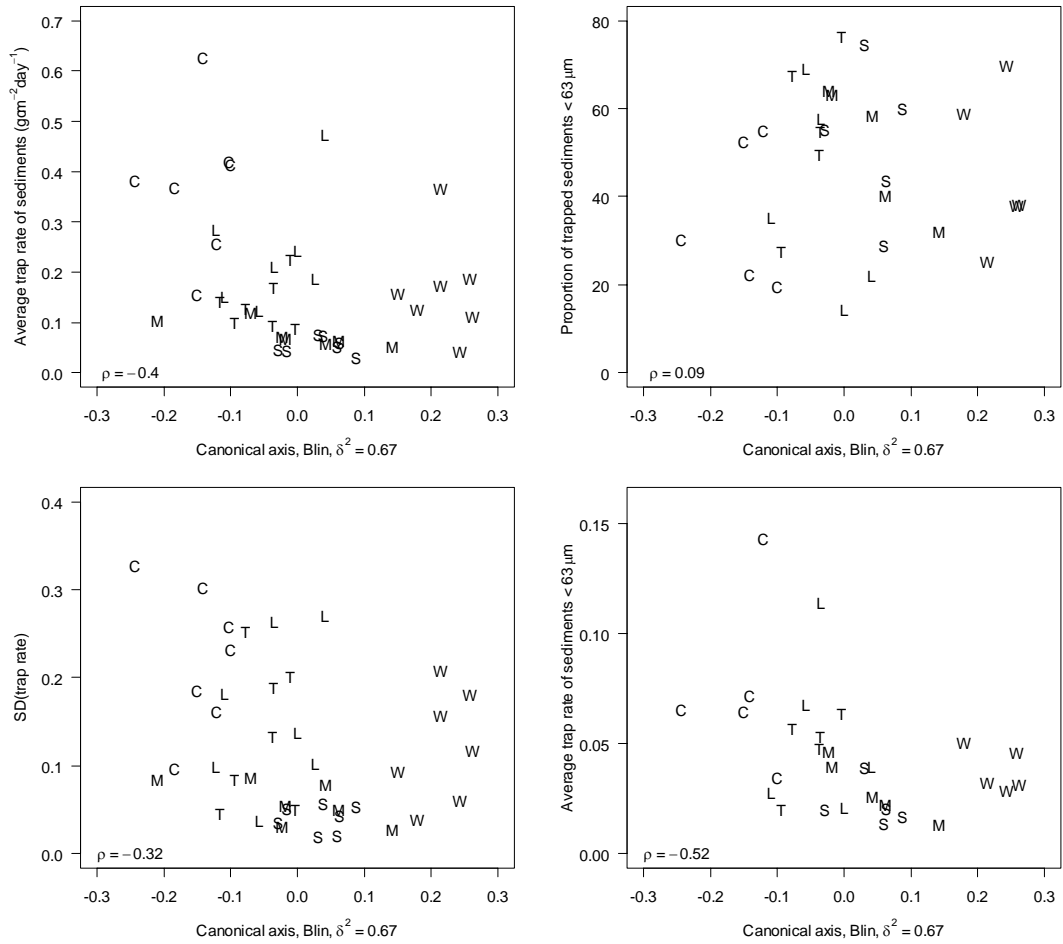
### 5.2.3 Relationships with sediment variables

The gradient of directional changes in assemblage structure through time (canonical axis for Ylin) was correlated with decreases in the proportion of fine sediments (< 63 mm) in traps and also with decreases in the average trap rate of fine sediments, but it was not related strongly to either average trap rate or SD(trap rate) (Fig. 14). In contrast, the gradient of change in assemblage structure from south to north (canonical axis for Blin) was correlated

with decreases in the average trap rate as well as decreases in SD(trap), but was not related to the proportion of fine sediments in traps (Fig. 15). Thus, in short, more sediment accumulates in traps and the amounts are also more variable as you go south. However, changes in assemblage structure through time, particular at the northern sites, was associated with decreasing proportions of fine sediments in traps.



**Fig. 14.** Relationship between each of several sediment variables and the canonical axis representing directional changes in assemblage structure through time (Ylin). W = Waiwera, S = Stanmore, M = Little Manly, L = Long Bay, T = Torbay and C = Campbells Bay.



**Fig. 15.** Relationship between each of several sediment variables and the canonical axis representing a spatial gradient in assemblage structure from south to north (Blin). W = Waiwera, S = Stanmore, M = Little Manly, L = Long Bay, T = Torbay and C = Campbells Bay.

## 5.2.4 Patterns in diversity and individual taxa

The best model fit (on the basis of the BIC criterion) for each of the fifteen most abundant individual taxa and also for the total number of individuals and total number of taxa are shown in Table 10. The ones of greatest interest are those which have shown either Ylin or Blin as a component in their best model, as these indicate trends (either increases or decreases) through time and in space, respectively.

### 5.2.4.1 Differences among bays

For subtidal assemblages, there were no consistent significant differences among the bays in either the total number of taxa, or in the total abundance of individuals (Table 10, Fig. 16). Spatial effects differed for the three species of brown algae of the genus *Carpophyllum* (Fig. 17). For *Carpophyllum maschalocarpum*, there has been a clear pattern of increasing abundance from north to south for the last three years, although not prior to that (Table 10, Fig. 17). In contrast, no consistent spatial trends were apparent for *C. plumosum*, while for *C. flexuosum*, there has been a clear pattern of decreasing abundance from north to south in the last three years, although not prior to that (Table 10, Fig. 17).

For other abundant species of brown algae, including *Zonaria turneriana* and *Cystophora sp.*, there was generally greater average abundance at northern bays than at southern bays (although neither B nor Blin were included in the model for *Zonaria*, Table 10, Fig. 18). In fact, virtually no *Cystophora sp.* has ever been recorded at Campbells Bay (Fig. 18). However, the kelp, *Ecklonia radiata*, showed no consistent differences among bays (Table 10, Fig. 18).

Spatial patterns in abundances of the herbivorous gastropods *Turbo smaragdus* and *Trochus viridus* have been variable from year to year (Table 10, Fig. 19). At the most recent census, there were greater average abundances of *Turbo smaragdus* at the southern locations of Campbells and Torbay than at the northern locations of Waiwera and Stanmore (Fig. 19). Significant differences among bays in the abundances of *Trochus viridus* vary among years and have not been correlated with a north-south gradient. No consistent bay effects were detected for *Cantharidus purpureus* either (Table 10, Fig. 19).

For some of the other reasonably abundant taxa, there are clear north-south gradients. For example, there are consistently increasing abundances from north to south for solitary ascidians and for the predatory gastropod *Cominella virgata* (Table 10, Appendices G3, G4). Also, there are consistently decreasing abundances from north to south for the sponge *Tethya aurantium* (Appendix G3). No consistent spatial patterns emerged for the brown alga *Sargassum sinclairii* (Appendix G3). Although the sea star *Patiriella regularis* demonstrated greater average abundances at the two northern sites than at other bays in 2003 and in

2005, this was not picked up by our modeling technique as demonstrating a clear north-south gradient (Table 10, Appendix G4). The sea urchin, *Evechinus chloroticus* demonstrated fairly consistently greater average abundances at Stanmore and at Long Bay compared to other bays (Table 10, Appendix G4).

**Table 10.** Results of negative binomial GLMMs for biotic variables in subtidal rocky reefs. The best model in each case is shown, along with the number of parameters ( $p$ ), degrees of freedom of the residual ( $df_{res}$ ), the variance component for variability among sites ( $\sigma^2$ ), estimate of the dispersion parameter ( $\theta$ ) and the information criterion ( $BIC$ ). Individual taxa are listed in decreasing order of overall abundance. The total number of taxa was analysed using a traditional linear mixed model with normal errors, instead of the negative binomial.

Variable	Model equation	$p$	$df_{res}$		$\sigma^2_{Site}$	$BIC$
Total no. species	Y	8	1462	-	0.573	6459
Total no. individuals	Y	8	1462	5.75	0.020	15122
Carpophyllum maschalocarpum	Y*Blin	15	1455	0.759	0.173	12534
Turbo smaragdus	Ylin*Blin	5	1465	1.442	0.402	11092
Zonaria turneriana	Y	8	1462	0.871	0.684	10947
Carpophyllum plumosum	Ylin	3	1467	0.097	7.970	4485
Ecklonia radiata	Ylin	3	1467	1.449	0.344	7576
Carpophyllum flexuosum	Y*Blin	15	1455	0.240	0.951	5204
Trochus viridus	Ylin*B	13	1457	0.661	0.124	6704
Cantharidus purpureus	Y	8	1462	0.431	0.508	4872
Solitary ascidians	Ylin + Blin	4	1466	0.419	0.382	5004
Cystophora sp.	Ylin + Blin	4	1466	0.256	4.988	3538
Sargassum sinclairii	Ylin	3	1467	0.190	1.151	3313
Cominella virgata	Ylin + Blin	4	1466	0.696	0.501	3568
Tethya aurantium	Y + Blin	9	1461	0.175	2.336	2038
Patiriella regularis	Y	8	1462	1.603	0.128	3350
Evechinus chloroticus	Lv0	3	1467	0.371	0.977	2450

#### 5.2.4.2 Temporal changes

There were greater average numbers of taxa recorded in the last 3 years (2003-2005) than in the preceding four years (1999-2002) (Table 10, Fig. 16). In addition, although there was significant year-to-year variation in the total abundances of individuals, no obvious trends were apparent (Table 10, Fig. 16).

For *Carpophyllum maschalocarpum*, there has been significant yearly variation and a trend of decreasing abundances from 2001-2005 across most bays, but particularly at Waiwera, Stanmore and Little Manly. Over this same period of time, there have been increases in the

average abundances of *Carpophyllum flexuosum* at these same three bays (Table 10, Fig. 17). This suggests there has been a gradual change at these northern sites in the relative abundance of these two species of *Carpophyllum*. In contrast, abundances of *Carpophyllum plumosum* have been quite variable, but have apparently simply decreased slightly across all sites through time (Table 10, Fig. 17).

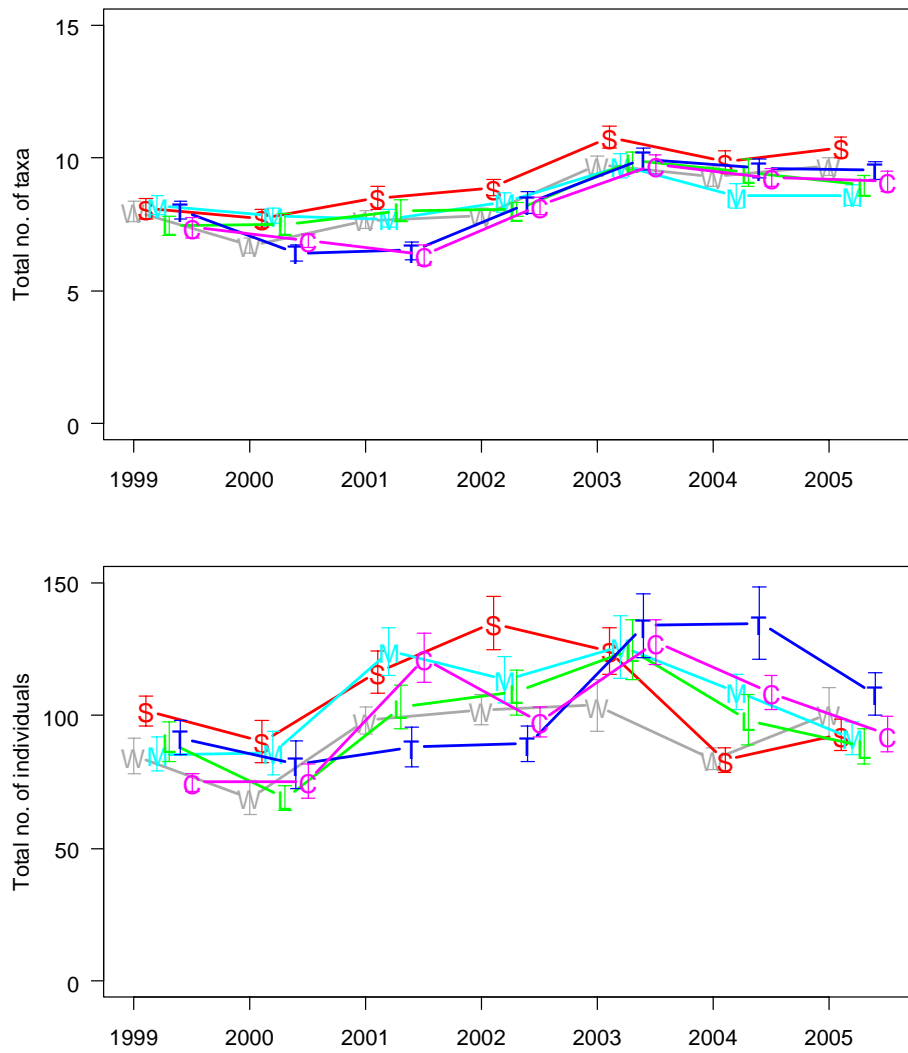
Although abundances of the brown alga *Ecklonia radiata* were fairly noisy, the model did detect a trend of slight increases through time across all sites (Table 10, Fig. 18). Year-to-year variability was also apparent for *Zonaria turneriana* (Table 10), which at northern bays generally increased through time from 1999-2003, and then have remained stable or decreased since then (Fig. 18). A clear trend of increasing abundances through time across all bays (especially at Little Manly, Stanmore and Waiwera) was demonstrated by the brown alga *Cystophora sp.* (Table 10, Fig. 18).

The herbivorous gastropod *Cantharidus purpureus* showed a pattern similar to that of *Zonaria*: there were significant yearly effects, with increases through time at all locations up to 2003, generally followed by a decrease after that (Table 10, Fig. 19). In contrast, *Turbo smaragdus* showed decreases through time at the three northern locations (Little Manly, Stanmore and Waiwera) and increases through time at the three southern locations (Long Bay, Torbay and Campbells). Increases through time were also detected for *Trochus viridus* at all bays except for Little Manly, where a decreasing trend through time was detected, and Long Bay which remained fairly stable through time (Table 10, Fig. 19).

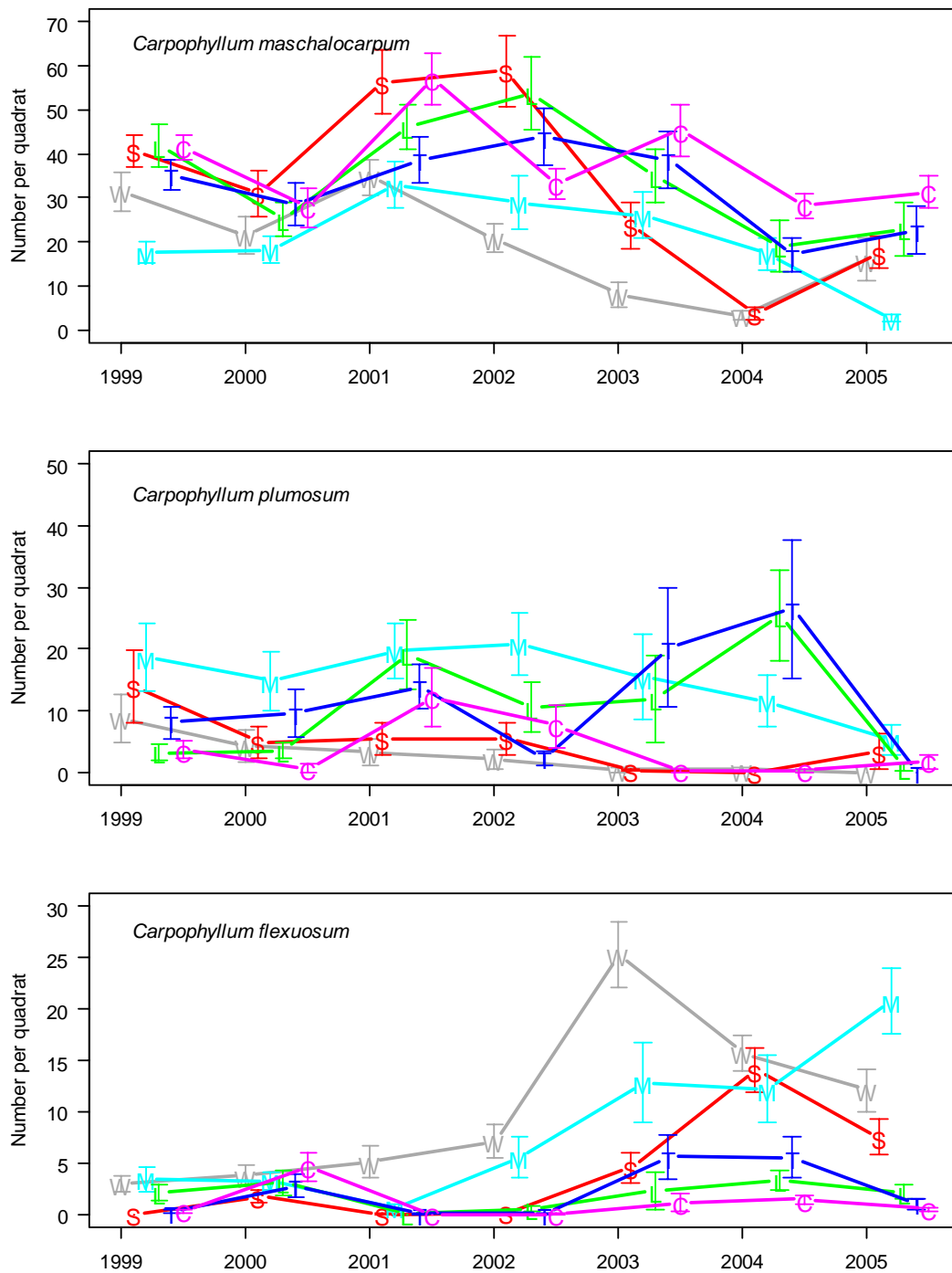
Abundances of the urchin *Evechinus chloroticus* were variable from year to year, showing no general trend, while the sea star *Patiriella regularis* tended to increase over the period from 2002-2004, especially at Waiwera (Table 10, Appendices G3, G4). In contrast, solitary ascidians and *Tethya aurantium* showed a trend of increasing abundance with time, while *Sargassum sinclairii* and *Cominella virgata* showed overall trends of decreasing abundance with time (Table 10, Appendices G3, G4).

No formal analyses have been done of size classes of individual species, but some general comments can be made on size distributions of common organisms (Appendix H). No obvious trends in size frequency are visible that correlate with either a north-south gradient or a change over time, however, some patterns are worthy of note. For example, *Carpophyllum flexuosum* increased in density at northern sites over the last three years but no clear change in size structure of *C. flexuosum* is evident over that period of time. The increasingly common alga *Zonaria turneriana*, has always had most individuals recorded in the 0-10 cm size range. *Turbo smaragdus* is the most abundant gastropod and has virtually always had most individuals in the 20 - 25 mm size range. Clear recruitment pulses have been visible for *C. maschalocarpum*, for example, at Stanmore in 2002 (Ford et al. 2003a) and at Long Bay in 2005 (Appendix H). A wide size range of individuals has been present for other common algae, but without clear peaks or patterns. Continued size frequency analysis may aid in the interpretation of any future changes in population structures,

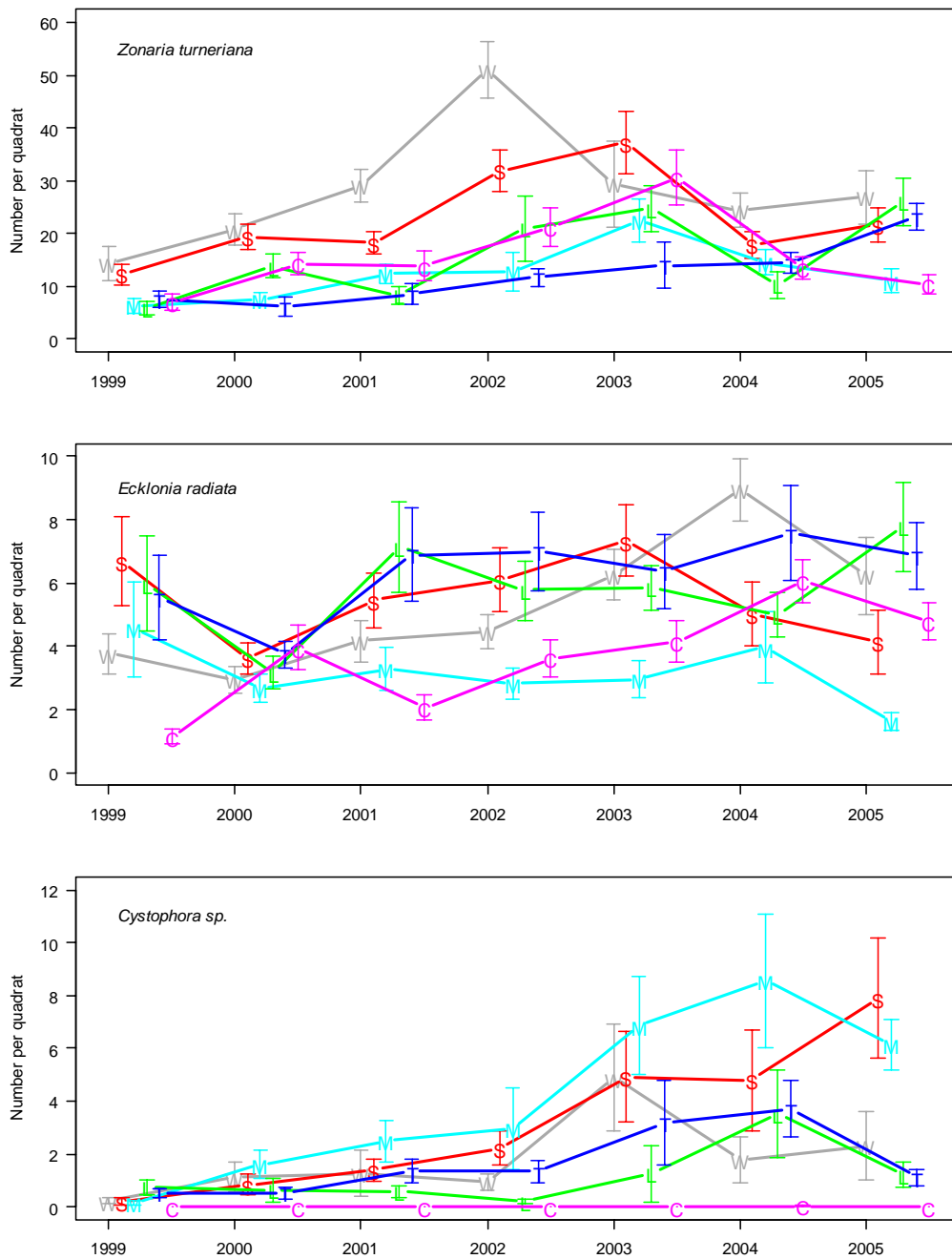
particularly with respect to recruitment pulses that might occur at particular bays or across the region as a whole.



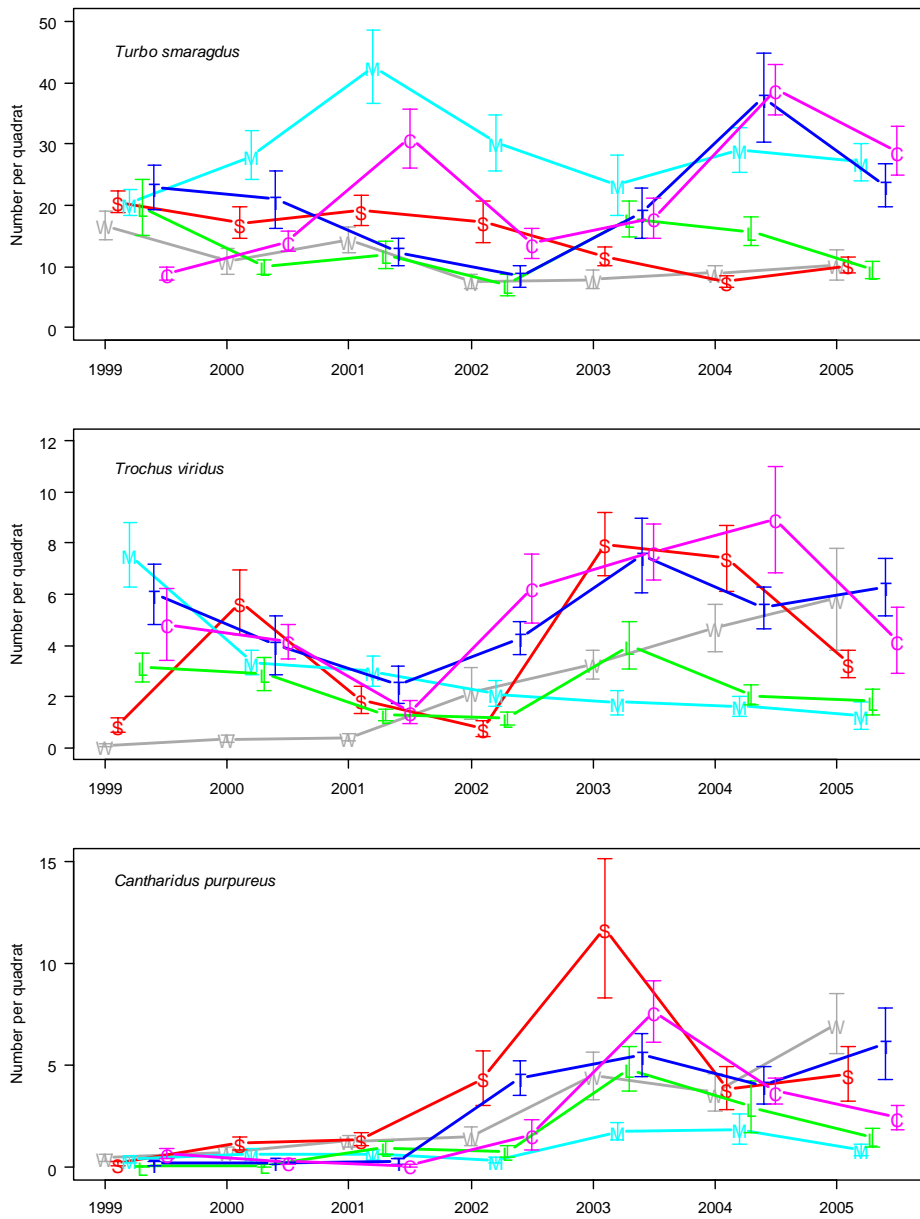
**Fig. 16.** Mean  $\pm$  1SE total no. of taxa and total no. of individuals per quadrat for subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats x 5 sites).



**Fig. 17.** Mean  $\pm$  1SE number per quadrat of each of three species of *Carpophyllum* (brown algae) for subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats  $\times$  5 sites).



**Fig. 18.** Mean  $\pm$  1SE number per quadrat of each of three species of brown algae for subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells. Sample sizes were  $n = 35$  (7 quadrats x 5 sites).



**Fig. 19.** Mean  $\pm$  1SE number per quadrat of each of three species of herbivorous gastropod for subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats  $\times$  5 sites).

## 6 DISCUSSION

### 6.1 Intertidal beach assemblages

#### 6.1.1 Salient intertidal results

The most salient results obtained for intertidal beach assemblages were:

1. Long Bay is clearly distinguishable from the other beaches in terms of the assemblages it contains.
2. Assemblages at Long Bay and at the other beaches have been fairly consistent through time.
3. Long Bay is distinguishable from other beaches by the following features:
  - a. lower average total abundances of individuals and numbers of taxa.
  - b. lower average abundances of polychaetes in the low-shore, but greater average abundances of polychaetes at Long Bay South in the mid-shore.
  - c. greater average abundances of amphipods (especially *Waitangi sp.*) at Long Bay North.
  - d. higher proportional abundances in the community (i.e. numerical dominance) of bivalves (primarily *Paphies*) and amphipods (although absolute abundances of bivalves were low compared to the beach at Torbay).
4. Temporal trends at Long Bay that were different from other beaches were extremely minor but include:
  - a. increases through time in abundance of *Waitangi sp.* at Long Bay North in the mid-shore.
  - b. decreases through time in abundances of the cumacean *Colurostylis sp.*, and in the polychaete *Magelona dakini*, while increases in these taxa were observed elsewhere.

#### 6.1.2 Discussion of intertidal patterns

All beaches showed assemblage structures that were consistently distinct over time. Browns Bay generally had the highest average number of taxa, while Long Bay (north and south) generally supported the fewest taxa and the smallest average number of individuals. This does not necessarily imply, however, that Long Bay is an impacted beach. A recent

international review of beach ecology (McLachlan and Dorvlo 2005) combined information from 161 beaches in 10 countries and concluded that species richness, abundance and biomass were closely linked to physical variables, especially sand particle size, beach face slope and spring tidal range. Beaches with the finest grains, steepest slopes and smallest tides generally showed the lowest values for richness, abundance and biomass per linear metre of beach. Tony Judd is presently completing an MSc. degree at the University of Auckland investigating the relationship between beach morphology and faunal diversity in the Auckland region. Although the four beaches surveyed in this monitoring programme covered a small range in terms of tidal range, grain size and slope, his preliminary findings indicate similar trends to what was reported in McLachlan and Dorvlo (2005).

At the mid-shore level, a statistically significant seasonal trend in diversity was detected across all beaches with greater diversity seen in spring (September) than in Autumn (March). These patterns may be due to consistent seasonal recruitment events. However, sandy beach species in South America have been seen to migrate up the beach in spring and summer and down the beach in winter and autumn (Defeo et al. 1986, de Alva and Defeo 1991, Jaramillo et al. 2000). The seasonal trend observed at the surveyed beaches was largely driven by mobile polychaetes and crustaceans that were also observed at low-shore sites, but not necessarily in decreased numbers in September. Movement of these mobile fauna up-shore into the mid-shore in September (although not enough to cause decreased numbers in the low shore) is, therefore, a probable cause of the observed seasonal pattern in diversity.

Recent estuarine work has shown that even thin layers of sediment may have catastrophic consequences for non-mobile species (Gibbs and Hewitt 2004). Mortality of organisms and recovery rate is dependant on the thickness of the sediment layer deposited and the duration of its stay (Gibbs and Hewitt 2004). In a dynamic beach environment, sediment deposits are unlikely to remain in place for very long. However, the frequency of sediment deposition events is likely to increase with urbanisation and these pulse events could result in sub-lethal stress on organisms, which in the long-term may also result in community changes and potentially mortality of some species.

In addition to the effects of sediment, however, there are a number of other stressors that should be considered and may be of more importance for the health of intertidal beach communities. As urban development proceeds, freshwater input is likely to increase due to increased stormwater flow. Concomitant with increased freshwater input may be an increase in contaminants and effluents flowing over the beach. This may occur as a constant or press event or, like sediment deposition events, may occur as periodic pulse events that increase in frequency with increased urban development. The potential effects of increased freshwater, contaminants and/or effluent on organisms are numerous and complex (see review in Gillanders and Kingsford 2002).

The Long Bay Marine Monitoring Programme is designed to detect changes in intertidal beach communities as they occur, particularly in relation to increasing urban development of the Long Bay catchment. The programme is not designed to determine the causes of existing differences among beaches in the present pre-development stage. However, with the information available, some explanations for observed differences can be proposed. One possible explanation for the relatively higher numbers of amphipods at the northern end of Long Bay and the relatively high numbers of polychaetes at the southern end of Long Bay, relative to its northern end, concerns the land-use in the catchments that drain onto these beaches. Awaruku stream drains a partially urbanised catchment at the southern end of Long Bay and supports lower numbers of crustacea than the non-urbanised Vaughans stream at the northern end (Leung 1999). It is possible that the outflow of urbanised or partially urbanised streams has caused decreased numbers of the crustacean *Waitangi sp.* in all of the beaches sampled relative to the northern end of Long Bay. Amphipods are particularly sensitive to pollution and are often used in ecotoxicological studies (Marsden 2004), although no specific references concerning the ecotoxicology of *Waitangi sp.* were found. Sediments periodically deposited from Awaruku creek may potentially stay within the beach matrix and support elevated numbers of polychaetes in the mid-shore at the southern end of Long Bay. More specific and directed research designed to test hypotheses concerning these various factors would need to be done in order to shed further light on these topics.

All beaches, apart from the northern end of Long Bay, are at least partially urbanised. Ideally, we would like to have other nearby beaches that were not urbanised against which to gauge the impact of urbanisation at Long Bay. Due to the spread of urbanisation and the relationship between beach form and faunal diversity, finding appropriate nearby reference beaches is not feasible. However, a clear indication of changes that might be associated with urbanisation at Long Bay will be detected by this monitoring programme: (1) if directional changes happening at Long Bay do not occur at the other beaches being monitored; (2) if there was a steady increase in dissimilarity between communities from beaches with relatively more-urbanised versus those with less-urbanised catchments and/or (3) if particular changes to key species that would be predicted to occur under a scenario of impact were in fact to occur. For example, a sharp decline in the average abundance of the amphipod *Waitangi sp.* from the northern end of Long Bay, concomitant with urban development, would provide evidence to signal an urbanisation impact. The programme is also robust and powerful enough: (1) to detect changes through time, (2) to place these changes into the context of other nearby beaches in the region and (3) to provide correlative relationships with relevant variables, such as the degree of urbanisation, stormwater outflow, or suspended sediments in the water column at Long Bay, which can be used to link any observed future changes in beach fauna to potential sources of impact.

To aid in the interpretation of patterns observed in intertidal beach fauna and to provide better information regarding probable causal links, we recommend that, in the future, this

project should include consideration of a number of concomitant factors associated with increased urbanisation. These include (but may not be limited to): (1) wastewater discharges, (2) measures of stormwater and wastewater inputs, (3) estimates of sediment runoff and (4) various land-use variables, such as the number of new dwellings, industrial sites, etc. in the catchment associated with each beach. These additional variables will provide an indication of the different potential stressors affecting individual beaches. In addition, if increased contamination and effluent pollution is anticipated it would be worthwhile to take periodic measures of heavy metal and enterococci levels in shellfish from monitored beaches, if possible. Information provided in the future by Tony Judd's MSc. research regarding the relationship between beach morphology and faunal diversity on Auckland beaches will also contribute to a better understanding and interpretation of monitoring data.

## 6.2 Subtidal rocky reef assemblages

### 6.2.1 Salient subtidal results

The most salient results obtained for subtidal rocky reef assemblages were:

1. There is a strong north-south gradient in subtidal community structure, which has become more pronounced in recent years (2004-2005).
2. The communities at Long Bay fall within this gradient and are broadly similar to those found at other bays (e.g., Torbay and Campbells) in the inner Hauraki Gulf.
3. The existing north-south gradient in community structure is correlated with increases in the average trap rate of sediments and increased variability in trap rate at southern sites.
4. There have been significant changes in community structure through time (since 1999, but especially in the last three years) for all bays. These changes have been most pronounced at the two northern bays (Waiwera and Stanmore).
5. Changes through time in assemblage structure across all bays are strongly correlated with decreases over the past seven years in the proportion of fine sediments (< 63  $\mu\text{m}$ ) obtained in traps.
6. At northern bays, changes in assemblage structure through time include:
  - a. increasing average abundances of the brown algae, *Carpophyllum flexuosum*, *Zonaria turneriana* and *Cystophora sp.*, of the sea cucumber *Stichopus mollis*, of the sea star *Patiriella regularis*, of the sponge *Tethya aurantium* and of the herbivorous gastropods *Cookia sulcata*, *Maoricolpus roseus* and *Cantharidus purpureus*.

- b. decreasing average abundances of the brown alga *Carpophyllum maschalocarpum* and the herbivorous gastropod *Turbo smaragdus*.
7. There were general increases across all bays through time in the average abundances of solitary ascidians, of the sea star *Coscinasterias* spp., of the brown alga *Cystophora* sp. and of the predatory gastropod *Buccinulum* sp.
  8. There were general decreases across all bays in the average abundances of the predatory gastropods *Cominella virgata* and *Thais orbita* (especially at the three southern sites) and of the brown alga *Sargassum sinclairii*.
  9. No strong trends were observed for the kelp *Ecklonia radiata* or for the urchin *Evechinus chloroticus*. These species warrant special consideration as *Ecklonia* is a major habitat-forming species and *Evechinus* can significantly alter habitat by its grazing activity.
  10. Diversity (number of taxa) and the total abundance of all organisms have been fairly constant through time, on average, and did not differ significantly among the bays.

## 6.2.2 Discussion of subtidal patterns

For the bays considered in the Long Bay Marine Monitoring Programme, *Carpophyllum maschalocarpum* was the numerically dominant macroalgae, along with *Zonaria turneriana*, *Carpophyllum flexuosum* and *Carpophyllum plumosum*. The most abundant macroinvertebrate was the herbivorous gastropod *Turbo smaragdus*, followed by *Trochus viridus*. The abundance of the sea urchin *Evechinus chloroticus* was low across all monitored bays in comparison to outer regions of the Hauraki Gulf (Walker 1999). A number of factors may account for these low numbers, such as disease, predation or physical processes that may limit recruitment to these areas. Recent research suggests sediment-induced mortality of larval and juvenile stages of *Evechinus* may be an important contributor to low numbers of urchins at sheltered inner Hauraki Gulf sites (J. Walker, pers. comm.).

Mixed algal assemblages found on sheltered, shallow, low-relief reefs tend to be dominated by *Carpophyllum flexuosum* (Grace 1983, Cole 1993, Walker 1999, Shears and Babcock 2004, Shears et al. 2004), often in association with high levels of sediment (Shears et al. 2004). Mixed algal stands comprising *Carpophyllum* spp., *Ecklonia radiata*, *Sargassum sinclairii* and *Cystophora retroflexa* are typical of sheltered sites in the 2-10 m depth range (Shears et al. 2004). On the shallowest sheltered reefs (< 2m) , *Carpophyllum maschalocarpum* is often dominant, with *C. flexuosum* becoming more dominant in the 4-6 m zone along with *Zonaria turneriana* (Shears and Babcock 2004). The sea urchin, *Evechinus chloroticus*, has been found to be rare at sheltered sites, as are the gastropods, *Cookia sulcata* and *Cantharidus purpureus* (Walker 1999, Shears and Babcock 2004). The herbivorous gastropod *Turbo smaragdus* has been found in high densities on shallow

sheltered reefs, with *Trochus viridis* found in moderate densities on deeper sheltered reefs (Walker 1999, Shears and Babcock 2004).

Patterns in monitored assemblages were consistent with the above broad-scale documented ecological patterns. In general, southern sites had higher abundances of the herbivorous gastropod *Turbo smaragdus*, the predatory whelk *Cominella virgata* and solitary ascidians. In the northern bays, *Zonaria turneriana* and *Cystophora sp.* were generally more abundant than at southern bays, consistent with the deeper more wave-exposed reefs at these sites (J. Walker, pers. comm.). For the last three years, there has been a clear pattern of increasing abundance from north to south for the brown alga, *Carpophyllum maschalocarpum*, while for *Carpophyllum flexuosum* there has been a clear pattern of decreasing abundance from north to south. Higher abundances of the herbivorous gastropod, *Turbo smaragdus*, at the more sheltered southern locations is consistent with other studies that have found higher densities of *T. smaragdus* in more sheltered sites (Walker 1999, Shears and Babcock 2004). In the absence of urchin grazing, *T. smaragdus* is thought to be the dominant herbivore (Walker 1999). The predatory gastropod, *Cominella virgata*, was also found to increase from north to south. *C. virgata* is commonly found in soft-sediment habitats as well as rocky reefs (Morton and Miller 1973, Stewart and Creese 2004) and is thus expected to be more tolerant of sheltered locations with higher sediment cover.

These patterns in community structure were correlated with the average rate of sediment trapped and its variability, which both increased from north to south. In particular, the greatest trap rates were observed at Campbells and Long Bay. A higher rate of sediment trapped and greater variability indicates that there is more sediment being mobilised in the water column above these southern reefs. There are many possible ways in which increased mobilisation of sediments above southern reefs could impact communities. These include reducing light, scouring of adults and juveniles, covering reef surfaces and thus either smothering organisms or reducing the area of reef available for settlement (e.g., Airoldi 2003). In 2005, the percentage cover of reefs by sediment was highest at Long Bay, Little Manly and Campbells, which generally agrees with the trend in rate and variability of sediment trapped. There are a number of other factors that also vary along the inner to outer Hauraki Gulf, such as exposure and turbidity, which were not explicitly measured in this study but may also play important roles in structuring communities.

Diversity (in terms of number of taxa) and total abundance of all organisms have been fairly stable through time at all bays. There were no consistent differences among bays in either the total number of taxa or in the total abundance of individuals. However, a clear north-south gradient in compositional community structure is apparent. Within this gradient, communities at Long Bay are broadly similar to those found in the other bays of the inner Hauraki Gulf, such as Torbay and Campbells Bay. Differences in community structure among bays and also the strength of the north-south gradient has generally increased

through time, becoming most pronounced in 2004 and 2005. The greatest changes through time occurred at the northern sites of Waiwera and Stanmore, which contributed to increase the strength of the north-south gradient. The increases in abundance of individual species observed at the northern bays were in some cases quite modest (e.g., for *Stichopus mollis* and *Cookia sulcata*), however their increased frequency of occurrence was clear and warrants further monitoring.

Correlated with these temporal changes at northern sites was a steady decrease across all the bays in the proportion and rate of accumulation of fine (<63µm) sediments in traps. A decrease in the proportion of trapped fine sediment does not necessarily represent a decrease in fine sediment inputs into the entire Hauraki Gulf, as various other factors, such as a change in wave climate, may alter the mobilisation and resuspension of sediments above monitored reefs. In addition, this observed trend may just be part of some long-term natural cycles in sediment characteristics, rainfall, or other climatic factors. The present trend may not continue, but rather may reverse when observed over longer periods of time. In any case, the observed trend of a decrease in the proportion of fine sediments is the opposite of what would be expected under the scenario of increased terrestrial runoff from urbanisation and land works. It is possible, however, that there has been a gradual but general shift in the sediment regime, in terms of the nature of suspended sediments, across the entire region monitored. It is, furthermore, possible that observed changes in assemblage structure, consisting primarily of observed increases in abundances of species at the northern bays, is a response to this regime shift which did not occur to the same extent, for whatever reasons, at the southern sites.

Generally, biotic communities at "control" (or "reference") sites are expected to remain relatively constant over time, while significant changes are expected to occur at impact sites. However, an equally important and plausible situation can occur where biotic communities at control sites change (due to natural positive conditions arising from various environmental factors, such as changes in temperature, sediment fluxes, etc.) while those at impact sites do not. The inability of communities at impact sites to respond to enhanced environmental conditions may be a sign of stress. Control sites might provide better recruitment sites, greater exposure to dispersing larvae, greater survivorship of juveniles post-recruitment, or any number of other factors. Increasing dissimilarity and the divergence of reference sites from impacted sites through time is therefore still an indication of potential impact, even if it is the control sites that are exhibiting directional temporal change. Higher abundances of some of the more sediment-tolerant species at southern bays suggests that these bays are already affected by existing elevated sediment levels and turbidity in the inner Hauraki Gulf. Small but consistent increases of some species at the northern sites clearly warrants further monitoring to see if the divergence between northern and southern sites continues through time, particularly as development proceeds.

Although it is tempting to speculate further about the potential causes of changes in assemblages at northern sites, there is genuinely little or no evidence to suggest that Long Bay has been impacted in any significant or negative way over the past seven years. The assemblages at Long Bay have remained relatively stable, and minor temporal trends observed there have also been observed at the other monitored bays. This result is to be expected, as the catchment areas surrounding Long Bay are still essentially in the pre-development stage. The important take-home messages here are:

1. The design of this monitoring programme is sensitive and has the power to detect relevant changes in community structure through time across the entire region, and at particular bays, even in the present, pre-development situation.
2. The information provided by sediment traps is relevant for linking environmental conditions to biotic patterns.
3. Monitoring should include an ongoing awareness of the additional potential for relatively pristine sites to change, while impacted sites may not.

As monitoring continues, we anticipate that longer-term trends will need interpretation within the context of available environmental and land-use factors. We therefore recommend that ongoing monitoring also include consideration of long-term climate variables, such as sea-surface temperature, and also (as for the intertidal assemblages) more specific information on catchment development as it proceeds. Such information will provide a clearer context within which the weight of evidence concerning potential impacts and causative factors can be assessed.

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## 8 Appendix A: GPS coordinates for intertidal beach transects

Global Positioning System (GPS) coordinates for each transect from the intertidal zone at each of the beaches in the monitoring programme. Latitude and Longitude are in degrees, minutes and seconds

Beach	Transect	Latitude	Longitude
Long Bay North	1	36° 40' 51" S	174° 44' 56" E
	2	36° 40' 53" S	174° 44' 56" E
	3	36° 40' 55" S	174° 44' 57" E
	4	36° 40' 58" S	174° 44' 58" E
	5	36° 41' 01" S	174° 44' 60" E
Long Bay South	1	36° 41' 05" S	174° 45' 01" E
	2	36° 41' 07" S	174° 45' 02" E
	3	36° 41' 09" S	174° 45' 03" E
	4	36° 41' 11" S	174° 45' 04" E
	5	36° 41' 14" S	174° 45' 06" E
Torbay	1	36° 42' 08" S	174° 45' 08" E
	2	36° 42' 09" S	174° 45' 07" E
	3	36° 42' 10" S	174° 45' 07" E
	4	36° 42' 11" S	174° 45' 06" E
	5	36° 42' 12" S	174° 45' 06" E
	6	36° 42' 13" S	174° 45' 05" E
Browns Bay	1	36° 42' 43" S	174° 45' 00" E
	2	36° 42' 45" S	174° 45' 00" E
	3	36° 42' 47" S	174° 44' 59" E
	4	36° 42' 53" S	174° 44' 58" E
	5	36° 42' 56" S	174° 44' 58" E
	6	36° 42' 59" S	174° 44' 59" E
Mairangi Bay	1	36° 44' 16" S	174° 45' 21" E
	2	36° 44' 17" S	174° 45' 21" E
	3	36° 44' 17" S	174° 45' 22" E
	4	36° 44' 18" S	174° 45' 22" E
	5	36° 44' 19" S	174° 45' 23" E
	6	36° 44' 20" S	174° 45' 24" E

## 9 Appendix B: Chronological synopsis of sampling methodology

### 9.1 Intertidal beach monitoring

#### 9.1.1 1998

See Babcock et al. (1998).

Intertidal sampling of Long Bay beach was initiated in February 1998 and sampling carried out in February, May, August and November of that year. This initial sampling period served to describe the distribution of organisms on the beach face and to determine an appropriate methodology for any future monitoring programmes.

Six transects were established running perpendicularly from the foot of the dunes to the mark of Mean Low Water Spring (MLWS). Transects were approximately evenly spaced along the beach with Transect 1 at the northern end and Transect 6 at the southern end (see Babcock et al. 1998 for location map). The placement of these transects was designed to determine whether there was any underlying long-shore gradient in abundance or diversity of beach infauna.

The basic design consisted of six stations, spaced along each transect, their position initially dictated by the relationship to the upper water table outflow, an important physical feature on dissipative ocean beaches. The position of this water table outcrop remained approximately constant on each sampling occasion, so the precise positions of the stations varied no more than 5-10 m from one time to the next (Table B1).

On the first sampling occasion (February), only five stations were sampled on transects 3 – 6 (station 1 at the top of the shore was excluded). In February, an additional station was sampled between stations 5 and 6 on transect 1 (station 5a). This extra sampling was also carried out on transects 1 and 2 in August and November. This was done to better document the distribution patterns of the bivalves that were more abundant at this end of the beach. Additional notes were also taken of any physical changes on the beach, especially in terms of the position of Vaughans Stream as it flowed across the beach face.

**Table B1.** Description and average position of stations sampled along the six beach transects at Long Bay, 1998. Values are the down shore distance of stations (m).

Station	Description	T1	T2	T3	T4	T5	T6
1	Dry sand above drift line	8	7	8	7	8	8
2	Damp sand before water table outcrop	15	15	15	20	15	15
3	In first 5 m of water table outcrop	25	40	25	30	25	25
4	Just seaward of water table outcrop	35	50	35	40	35	40
5	Midway between water table outcrop and water's edge	65	75	70	70	70	80
5a	Midway between stations 5 and 6	90	100				
6	At water's edge close to low tide time	130	130	130	120	120	120

Five haphazardly placed, replicate quadrats (0.02 m<sup>2</sup> × 10 cm deep) were dug out at each station. Material from each quadrat was sieved through a 1 mm mesh and the retained material sorted *in situ* wherever possible due to the marine reserve status of Long Bay Beach. Macro-benthic organisms in each sample were identified as fully as possible, counted on the beach and returned to the sand at the point of their collection. Voucher specimens of species which could not be immediately identified (especially the worms) were collected and later preserved for microscopic examination. In February 1998, juvenile pipi (*Paphies australis*) were so abundant that samples were placed in labelled jars with seawater and taken to the Leigh Marine Laboratory where they were spread out on large sorting trays and carefully searched. Animals found in these samples were kept alive in seawater and returned to Long Bay beach as soon as practicable.

All bivalves, initially the most abundant group, were measured with vernier callipers to the nearest 1 mm before being returned to the sand. This was done to allow an assessment of changes to their population structure through time. In August and November 1998, tuatua were very scarce on the beach itself, so an additional sample was collected in the immediate subtidal region by wading into the water and 'finger dredging' for five minutes. This was done by three people and the tuatua encountered were collected, measured and then returned to the swash zone where they quickly reburied.

### 9.1.2 1999

See Babcock et al. (1999).

Long Bay beach was re-sampled in February, May and September of 1999 following similar methodology as used in 1998. The number of stations sampled per transect was reduced from six in 1998 to three stations per transect in 1999. The three stations were approximately evenly spaced across the beach face from the upper water table outcrop to MLWS. The upper station was located at, or just below, the upper water table outcrop, the

low-shore station at the level of MLWS, and the mid-shore station approximately equidistant between these two.

In September 1999, three additional North Shore beaches were added to the monitoring programme. This was to provide a regional context within which any changes in beach fauna at Long Bay could be assessed. The same six transects were sampled at Long Bay, with each transect running perpendicularly from the foot of the dunes to the mark of Mean Low Water Spring (MLWS). Three additional beaches were surveyed, Torbay, Browns Bay and Mairangi Bay. At each of these beaches, four transects were sampled, in the same manner as for Long Bay (Table B2).

**Table B2.** Allocation of intertidal sampling transects and stations at four North Shore Beaches. The upper station was located at, or just below, the upper water table outcrop, the low station at the level of MLWS and the mid-shore station approximately equidistant between these two. Values in the upper, mid-shore and low-shore columns are the downshore distance of stations (m).

Site	Number of Transects	Upper	Mid-shore	Low-shore
Long Bay	6	40	80	120
Torbay	4	20	60	100
Browns Bay	4	20	60	110
Mairangi Bay	4	20	60	110

Abundance and size distribution of macroinvertebrates was determined using the same methodology as in 1998 (Babcock et al. 1998).

### 9.1.3 March 2000 – March 2001

See Walker et al. (2000 and 2001).

Sampling frequency was reduced to twice yearly, March and September, in 2000.

Methodology remained consistent with that used in 1999, up to and including March 2001.

### 9.1.4 September 2001 – March 2002

See Ford et al. (2003a).

Methodology was modified for the September 2001 and March 2002 beach sampling in order to bring the Long Bay monitoring in line with other ARC monitoring programmes such as that run in the Mahurangi Estuary (Cummings et al. 1999). The same number of transects (6 at Long Bay and 4 at Torbay, Browns Bay and Mairangi) were utilised with three stations per transect. However, one core sample was taken at each station (as in Cummings et al. 1999), instead of the five replicate quadrats previously used. Each core

(132.7 cm<sup>2</sup> × 15 cm deep) was dug out and the sample sieved through a 1 mm mesh. The retained material was preserved in 10% formalin and 0.001% Rose Bengal so that samples could be sorted and identified more thoroughly in the laboratory. Macrobenthic organisms were counted and identified to the lowest possible taxonomic level in the laboratory. All bivalves were classified into three different sizes: <4 mm, 4-15 mm or >15 mm.

#### 9.1.5 September 2002 – March 2003

See Ford et al. (2003a).

In September 2002 and March 2003, new sampling methodology was implemented following recommendations on the rationalization of beach monitoring made by NIWA (Lohrer et al. 2002).

First, at all beaches the number of sampling stations on each transect was decreased from three to two, with the high-shore station being omitted. For all sites, except Long Bay, the lowest numbers of organisms were found in the high-shore positions. Lohrer et al. (2002) recommended that sampling be concentrated in the mid to near low-tide area. By removing the high shore station on transects, the variation in macrofaunal communities on beaches was decreased, providing a more reliable data set and increasing the power with which data could be analysed. The low-shore station at Mairangi Bay was relocated to 85 m due to logistic difficulties in sampling this low-shore position (Table B3).

**Table B3.** Allocation of intertidal sampling transects and stations at four North Shore Beaches. Values in the upper, mid-shore and low-shore columns are the down shore distance of stations (m) Changes in distance from previous sampling are shown in bold with the previous sampling distance shown in brackets.

Site	Number of Transects	Upper	Mid-shore	Low-shore
Long Bay	10	Removed	80	120 m
Torbay	6	Removed	60	110
Browns Bay	6	Removed	60	110
Mairangi Bay	6	Removed	60	<b>85</b> (110)

Second, the number of transects was increased at all beaches to maintain or increase the number of samples taken per beach (Table B3). At Long Bay the beach was divided into North and South ends and in each area the number of transects was increased from three to five. At Torbay, Browns Bay and Mairangi the number of transects was increased from four to six.

Third, the number of replicate cores (132.7 cm<sup>2</sup> × 15 cm deep) was increased, from the one core per station taken in September 2001 and March 2002, to three cores per station.

Fourth, the mesh size on sieves was reduced from 1 mm to 0.5 mm. Lohrer et al. (2002) showed that samples would include nearly twice as many individuals from groups such as polychaetes and crustaceans when the finer mesh was used. Greater retention of juvenile *Paphies sp.* (tuatua and pipi) was also expected using the finer mesh, thus augmenting information about recruitment and year class strength (Lohrer et al. 2002).

Each core (132.7 cm<sup>2</sup> × 15 cm deep) was dug out and the sample sieved through a 0.5 mm mesh. The retained material was preserved in 10% formalin and 0.001% Rose Bengal. Macrobenthic organisms were counted and identified to the lowest possible taxonomic level. All bivalves were classified into three different sizes: <4 mm, 4-15mm or >15 mm.

#### 9.1.6 September 2003 – March 2005 (*Current report*)

Intertidal sample methodology was similar to that used in the previous report (Ford et al. 2003a). The same number of transects per beach was used, with ten transects for Long Bay beach and six transects for each of Torbay, Browns Bay and Mairangi beaches.

Two core samples (instead of the three in the previous report (Ford et al. 2003a) from each station were collected (as recommended in Lohrer et al. 2002). The distance measured to the stations for Long Bay beach were changed as previous distances proved impractical on all but the lowest tides (Table B4). Transects have been relabelled for consistency (Table B5).

**Table B4.** Allocation of intertidal sampling transects and stations at four North Shore Beaches. Values are the down shore distance of stations (m) Changes in distance from previous sampling are shown in bold with the previous sampling distance shown in brackets.

Site	Number of Transects	Mid-shore	Low-shore
Long Bay	10	<b>70 m</b> (80 m)	<b>100 m</b> (120 m)
Torbay	6	60	110
Browns Bay	6	60	110
Mairangi Bay	6	60	85

**Table B5.** New transect labels implemented for 2005 report and future reports. Transects labelled with a and b represent new transects added in September 2002.

Long Bay (N = 1-5 and S = 6-10)		Torbay		Browns Bay		Mairangi Bay	
Previous transect	Present transect	Previous transect	Present transect	Previous transect	Present transect	Previous transect	Present transect
1	1	1	1	1	1	1	1
1a	2	1a	2	1a	2	1a	2
2	3	2	3	2	3	2	3
2a	4	3	4	3	4	3	4
3	5	3a	5	3a	5	3a	5
4	6	4	6	4	6	4	6
4a	7						
5	8						
5a	9						
6	10						

Table B6 summarises changes in methodology used for intertidal sampling for the Long Bay Marine Monitoring Programme, from 1999 to March 2005 (current report).

**Table B6.** Summary of changes over time to intertidal beach sampling methodology.

Date	No. transects		No. Stations	No. cores	Size of cores	Sieve mesh size	Method of sorting
	Long Bay	Other beaches					
1998	6	0	6	5	200 cm <sup>2</sup> × 10 cm deep	1 mm	Sorted <i>in situ</i>
1999	6	4	3	5	200 cm <sup>2</sup> × 10 cm deep	1 mm	Sorted <i>in situ</i>
2000	6	4	3	5	200 cm <sup>2</sup> × 10 cm deep	1 mm	Sorted <i>in situ</i>
Mar 2001	6	4	3	5	200 cm <sup>2</sup> × 10 cm deep	1 mm	Sorted <i>in situ</i>
Sep 2001 – Mar 2002	6	4	3	1	132.7 cm <sup>2</sup> × 15 cm deep	1 mm	Organisms preserved and counted in lab
Sep 2002 – Mar 2003	10	6	2	3	132.7 cm <sup>2</sup> × 15 cm deep	0.5 mm	Organisms preserved and counted in lab
Sep 2003 – Mar 2005	10	6	2	2	132.7 cm <sup>2</sup> × 15 cm deep	0.5 mm	Organisms preserved and counted in lab

## 9.2 Subtidal reef monitoring

### 9.2.1 February, May, August and November 1998

See Babcock et al. (1998).

Eight subtidal reef sites in the Long Bay-Okura Marine Reserve were surveyed quarterly during 1998 (February, May, August and November). The placement of the sites was designed to provide four putative impact sites close to Vaughan and Awaruku stream mouths and four control sites further afield. Sites covered the area just north of Piripiri Point adjacent to the Okura estuary and south to Toroa Point (Table B7).

**Table B7.** Details of location and bottom type for Long Bay subtidal study sites.

Site	Treatment	Location	Depth (m)	Rock Type
1	Control	Okura estuary	1.5	Flat bedrock and boulders
2	Control	Piripiri point	1.5	Flat bedrock
3	Control	Pohutukawa Bay	3	Flat bedrock
4	Impact	Vaughan Stream north	1	Flat bedrock
5	Impact	Vaughan Stream	1	Flat bedrock
6	Impact	Awaruku Creek	1	Flat bedrock
7	Impact	Offshore Awaruku Creek	3	Flat bedrock
8	Control	Toroa Point	2	Flat bedrock

All sites had areas of shallow subtidal sandstone reef which were dominated by a macroalgal habitat which extended down to a maximum depth of 4 m (below MLWS). All sampling was carried out on these macroalgal dominated habitats.

#### 9.2.1.1 **Abundance and size distribution of macroalgae and macroinvertebrates**

The density and size structure of organisms at each site was estimated from each of ten haphazardly placed 1 m<sup>2</sup> quadrats. In each quadrat, all organisms were counted to provide density estimates. The only exceptions to this were colonial encrusting organisms such as bryozoans and some sponges and turfing algae. Organisms were measured in five of the ten quadrats to provide information on size distributions. The total length of macroalgae was measured to the nearest centimetre using a plastic tape and additional measurements of stipe length (cm) and basal diameter (mm) were made for the stipitate kelp, *Ecklonia radiata*. For gastropods, either shell length or shell width (dependant on shell form) was measured to the nearest millimetre using vernier callipers. Shell length was measured for all species except *Turbo smaragdus*, *Trochus viridis* and *Cookia sulcata*, for which diameter was measured. Test diameter of the common sea urchin *Evechinus chloroticus* was also measured to the nearest millimetre with callipers.

#### 9.2.1.2 **Substratum cover (Percent cover of encrusting forms)**

The percent cover of encrusting organisms was estimated using a point intercept method to provide information on a finer scale. Five 0.1 m<sup>2</sup> gridded quadrats were haphazardly placed on the substratum at each site and counts of the cover type under each of the 49 intercepts were made. Substratum cover included sediment, bare rock, encrusting algae, various encrusting invertebrates and holdfasts of macroalgae.

## 9.2.2 May 1999

See Babcock et al. (1999).

Following the recommendations of the 1998 report for the Long Bay Marine Monitoring Programme (Babcock et al. 1998) a number of changes were made in 1999.

In 1998, the Okura River system was the dominant source of sediment into Long Bay. In addition, it was thought that the impacts of inputs from Vaughans and Awaruku streams may be well spread around Long Bay. In this context, localised impacts by smaller streams may be difficult to detect and viable control sites needed to be established in other bays along the coast. The spatial extent of monitoring was increased to allow placement of reef assemblages in a regional context that could then be used to determine shifts in Long Bay's position on that regional gradient.

In addition, the frequency of sampling was reduced to once per year. Systematic seasonal variation in benthic populations was pronounced only in *Carpophyllum maschalocarpum*, suggesting that annual monitoring was adequate for assessing subtidal reef communities at Long Bay. It was suggested that this survey should take place in the first quarter of the year in order to obtain maximum information from *C. maschalocarpum*, which recruits at this time of year. Recruits are likely to be sensitive to a range of potential impact factors such as sediment smothering (Devinny and Vorse 1978) or toxic effects of pollutants.

### 9.2.2.1 Bay and site locations

Six bays were chosen for sampling: Waiwera, Stanmore, Little Manly, Long Bay, Torbay and Campbells Bay. Benthic communities of these bays were previously assessed within the context of the entire Hauraki Gulf and were found to have similarities in reef communities (Walker 1999). The bays therefore had potential to serve as control bays for Long Bay.

Within each of the six bays five sites (30 sites in total) were located on subtidal reefs dominated by macroalgae. Sites were placed near intertidal platforms and prominent landmarks for ease of site relocation. The number of sites sampled in the Okura/Long Bay Marine Reserve was reduced from eight in 1998 to five sites as used for the other bays (See Figure 2, pp. 10-11 in Babcock et al. 1999)

### 9.2.2.2 Counts and size distribution of macroalgae and macroinvertebrates

A number of modifications were made to sampling procedures to allow time for sampling the increased number of bays. The number of quadrats used was reduced from ten in 1998 to seven in 1999. At each site, seven 1 m<sup>2</sup> quadrats were haphazardly placed on subtidal reef dominated by macroalgal communities and all organisms were counted to provide density estimates. The only exceptions to this were colonial encrusting organisms such as

bryozoans and some sponges and turfing algae. In five of the seven 1 m<sup>2</sup> quadrats, the size structure of organisms was measured using 5 mm interval 110 mm rule bars for macroinvertebrates and 5 cm interval 260 cm tape measures for macroalgae. The total length of macroalgae was recorded. Shell width was measured for *Turbo smaragdus*, *Trochus viridis* and *Cookia sulcata* only. The test diameter was measured for the common urchin *Evechinus chloroticus*.

#### 9.2.2.3 Dominant substratum coverage

Dominant substratum coverage was estimated using a visual estimate of percent cover, rather than the point intercept method used in 1998, to reduce sampling time. The percentage cover of the substratum by encrusting (e.g. sponges) and turfing (small articulating algae) forms was estimated visually in all quadrats used for obtaining counts for subtidal organisms. Percentage cover was estimated for the smallest components first, using a 10 cm × 10 cm area as 1 % cover, until only one cover type remained. This was then allocated the remainder to a total of 100%. When uneven topography made the surface area under the quadrat greater than 100 cm × 100 cm, then an area larger than 10 cm × 10 cm was used to estimate 1% cover. For example, if an overhang meant there was an extra area of approximately 50% under the quadrat, then an area of 15 cm × 10 cm was used to estimate 1% cover. Dominant categories of substratum coverage included sediment, bare rock, holdfasts of macroalgae and various encrusting and turfing species.

#### 9.2.2.4 Key changes in subtidal reef monitoring methodology from 1998 to 1999

- ❑ Sampling frequency was reduced from four times per year to once per year.
- ❑ Five bays, in addition to Long Bay, were sampled, from Waiwera to Campbells Bay.
- ❑ Five sites per bay were sampled. This number of sites sampled at Long Bay was therefore also reduced from eight to five.
- ❑ The number of quadrats in which organisms were counted was reduced from ten to seven.
- ❑ Percentage cover of the substratum was estimated visually rather than using the point-intercept method.

#### 9.2.3 March 2000 – March 2005

See Walker et al. (2000 and 2001), Ford et al. (2003a), and the current report.

Thirty subtidal rocky reef sites at six locations from Waiwera (in the north) to Campbells Bay (to the south) have been surveyed each year as part of the Auckland Regional Council's (ARC) Long Bay Marine Monitoring Programme. Each year, sampling has been carried out

as per the methodology described in Babcock et al. (1999). There have been no methodological changes to the subtidal sampling programme since 1999.

### 9.3 Sediment Trap Monitoring

#### 9.3.1 1999/2000

See Walker et al. (2000).

##### 9.3.1.1 Sediment collection

Since the major concern for the Long Bay marine environment was the threat of increased sediment levels and the effect this may have on subtidal algal communities, information on the types and quantities of sediment entering the marine ecosystem was needed. Therefore a programme was initiated to quantify levels of sediment where community sampling was already being done. The first samples from sediment traps were obtained in September 1999 (Walker et al. 2000).

Sediment traps were placed near the locality where community sampling took place at each of the thirty sites. Sediment collectors were positioned between 1-3 meters depth. Collectors were constructed from two size ranges of D-class, PVC pipe. The trap was made from PVC pipe 32 mm in diameter and 250 mm in length, with one end of the pipe sealed by a plastic cap. A length to diameter aspect ratio of 7:1 was used so that trapped material could not be resuspended (Knauer and Asper 1989). This first pipe (the trap) was then inserted into a second PVC pipe, 40 mm in diameter and 200 mm in length also with a semi-sealed end cap. This second pipe was then attached to a 12 mm reinforcing rod (400 mm in length) using stainless steel hose clamps.

Sediment collectors were installed within 5-7 m of where quadrat sampling was undertaken, depending on substrate type and topography. Reinforcing rod was first driven into either a crack or a hole within the rocky substrate. The rod was then cemented into the substrate using Expocrete. The two lengths of PVC pipe were attached to the rods using stainless steel hose clamps. A surface net float was attached to make relocation of sediment collectors easier. It was intended for the traps to be cleared every four weeks. However, sediment traps were cleared every four-six weeks, depending on weather conditions.

##### 9.3.1.2 Sediment analysis

Upon collection, sediment traps were returned to the Leigh Marine Laboratory for analysis. The contents of the thirty collectors were emptied into filter bags for water separation.

Sediment samples were then oven dried for 24 hours at 80°C and then weighed to obtain a total dry weight.

Each sample was sieved for five minutes using a mechanical sieve shaker to separate samples into varying grain size fractions. Five sieve sizes (1mm<sup>+</sup>, 500µm, 250µm, 125µm and less than 125µm) were used. Samples containing high amounts of mud and fine silts were baked solid in the drying process. Therefore, these samples needed to be manipulated through the 1 mm and 500 µm sieves. After a period of five minutes each of the five size fractions from every sample were placed in pre-weighed re-sealable plastic bags to determine the proportions of shell, coarse sand and the finer size fractions (such as fine sediments and sand) present in each sample.

The rate at which sediments were accumulating in sediment traps was calculated. The total amount of fine sediment from the five sediment collectors at each area was divided by the mean number of days the five collectors were in the field. The surface area of the opening of a sediment trap was calculated using the formula  $A^2$ . This gives an estimate of the rate (in grams per cm<sup>2</sup> per day) at which trapped sediment is accumulating at each of the six monitoring sites.

The method for trapping sediments has remained the same since 1999. Therefore total trapped sediment rates are comparable from 1999 to the present. The textural analysis of these sediments has however, changed over time.

### 9.3.2 2001

See Walker et al. (2001).

In 2001, six sieve sizes (1mm<sup>+</sup>, 500µm, 250µm, 125µm, 63µm and <63µm) were used. Thus, two extra grain size categories were included: 63µm and <63µm. 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 2000, 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. Sediment accumulating in sediment traps was calculated using the total amount of sediment from the five sediment collectors at each area. This value was then divided by the mean number of days the collectors were in the field and the surface area of the opening of the sediment trap (g/cm<sup>2</sup>/day).

### 9.3.3 2002 – March 2003

See Ford et al. (2003a).

Sedimentation rate was investigated by deploying sediment traps at each of the 30 sites and analysing contents on an approximately monthly basis. After collection, the contents of traps were filtered through filter bags (equivalent to 1.2 micron filter papers), 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 sediment within traps ( $\text{g}/\text{cm}^2/\text{day}$ ). Samples were then individually analysed using a Galai particle size analyser to determine the percentage of the sample sediments volume that was less than 63 $\mu\text{m}$  in diameter. Note that samples were not sieved into separate size classes using the mechanical shaker first. That is, the Galai particle analyser was used to analyse the whole sediment sample.

As problems retrieving sediment traps had been encountered previously, due either to disturbance by weather events or public interference, several different designs for securing traps to the substratum were trialled. The most effective method was where large, heavy, steel base plates were constructed to contain the traps and these 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 buoys were used to mark the sites. Due to the uneven replication and sometimes sparse monthly data, values were first standardised for each time period prior to trap collection. The yearly averages per site were then generated from these values.

### 9.3.4 2003 – 2005 (Current report)

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

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

1. Hydrogen peroxide treatment (6-30%) until frothing ceases
2. Bulking, homogenisation and sub-sampling
3. Dispersion with Calgon ( $2\text{g}\cdot\text{l}^{-1}$ )

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

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

(<63µm). However, due to a strong relationship between pre-treated and untreated sediments, untreated sediments can be converted using the regression model in Ford et al. (2003b). However, care must be taken to ensure data lie within the range modelled in that report (i.e., 38 to 97% fines untreated). Therefore, with a little care, <63µm fractions (fines) can be compared from 2001 onwards. Care needs to be taken when comparing absolute values, particularly for samples with lower levels of fine sediments i.e. below 80%. The method for trapping sediments has remained the same, however, since 1999. Therefore total trapped sediment rates are comparable from 1999 to the present.

Sediment samples were collected as per previous reports, with five sediment traps deployed at each of the six bays monitored. A full description of trap design is given in Walker et al. (2000). Modifications to trap deployment are given in Ford et al. (2003a)

After collection, the traps were brought back to the laboratory for the first stage of processing. The contents of the traps were then filtered through pre-weighed filter bags (equivalent to 1.2 micron filter papers) and 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 trapped sediment (g/cm<sup>2</sup>/day).

A 60 g sub-sample of each individual dried sediment sample was then taken. Samples were thoroughly mixed beforehand to insure a representative sub-sample was taken. 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<sup>-1</sup>), before being analysed for the percentage volume of fine sediments (<63µm) using a Malvern laser particle analyser.

### 9.3.5 Summary of methodology for sediment processing

#### 9.3.5.1 1999/2000 (Walker et al. 2000)

Sediment traps were first introduced with five traps (one at each site) at each the six bays. Sediments from each trap were oven dried, then sieved through a series of sieves using a mechanical shaker. Sieve sizes were 1mm<sup>+</sup>, 500µm, 250µm, 125µm and less than 125µm.

#### 9.3.5.2 2001 (Walker et al. 2001)

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

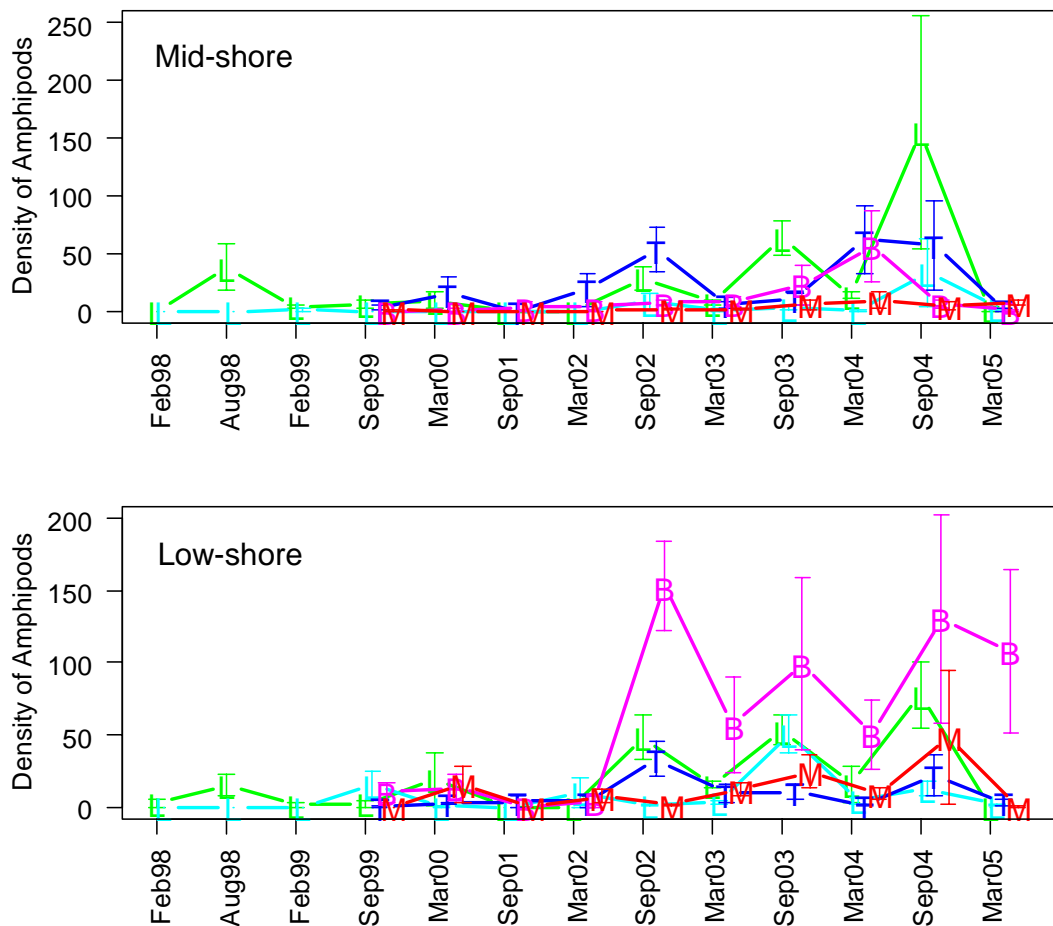
#### 9.3.5.3 July 2002-June 2003 (Ford et al. 2003a)

Trap deployment was modified to improve trap retention. Trap design did not change. 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.

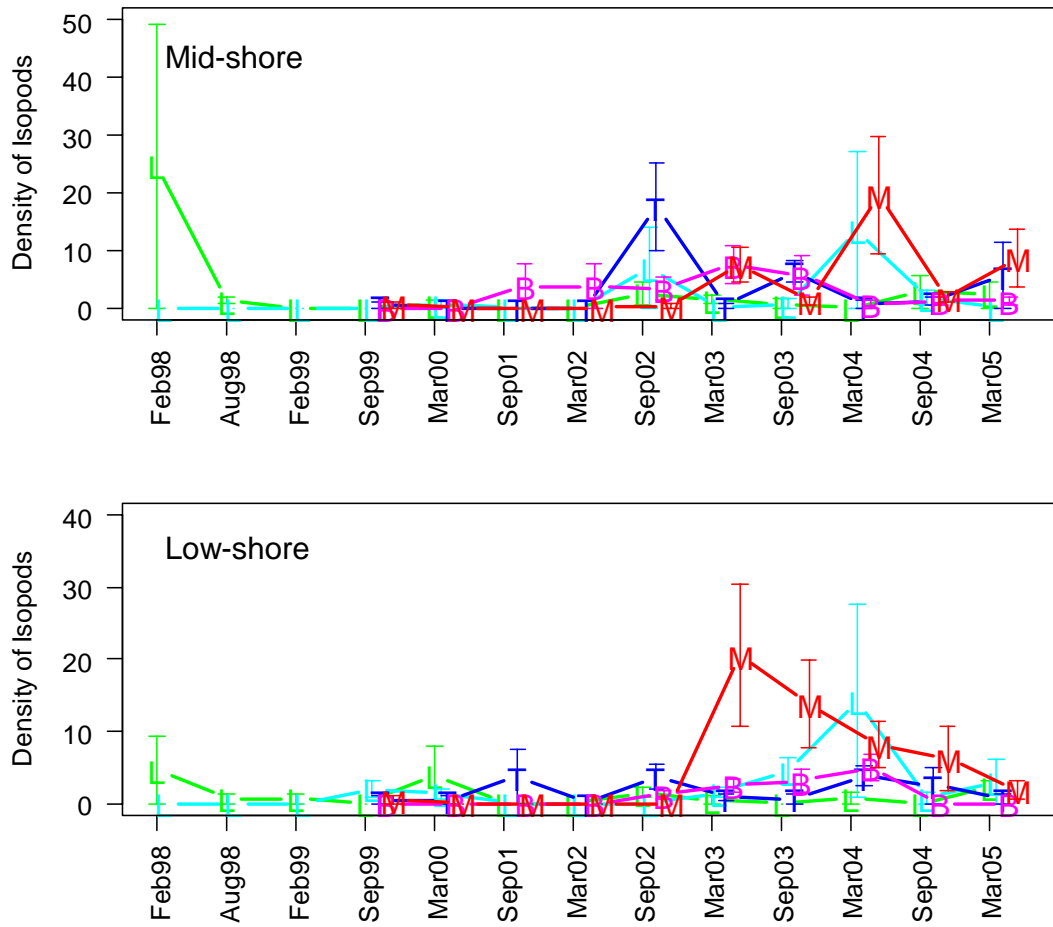
#### 9.3.5.4 2004-2005 (Current report)

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.

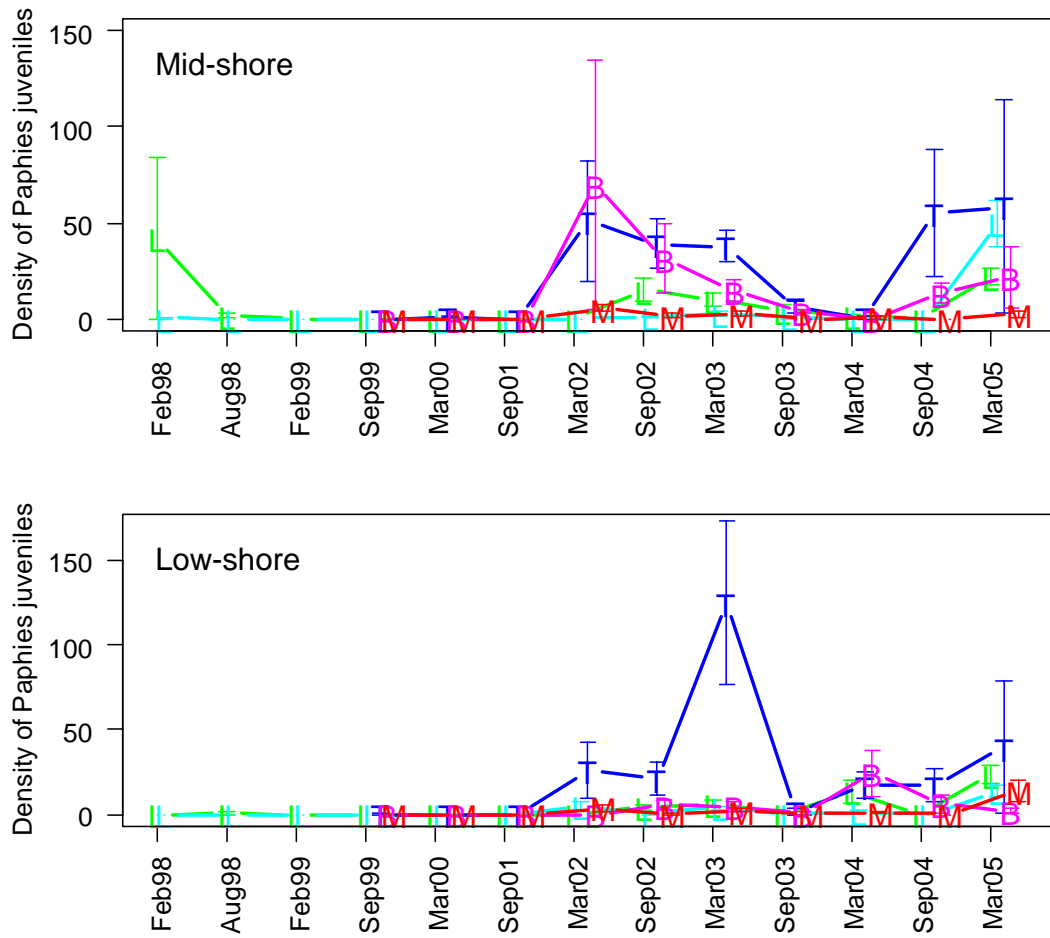
## 10 Appendix C: Long-term univariate time series of intertidal beach fauna



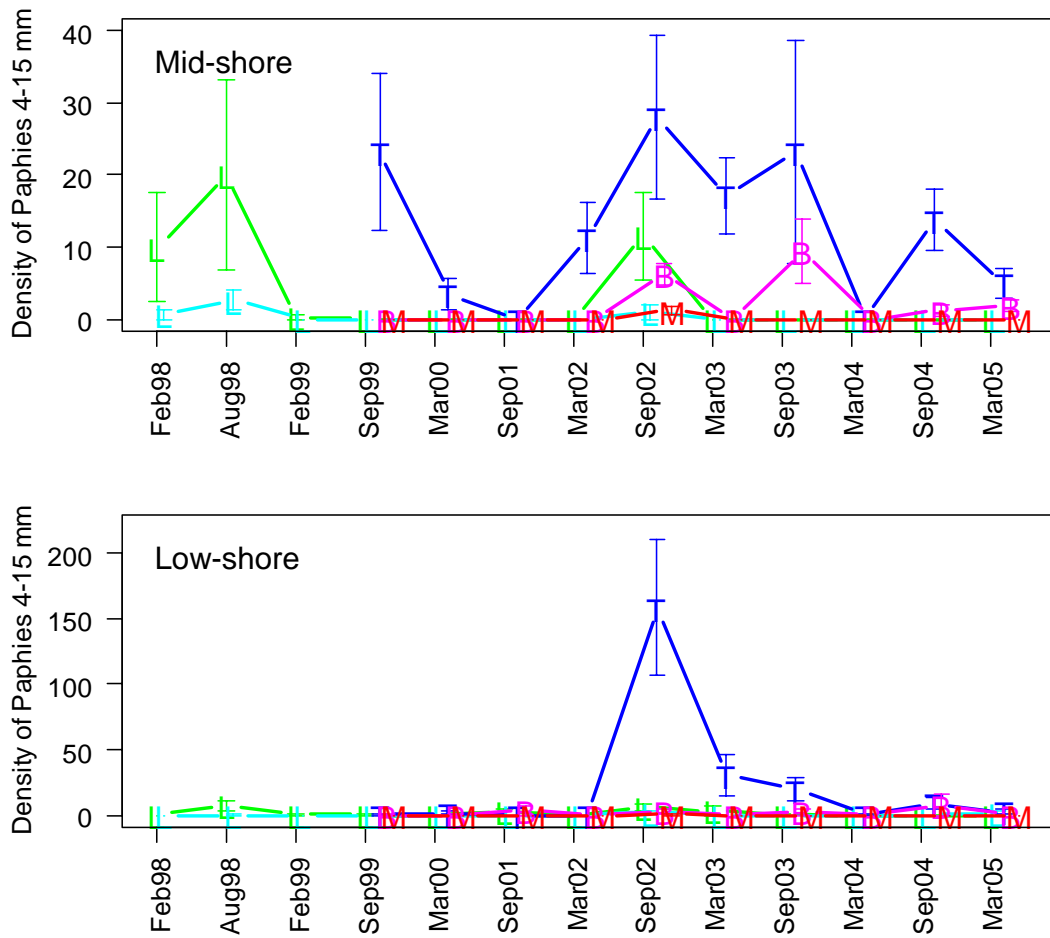
**Appendix C1.** Mean ( $\pm$  1SE) density of amphipods per 0.1 m<sup>2</sup> measured approximately biannually through time from February 1998 to March 2005 from intertidal beaches. Colours and labels used for the beaches are as in Fig. 5 in the text. Means and standard errors were calculated from replicate transects. Details concerning the number and size of cores and the number of transects at each time and at each beach are given in Appendix B.



**Appendix C2.** Mean ( $\pm 1$ SE) density of isopods per 0.1 m<sup>2</sup> measured approximately biannually through time from February 1998 to March 2005 from intertidal beaches. Colours and labels used for the beaches are as in Fig. 5 in the text. Means and standard errors were calculated from replicate transects. Details concerning the number and size of cores and the number of transects at each time and at each beach are given in Appendix B.

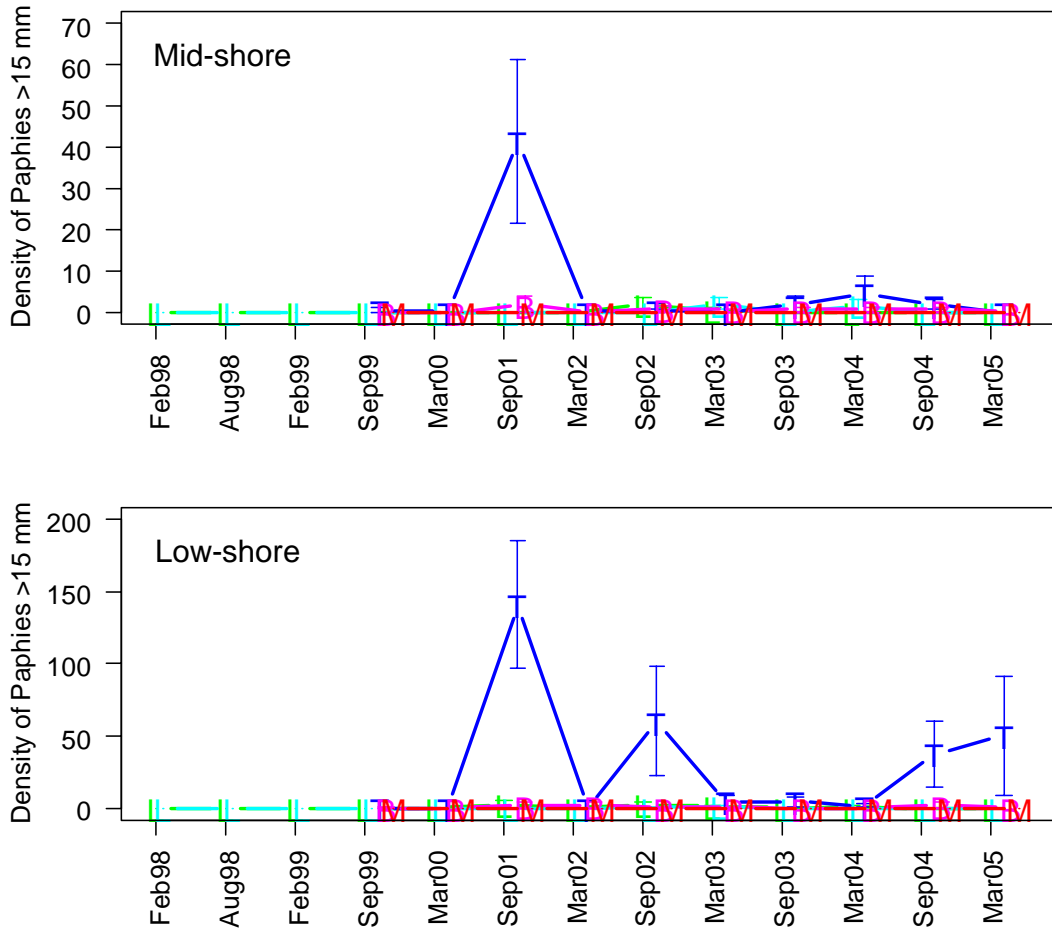


**Appendix C3.** Mean ( $\pm$  1SE) density of *Paphies* juveniles (< 4 mm) per 0.1 m<sup>2</sup> measured approximately biannually through time from February 1998 to March 2005 from intertidal beaches. Colours and labels used for the beaches are as in Fig. 5 in the text. Means and standard errors were calculated from replicate transects. Details concerning the number and size of cores and the number of transects at each time and at each beach are given in Appendix B.

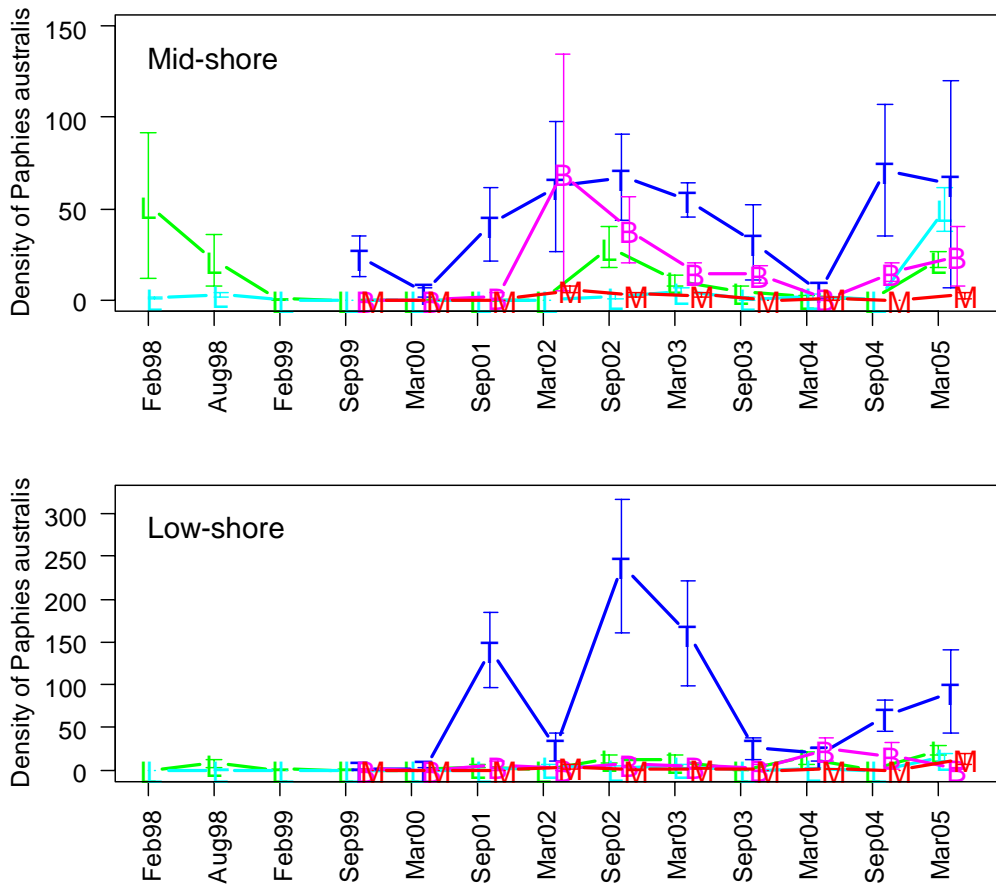


**Appendix C4.** Mean ( $\pm$  1SE) density of *Paphies australis* (4-15 mm) per 0.1 m<sup>2</sup> measured approximately biannually through time from February 1998 to March 2005 from intertidal beaches. Colours and labels used for the beaches are as in Fig. 5 in the text. Means and standard errors were calculated from replicate transects.

Details concerning the number and size of cores and the number of transects at each time and at each beach are given in Appendix B.



**Appendix C5.** Mean ( $\pm$  1SE) density of *Paphies australis* (> 15 mm) per 0.1 m<sup>2</sup> measured approximately biannually through time from February 1998 to March 2005 from intertidal beaches. Colours and labels used for the beaches are as in Fig. 5 in the text. Means and standard errors were calculated from replicate transects. Details concerning the number and size of cores and the number of transects at each time and at each beach are given in Appendix B.

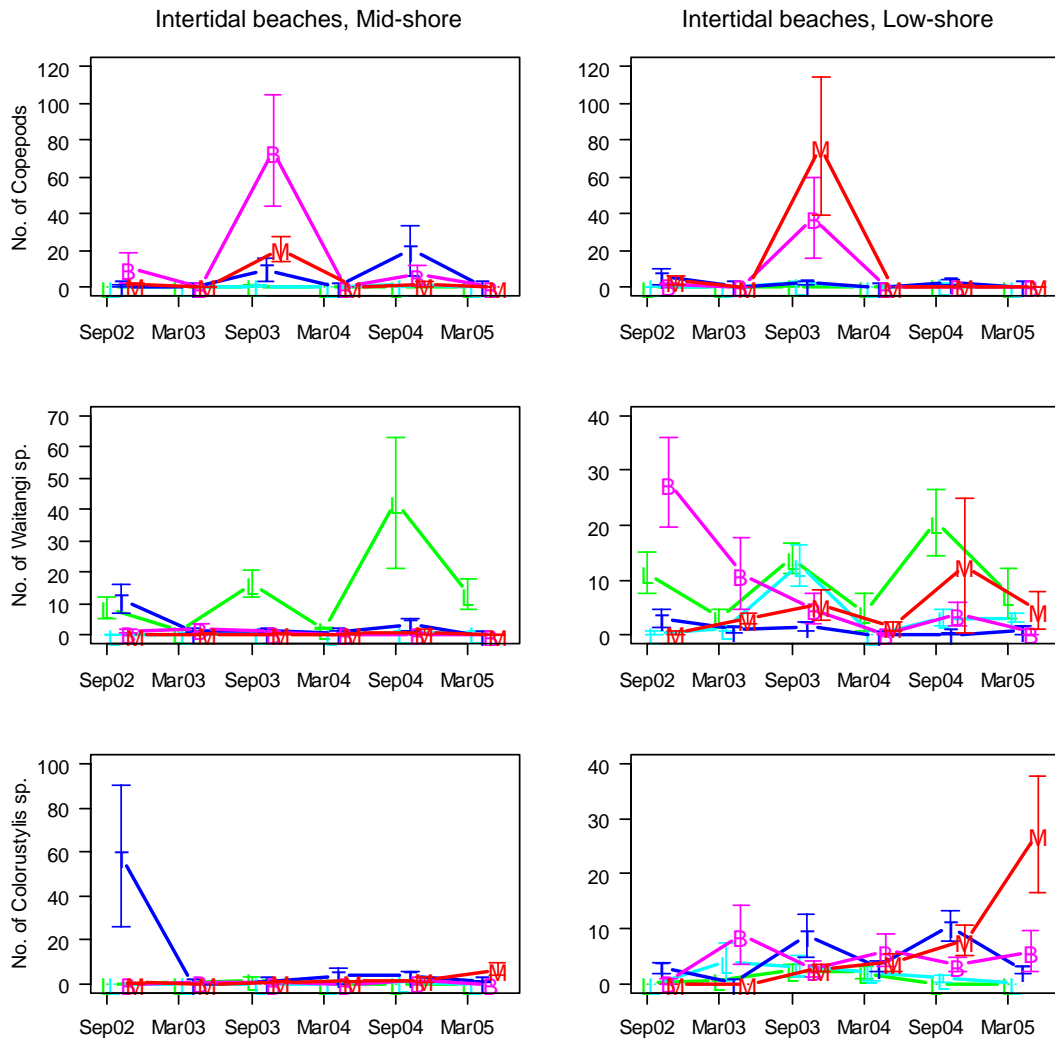


**Appendix C6.** Mean ( $\pm$  1SE) density of *Paphies australis* of all size classes per 0.1 m<sup>2</sup> measured approximately biannually through time from February 1998 to March 2005 from intertidal beaches. Colours and labels used for the beaches are as in Fig. 5 in the text. Means and standard errors were calculated from replicate transects. Details concerning the number and size of cores and the number of transects at each time and at each beach are given in Appendix B.

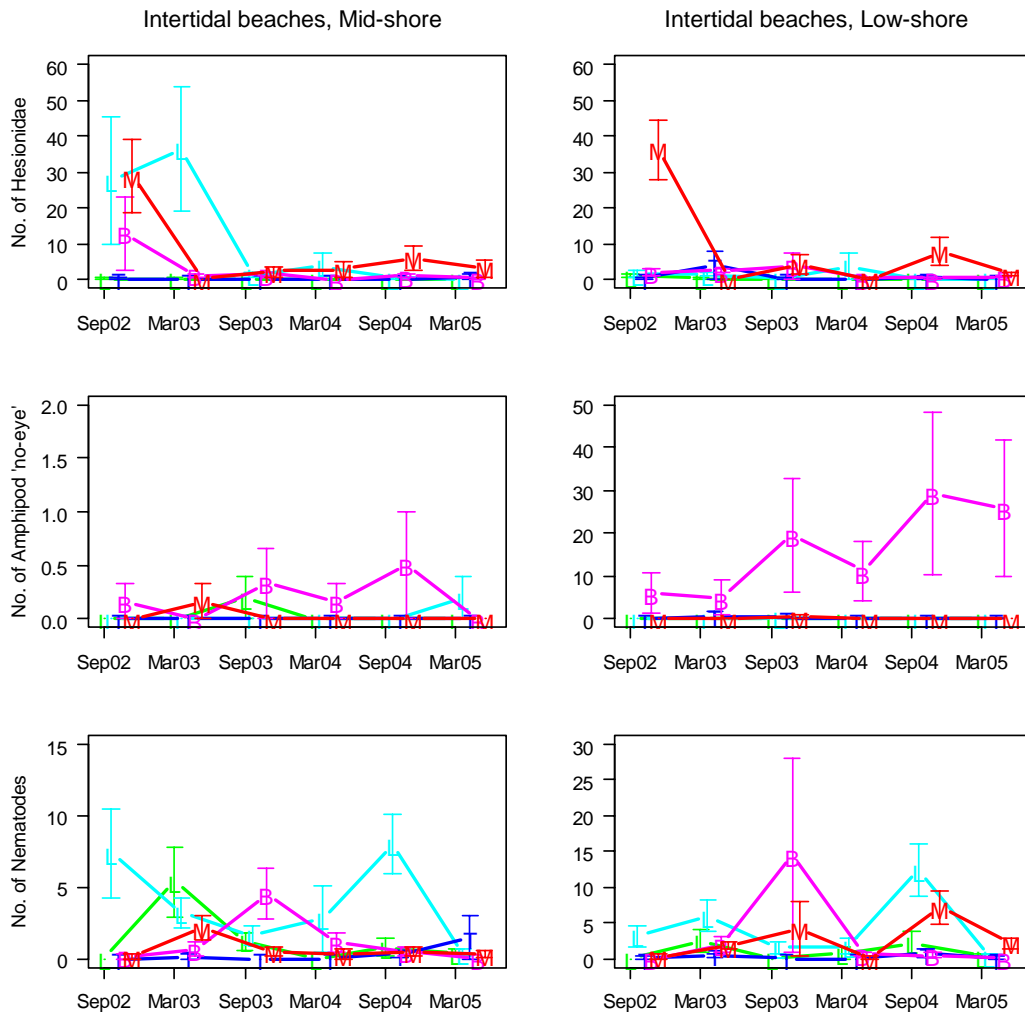
## 11 Appendix D: GPS coordinates for subtidal rocky reef sites

Bay	Site	Latitude	Longitude
Waiwera	1	36° 32.24' S	174° 43.06' E
	2	36° 32.61' S	174° 43.32' E
	3	36° 33.06' S	174° 42.70' E
	4	36° 33.31' S	174° 42.67' E
	5	36° 33.67' S	174° 42.67' E
Stanmore Bay	1	36° 37.04' S	174° 44.43' E
	2	36° 37.06' S	174° 44.58' E
	3	36° 36.27' S	174° 46.11' E
	4	36° 36.23' S	174° 46.23' E
	5	36° 36.24' S	174° 46.83' E
Little Manly	1	36° 38.53' S	174° 44.44' E
	2	36° 38.22' S	174° 45.29' E
	3	36° 38.13' S	174° 45.96' E
	4	36° 38.03' S	174° 46.10' E
	5	36° 37.49' S	174° 46.19' E
Long Bay	1	36° 39.53' S	174° 44.57' E
	2	36° 40.16' S	174° 44.54' E
	3	36° 40.34' S	174° 44.58' E
	4	36° 41.21' S	174° 45.17' E
	5	36° 41.22' S	174° 45.24' E
Torbay	1	36° 41.92' S	174° 45.60' E
	2	36° 42.12' S	174° 45.55' E
	3	36° 42.50' S	174° 45.25' E
	4	36° 42.70' S	174° 45.30' E
	5	36° 43.12' S	174° 45.08' E
Campbells Bay	1	36° 43.88' S	174° 45.45' E
	2	36° 44.12' S	174° 45.42' E
	3	36° 44.48' S	174° 45.63' E
	4	36° 44.87' S	174° 45.96' E
	5	36° 45.00' S	174° 45.95' E

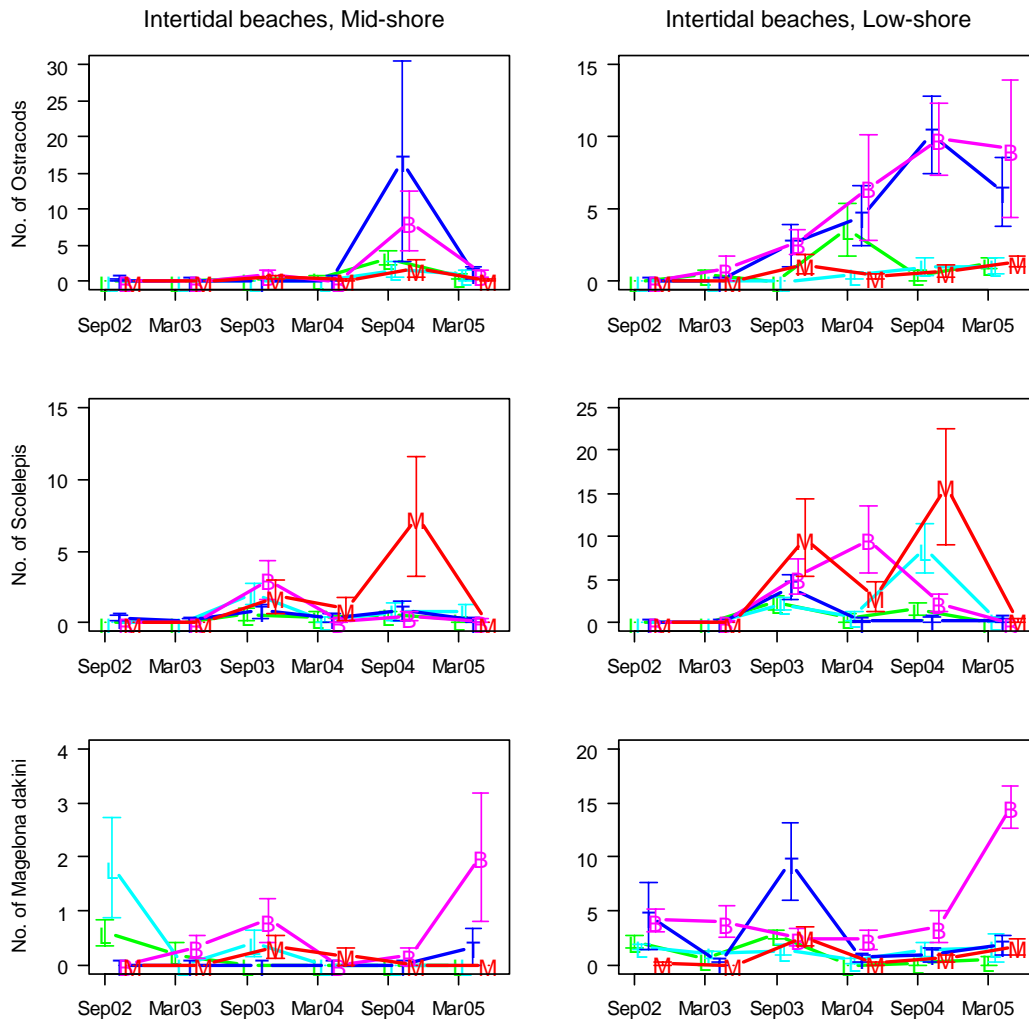
## 12 Appendix E: Additional univariate time series graphics for intertidal assemblages



**Appendix E1.** Mean  $\pm$  1SE abundance of Copepods, *Waitangi* sp. and *Colurostylis* sp. in each of the low-shore and mid-shore for intertidal beaches. L (green) = Long Bay North, L (cyan) = Long Bay South, T (blue) = Torbay, B (magenta) = Browns Bay and M (red) = Mairangi. Sample sizes were  $n = 5$  transects for Long Bay and  $n = 6$  elsewhere.



**Appendix E2.** Mean  $\pm$  1SE abundance of Hesionidae, Amphipod 'no-eye' and Nematodes in each of the low-shore and mid-shore for intertidal beaches. L (green) = Long Bay North, L (cyan) = Long Bay South, T (blue) = Torbay, B (magenta) = Browns Bay and M (red) = Mairangi. Sample sizes were  $n = 5$  transects for Long Bay and  $n = 6$  elsewhere.



**Appendix E3.** Mean  $\pm$  1SE abundance of Ostracods, *Scolelepis* sp. and *Magelona dakini* in each of the low-shore and mid-shore for intertidal beaches. L (green) = Long Bay North, L (cyan) = Long Bay South, T (blue) = Torbay, B (magenta) = Browns Bay and M (red) = Mairangi. Sample sizes were  $n = 5$  transects for Long Bay and  $n = 6$  elsewhere.

## Appendix F: Results of ANOSIMs and Mantel tests for percentage cover data

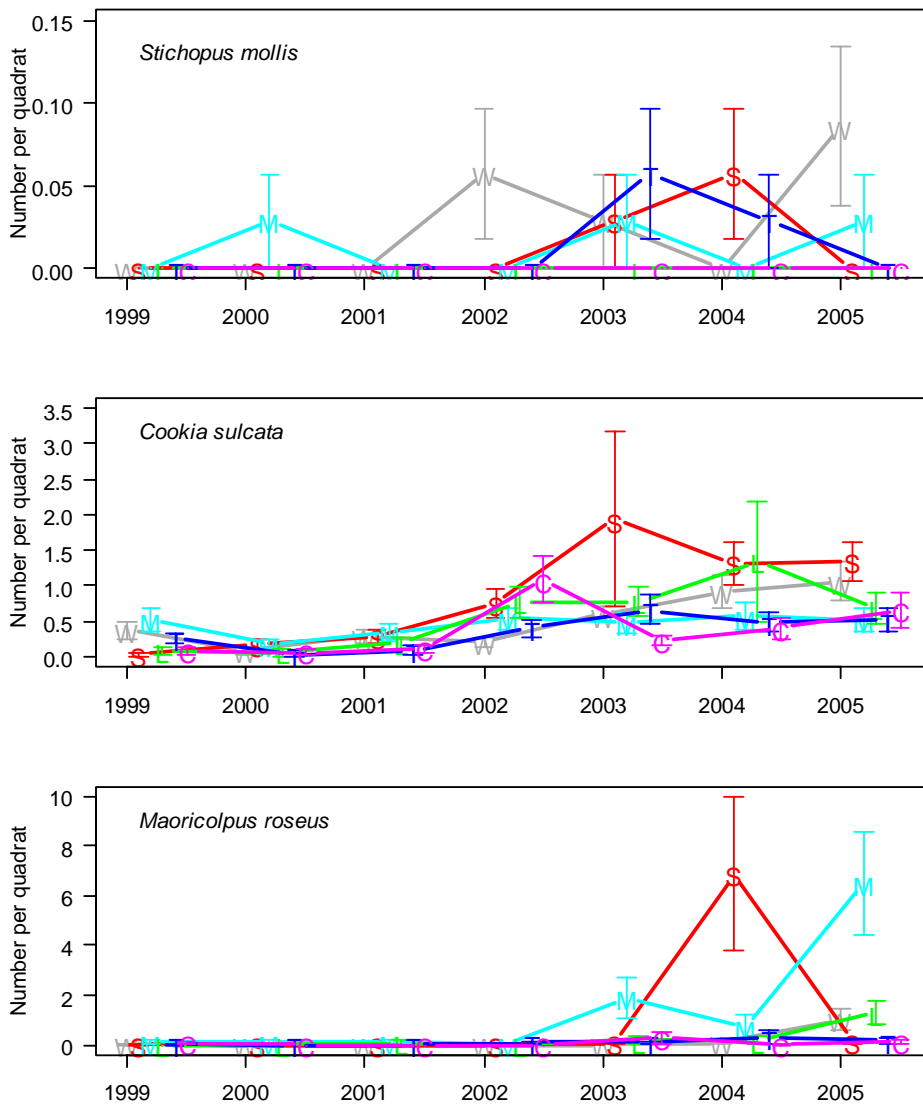
**Appendix F1.** ANOSIM  $R$ -statistic and test for Year effects and Mantel test for seriation through time (using Spearman's  $\rho$ ), done separately for each Bay (listed from south to north) on the percentage cover data from subtidal assemblages.

<i>Bay</i>	Year effects		Seriation	
	$R$	$P$	$\rho$	$P$
Campbells	0.480	0.0001	0.252	0.0001
Torbay	0.242	0.0003	0.254	0.0001
Long Bay	0.378	0.0001	0.367	0.0001
Little Manly	0.436	0.0001	0.348	0.0001
Stanmore	0.597	0.0001	0.506	0.0001
Waiwera	0.566	0.0001	0.552	0.0001

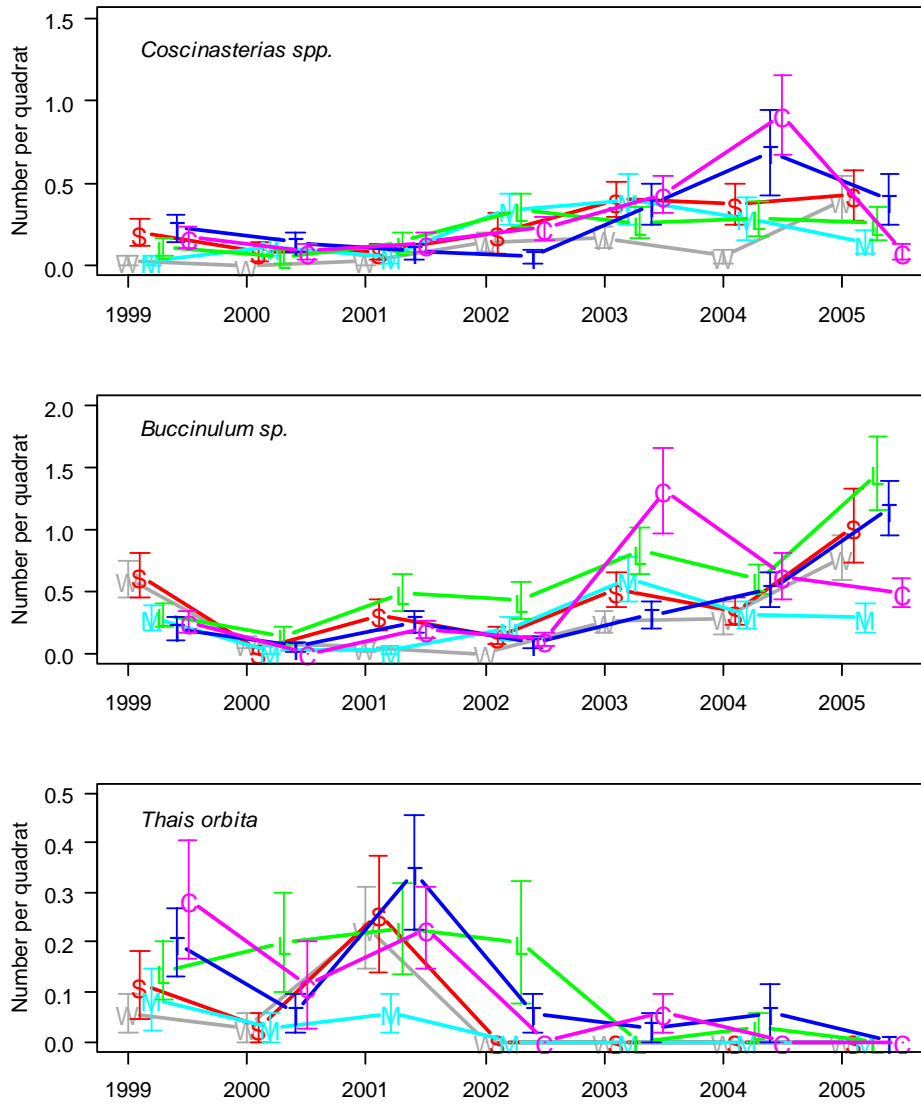
**Appendix F2.** ANOSIM  $R$ -statistic and test for Bay effects and Mantel test for seriation from north to south (using Spearman's  $\rho$ ), done separately for each year on the percentage cover data from subtidal assemblages.

<i>Year</i>	Bay effects		Seriation	
	$R$	$P$	$\rho$	$P$
1999	0.127	0.0260	0.141	0.0176
2000	0.117	0.0180	0.109	0.0470
2001	0.186	0.0020	0.134	0.0207
2002	0.249	0.0001	0.099	0.0649
2003	0.313	0.0002	0.228	0.0008
2004	0.419	0.0001	0.340	0.0001
2005	0.461	0.0001	0.350	0.0001

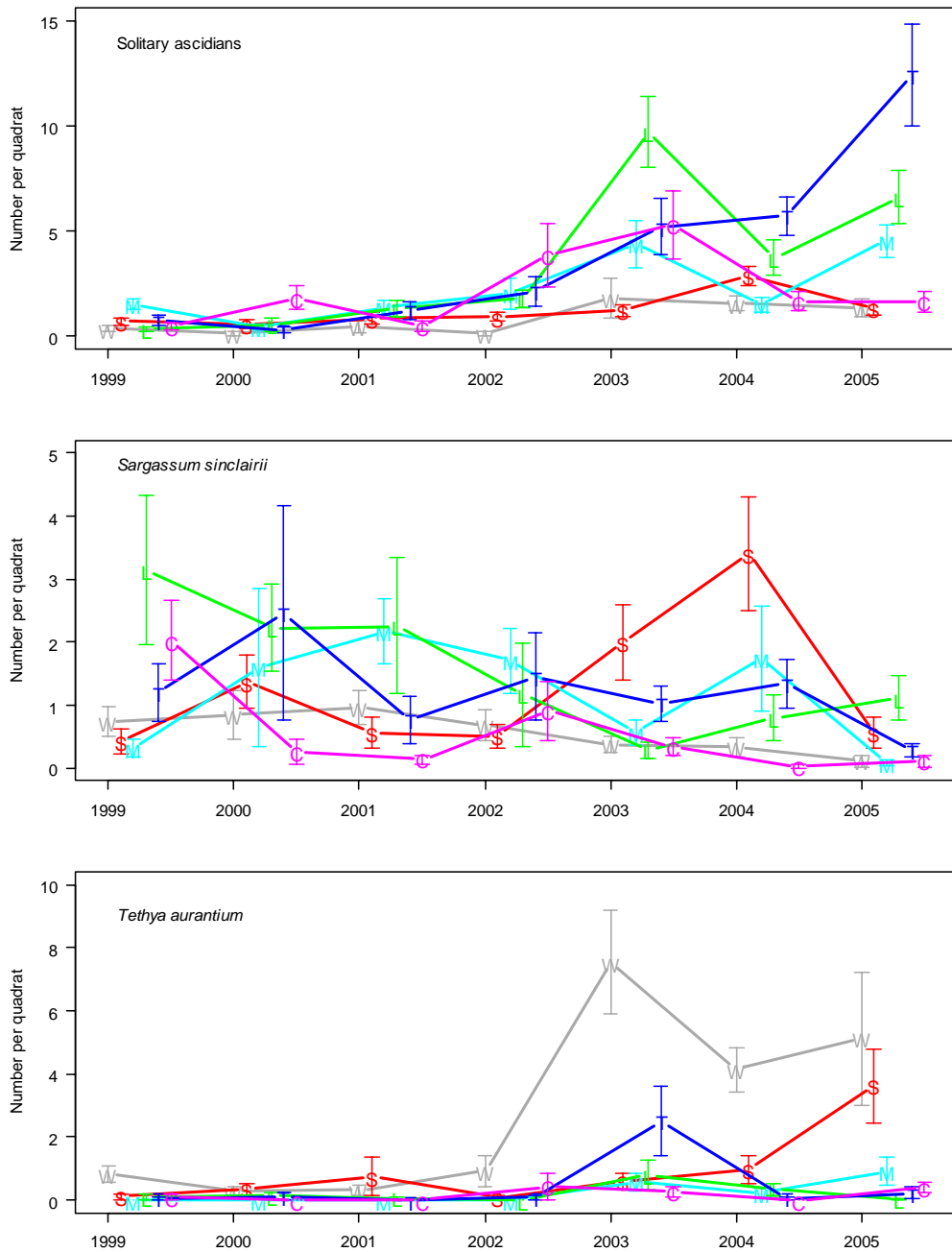
## 13 Appendix G: Additional univariate time series graphics for subtidal assemblages



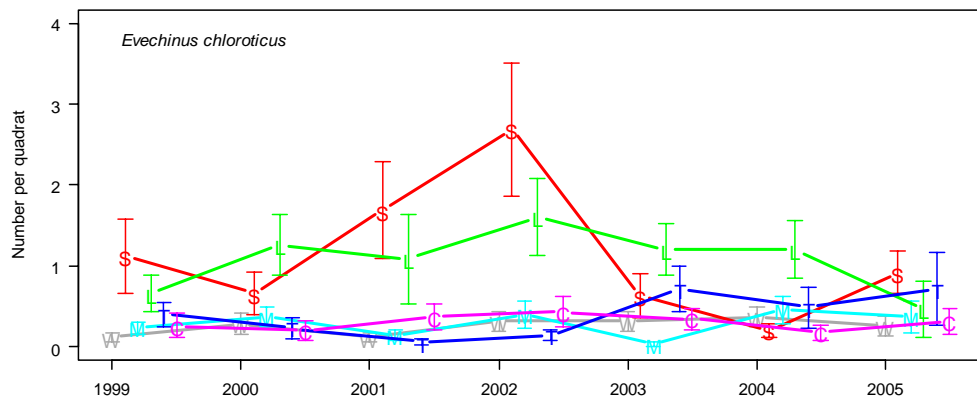
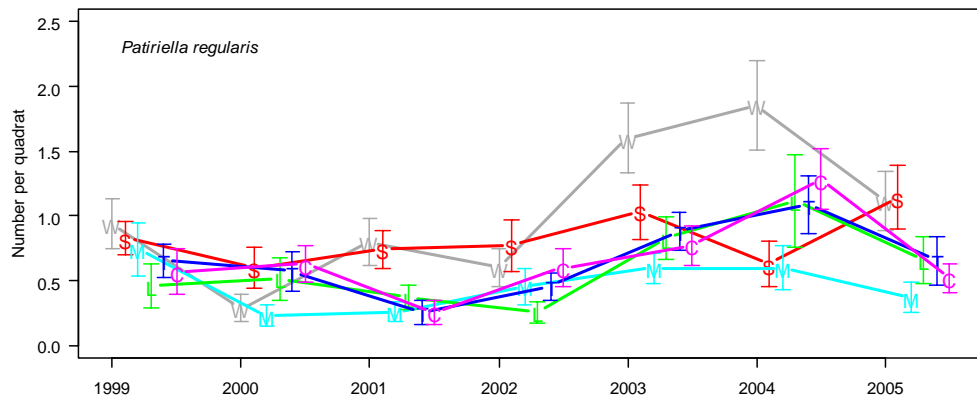
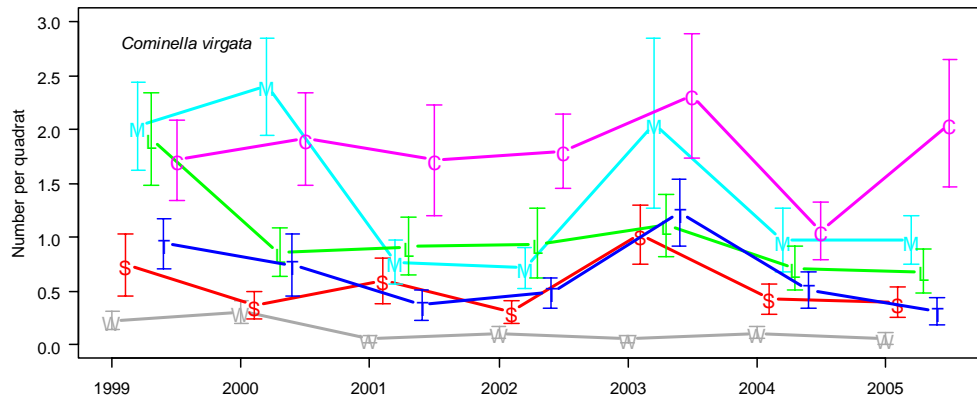
**Appendix G1.** Mean  $\pm$  1SE number per quadrat of the sea cucumber *S. mollis*, and the herbivorous gastropods *C. sulcata* and *M. roseus* from subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats x 5 sites).



**Appendix G2.** Mean  $\pm$  1SE number per quadrat of the sea star *Coscinasterias* spp., and the predatory gastropods *Buccinulum* sp. and *Thais orbita* from subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats  $\times$  5 sites).



**Appendix G3.** Mean  $\pm$  1SE number per quadrat of solitary ascidians, the brown alga *S. sinclairii* and the encrusting sponge *T. aurantium* from subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats x 5 sites).



**Appendix G4.** Mean  $\pm$  1SE number per quadrat of the predatory gastropod *C. virgata*, the seastar *P. regularis* and the sea urchin *E. chloroticus* from subtidal assemblages. W (grey) = Waiwera, S (red) = Stanmore, M (cyan) = Little Manly, L (green) = Long Bay, T (blue) = Torbay and C (magenta) = Campbells Bay. Sample sizes were  $n = 35$  (7 quadrats  $\times$  5 sites).

14 Appendix H: Size class distributions of subtidal species for 2004 and 2005 and 2005

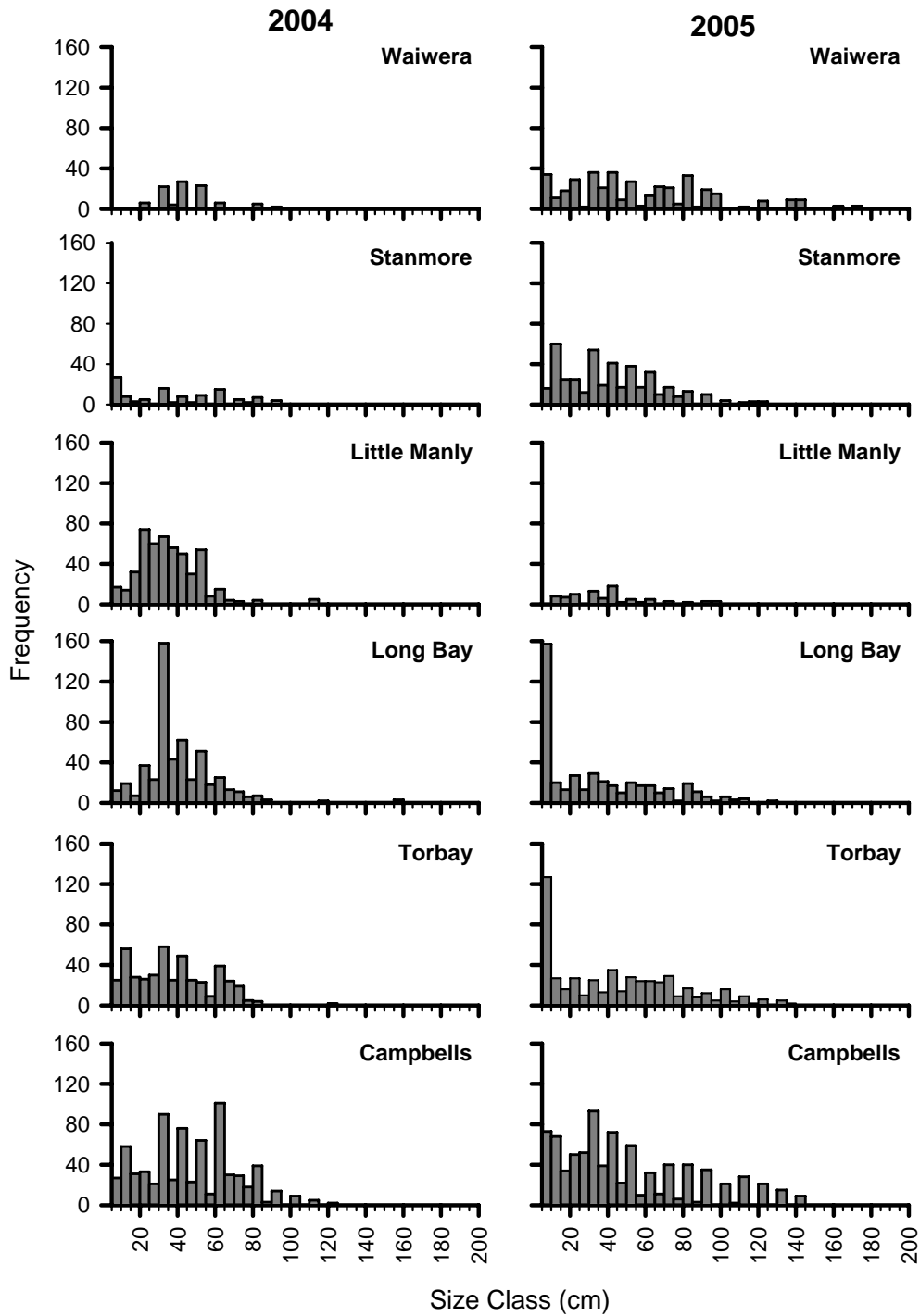
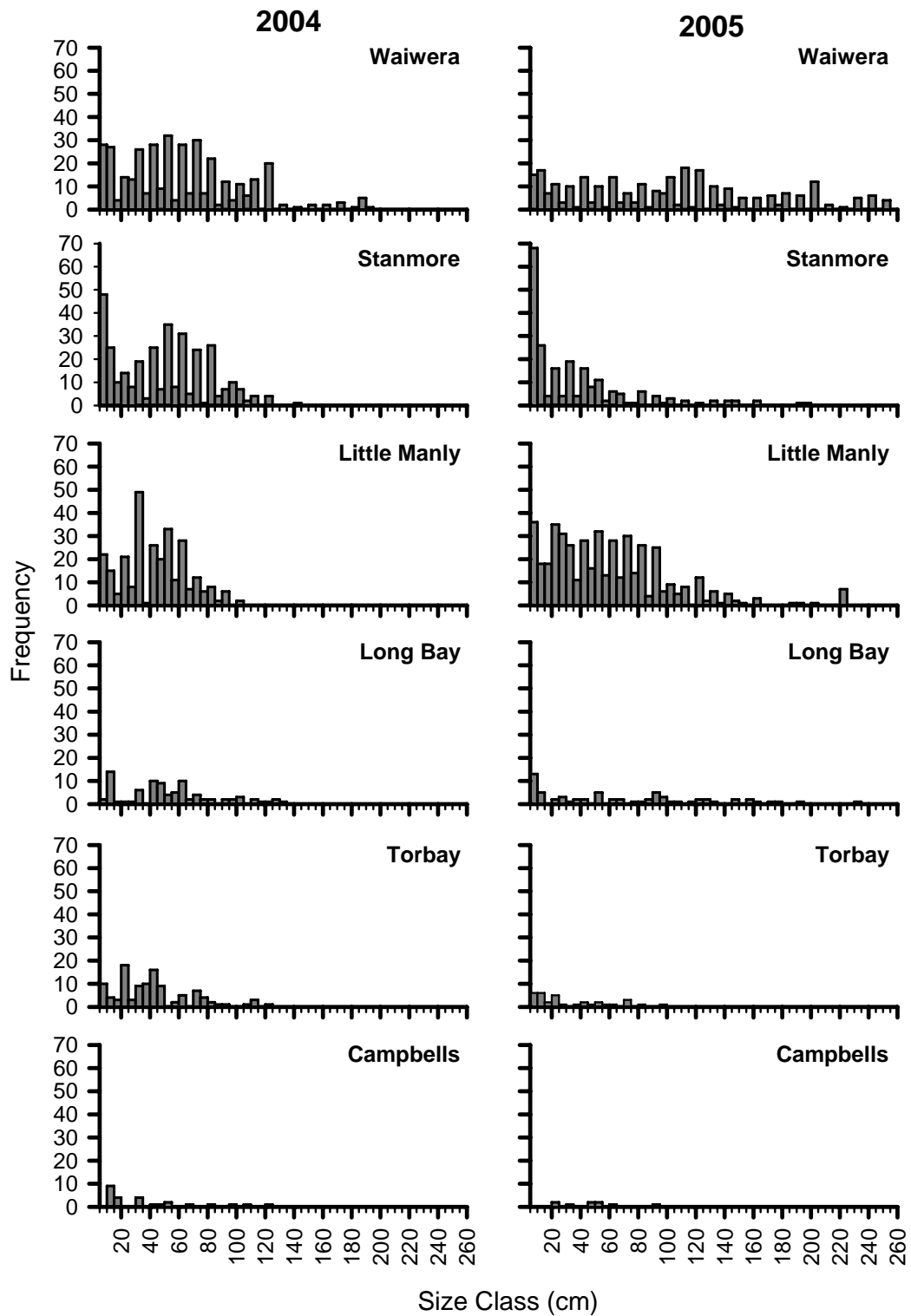
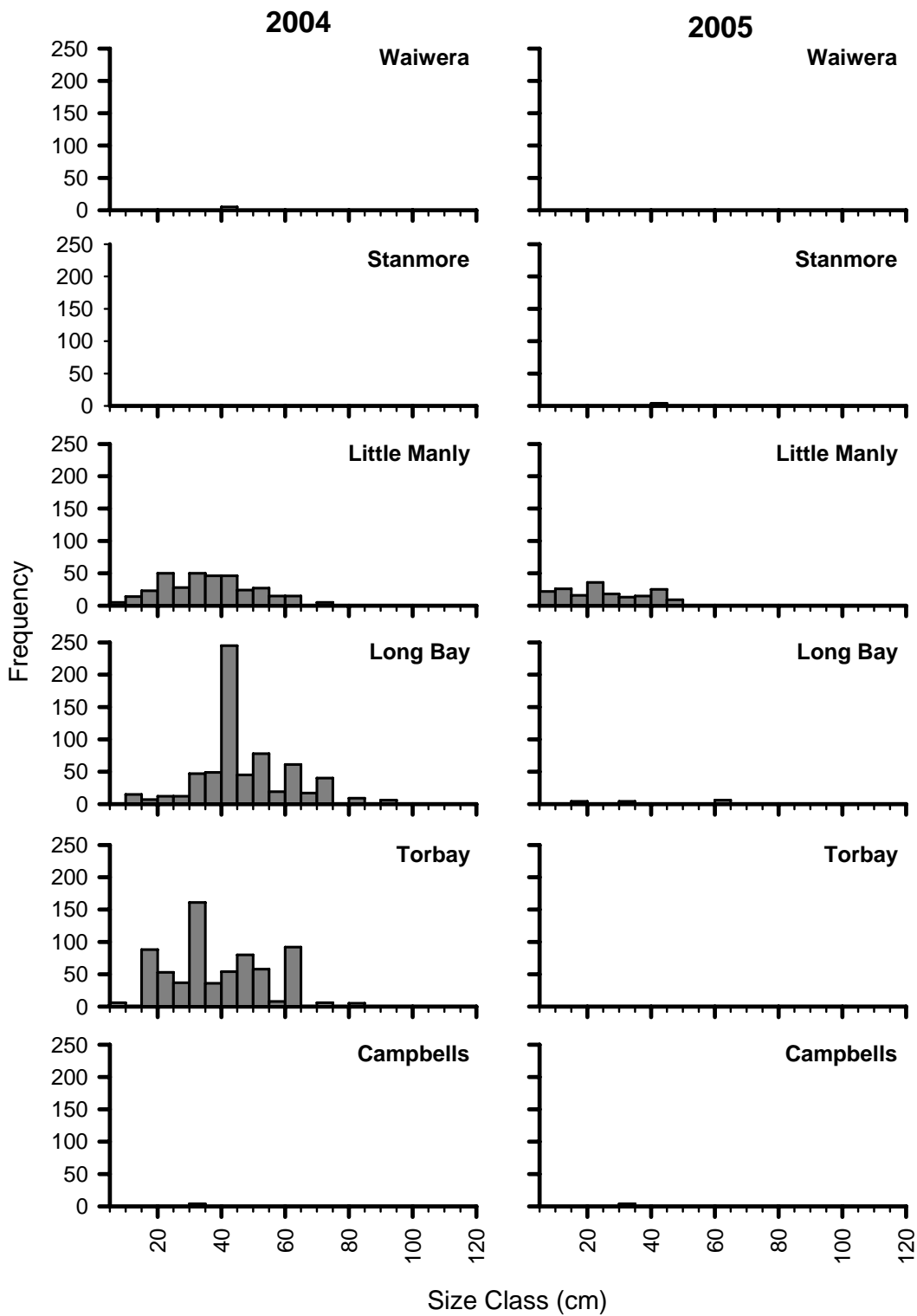


Figure H1. Size frequency distributions for *Carpophyllum maschalocarpum*.



**Figure H2.** Size frequency distributions for *Carpophyllum flexuosum*.



**Figure H3.** Size frequency distributions for *Carpophyllum plumosum*.

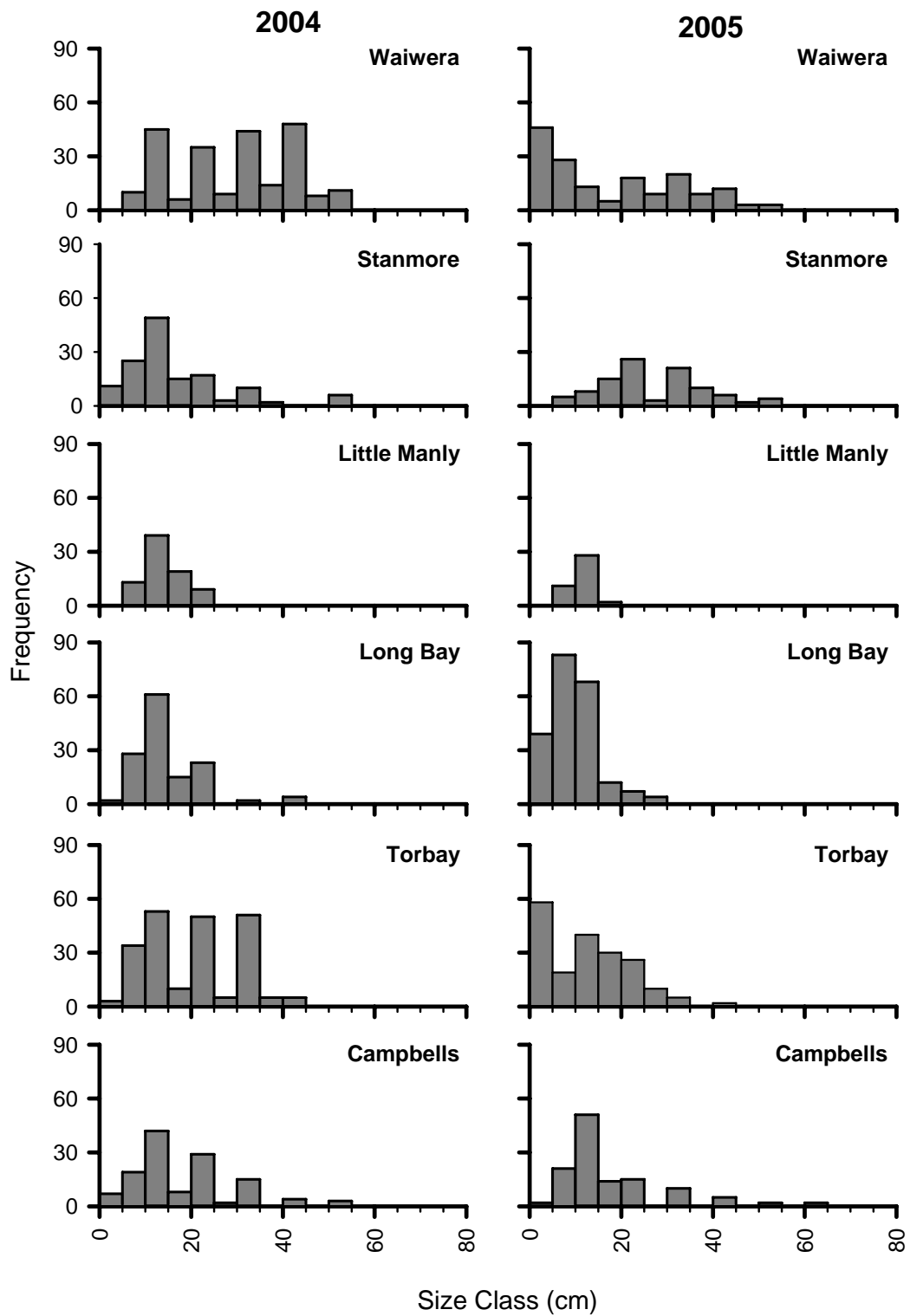
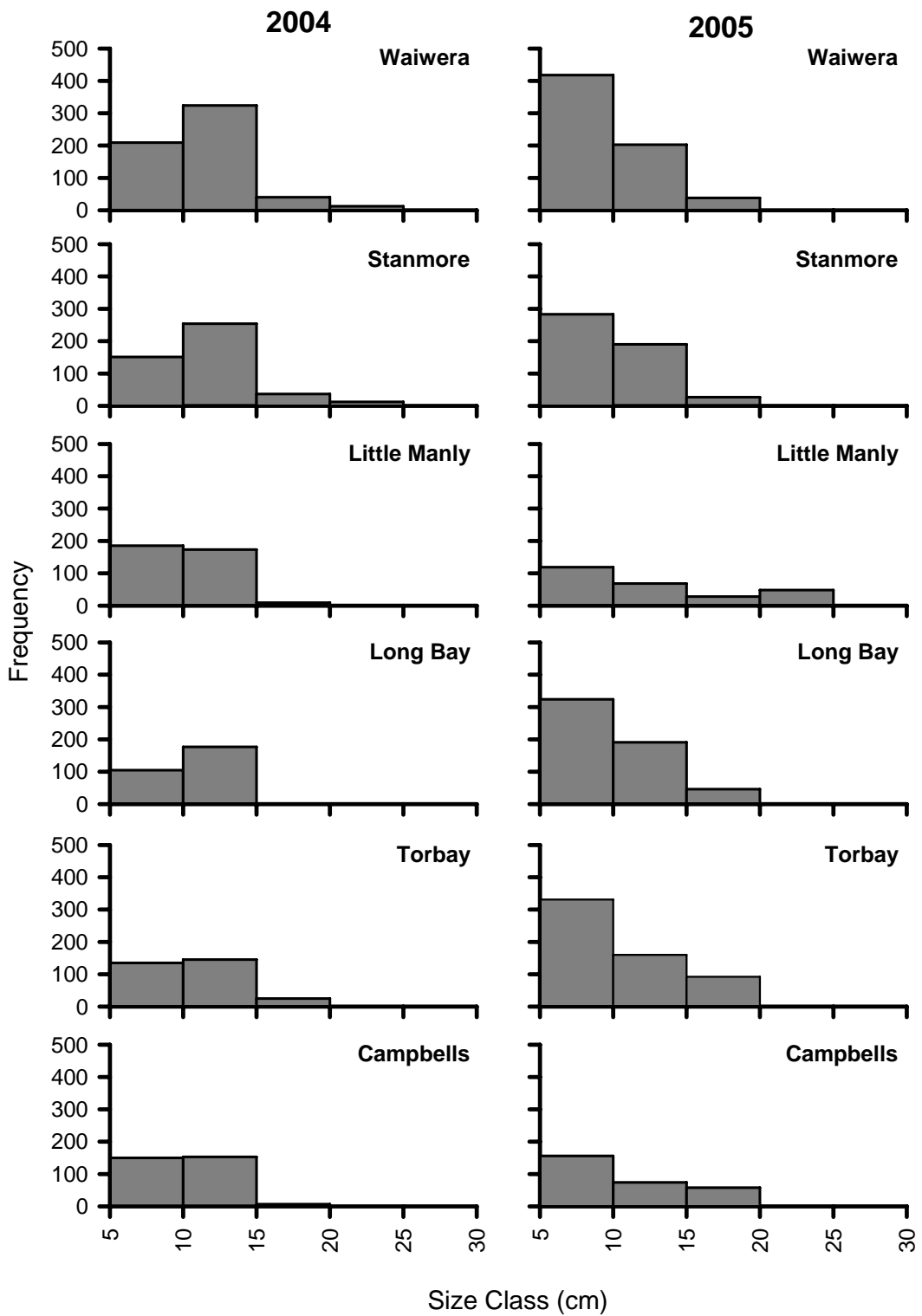


Figure H4. Size frequency distributions for *Ecklonia radiata*.



**Figure H5.** Size frequency distributions for *Zonaria turneriana*.

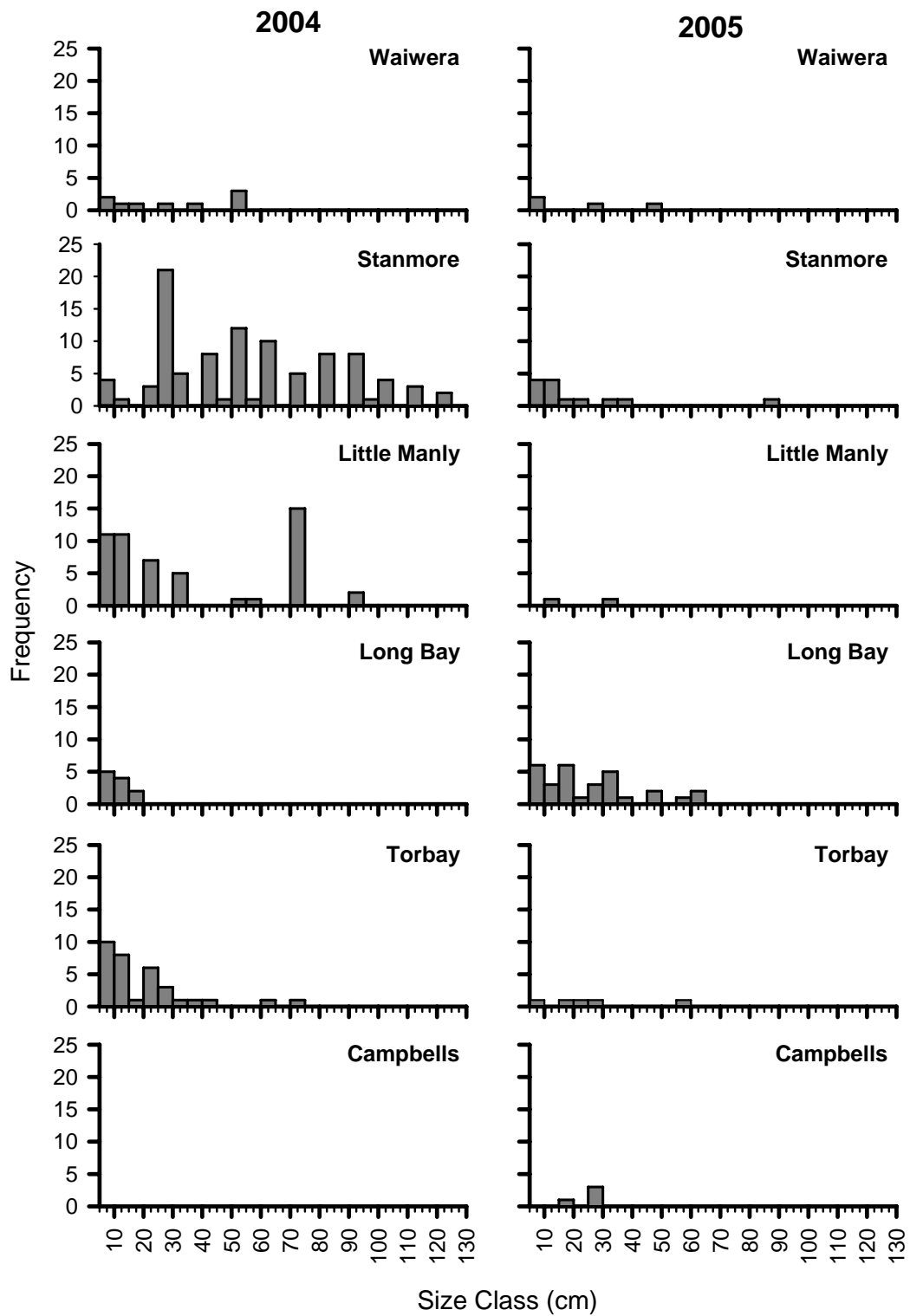
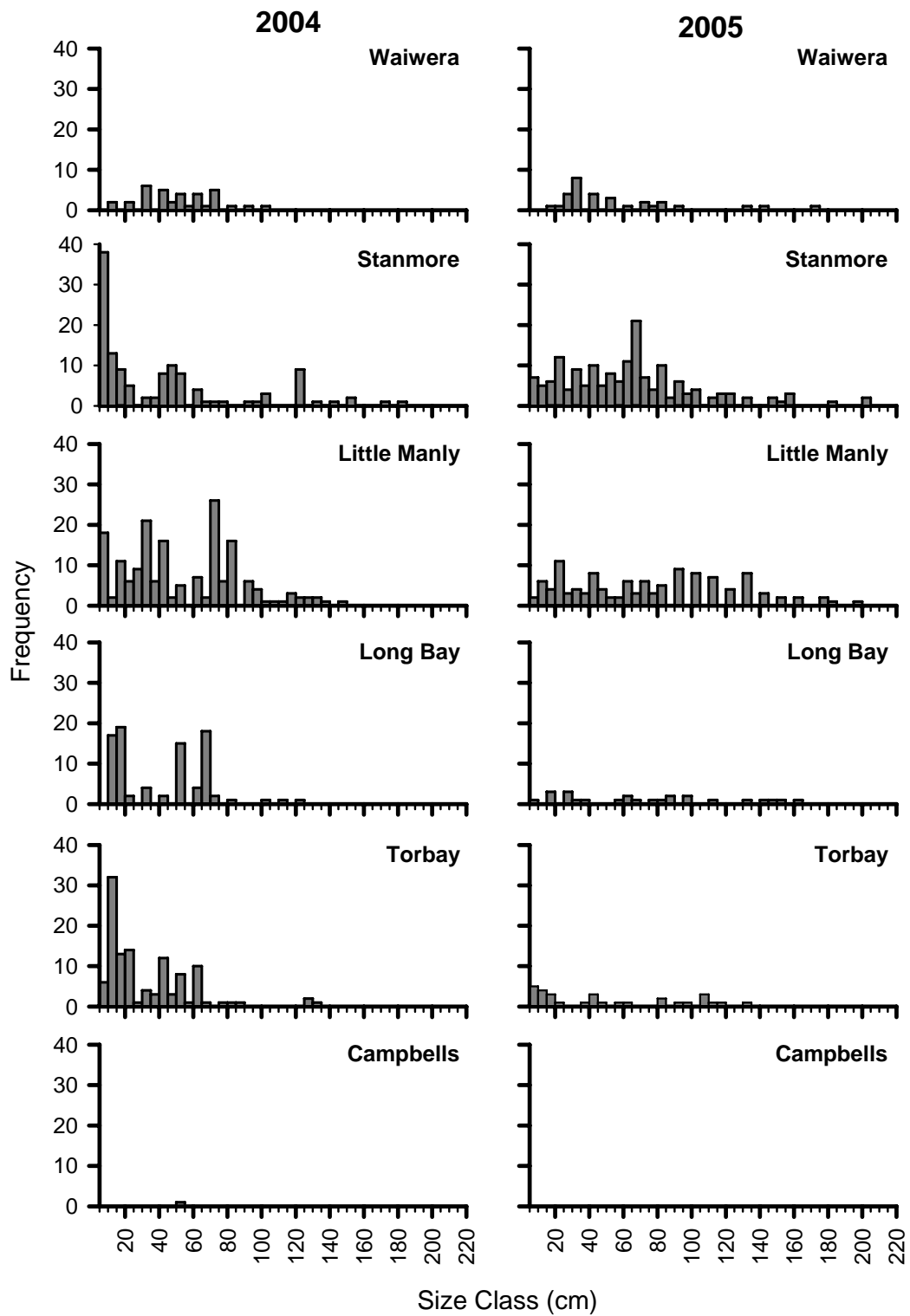


Figure H6. Size frequency distributions for *Sargassum sinclairii*.



**Figure H7.** Size frequency distributions for *Cystophora* spp.

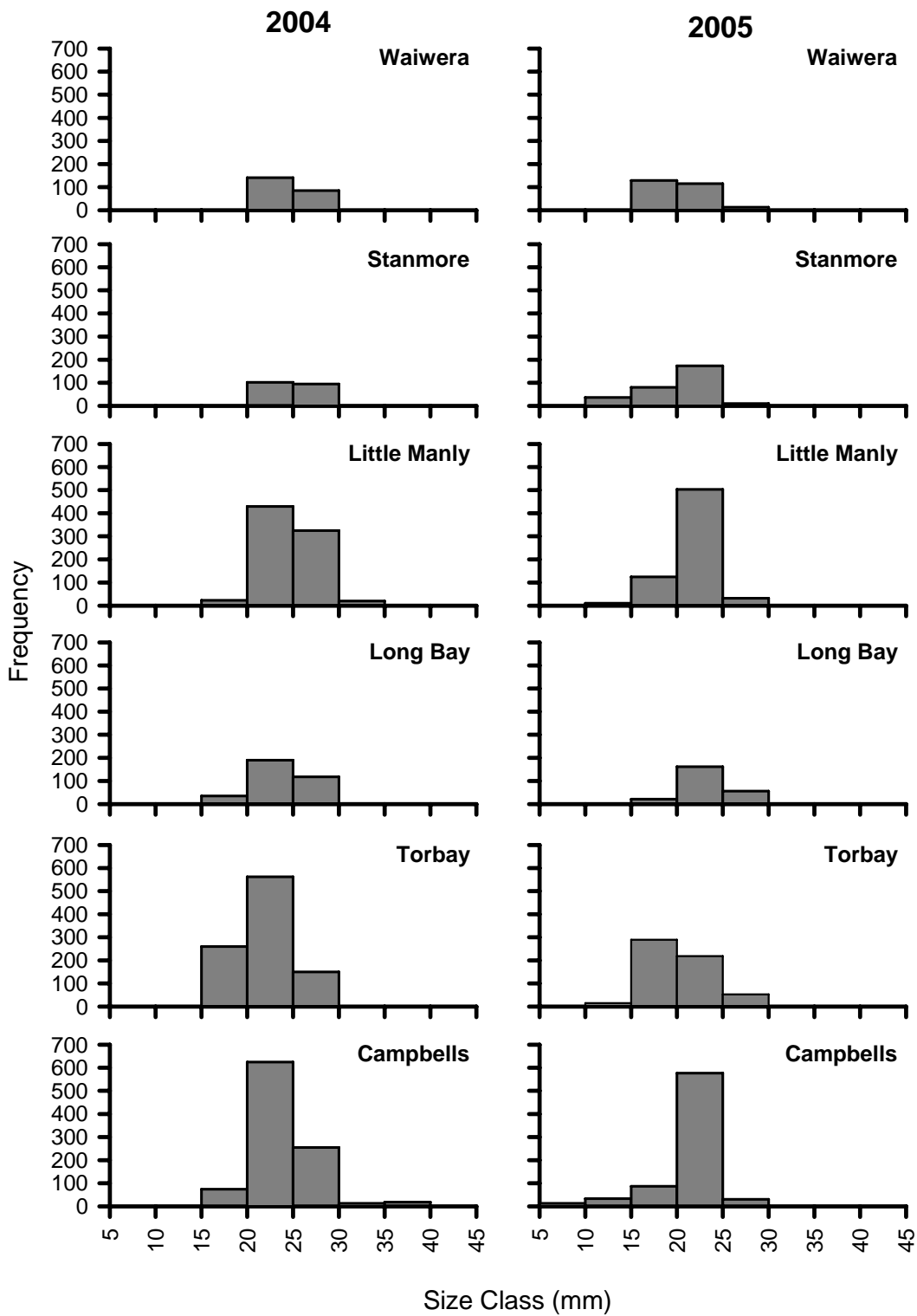
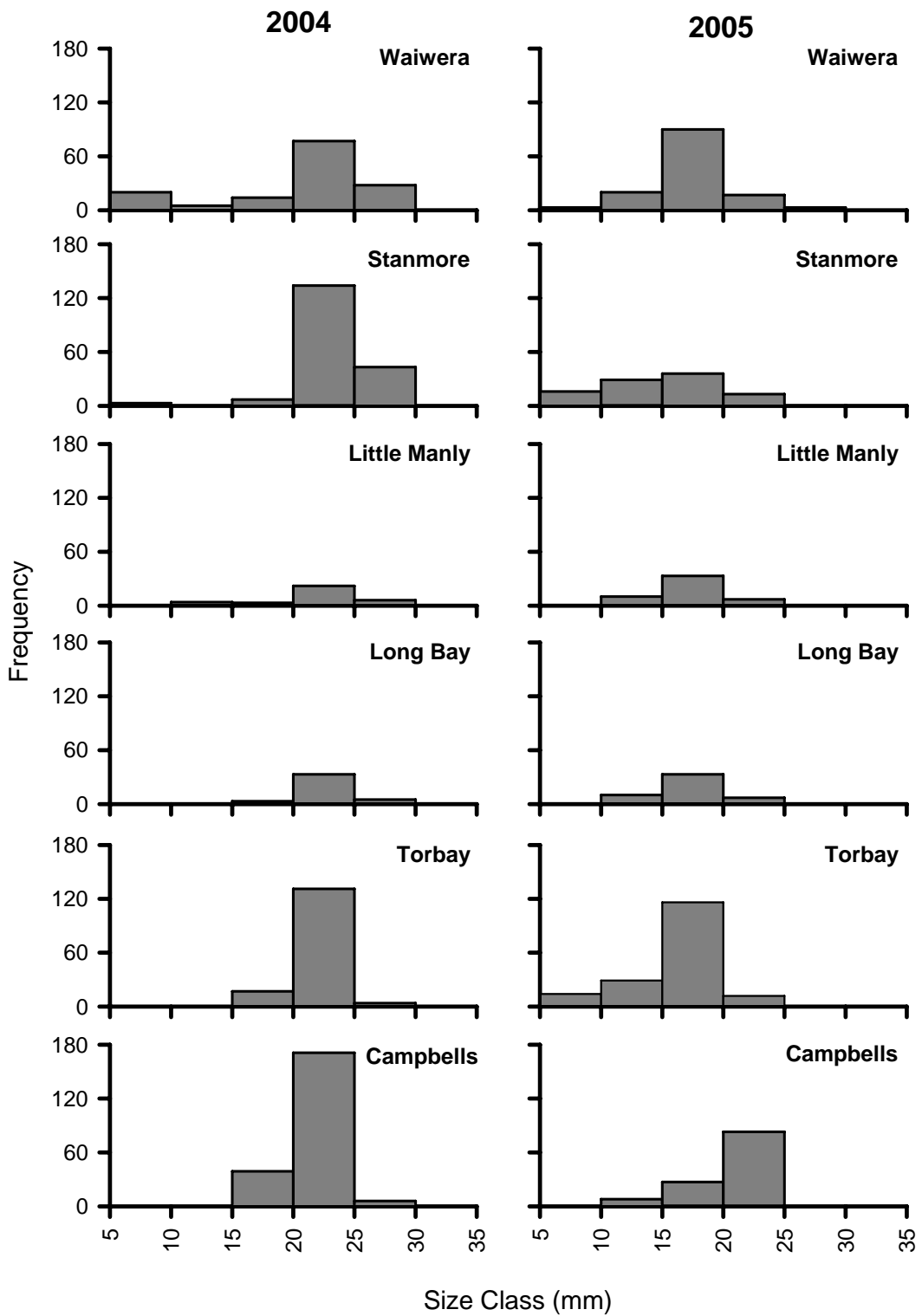


Figure H8. Size frequency distributions for *Turbo smaragdus*.



**Figure H9.** Size frequency distributions for *Trochus viridus*.

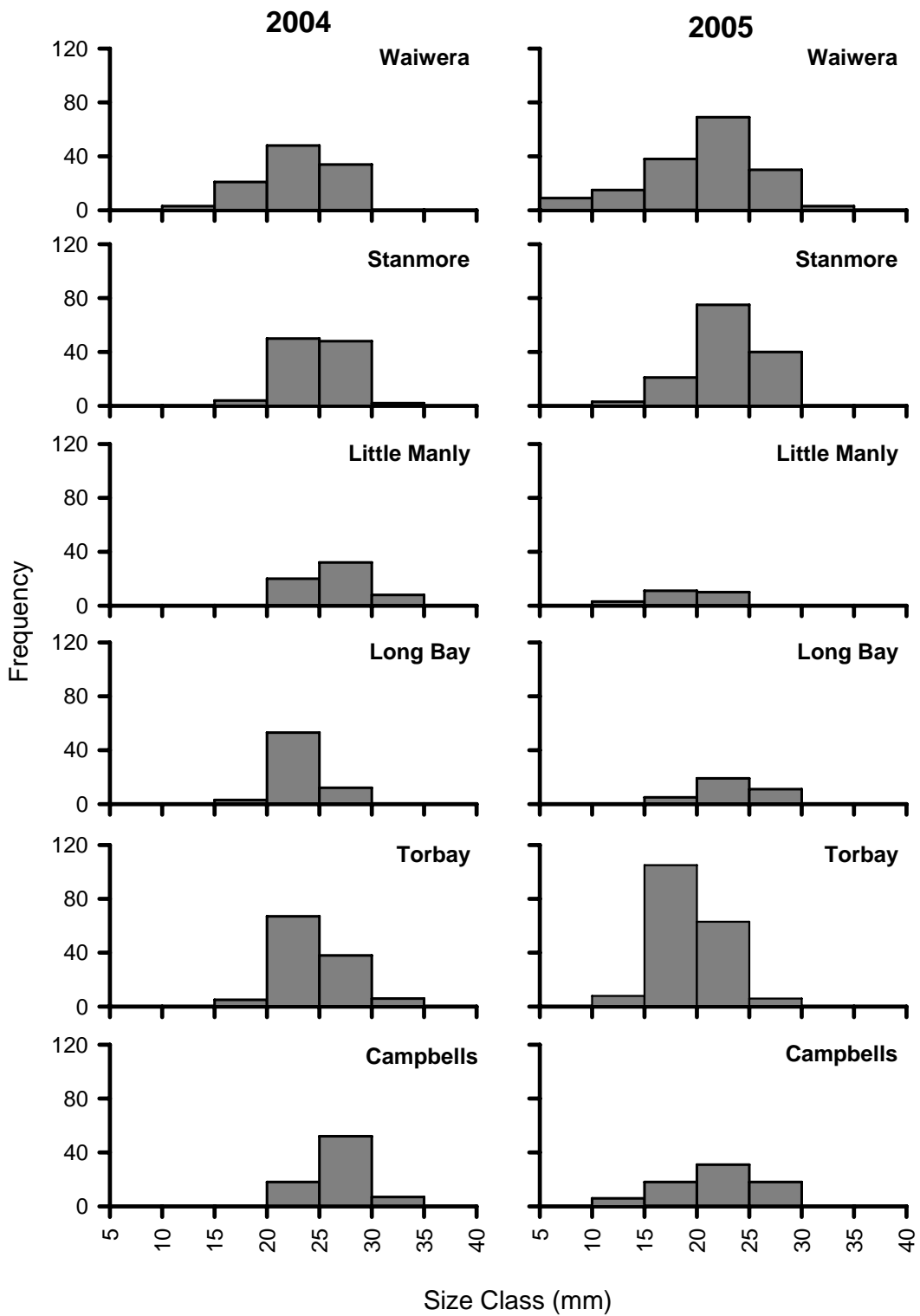


Figure H10. Size frequency distributions for *Cantharidus* spp.