Figure 29
Diversity of cover species - figure details are explained in the caption of Figure 12.

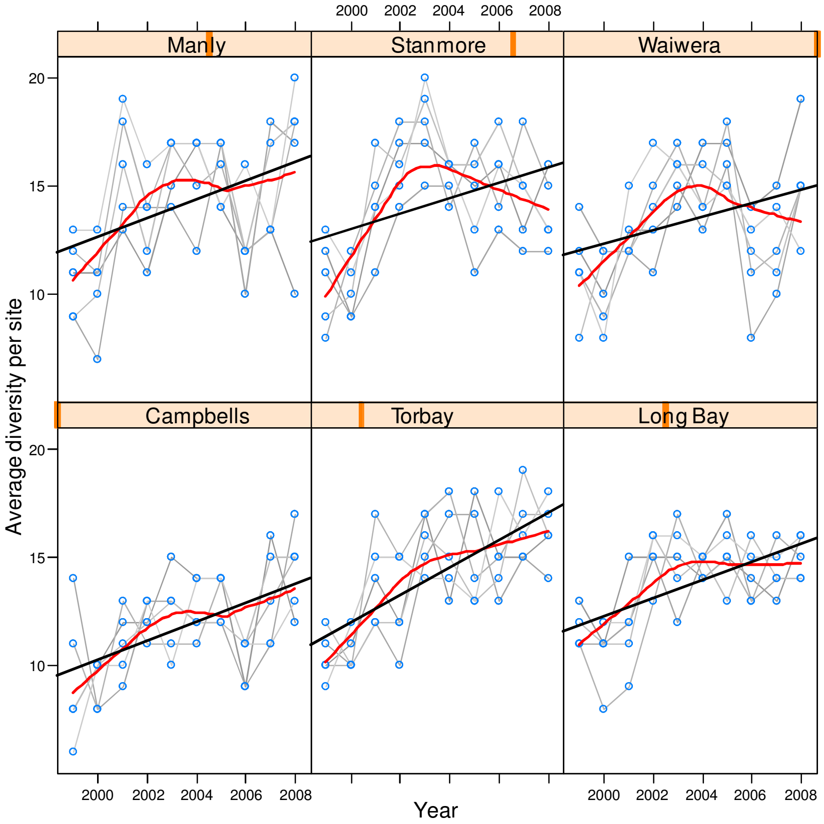


Figure 30
Evenness of cover species– figure details are explained in the caption of Figure 12.

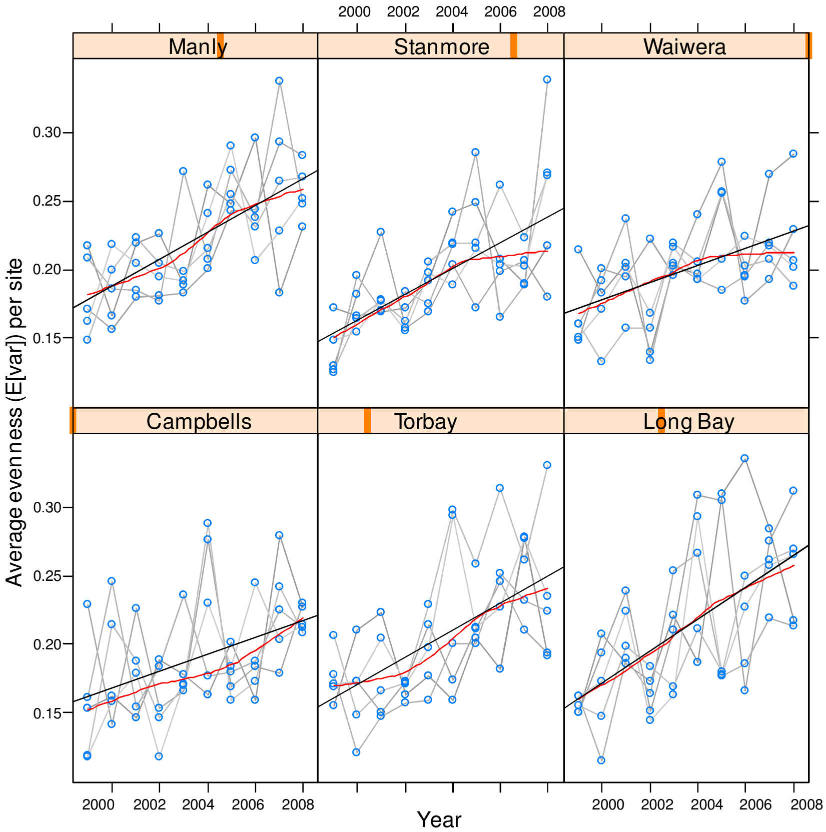


Figure 31
CCA cover— figure details are explained in the caption of Figure 12.

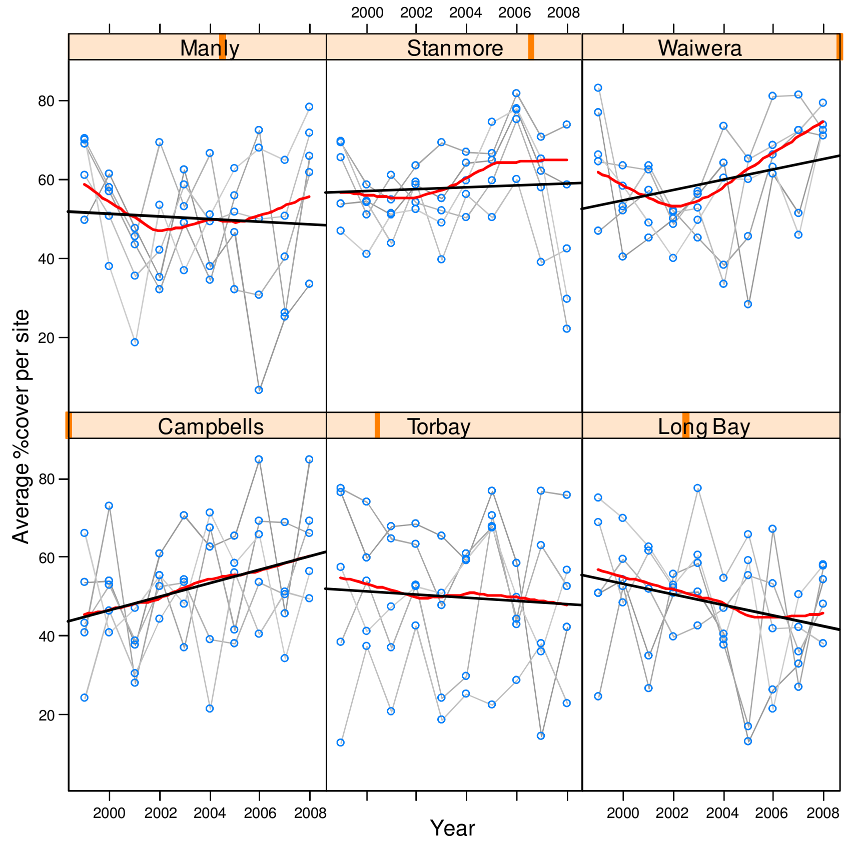
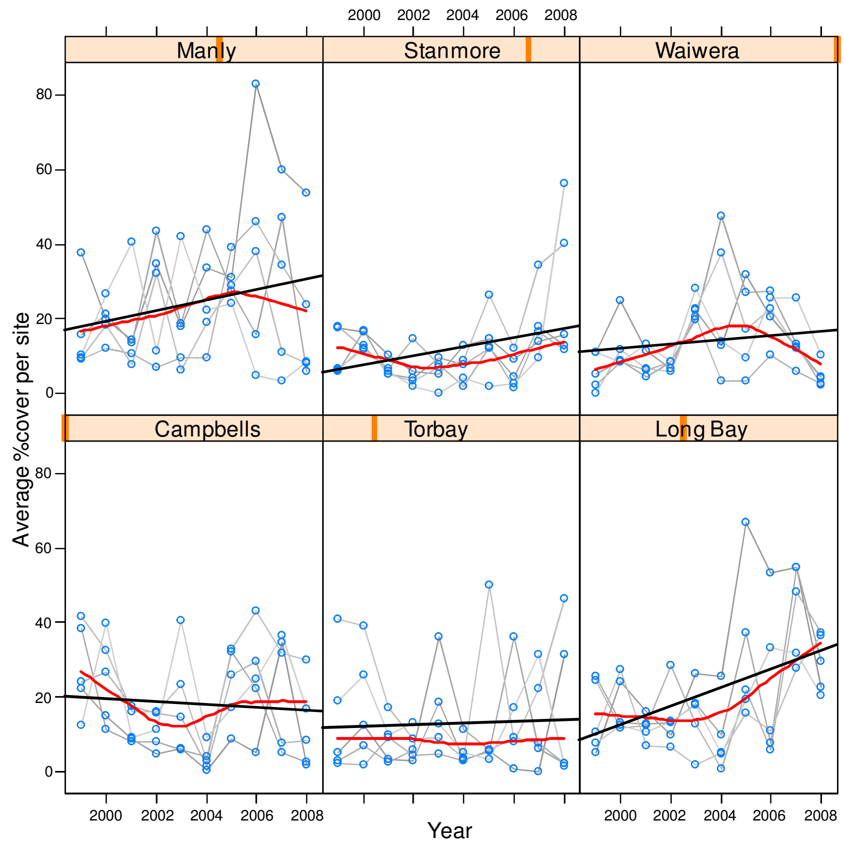


Figure 32
Sediment cover - figure details are explained in the caption of Figure 12.



4.2.3.3 Temporal patterns in trapped sediment

Sediment trap rate

There was strong evidence of a difference in sediment trap rate between bays when averaged over all sampled time ($p < 0.001$). Tukey's HSD pair-wise comparisons revealed a gradient in average trapped sediment rate, as follows: C > L > W > T > M > S (significant differences between bays are shown in Table 12 and Figure 33).

All bays showed significant evidence ($p < 0.05$) of a decline over time in sediment trap rate (Figure 34). Manly and Torbay have had a comparatively small but steady decline in trapped rate. In contrast, the other bays showed a non-linear change over time – a large decline before 2004, followed by a more modest recovery and relative stability in the last few years.

There was evidence that ENSO was negatively correlated with sediment trap rate at Campbells, Torbay, and Waiwera ($p < 0.05$), i.e. sediment trap rate was generally higher during La Niña years.

Table 12
Differences in sediment trap rate (ranked North to South) between bay averaged over time. Bays sharing a group letter are not significantly different, e.g. Campbells and Long Bay are not significantly different (they share group membership A); similarly Long Bay and Waiwera are not different (both members of B), but Campbells and Waiwera are different.

	Waiwera	Stanmore	Manly	Long Bay	Torbay	Campbells
Groups: *trap rate*	*B*	*C*	*C*	*A & B*	*C*	*A*

Figure 33
Log (average sediment trap rate) for each bay. Letters indicate group membership (see Table 12 for a detailed explanation).

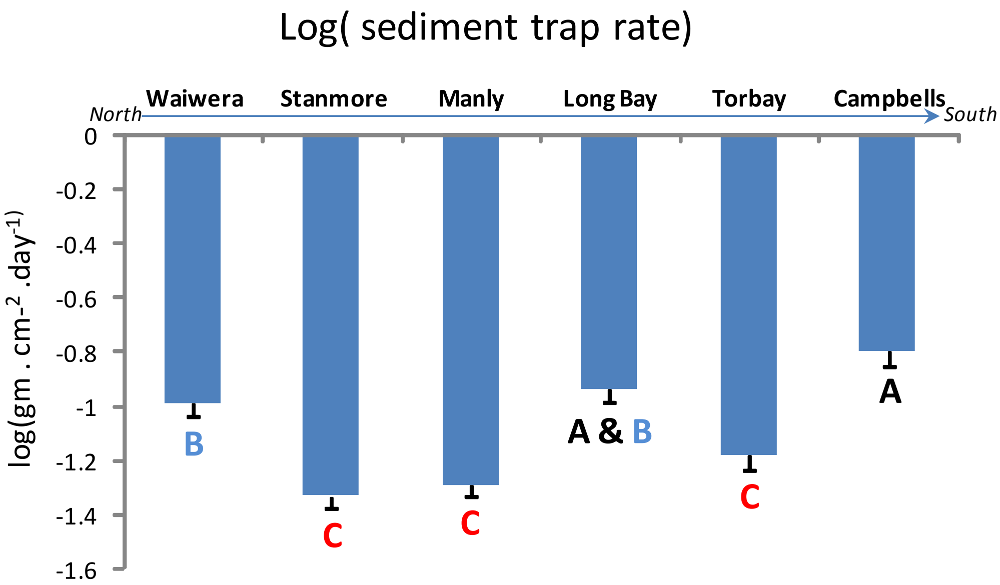
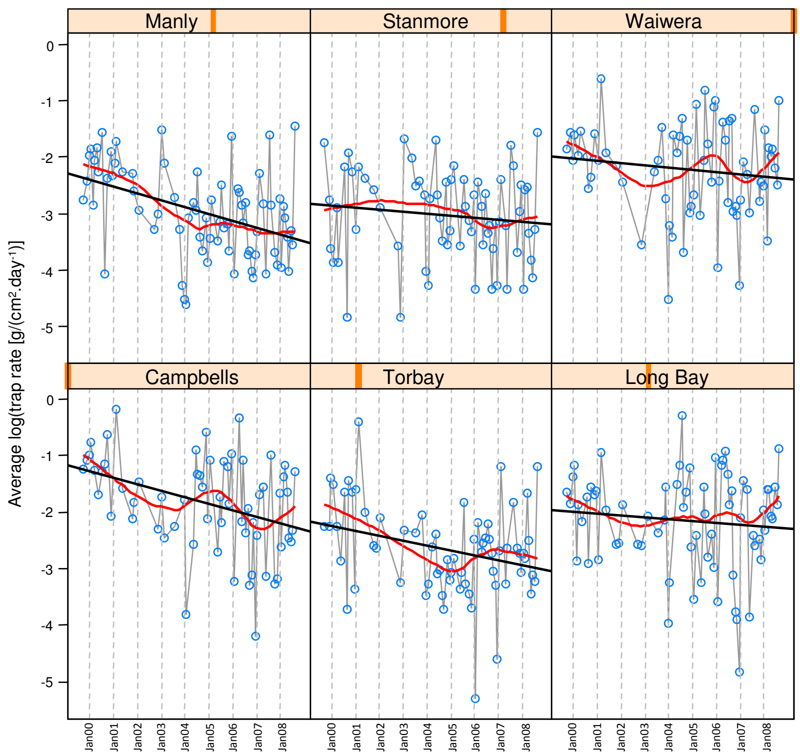


Figure 34
Scatter plot showing the change in the log (sediment trap rate) over time (averaged for each bay).



Fine sediment trap rate

There was strong evidence of differences in the fine sediment trap rate (i.e. sediment less than 63 μm) when averaged over time amongst the bays ($p < 0.001$). Tukey's HSD pair-wise comparisons revealed a gradient in average trapped sediment rate, as follows: C > L > W > T > M > S (significant differences between bays are shown in Table 13 and Figure 35).

The change in fine sediment trap rate declined between 2002 and 2005, but has been comparatively stable since that year (Figure 36). There is no evidence that ENSO was correlated with fine sediment trap rate at any of the LBMMP bays.

Table 13

Differences between bay fine sediment trap rate (<63μm) (ranked North to South) averaged over time. Bays sharing a group letter are not significantly different (see Table 12 caption for an example).

	Waiwera	Stanmore	Manly	Long Bay	Torbay	Campbells
Groups: rate of fine sediment	*B*	*B*	*B*	*B*	*B*	*A*

Figure 35
Log (average trapped fine sediment rate) for each bay. Letters indicate group membership (see Table 12 for a detailed explanation).

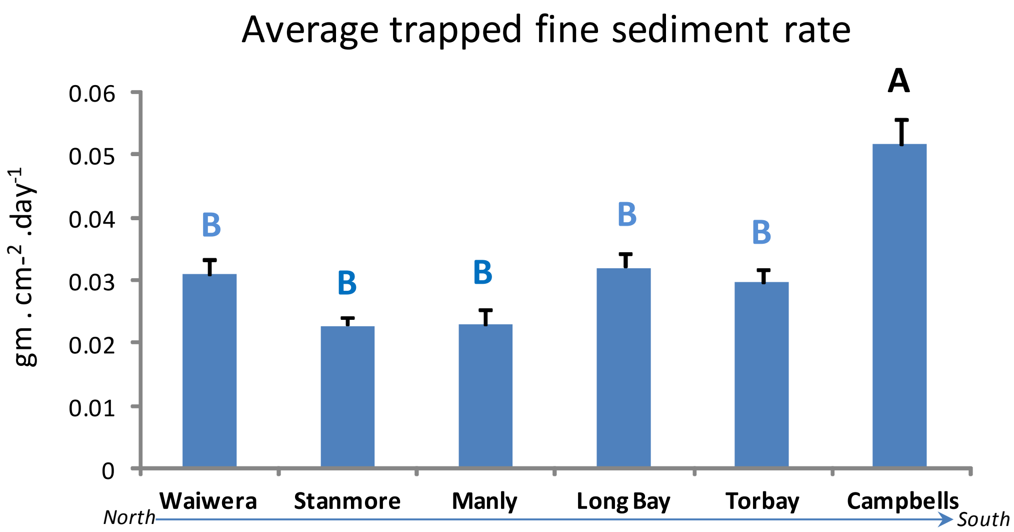
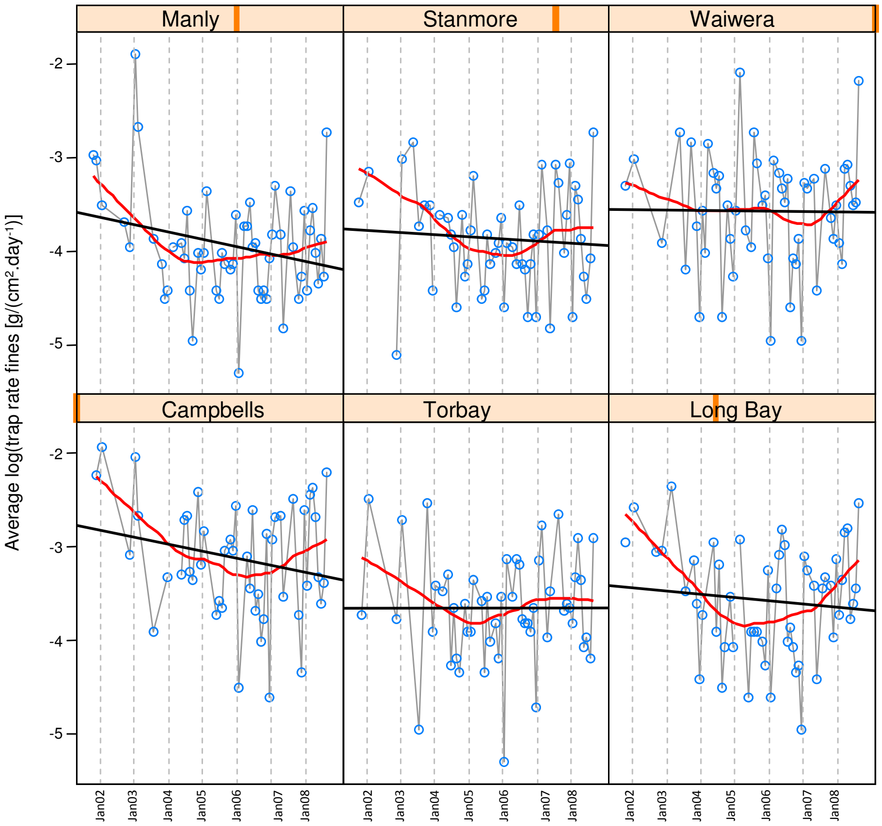


Figure 36
Scatter plot showing changes over time in the trapped fine sediment rate (<63μm) over time (averaged for each bay). Note: measurement of fine sediment started later in LBMMP, so there is a different time scale to Figure 34.



Fine sediment proportions

There was strong evidence of differences among the bays in the proportion of fine sediment (less than 63 μm) in traps, when averaged over time ($p < 0.001$). Tukey's HSD pair-wise comparisons revealed a gradient in average trapped sediment rate, as follows: T > S > M > C > L > W (significant differences between bays are shown in Table 14 and Figure 37).

All bays show the same general (non-linear) pattern in the proportion of trapped fine sediment over time: (i) a sharp drop between 2002 and 2004, followed by (ii) a slight increase until 2006-7, (iii) then a comparatively stable period in the last year for most bays (Waiwera showed another decline in fine sediment proportions) (Figure 38).

ENSO was positively correlated with the proportion of fine sediment; that is, the proportion of trapped fine sediment was generally lower during La Niña years. Significant positive correlations ($p < 0.05$) were found at Campbells, Long Bay, Manly and Waiwera.

Table 14

Differences between bays in the proportions of fine sediment (<63μm) averaged over time (ranked North to South). Bays sharing a group letter are not significantly different (see Table 12 caption for an example).

	Waiwera	Stanmore	Manly	Long Bay	Torbay	Campbells
Groups: %fine sediment	*C*	*A & B*	*A, B & C*	*C*	*A*	*B & C*

Figure 37
Average proportion of fine sediment) for each bay. Letters indicate group membership (see Table 12 for a detailed explanation).

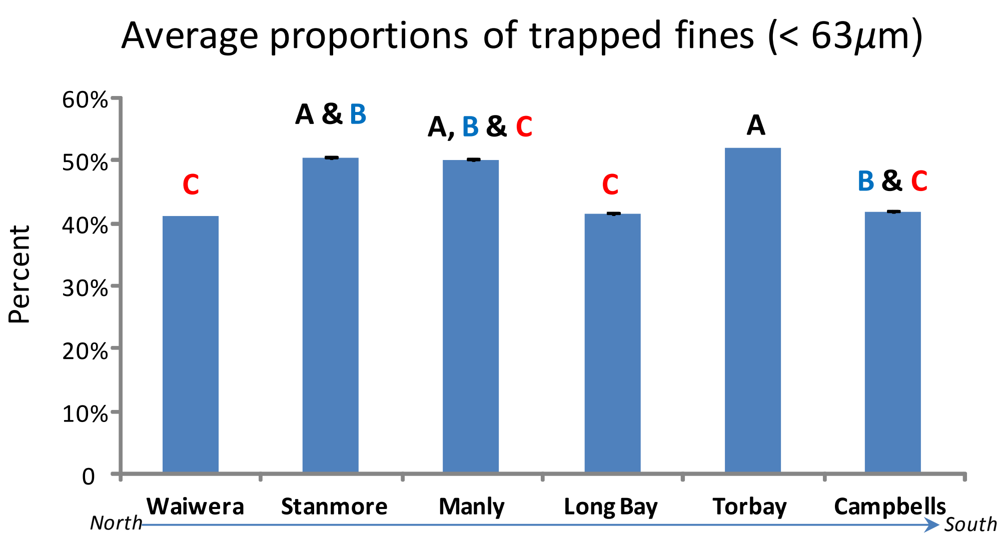
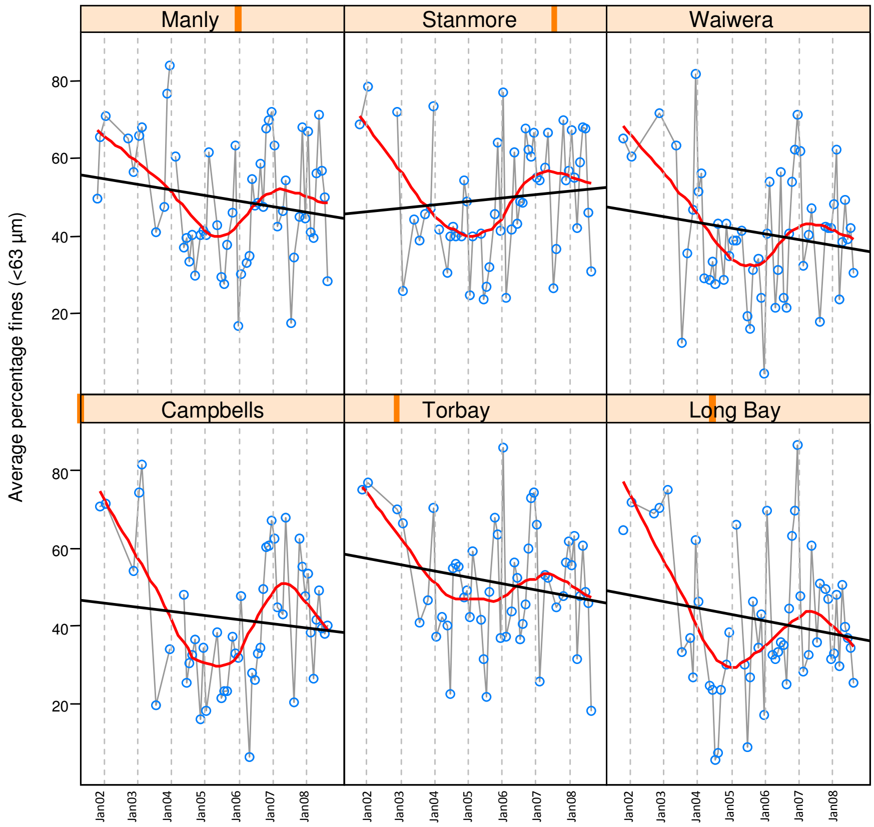


Figure 38
Scatter plot showing the change in the proportion of trapped fine sediment (<63μm) over time (averaged for each bay). Note: measurement of fine sediment started later in LBMMP, so there is a different time scale to Figure 34.



4.3 Examining the relationship between environmental variables and biotic abundance

4.3.1 Environmental variables and the biotic assemblage (multivariate analyses)

All six environmental variables explained 46% of the variability at the bay level (Table 15). The single most important environmental variable was the fetch of each bay ('*Fetch_bay*'), which alone explained 22.7% of the biotic variation. In the forward selection procedure, this was followed by tidally corrected depth ('*Depth*') which added another 12.4%, followed by average trapped sediment rate at each bay ('*bay trap_rate*') and sediment cover ('*sed.cover*'). These variables together explained over 43% of the biotic variation (Table 15). The rate of trapped fines ('*bay fines_rate*') and the short-term ENSO variable (i.e. the MEI averaged over the 3 month period prior to sampling), were also useful predictors, but these variables were dropped when a more parsimonious model was obtained using the 2nd-order corrected AIC criterion (AICc).

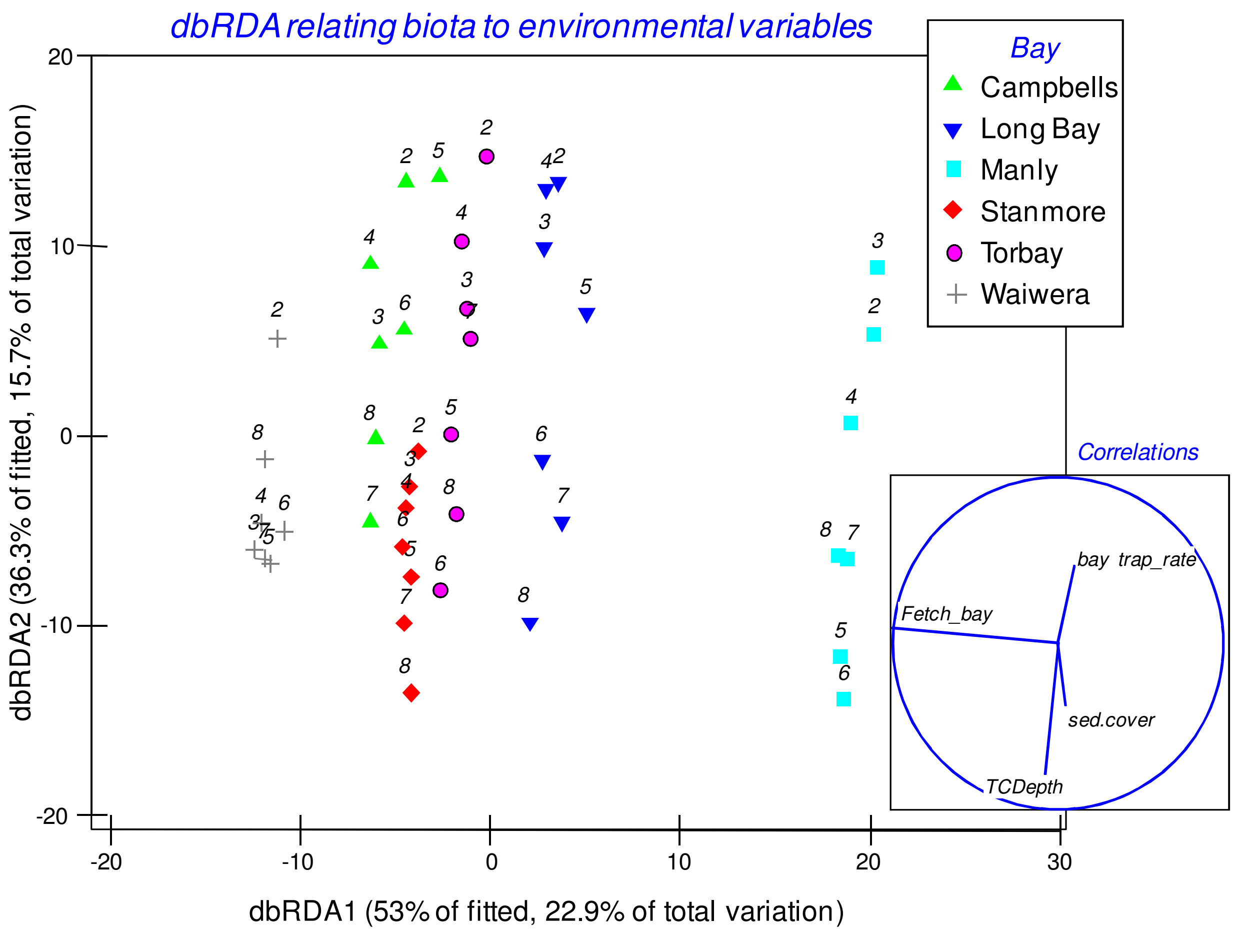
Table 15
Results of DISTLM analyses relating count biotic data, based on Bray-Curtis dissimilarities of log(x+1) transformed data, with environmental variables (as described in section 3.5.1). Prop. = proportion of explained variation, Cumul. = cumulative proportion of explained variation.

	Marginal tests			***Sequential tests***			
Variable	**F**	***p*-value**	**Prop.**	**F**	***p*-value**	**Prop.**	**Cumul.**
Fetch_bay	11.75	0.001	0.227	10.23	0.001	0.227	0.227
Depth	5.78	0.001	0.126	7.4	0.001	0.124	0.350
bay trap_rate	2.54	0.013	0.060	2.8	0.006	0.046	0.395
Sed.cover	4.23	0.002	0.0954	7.4	0.013	0.037	0.432
bay fines_rate	4.46	0.001	0.126				
ENSO_st	2.47	0.02	0.05				

The first two axes of a dbRDA fit to the environmental variables (described in Table 15) allowed most of the fitted variation (89%) to be visualized (Figure 39). The inset circle in the figure shows the Spearman rank correlation between each of the environmental variables and the two dbRDA axes: the longer the arrow, the stronger the relationship.

The horizontal axis is clearly well described by the differences in fetch, while the vertical axis is described by (tidally corrected) depth and bay averaged sediment trap rate. Broadly speaking, early surveys (e.g. 2002) are placed higher in the y-plane of the ordination plot than later surveys, suggesting (i) increasing depth for some bays and (ii) an initial decrease in the rate of trapped fine sediment over time.

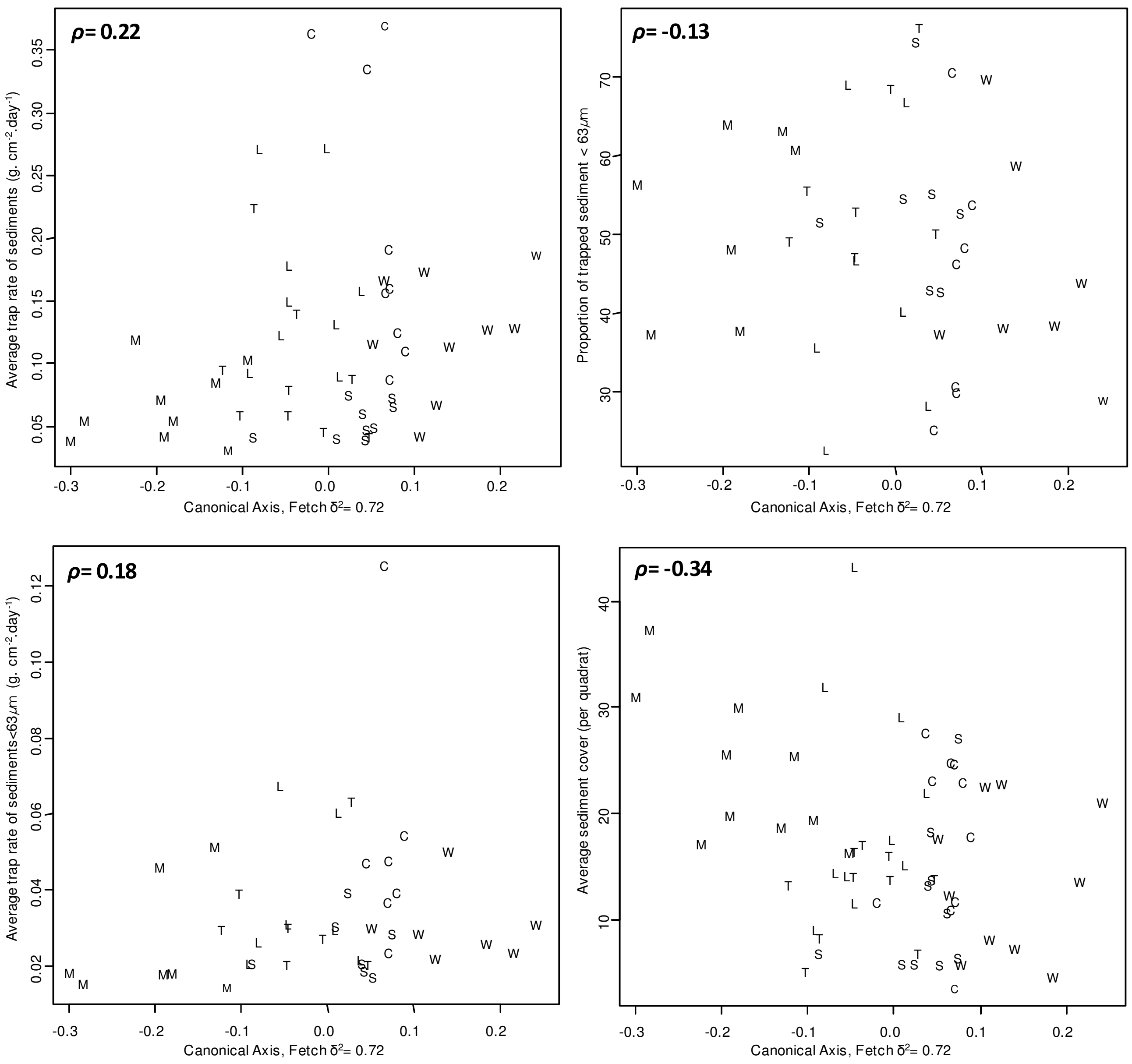
Figure 39
Distance-based redundancy analysis relating biota to environmental variables. The inset shows a unit circle (radius =1) with the raw Spearman rank correlations of individual environmental variables with each of the dbRDA axes as arrows. Numbers indicate the year of the survey, i.e. 2= 2002, …, 8 = 2008.



The relationship between fetch and sediment variables

Plotting the gradient in assemblage structure with respect to fetch against the other sediment variables (Figure 40) corroborated the evidence found in the dbRDA, i.e. the effect of fetch on the biotic data correlated most strongly with decreases in sediment cover and increases in average trap rate, but only poorly related to the rate or proportion of trapped fine sediment (less than 63 μm). In short, sediment cover decreased, but average trap rate increased with exposure (fetch).

Figure 40
The relationship between each of several sediment variables and the canonical axis representing a gradient in assemblage structure based on fetch. W= Waiwera, S = Stanmore, M = Manly, L = Long Bay, T =Torbay and C = Campbells.



4.3.2 Environmental variables and specific biota (univariate analyses)

Note: For brevity, quantification of environmental effects on: *Trochus*, *Cantharidus*, Solitary ascidians, *Cystophora*, *Tethya* and *Evechinus* are shown in Appendix I.

4.3.2.1 Climate effects on biotic abundance

The short time scale of the time series meant that estimation of ENSO effects, in general, were extremely imprecise (consider the size of the confidence intervals in

Table 16 and Table 197 [Appendix I]). However, despite the uncertainty of the ENSO estimates, their inclusion as a covariate in the model is important since the term helps to remove cyclicity from the data (which in turn allows more accurate quantification of the other effects).

There was evidence that the ENSO (as measured by the short term MEI average) was positively correlated with abundance (or algal biomass) at several bays, i.e. abundance for most species increased in El Niño years at some bays. ENSO appeared to have little effect on the cover variables - it was positively correlated with sediment cover at Waiwera, and negatively associated with CCA cover at Manly (Table 16).

Table 16
GLMM model results showing the effect of Climate (ENSO) on (i) indices (ii) count abundance and (iii) cover data (after accounting for year and depth effects). Values indicate the 95% confidence interval of the estimated change per MEI unit. ENSO effect

Index	*Campbells*	*Torbay*	*Long Bay*	*Manly*	*Stanmore*	*Waiwera*
Total abundance				(3-23)%	(7-28)%	
Algal biomass				(18-78)%		
Diversity (count)						
Evenness (count)						
Counted biota						
C. maschalocarpum		(18-75)%				
Turbo smaragdus						
Zonaria turneriana						
C. plumosum			-(6-58)%		-(40-79)%	
C. flexuosum				(32-126)%	(33-120)%	
Ecklonia radiata	(8-47)%					
Cover variables						
CCA				-(1-12)%		
Sediment cover						(5-12)%
Diversity (cover)						
Evenness (cover)						

4.3.2.2 Depth effects on biotic abundance

Most depth effects on the (log transformed) biotic abundance (and evenness) were well modelled by a linear term (Table 17). An increase in depth was associated with a linear *decrease* in: (i) total abundance (at Campbells, Torbay, Long Bay and Waiwera), (ii) *C. maschalocarpum* (Campbells and Long Bay), and (iii) *C. plumosum* (Campbells and Manly).

In contrast, increasing depth was associated with *increases* in: (i) evenness (at Stanmore and Waiwera), (ii) *Zonaria* (Campbells, Manly and Stanmore), (iii) *Turbo* (Long Bay) and (iv) *C. flexuosum* (Campbells, Long Bay, Manly and Stanmore).[12]

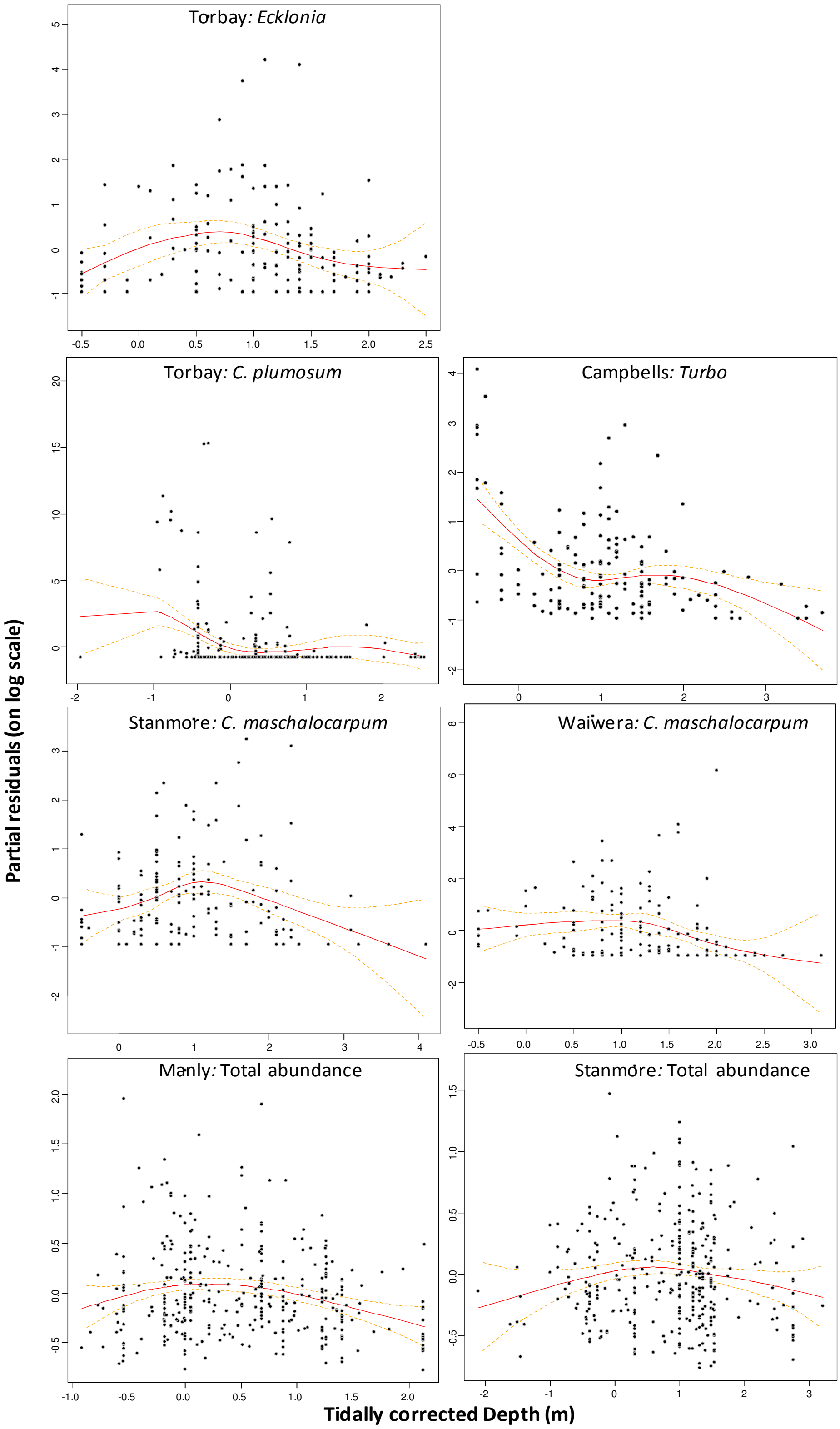
At a variety of bays, there was also strong evidence of a non-linear depth effect on log (transformed) abundance (Figure 41). Abundance of *C. maschalocarpum* peaked at approximately 1 m depth at Stanmore and Waiwera. At Campbells, *Turbo* abundance rapidly dropped between the (intertidal) sublittoral fringe and subtidal zones, stabilized and dropped beyond 2 m depth. Modal peaks of total abundance were evident at an approximate depth of 0.5 m depth Manly and Stanmore and for *Ecklonia* at Torbay.

Table 17
GLMM model results showing the effect of depth on (i) indices (ii) count abundance and (iii) cover data (after accounting for year and climate effects). NL indicates a non-linear change with depth (shown in Figure 41). Values indicate the 95% confidence interval of the estimated change per meter (of depth).

Index	*Campbells*	*Torbay*	*Long Bay*	*Manly*	*Stanmore*	*Waiwera*
Total abundance	-(4-18)%	-(4-20)%	-(1-17)%	*NL*	*NL*	-(8-26)%
Algal biomass						
Diversity (count)						
Evenness (count)					(0.1-0.2)	(0.01-0.2)
Counted biota						
C. maschalocarpum	-(17-38)%		-(17-53)%		*NL*	*NL*
Turbo smaragdus	*NL*		(0-33)%			
Zonaria turneriana	(17-64)%			(37-94)%	(19-62)%	
C. plumosum	-(13-76)%	*NL*	-(27-53)%	-(23-59)%		-(41-91)%
C. flexuosum	(25-124)%		(30-194)%	(17-116)%	(18-98)%	
Ecklonia radiata		*NL*	-(4-39)%			
Cover variables						
CCA						
Sediment cover	(3-12)%			(1-11)%		
Diversity (cover)						
Evenness (cover)						

[12] It should be noted that quantified relationships between species abundance and depth are bay-specific because they are dependent upon the subtidal topology and local incidence of light within each bay. Any quantified depth effect should therefore not be considered a general relationship attributable to other bays. Indeed, it seems sensible that depth effects are modal, because species are likely to be found in greater abundance in certain depth ranges.

Figure 41
Partial residual plots showing those non-linear relationships between depth and abundance when fitting the models described in Table 17. The y-axis shows the model residuals on the log scale - both x and y-axis scales vary for individual plots. Solid red line shows the change in average abundance (on log scale) as depth changes. The dashed red line shows the bootstrapped 95% confidence envelope of the depth effect.



4.3.2.3 Sediment trap relationship with biotic abundance

Sediment trap rate

Sediment trap rate was found to be only rarely correlated with the abundance of species (or diversity) in LBMMP (Table 18). Specifically, there was evidence that an increase in trap rate negatively correlated with abundances of *C. plumosum* at Long Bay and *C. flexuosum* at Stanmore, and positively correlated with *Turbo* abundance (at Manly and Waiwera).

Sediment trap rate positively correlated with cover diversity at Torbay but negatively correlated with cover diversity at Waiwera. There was also evidence that it correlated with sediment cover (at Waiwera).

Table 18

GLMM model results showing the effect of the sediment trap rate (after accounting for year, depth and climate effects). Values indicate the 95% confidence interval of the estimated change in abundance (or index value) given a change in rate of 1 g per cm^2 per day.

Index	*Campbells*	*Torbay*	*Long Bay*	*Manly*	*Stanmore*	*Waiwera*
Total abundance						
Algal biomass						
Diversity (count)						
Evenness (count)						
Counted biota						
C. maschalocarpum						
Turbo smaragdus				(7–130)%		(0-51)%
Zonaria turneriana						
C. plumosum			-(38-82)%			
C. flexuosum					-(47–86)%	
Ecklonia radiata						
Cover variables						
CCA						
Sediment cover						(2-14)%
Diversity (cover)		(0.6-4.1)				-(0.3-3.5)
Evenness (cover)						

Trapped fine sediment

The percentage of trapped fine sediment did not correlate with the abundance of any of the most common biota. We estimate that a one percent increase in trapped fine sediment (less than 63 μm) correlates with: (i) a decrease in species diversity of between 0 - 0.1 per year at Waiwera, (ii) an increase in sediment cover of 0.1 - 0.5% per year at Long Bay and (iii) an increase in CCA cover of 0.3 – 1.1% per year at Waiwera. However, there was evidence that it negatively correlated with diversity of the cover taxa and positively correlated with sediment cover at Long Bay. Unusually, it also positively correlated with CCA cover at Waiwera ($p < 0.05$).

4.3.2.4 Sediment cover effects on abundance

Scatterplots of the most abundant biota were plotted against a gradient of sediment cover (Figure 42). Relationships were one of: (i) decreasing with increasing sediment cover (e.g. *C. maschalocarpum, Ecklonia, Cantharidus*, *Evechinus*), (ii) a modal response with a broad tolerance (e.g. *Turbo*, *Zonaria, C. plumosum or Cystophora*), (iii) increasing with increasing sediment cover (*C. flexuosum*, solitary ascidians and *Maoricolpus*) or (iv) no discernable relationship between sediment cover and abundance (e.g. and *Tethya*).

Figure 42

Relationship between individual taxa (as indicated) and percentage sediment cover. The polynomial regression spline model for the 95th percentile is shown in blue, with the maximum from the model (interpretable as an estimated optimum for the taxon) indicated by a red line.

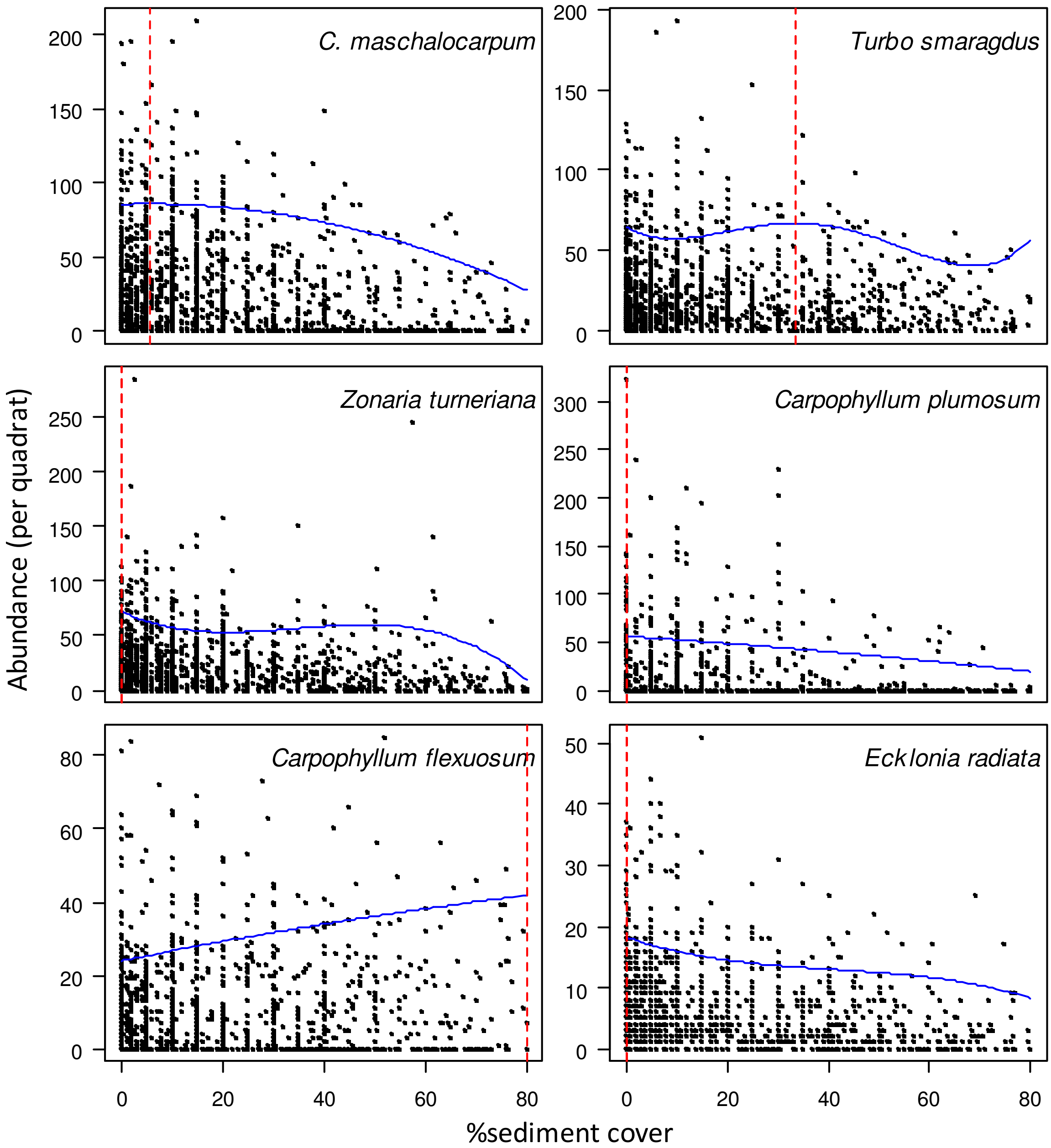
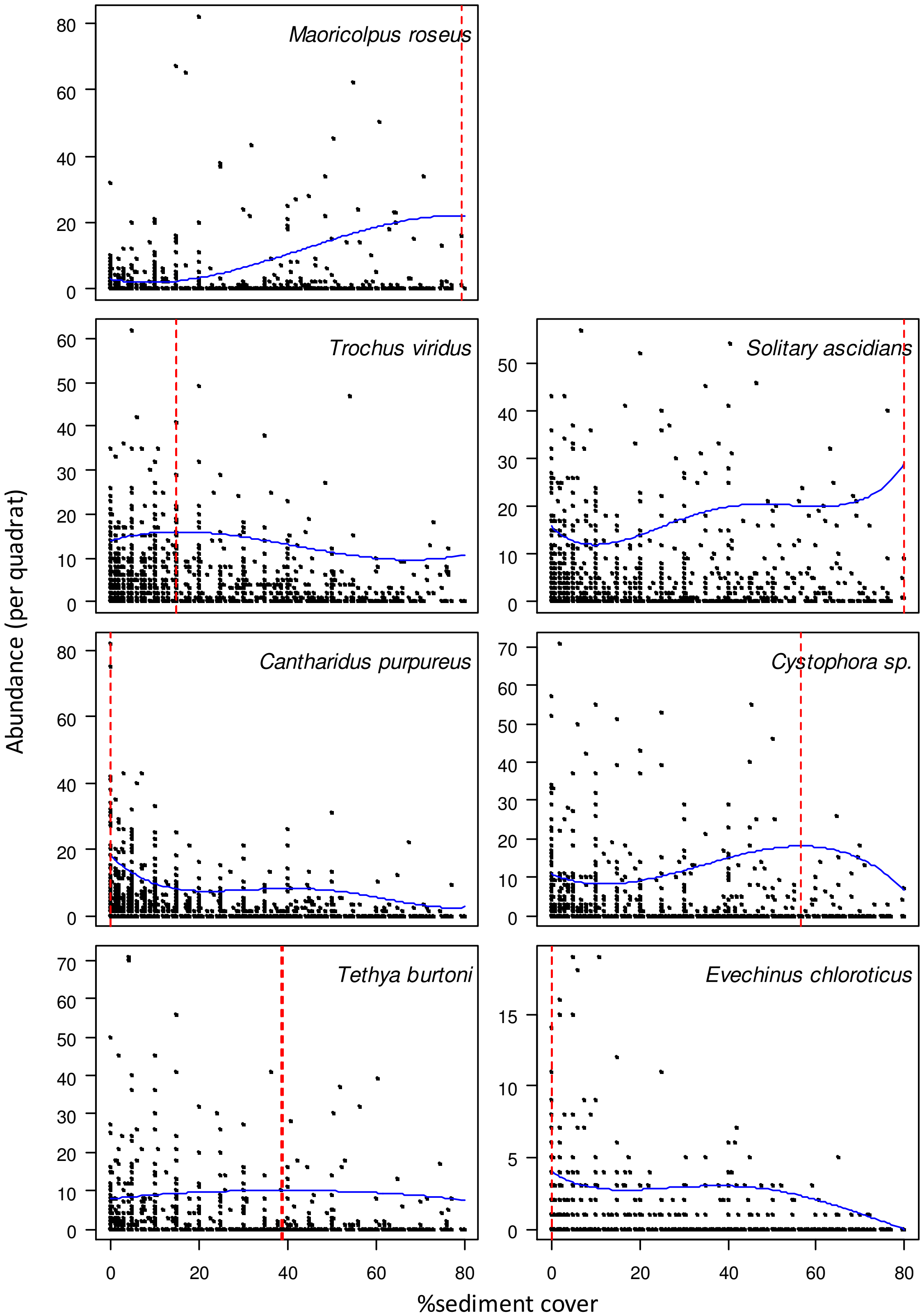


Figure 432-continued
Relationship between individual taxa (as indicated) and percentage sediment cover. The polynomial regression spline model for the 95th percentile is shown in red, with the maximum from the model (interpretable as an estimated optimum for the taxon) indicated by a red line.



5 Discussion

5.1 Characterization of the bays

On a national scale, the LBMMP bays are all comparatively sheltered from wind and waves (due to the influence of the Coromandel and Whangaparoa peninsulas as well as Great Barrier and inner Hauraki Gulf islands). Despite this, bays in the LBMMP show a general gradient in community structure that is strongly correlated with exposure (as measured by wind fetch). This gradient better explained the variation in community structure than the north-south gradient found by Anderson et al. (2005) (although both methods ranked bays similarly). It was unsurprising therefore, that those bays at the two extremes of the exposure scale, Waiwera and Manly, contained the most distinct biotic assemblages. The remaining bays had comparatively similar exposure levels and showed considerable overlap in their biotic assemblages. In particular, Stanmore (ranked roughly in the middle of the fetch gradient) had no simple distinguishing characteristics in its biotic assemblage compared to other LBMMP bays.

The patterns in biotic assemblages in the LBMMP are consistent with the well documented, broad-scale effects of exposure and depth and the taxa are typical of what is found on rocky reefs in the Hauraki Gulf. For example, all sites typically had a canopy dominated by mixed brown algae of the orders Fucales and Laminariales and an understory dominated by *Zonaria* (Schiel & Foster 1986, Shears et al. 2004). High exposure sites (such as Waiwera) had comparatively low abundance of *Turbo* (the dominant macroinvertebrate) and relatively high abundance of *Cantharidus* (Walker 1999, Shears & Babcock 2007). *Cystophora* abundance was generally greater at the deeper, northern reefs, a spatial pattern also emulated by *Trochus*.

The most comparable data to the LBMMP is from the Meola Reef Monitoring Programme (MRMP). Although methods are identical between programmes, comparison between these systems should only be qualitative due to the physically differing environments between the LBMMP and MRMP (see Ford and Pawley 2008 section 6.3 for a discussion of these differences) and the smaller depth range of sampling at Meola reef (1 – 2 m below chart datum; cf. -0.5 to 4.1 m below chart datum in the LBMMP).

5.2 Assessment of change over time

In the previous LBMMP report, Anderson et al. (2005) found significant changes in community structure through time for all bays, but particularly at the two northern bays (Waiwera and Stanmore). In particular they noted that these had: (i) increasing average abundances of the sponge *Tethya burtoni* and brown algae, *C. flexuosum* and *Zonaria*, and (ii) a contrasting decrease in average abundances of the brown alga *C. maschalocarpum* and the herbivorous gastropod *Turbo*.

Since 2005, *Turbo* abundance has stabilized at Stanmore and Waiwera. However, over this period *Tethya* abundance has increased at all bays, with particularly large increases in high fetch bays (i.e. Campbells, Stanmore and Waiwera). Since 2005, *C. flexuosum* abundance has increased at the three southernmost bays and Waiwera, but has stabilized at Manly and Stanmore. *Zonaria* abundance stabilized at most bays, but increased at Campbells (and to a lesser extent at Waiwera) since 2007 – future monitoring will be required to determine if these changes are part of a trend or a cycle. The rapid decline in *C. maschalocarpum* at the northern bays noted by Anderson et al. (2005) has since stabilized since 2006, but a decline of *C. maschalocarpum* continues in the southern bays.

Anderson et al. mentioned general increased abundances (in all bays) of the following species between 1999 and 2005: *Australostichopus, Cookia, Cantharidus*, *Maoricolpus*, *Patiriella, Coscinasterias* and *Buccinulum lineum.* Also mentioned is a decline abundance of *Dicathais, Sargassum* and *C. virgata*. Since 2005, abundances of all those species have stabilized (although the predatory gastropod, *Buccinulum lineum* has continued to increase in Long Bay and Torbay).

In early LBMMP surveys, *C. maschalocarpum* was the numerically dominant canopy macroalga; however, since 2007 *C. flexuosum* has been just as abundant. The distributional expansion of and replacement of resident algae by *C. flexuosum* has been previously documented at both wave sheltered and exposed sites across the 0 – 10 m depth range in the Hauraki Gulf (Cole et al. 2001). These authors documented decadal scale changes in algal assemblages and pointed to ENSO related changes in wave energy as probable causative agents. The evidence of this change relied upon a number of surveys conducted over decades at Goat Island and nearby areas.

However, without experimental evidence, it is difficult to do anything other than speculate about the potential mechanisms behind the change in the macroalgal community. Although long term climactic processes may cause changes in algal beds, their influences are known to depend on various dynamics within the algal communities. For example, algal canopies are known to inhibit algal recruitment, probably via limiting both space and light and gaps in the canopy are an important opportunity for changes in algal composition (Schiel 1988). Recruitment to these gaps is known to be influenced by various factors including spore availability and sediment cover (Schiel 1988, Schiel et al 2006). Given that *C. maschalocarpum* is typically dominant on shallower reefs (< 2m), with *C. flexuosum* becoming more dominant at greater depths (in the 4 - 6 m zone) (Shears and Babcock 2003, 2004), it seems plausible that the difference in habitat depths between these species will result in differential impact from storm events. If such an event reduces the algal canopy of *C. maschalocarpum* but has not impacted *C. flexuosum,* then the relative abundance of *C. flexuosum* seem likely to enhance its probability of spore settlement in nearby canopy gaps. In addition, the abundance of *C. flexuosum* appears to be highly tolerant of sediment cover compared to *C. maschalocarpum* (which declines in abundance after even low levels of sediment cover (see Figure 42)). So it seems plausible that even slightly raised levels of sediment cover may also differentially enhance recruitment in favour of *C. flexuosum*.

C. flexuosum has only ever been found in its long, bushy form in the LBMMP (which is typical of wave sheltered conditions) (Cole et al. 2001), so more space is typically available under this form of *C. flexuosum* for understory algae such as *Zonaria (pers. obs.)* compared to the shorter, denser forms of *C. plumosum or maschalocarpum* (Adams 1994). Consequently, it seems reasonable to believe that the changes in the composition of canopy algae will also affect *Zonaria* abundance, i.e. the replacement of *C. maschalocarpum* and *C. plumosum* with the long, bushy morphology of *C. flexuosum* leaves more room for the understory *Zonaria*. Although *Zonaria* abundance has generally increased since the inception of the LBMMP, it has actually been relatively stable at the northern bays since around 2003.

Algal biomass may be the most important measurement of sedimentation related effects, due to its correlation with productivity (Lobban & Harrison 1997). Notably, the changes in canopy algal composition (described above) have not led to any change in algal biomass (Figure 13).

In contrast, diversity has increased over time. The increase in diversity is likely to be due, in whole or part, to the arrival of two invasive organisms (*Chaetopterus* and *Styela clava*) and the discovery of a number of new taxa (the sponge *Aaptos aaptos,* chitons, the sea cucumber *Australostichopus,* and the gastropods *Cabestana spengleri, Cominella maculosa, Cominella quoyana* and *Cominella* "red foot" [unidentified at the time of writing]). Apart from *Chaetopterus,* all of the species are relatively rare (less than 60 individuals per taxon over the entire LBMMP). Over 700 tubes of *Chaetopterus* have been recorded, 641 of these in the 2008 survey. Some of this increase may have been due to improved taxonomic ability. For example, the rare *Cominella* species may have previously been misidentified as the more common *Cominella virgata*, and *Aaptos* could have been misidentified as a *Tethya*. However, for large or easily identified species such as chitons, *Cabestana spengleri* and *Australostichopus*, the likely explanation is that these taxa were not present in previous years. Due to all these reasons, i.e. the contribution of invasive species, the relatively short time scale, the possible contribution of taxonomic improvements and depth related issues (see section 5.2.1), we believe no management decisions should be based upon this increase in diversity at this time.

Most of the measured taxa showed changes in size frequency distribution over time, but there were few clear trends over time. Stanmore and Waiwera had very few numbers of all sizes of *C. maschalocarpum* in 2004; and since then there have been comparatively few smaller individuals (less than 30 cm) at all bays. In contrast, *C. flexuosum*, *C. plumosum* and *Ecklonia* generally increased in size in recent years. No clear patterns were apparent in the size frequency distributions of any of the more numerous gastropods (*Turbo, Trochus* or *Cantharidus*).

Changes specific to Long Bay

The list of biotic changes found only at Long Bay is very short. They include declines in:

1. the abundance of the urchin, *Evechinus*.
2. the cover of crustose coralline algae.

We estimate that the abundances and *Evechinus* at Long Bay have declined by between 2 - 15% per year respectively. The abundances of *Evechinus* have always been low at Long Bay, so the decrease is small in terms of absolute abundance. The estimated decline in CCA cover at Long Bay has been relatively minor (0 - 3% per year). However, these taxa should be considered carefully in future years.

5.2.1 Depth changes over time

There has been some suggestion that community changes seen in the program in the past were the result of a change in depth of some sites over time (Haggitt & Mead 2006). This appears to be true (at least in part) – depth was found to be an important variable in many univariate analyses (section 4.3). The *Carpophyllum* spp. were, in particular, grossly affected by changes in depth. For example, we estimated that an increase in depth of 1 m at Manly resulted in an increase of between 17 and 116% in the abundance of *C. flexuosum*.

Unfortunately, accurate depth records of each quadrat were not kept between 2003 and 2005, a period containing relatively rapid change in the abundance of *C. maschalocarpum* and *C. flexuosum*. However, tidally corrected depth measurements were recorded in all other years (both before and after changes in the site locations), so by including depth as a covariate in the models, we were able to estimate the change in abundance for all major taxa after partitioning (removing) depth effects. We found strong evidence, that the changes in macroalgal populations (in particular the *Carpophyllum* spp. and *Zonaria*) are not solely a result of changes in sample depth over time. The abundance changes of these species (as seen in Figure 16 - Figure 19) were still present even after partitioning out the effect of changes in depth (and ENSO) (see Table 9).

5.3 The effect of sediment

Although exposure and depth were the most important variables in explaining the biotic community structure (explaining around 35% of all variability), the rate of trapped sediment and (trapped) fine sediment were also important variables. Anderson et al. (2005) found a general decrease in trapped fine sediment between 1999 and 2005. Since 2005, the trap rate of fine sediment has stabilized at all bays (and even increased slightly at Manly) (see Figure 36). There is, however, relatively scant evidence demonstrating a gulf-wide effect of fine sediment trap rate on any specific taxa in the LBMMP. Sediment trap rate effects also appear to be bay-specific. For instance, there was evidence that *C. flexuosum* and *C. plumosum* decreased in abundance with increased trap rate, but only at Long Bay and Stanmore respectively. Similarly, an increase in trap rate coincided with increases in *Turbo*, but only at Manly and Waiwera. Likewise, there was evidence that cover diversity was negatively associated with fine sediment trap rate at Torbay, but positively associated at Waiwera. The difficulties in quantifying fine sediment trap rate (and other trap variables) are likely to be, in part, due to past problems with data collection. However, with better attachment and relocation of these traps (implemented since the audit in 2006), we do not anticipate the same data issues in the future. Moreover, at this pre-development stage of the monitoring project we do not necessarily expect sedimentation measures to be a strong influence on community structure.

It should be noted that all bays within the LBMMP and the MRMP have historically been subject to a relatively high degree of sedimentation. In the 1930s, sewage was discharged from Orakei wharf, Northcote Point and North Head (Hounsell 1935). Auckland's wharves have been dredged on numerous occasions in the past sixty years to remove mud or allow access for larger ships as mud accumulated in the sheltered waters (Rangitoto Channel has also been deepened by dredging to allow larger ships to access the harbour) (Hayward et al. 1997). In addition, clearance of natural forests (starting in pre-European times) and the vast increase in urbanization in the harbour catchment in the past seventy years would have increased sediment discharge into the harbour (van Roon 1983). When considered in this context, it is unsurprising that the communities found in the LBMMP appear resilient to sedimentation. All of the examined species showed a broad tolerance to sediment cover (see Figure 42 and Figure 43). A similar high tolerance to sediment cover was also found in the Meola Reef subtidal community.

Algal communities can influence sediment cover on the substrate, either by direct physical trapping of the sediment, or decreasing sediment cover due to their sweeping effect on hard substrates (Valentine and Johnson 2003, Kennelly and Underwood 1993). The algae, for those species that can live there, provide extra substrate and a refuge from the impacts of sediment deposition on the seabed. Therefore, as long as algal cover is retained, sediment impacts are likely to be less marked in the subtidal (when compared to the intertidal region). Mature algal communities are known to inhibit algal recruitment (Schiel 1988); therefore algal change is likely to be influenced largely through gaps in the canopy. Recruitment to these gaps is further influenced by factors such as: spore availability, sediment cover, predation and competition amongst spores (Schiel 1988, Schiel et al. 2006). The timing of these gaps can be crucial in determining the outcome of disturbance and result in changes to the dominant algal cover, e.g., Valentine and Johnson (2003) describe how replacement of native canopy by *Undaria pinnatifida* occurred more strongly in winter (when *Undaria* sporophytes were appearing) than spring (when *Undaria* spores were being released). Although experimental evidence suggests even thin coverings of sediment at these times can inhibit algal settlement (Schiel et al. 2006). Therefore it is likely a threshold exists whereby algal communities can tolerate disturbances until a critical threshold of sediment cover is reached (experimental evidence suggests 100% sediment cover exceeds this threshold, Schiel et al. 2006). Thereafter each loss of alga would occur without replacement and the invertebrate community would be expected to decrease correspondingly.

5.4 ENSO effects

Climate effects were detected using both multivariate and univariate methods. However, the relatively short-term nature of the data set means that their quantification should be interpreted cautiously. Notably, none of the ENSO correlations explained more than 5% of the multivariate variance in community composition. This low variance explained is consistent with the fact that ENSO is only thought to explain approximately 25% of the year-to-year variance in rainfall and temperature (Mullan 1996).

ENSO (as measured by the MEI) was nearly always positively correlated with increased abundance in the univariate models. During El Niño conditions, when conditions were generally cooler, wetter and windier, bay specific increases were found in all the numerically dominant biota (i.e. *C. maschalocarpum*, *Turbo, Zonaria, C. flexuosum* and *Ecklonia*). Unsurprisingly, positive correlations were also found between El Niño years and total abundance (at Torbay and Stanmore) and algal biomass (at Waiwera).

The algal patterns observed in response to ENSO are corroborated by the limited literature available concerning algal growth and reproduction. *Ecklonia* are known to grow optimally in 13 - 16°C, where the average daily quantum dose of light exceeds 200 $\mu E.cm^{-2}$ and when there is high nutrient availability (Taylor 1981). As winter water temperatures in the region are usually 12 - 16°C (J. Evans pers. comm., Greig et al. 1988), then the quickest growth might be expected in years where water temperatures stayed low for longer, i.e., El Niño conditions when cooler surface water does not inhibit the upwelling of nutrient-rich deeper water (Glynn 1988). *Ecklonia* reproduction in light saturating conditions has a broad temperature optimum (12 - 20°C, Novaczek 1984). The effects of ENSO fluctuations on *Ecklonia* reproduction are therefore less predictable. No published data was available on the temperature optima of *Zonaria* for growth and reproduction.

A mechanistic response of *Turbo* to ENSO seems likely. *Turbo* can grow ~6 mm a year and are thought to move down shore via wave-induced redistribution, such that the largest individuals are found at the greatest depths (Walsby 1977). Therefore, a correlation with ENSO from the previous year may be reflecting either reproductive changes or movement of individuals by waves in the past year.

5.5 Recommendations

There is little or no evidence to suggest that Long Bay has been impacted in any significant or negative way since the inception of the LBMMP. The changes in algal composition seen at Long Bay are also seen at all other 'control' bays within the LBMMP.

Specific changes to other Long Bay taxa have been either relatively minor (cf. small declines in *Evechinus*), or have also been seen at other control sites (cf. *Trochus*, *Tethya* and solitary ascidian abundance).

The design of the LBMMP appears sensitive, and has the power to detect changes in biotic assemblages between bays, even in the current, pre-development situation. This power will only increase with ongoing monitoring. As monitoring continues, we anticipate the ability to more accurately quantify those environmental variables that help determine the abundance and structure of the biota in LBMMP. In particular, continued monitoring will aid with the quantification of depth and climate effects, and should help in determining the relationship between trapped sediment variables and biotic changes.

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7 Appendices

7.1 Appendix A. Chronological synopsis of sampling methodology

7.1.1 Biotic monitoring

February, May, August and November 1998 (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 A7
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.

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^2 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 measure 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.

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^2 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.

May 1999 (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, localized 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 & Volse 1978) or toxic effects of pollutants.

Bay and site locations

Six bays were chosen for sampling: Waiwera, Stanmore Bay, 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, pages 10-11, Babcock et al. 1999)

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^2 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^2 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 only: *Turbo smaragdus*, *Trochus viridis* and *Cookia sulcata*. The test diameter was measured for the common urchin *Evechinus chloroticus*.

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.

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. The 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.

March 2000 – March 2007 (Walker et al. 2000, 2001, Ford et al. 2003a, Anderson et al. 2005, 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.

March 2008 (Current report)

In the review of this project by Haggitt and Mead (2006) concern was expressed over the rate of trap loss and that some of the patterns observed may have been a result of changes in the depth of some sites over time. Therefore, during the 2007-8 year all bases were attached to the substrate and marker buoys were anchored to the substrate (as opposed to the trap base). This means that trap bases now form a semi-permanent site marker that cannot easily be tampered with. In addition elastic cord was fitted to the trap base in a way that minimized the chance of loss of traps from the trap base.

Due to misinterpretation, some of the *Ecklonia radiata* length measures collected from 2001-2007 were not directly usable in converting algal length to algal biomass because total length was recorded instead of primary lamellae length. Therefore, for the 2008 survey: stipe length, primary lamellae length and total length were all recorded and the relationship between these variables was modelled. Within the model, primary lamellae length was found to have a relatively strong linear relationship with total length and stipe length within each bay (R^2 = 67%). The predicted primary lamellae length was then used to model *Ecklonia* primary lamellae algal biomass for each bay.

7.1.2 Sediment trap monitoring

1999/2000 (Walker et al. 2000)

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 & 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.

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 80ºC 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 (1 mm^{+}, 500 µm, 250 µm, 125 µm and less than 125 µm) 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 r^2. This gives an estimate of the rate (in grams per cm^2 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.

2001 (Walker et al. 2001)

In 2001, six sieve sizes (1mm^{+}, 500 µm, 250 µm, 125 µm, 63 µm and < 63 µm) were used. Thus, two extra grain size categories were included: 63 µm and < 63 µm. The < 63 µm 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 63 µm were further analysed using a Galai particle size analyser. This apparatus measures grain sizes and can detect particles as small as 2 µm. According to the Wentworth grain size scale (Lewis 1984), grains of this size are clay. From each of the less than 63 μm 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 ($g/cm^2/day$).

2002 – March 2003 (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 ($g/cm^2/day$). Samples were then individually analysed using a Galai particle size analyser to determine the percentage of the sample sediments volume that was less than 63µm 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 from June 2002. All of these designs included traps that were 38 mm inside diameter by 50 cm deep to allow increased room for sediment storage. The most effective method for securing traps was large, heavy, steel base plates that were constructed to contain the traps and these were deployed in May 2003. To decrease the influence of swell, a 1 m 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 standardized for each time period prior to trap collection. The yearly averages per site were then generated from these values.

2003 – 2008 (Anderson et al. 2005)

Following the 2003 report, the analysis of grain size fractions was modified to take account of the influence of organic material. This followed a rationalization 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, homogenization and sub-sampling
3. Dispersion with Calgon ($2g.l^{-1}$)

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

According to Ford et al. (2003b), previous analyses conducted without the use of a pre-treatment to remove organics would have resulted in a small overestimation of fine grains (<63μm). 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 - 80ºC for 24 hours or until dry. The filter and contents were then weighed to determine total dry weight, which was then converted into a daily rate of trapped sediment ($g/cm^2/day$).

Up to 60 g sub-sample of each individual dried sediment sample was then taken. Samples were thoroughly mixed beforehand to ensure 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 ($5g.l^{-1}$), before being analysed for the percentage volume of fine sediments (<63μm) using a Malvern laser particle analyser.

Summary of methodology for sediment processing

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 $1mm^+$, 500μm, 250μm, 125μm and less than 125μm.

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 $1mm^+$, 500μm, 250μm, 125μm, 63μm and <63μm. The <63μm fraction (fines) was further analysed using the Galai particle analyser.

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.

2004-2008 (Anderson et al. 2005)

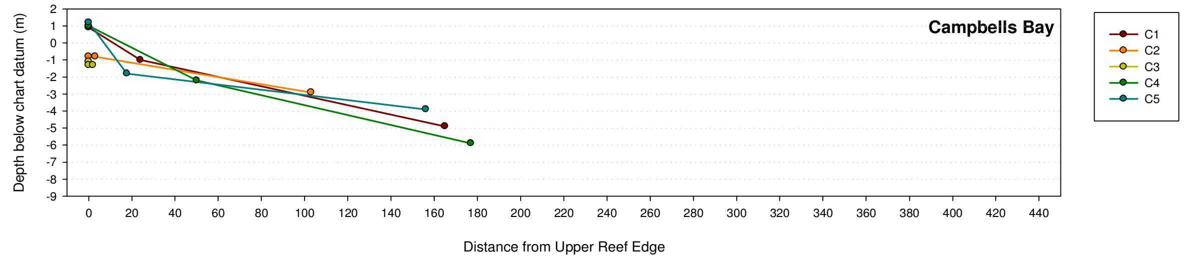
Sediments from each trap were pre-treated with hydrogen peroxide (to remove organics) and Calgon (to prevent clumping) prior to laser analysis. The percentage of sediment <63μm was determined by analysing the entire sample using a Malvern particle analyser.

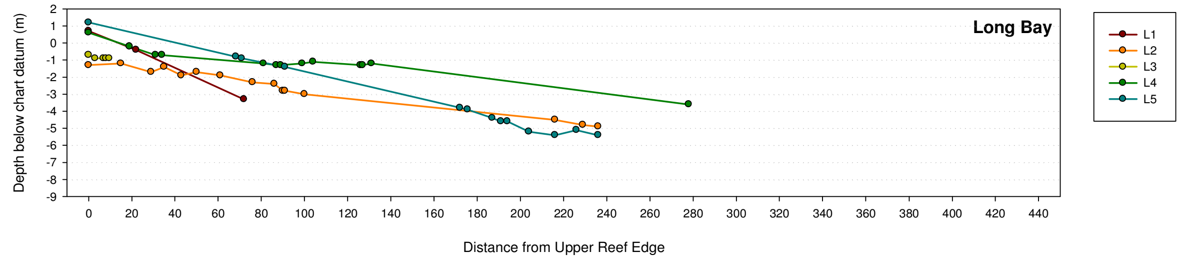
7.2 Appendix B. Global Positioning System (GPS) coordinates and depths for the LBMMP.

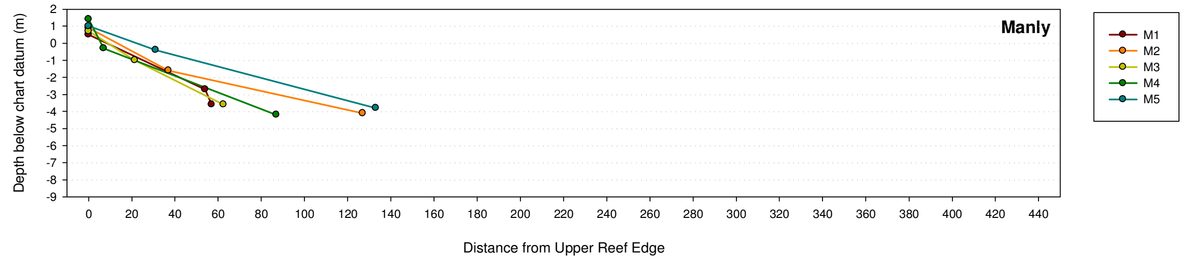
Site	Latitude (Oct 06)	Longitude (Oct 06)	depth below CD at 2008
C1	36 43 48.4290 S	174 45 29.9460 E	0.66
C2	36 44 08.0906 S	174 45 24.1162 E	1.30
C3	36 44 30.7 S	174 45 40.3 E	1.27
C4	36 44 57.5 S	174 46 01.5 E	2.67
C5	36 45 05.5 S	174 45 58.0 E	1.13
L1	36 39 53.5550 S	174 44 59.6583 E	1.20
L2	36 40 13.2268 S	174 44 55.1609 E	1.19
L3	36 40 31.7525 S	174 44 59.2138 E	1.97
L4	36 41 20.8613 S	174 45 21.9290 E	1.40
L5	36 41 35.86 S	174 45 43.69 E	0.60
M1	36 38 43.8354 S	174 44 47.2264 E	1.26
M2	36 38 31.3491 S	174 45 32.2891 E	1.51
M3	36 38 13.0826 S	174 45 57.7539 E	1.89
M4	36 38 02.6859 S	174 46 10.3320 E	0.69
M5	36 37 50.6312 S	174 46 19.1630 E	0.00
S1	36 37 05.8316 S	174 44 40.1266 E	2.00
S2	36 37 08.5043 S	174 44 59.1928 E	1.66
S3	36 36 25.2933 S	174 46 11.4292 E	1.80
S4	36 36 21.0 S	174 46 25.7 E	0.51
S5	36 36 15.1346 S	174 46 50.6096 E	1.10
T1	36 41 48.2108 S	174 45 39.8679 E	0.25
T2	36 42 02.0134 S	174 45 27.2842 E	0.86
T3	36 42 28.7 S	174 45 14.9 E	1.33
T4	36 42 28.6 S	174 45 14.8 E	1.19
T5	36 43 03.1324 S	174 45 08.2407 E	1.10
W1	36 32 11.61 S	174 43 02.0528 E	1.49
W2	36 32 38.5638 S	174 43 16.5145 E	2.49
W3	36 33 02.6153 S	174 42 41.8434 E	2.19
W4	36 33 19.6 S	174 42 38.1 E	2.11
W5	36 33 39.56 S	174 42 38.19 E	1.79

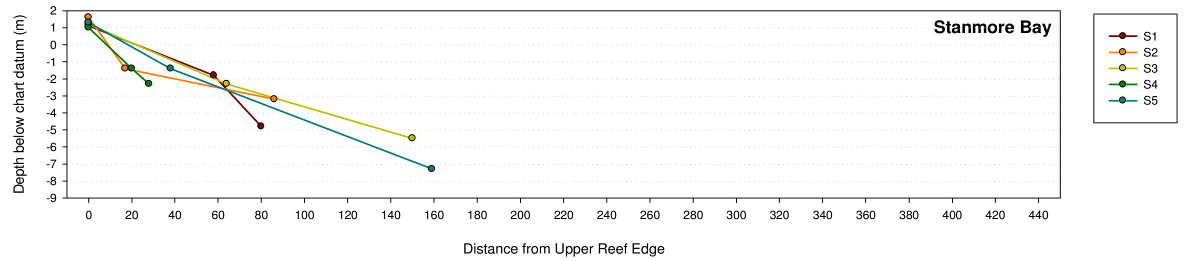
7.3 Appendix C. Depth profiles for LBMMP sites

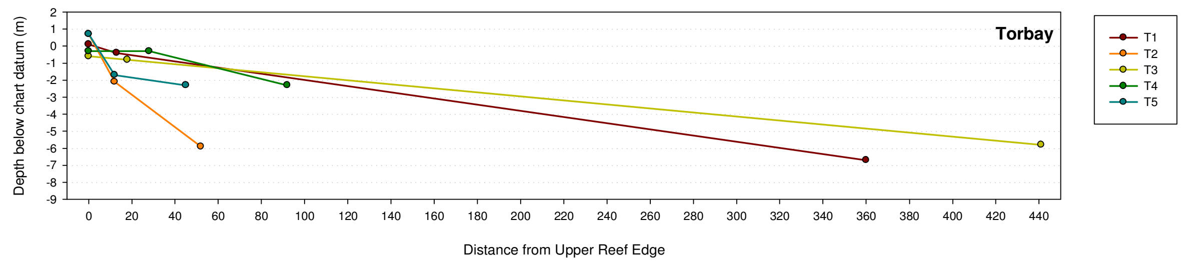
Appendix C1.
Depth profiles for all bays. Separate lines represent the depth of each site using a transect run perpendicular to shore.

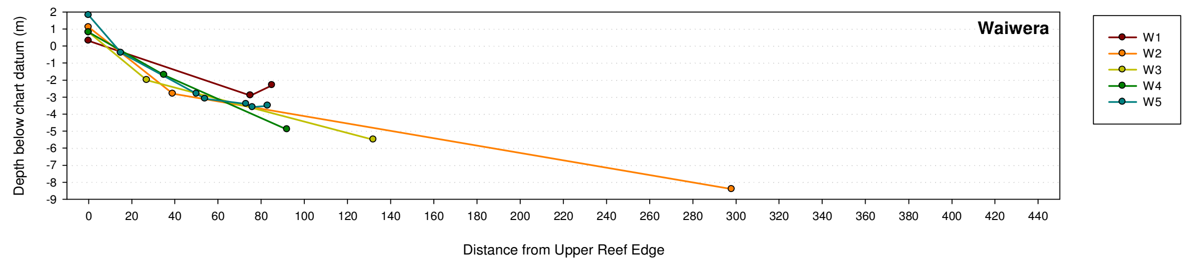












7.4 Appendix D. Taxa lists

Appendix D1.
Count data per quadrat averaged across all times in the LBMMP. Abund. = Abundance, Abbrev. = Abbreviation.

Taxa	Group	Abund.	Abbrev.
Carpophyllum maschalocarpum	Brown algae	24.29	Cm
Zonaria turneriana	Brown algae	18.92	Zt
Carpophyllum plumosum	Brown algae	6.99	Cp
Carpophyllum flexuosum	Brown algae	6.31	Cf
Ecklonia radiata	Brown algae	4.95	Er
Cystophora sp.	Brown algae	1.85	Cs
Sargassum sinclairii	Brown algae	1.08	Ss
Hormosira banksii	Brown algae	0.06	Hb
Glossophora kunthii	Brown algae	0.01	Gk
Dictyota sp.	Brown algae	0.01	Ds
Xiphophora chondrophylla	Brown algae	0.01	Xc
Halopteris sp.	Brown algae	0.01	Hs
Turbo smaragdus	Gastropod	17.76	Ts
Trochus viridus	Gastropod	3.63	Tv
Cantharidus purpureus	Gastropod	2.24	Cap
Maoricolpus roseus	Gastropod	0.90	Mr
Cominella virgata	Gastropod	0.89	Cv
Buccinulum lineum	Gastropod	0.52	Bl
Cookia sulcata	Gastropod	0.51	Csu
Haustrum haustorium	Gastropod	0.14	Hh
Cryptoconchus porosus	Gastropod	0.12	Cpo
Micrelenchus sp.	Gastropod	0.11	Ms
Dicathais orbita	Gastropod	0.05	To
Cominella 'red foot'	Gastropod	0.02	Crf
Cominella adspersa	Gastropod	0.02	Ca
Cabestana spengleri	Gastropod	0.01	Cas
Penion sulcatus	Gastropod	0.01	Ps
Buccinulum vitatum	Gastropod	0.00	Bv
Muricopsis octogonus	Gastropod	0.00	Mo
Cominella maculosa	Gastropod	0.00	Cma
Cominella quoyana	Gastropod	0.00	Cq
Charonia spp.	Gastropod	0.00	Crs
Gastropod (unknown)	Gastropod	0.00	G
Cellana sp.	Gastropod	0.00	Ces
Poiriera zelandica	Gastropod	0.001	Pz
Cominella glandiformis	Gastropod	0.001	Cgl
Maoricrypta costata	Gastropod	0.001	Mc
Scutus breviculus	Gastropod	0.001	Sb
Paratrophon quoyi	Gastropod	0.000	Pq
Tugali elegans	Gastropod	0.000	Te
Turbonilla sp.	Gastropod	0.000	Tus
Xymene plebius	Gastropod	0.000	Xp
Solitary Ascidians	Ascidian	3.109	SA
Patiriella regularis	Echninoderm	0.704	Pr
Evechinus chloroticus	Echninoderm	0.504	Ec
Coscinasterias muricata	Echninoderm	0.220	Cos
Stegnaster inflatus	Echninoderm	0.204	Si
Stichopus mollis	Echninoderm	0.016	Sm
Echinus elevatus	Echninoderm	0.001	Ee
Tethya burtoni	Sponge	1.472	Ta
Tethya ingalli	Sponge	0.058	Ti
Aaptos aaptos	Sponge	0.027	Aa
Sponges	Sponge	0.001	S
Chaetopterus sp.	Polychaete	0.336	Chs
Red foliose algae	Red Algae	0.142	RFA
Nudibranch (other)	Opisthobranch	0.010	No
Bursatella leachii	Opisthobranch	0.007	Bul
Ceratosoma amoena	Opisthobranch	0.002	Cam
Opisthobranch	Opisthobranch	0.000	O
Dendrodoris citrina	Opisthobranch	0.005	Dc
Aplysia dactylomela	Opisthobranch	0.001	Ad
Styela clava	Tunicate	0.014	Sc
Anemone	Cnidarian	0.008	A
Chiton	Chiton	0.005	C
Crassostrea gigas	Bivalve	0.002	Cg
Perna canaliculus	Bivalve	0.001	Pc
Chlamys sp.	Bivalve	0.000	Cls
Codium (globular)	Green Algae	0.002	Cog
Codium fragile	Green Algae	0.000	Cfr

Appendix D2

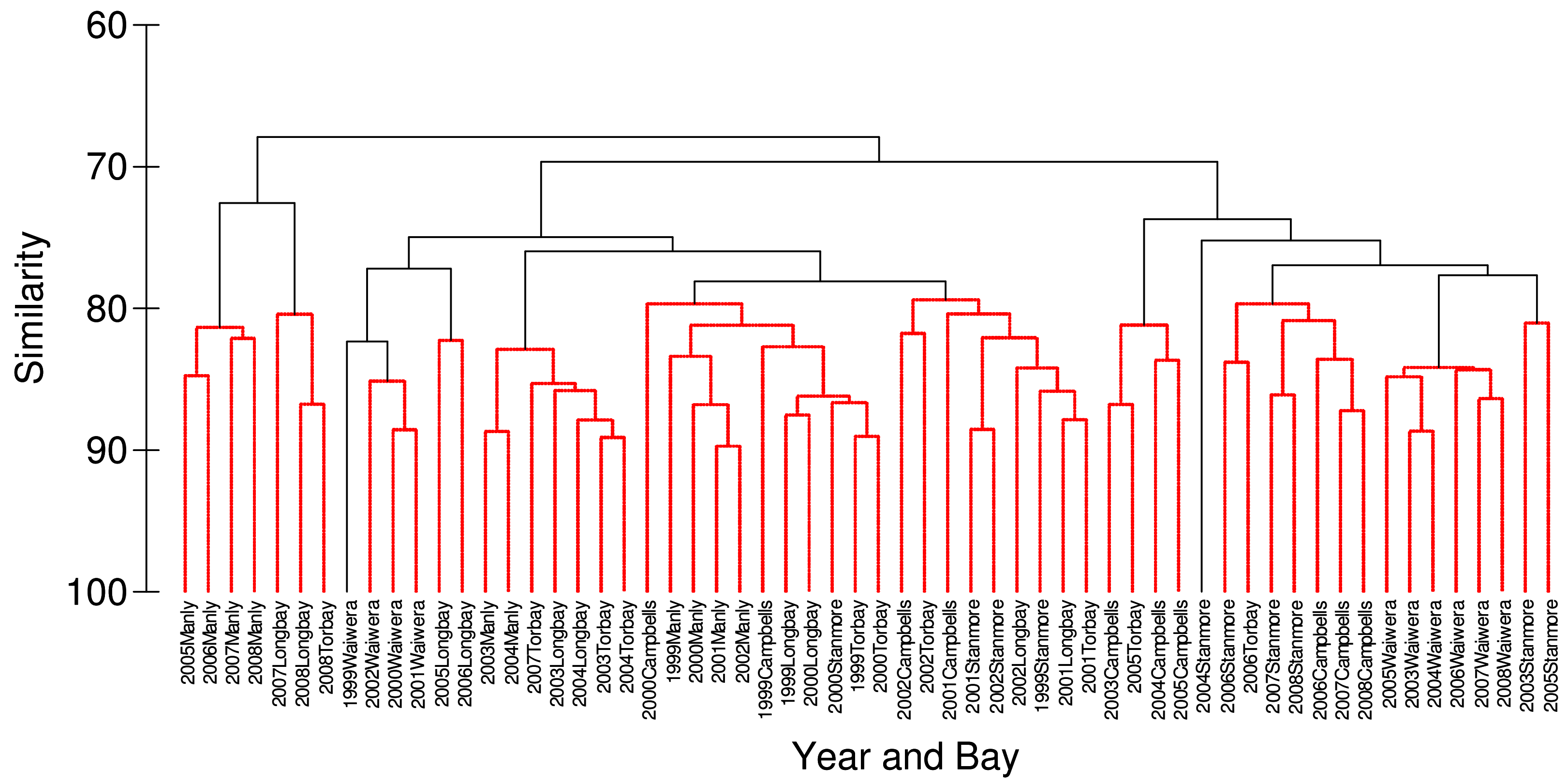
Cover data per quadrat averaged across all times in the LBMMP. Abund. = Abundance, Abbrev. = Abbreviation.

Taxa	Group	Abund.	Abbrev.
Crustose coralline algae	Red algae	52.856	CCA
Ralfsia sp.	Red algae	1.806	Ra
Coralline Turfing Algae	Red algae	1.392	CTA
Red turfing algae	Red algae	0.013	RTA
Red foliose algae	Red algae	0.091	RFA
Sediment	Substrate	16.896	Sed
Sand	Substrate	5.091	Sand
Bare rock	Substrate	3.660	Br
Shell	Substrate	2.057	She
Gravel	Substrate	0.724	Gra
Carpophyllum maschalocarpum	Brown algae	4.413	Cm
Zonaria turneriana	Brown algae	2.926	Zt
Ecklonia radiata	Brown algae	1.889	Er
Carpophyllum plumosum	Brown algae	1.060	Cp
Carpophyllum flexuosum	Brown algae	0.709	Cf
Cystophora sp	Brown algae	0.216	Cs
Sargassum sinclairii	Brown algae	0.169	Ss
Colpomenia sinuosa	Brown algae	0.022	Col
Brown turfing scum	Brown algae	0.020	BTS
Hormosira banksii	Brown algae	0.013	Hb
Xiphophora chondrophylla	Brown algae	0.002	Xc
Glossophora kunthii	Brown algae	0.002	Gk
Dictyota sp	Brown algae	0.001	Ds
Halopteris sp	Brown algae	0.001	Hs

Taxa	Group	Abund.	Abbrev.
Sponges	Sponge	1.721	S
Cliona celata	Sponge	0.319	Cc
Tethya burtoni	Sponge	0.222	Ta
Ancorina sp.	Sponge	0.197	As
Phorbasidae	Sponge	0.069	P
Tethya ingalli	Sponge	0.009	Ti
Polymastia sp.	Sponge	0.009	Psp
Aaptos aaptos	Sponge	0.006	Aa
Green turf	Green Algae	0.481	Gt
green filamentous algae	Green Algae	0.023	GFA
Codium (globular)	Green Algae	0.000	Cog
Codium fragile	Green Algae	0.000	Cf
Solitary ascidians	Ascidians	0.401	SA
Colonial ascidians	Ascidians	0.015	CA
Styela clava	Ascidians	0.004	Sc
Encrusting ascidian	Ascidians	0.000	EA
Bryozoan	Bryozoan	0.208	Bry
Barnacles	Crustacean	0.108	B
Chaetopterus sp.	Polychaete	0.068	Chs
Spirorbis sp.	Polychaete	0.000	Sps
Hydroids	Hydroids	0.025	H
Anemone	Cnidarian	0.007	A
Perna canaliculus	Bivalve	0.001	Pc
Crassostrea gigas	Bivalve	0.000	Crg

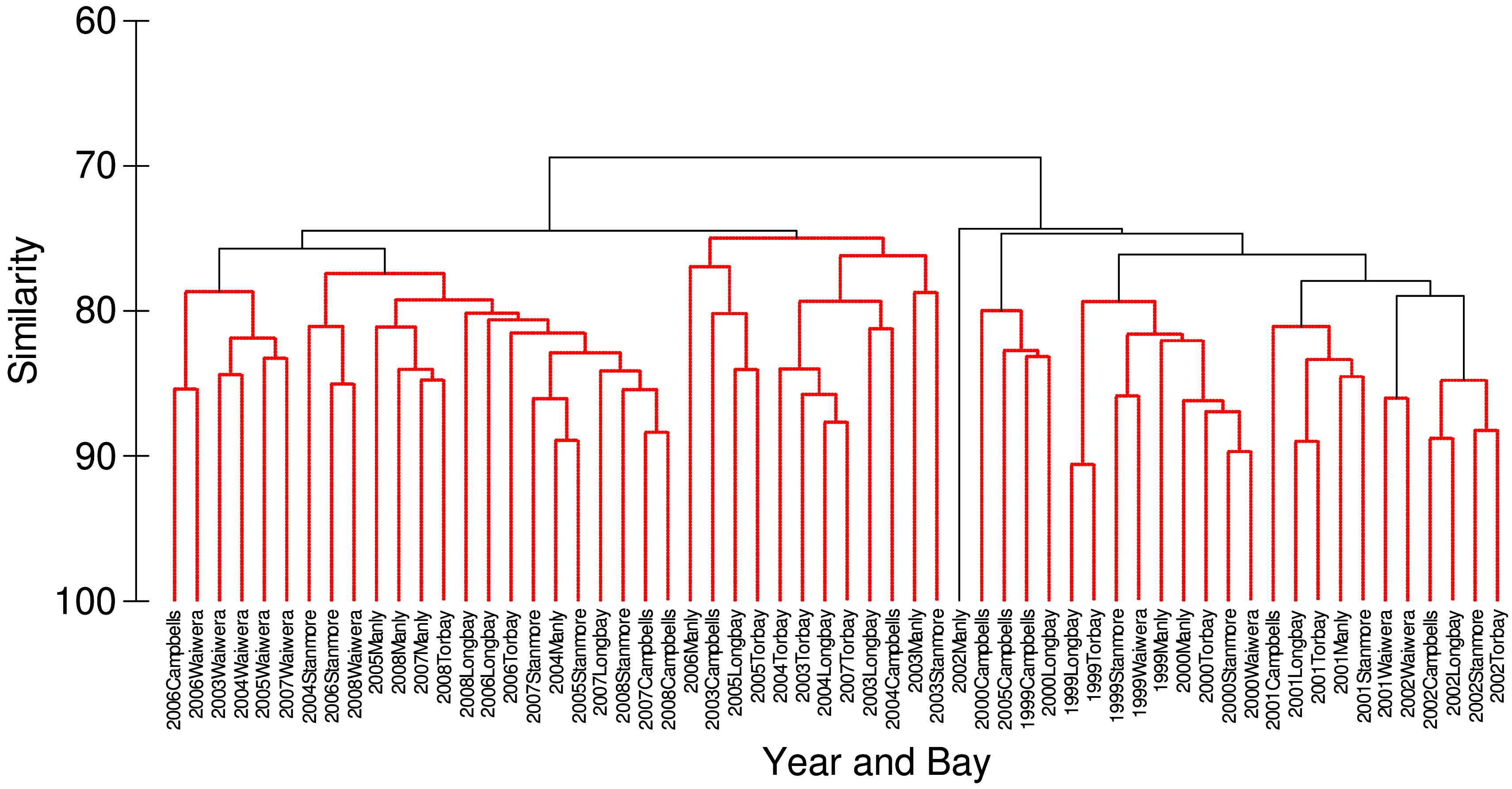
7.5 Appendix E. Dendograms of year and bay combinations

Appendix E1
CLUSTER analysis dendrogram with SIMPROF analysis on Bray-Curtis dissimilarities of ln(x+1) transformed count data grouped at the year by bay level. Non-significant branches are shown in red, significant branches are shown in black



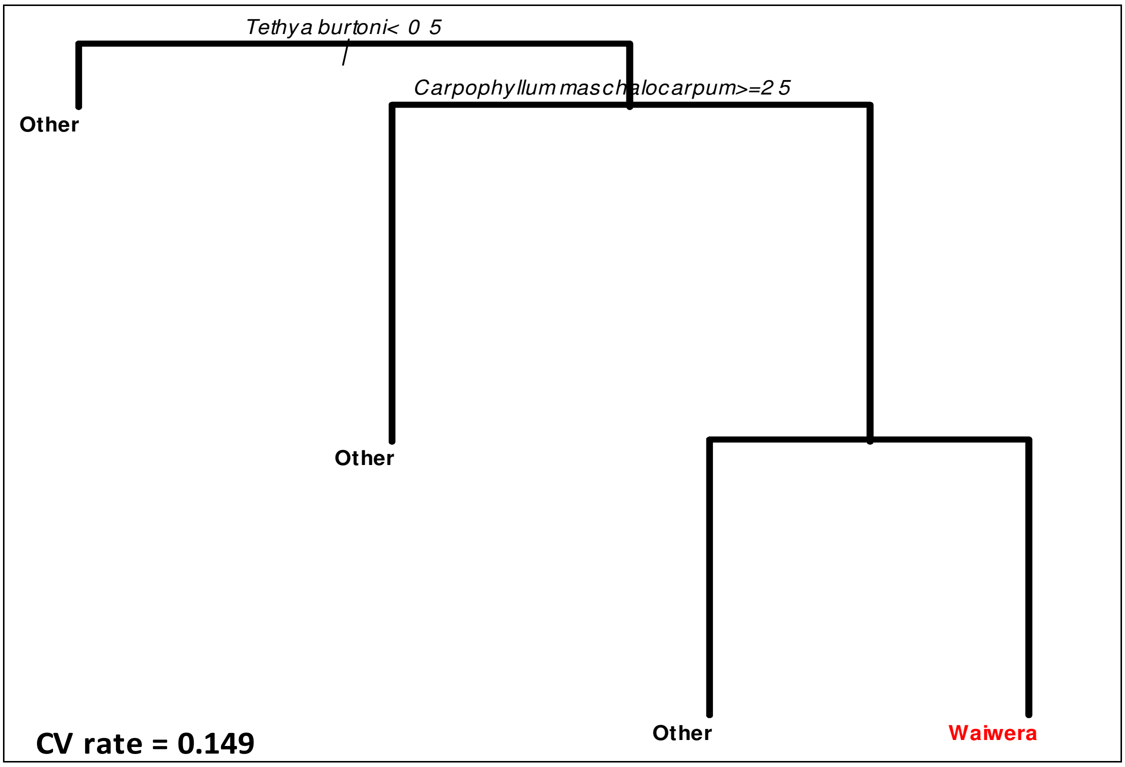
Appendix E2

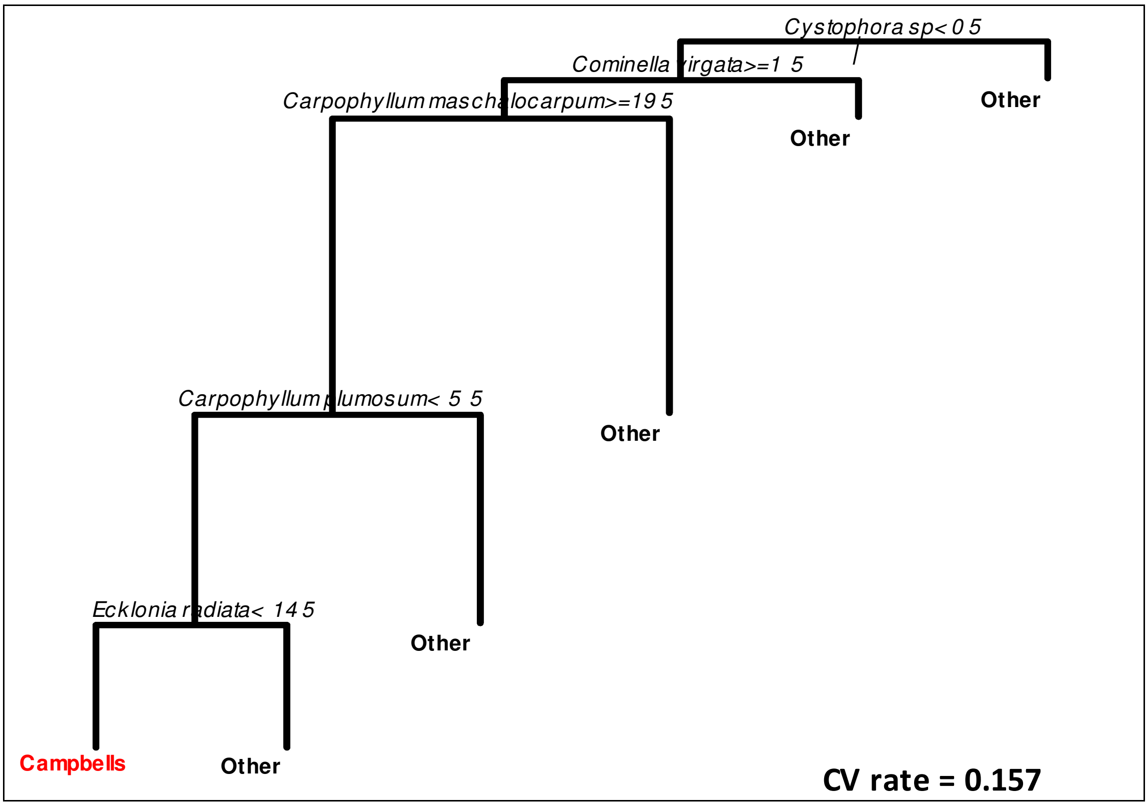
CLUSTER analysis dendrogram with SIMPROF analysis on Bray-Curtis dissimilarities of ln(x+1) transformed cover? data, non-significant branches are shown in red, significant branches are shown in black

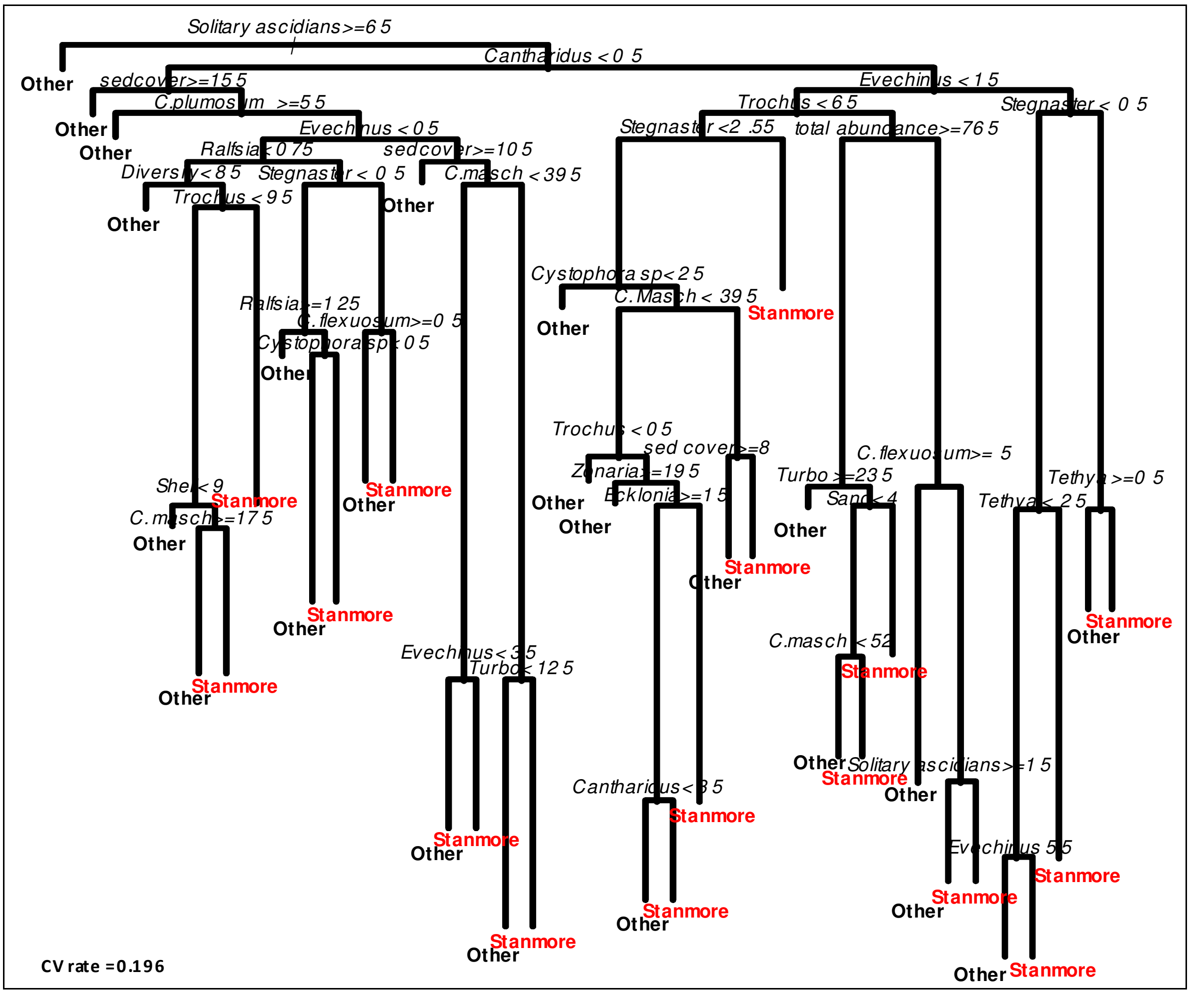


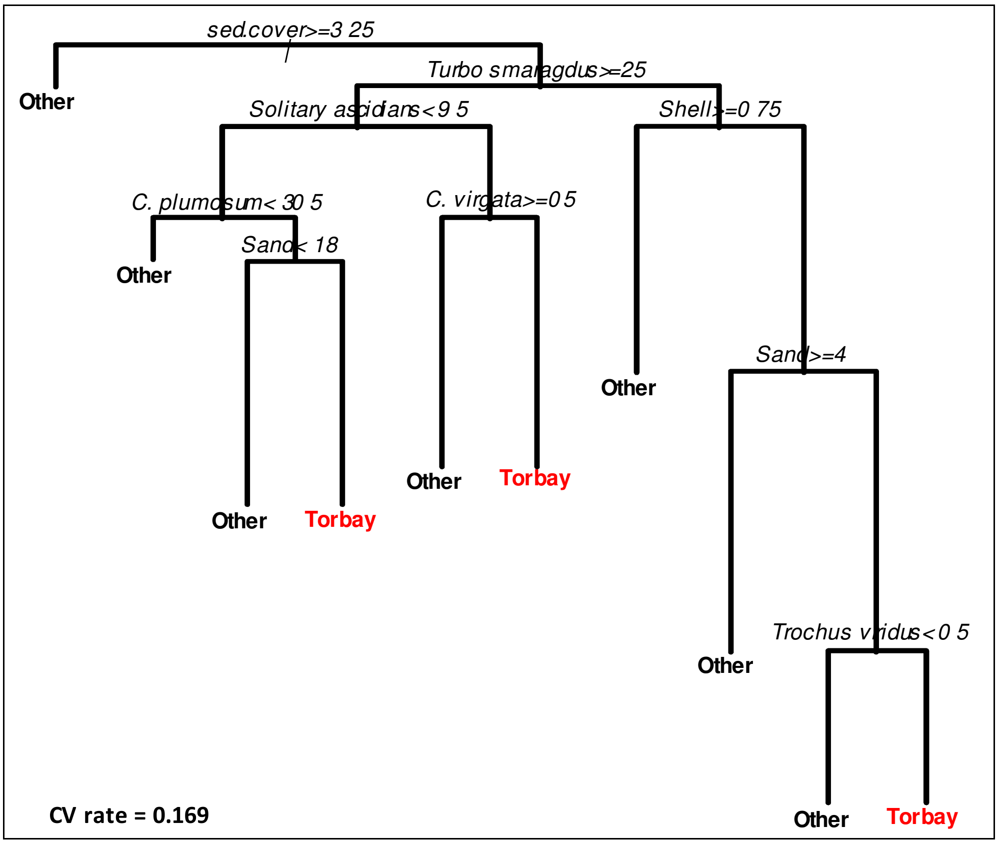
7.6 Appendix F. Classification trees of each bay

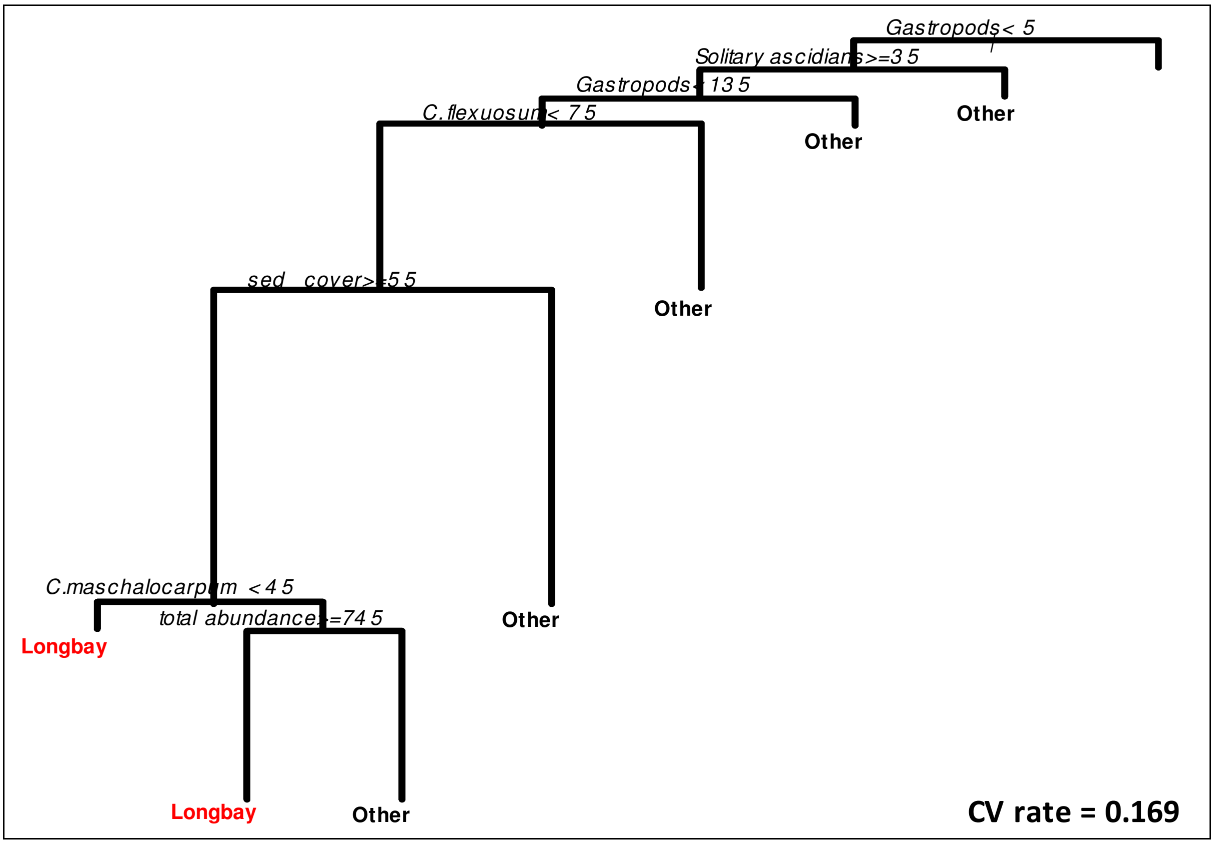
Appendix F
Classification trees distinguishing the six LBMMP bays. If a specified criterion at a node is satisfied, take the branch to the left. The bay at the bottom is therefore reached using a series of binary decisions. CV rate is the cross-validation error rate, i.e. the expected error rate when predicting bay membership with new data.

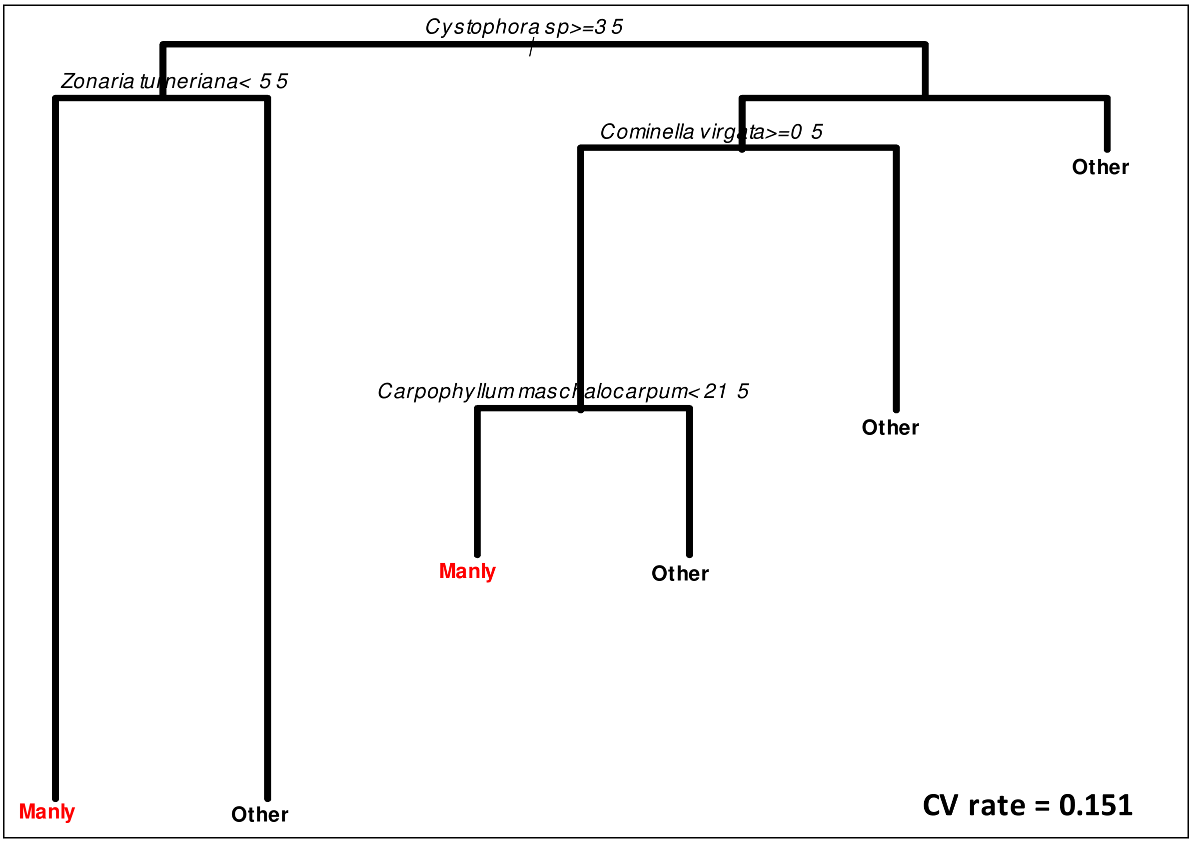





Solitary ascidians>=6 5
Cantharidus < 0 5
Other
sedcover>=15 5
Evechinus < 1 5
C.plumosum >=5 5
Trochus < 6 5
Stegnaster < 0 5
Other
Evechinus < 0 5
Stegnaster <2 .55
total abundance>=76 5
Other
Ralfsia< 0 75
sedcover>=10 5
Diversity< 8 5
Stegnaster < 0 5
C.masch < 39 5
Trochus < 9 5
Other
Other
Cystophora sp< 2 5
C.Masch < 39 5
Stanmore
Other
Ralfsia>=1 25
C.flexuosum>=0 5
Cystophora sp< 0 5
Other
Trochus < 0 5
sed cover>=8
C.flexuosum>= 5
Zonaria>=19 5
Turbo >=23 5
Tethya >=0 5
Ecklonia>=1 5
Sand< 4
Tethya< 2 5
Shell< 9
Stanmore
Stanmore
Other
Other
Other
Other
C.masch>=17 5
Other
Stanmore
Other
Stanmore
Other
Stanmore
Other
C.masch < 52
Stanmore
Evechinus< 3 5
Turbo< 12 5
Stanmore
Other
Other
Solitary ascidians>=1 5
Stanmore
Cantharidus< 3 5
Other
Stanmore
Evechinus 5 5
Stanmore
Other
Stanmore
Stanmore
Other
Stanmore
Other
Stanmore
Other
Other
Stanmore
CV rate =0.196

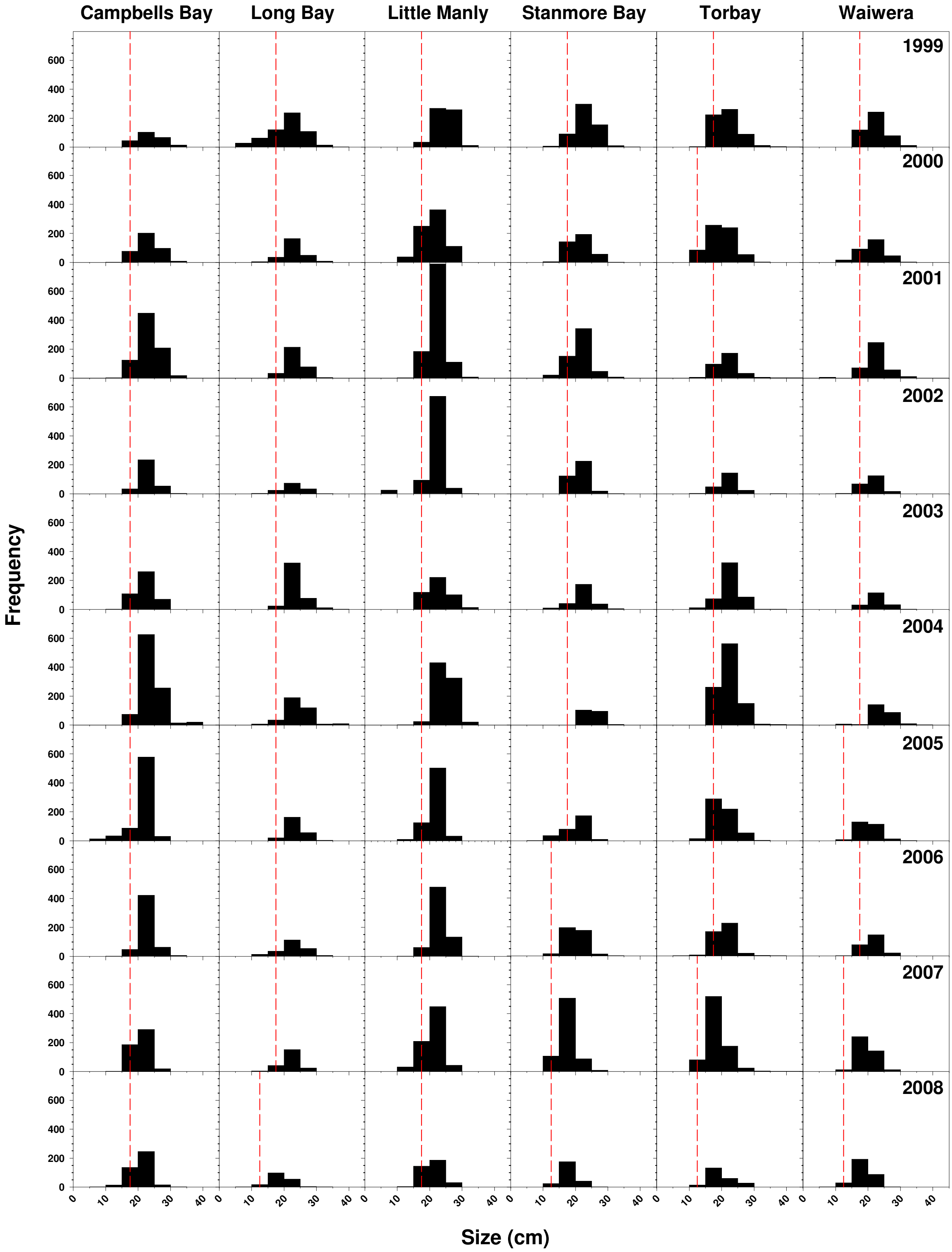

sed.cover>=3 25
Turbo smaragdus>=25
Other
Solitary ascidians<9 5
Shell>=0 75
C. plumosum< 30 5
C. virgata>=0 5
Other
Sand< 18
Sand>=4
Other
Other
Torbay
Other
Torbay
Trochus viridus<0 5
Other
Other
Torbay
CV rate = 0.169


Gastropods< 5
Solitary ascidians>=3 5
Gastropods< 13 5
C. flexuosum< 7 5
sed cover>=5 5
C.maschalocarpum <4 5
total abundance>=74 5
Other
Other
Other
Other
Longbay
Longbay
Other
CV rate = 0.169

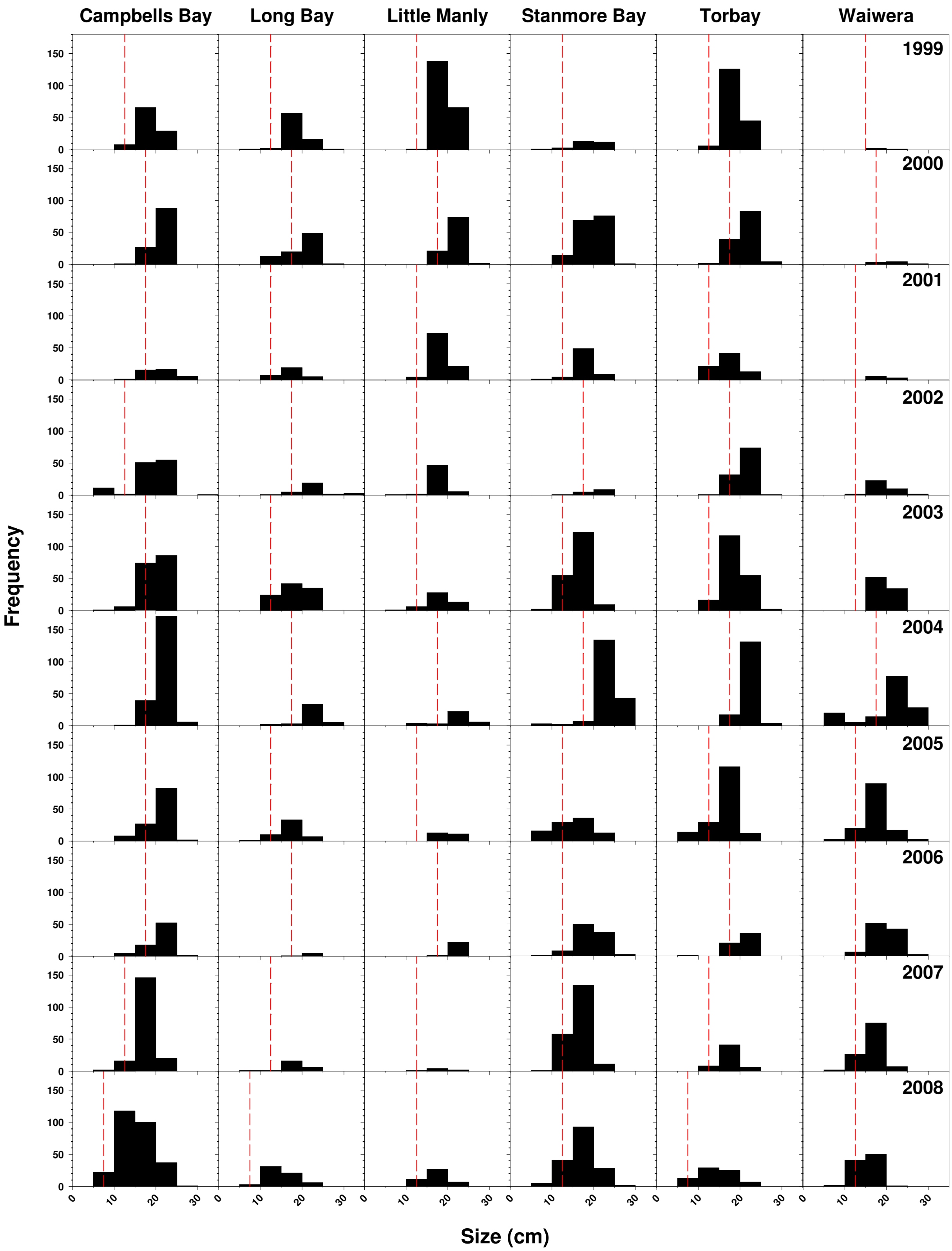

Cystophora sp>=3 5
Zonaria turneriana< 5 5
Cominella virgata>=0 5
Other
Carpophyllum maschalocarpum< 21 5
Other
Manly
Other
Manly
Other
CV rate = 0.151

7.7 Appendix G. Size frequency plots for LBMMP gastropods

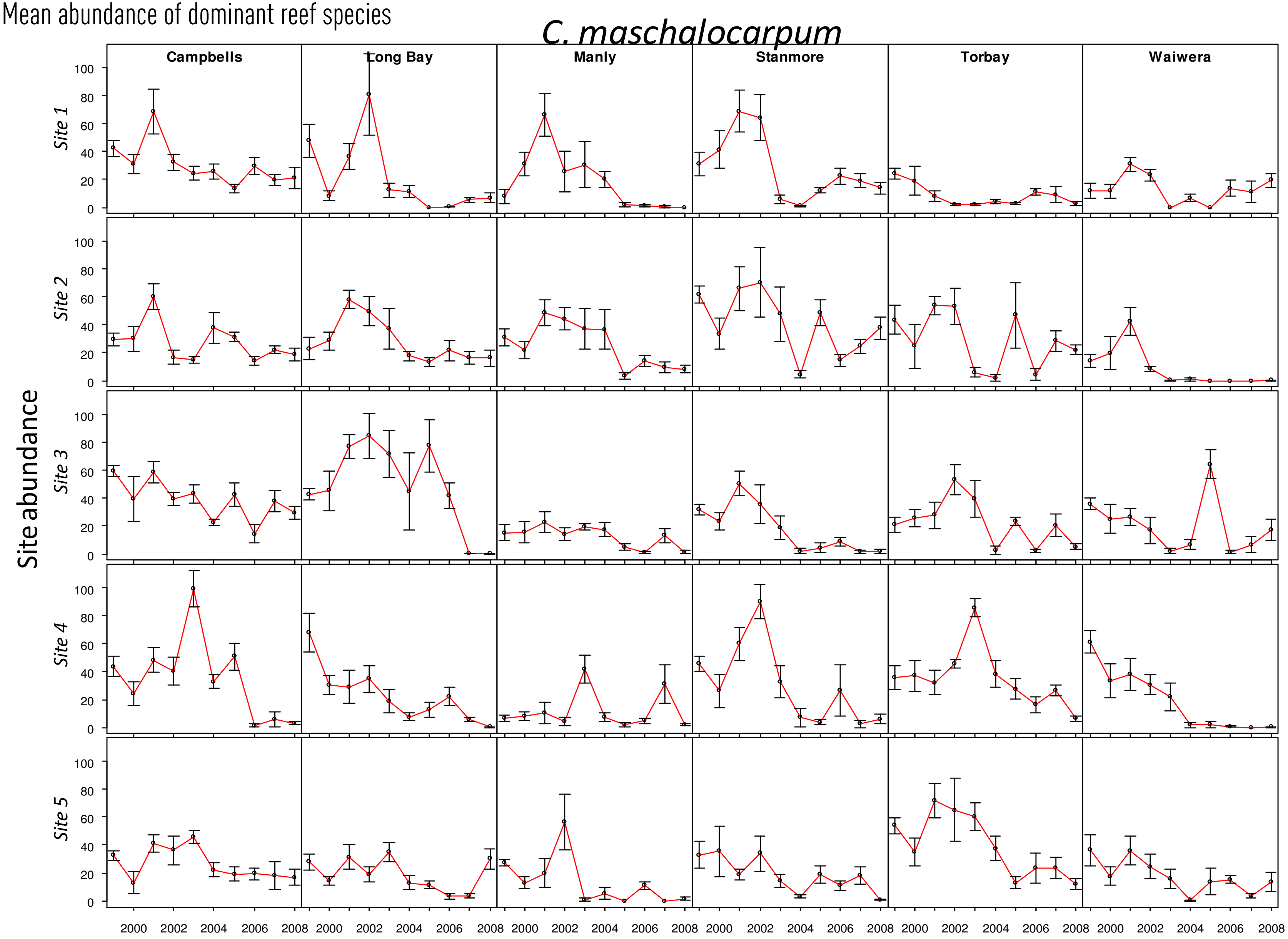
Appendix G1
Size frequency distribution for *Turbo smaragdus*. The red dashed line indicates the median length. For comparability to early years, recent size frequency distributions are also shown at the 5 mm resolution.

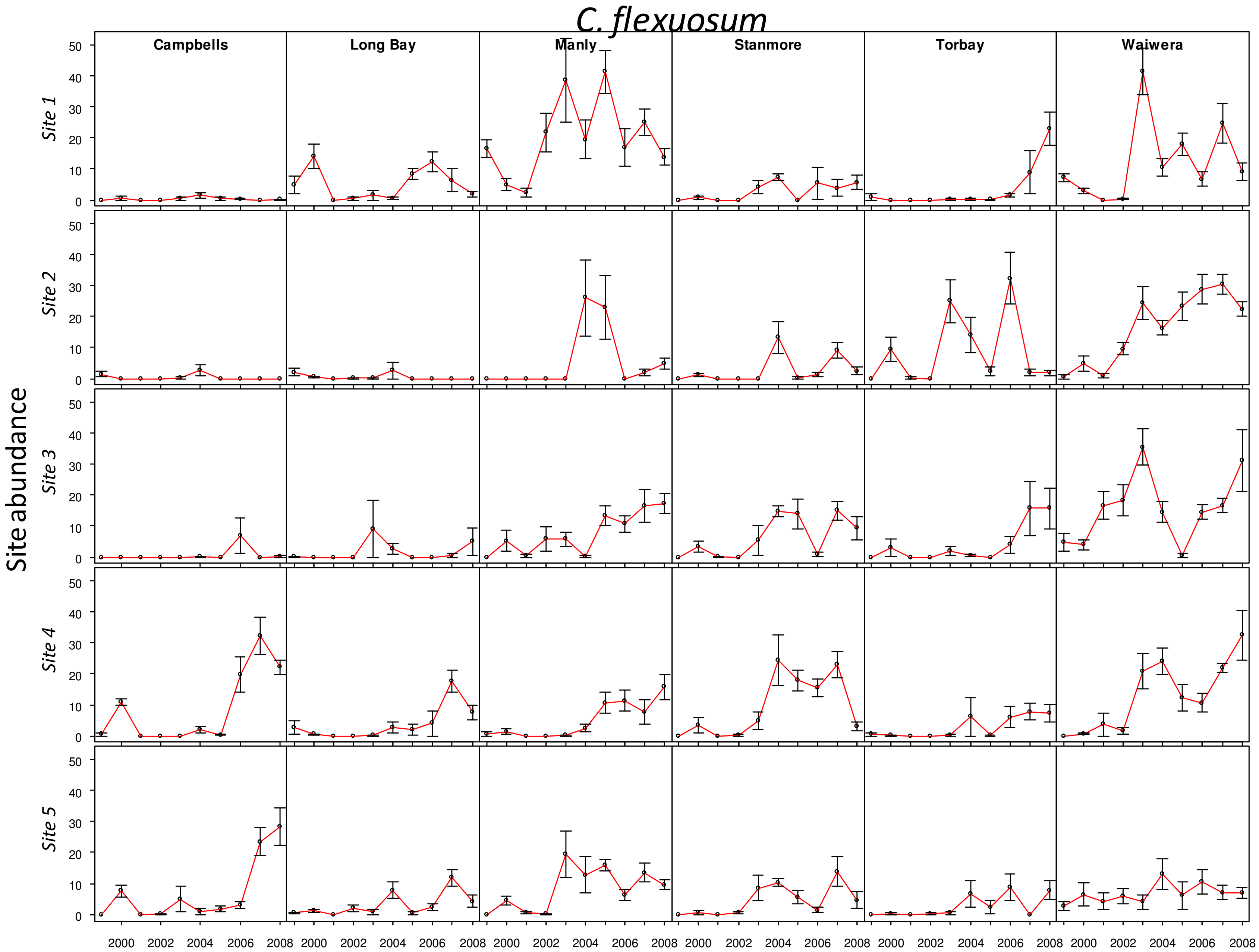


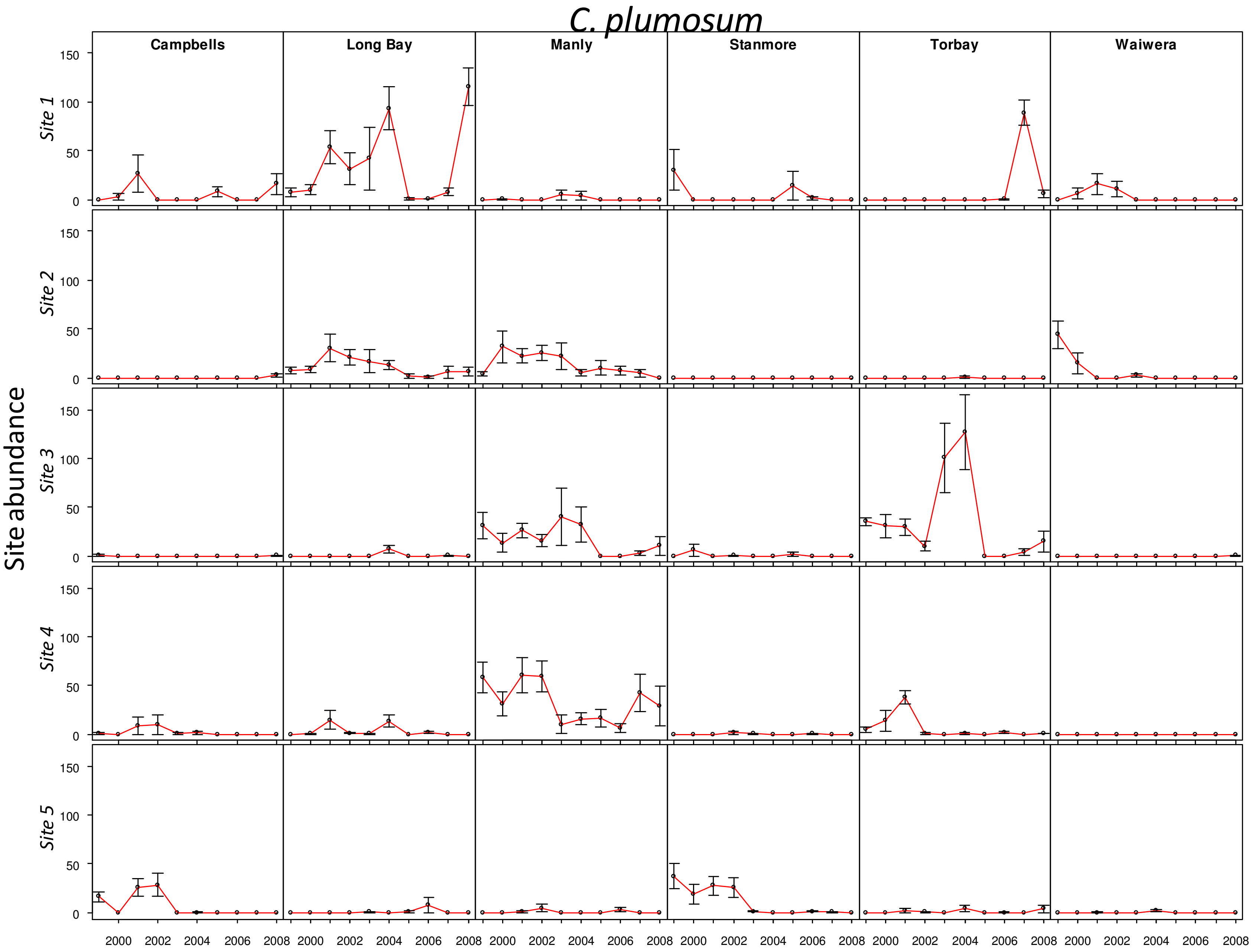
Appendix G2
Size frequency distribution for *Trochus viridus*. The red dashed line indicates the median length. For comparability to early years, recent size frequency distributions are also shown at the 5 mm resolution.

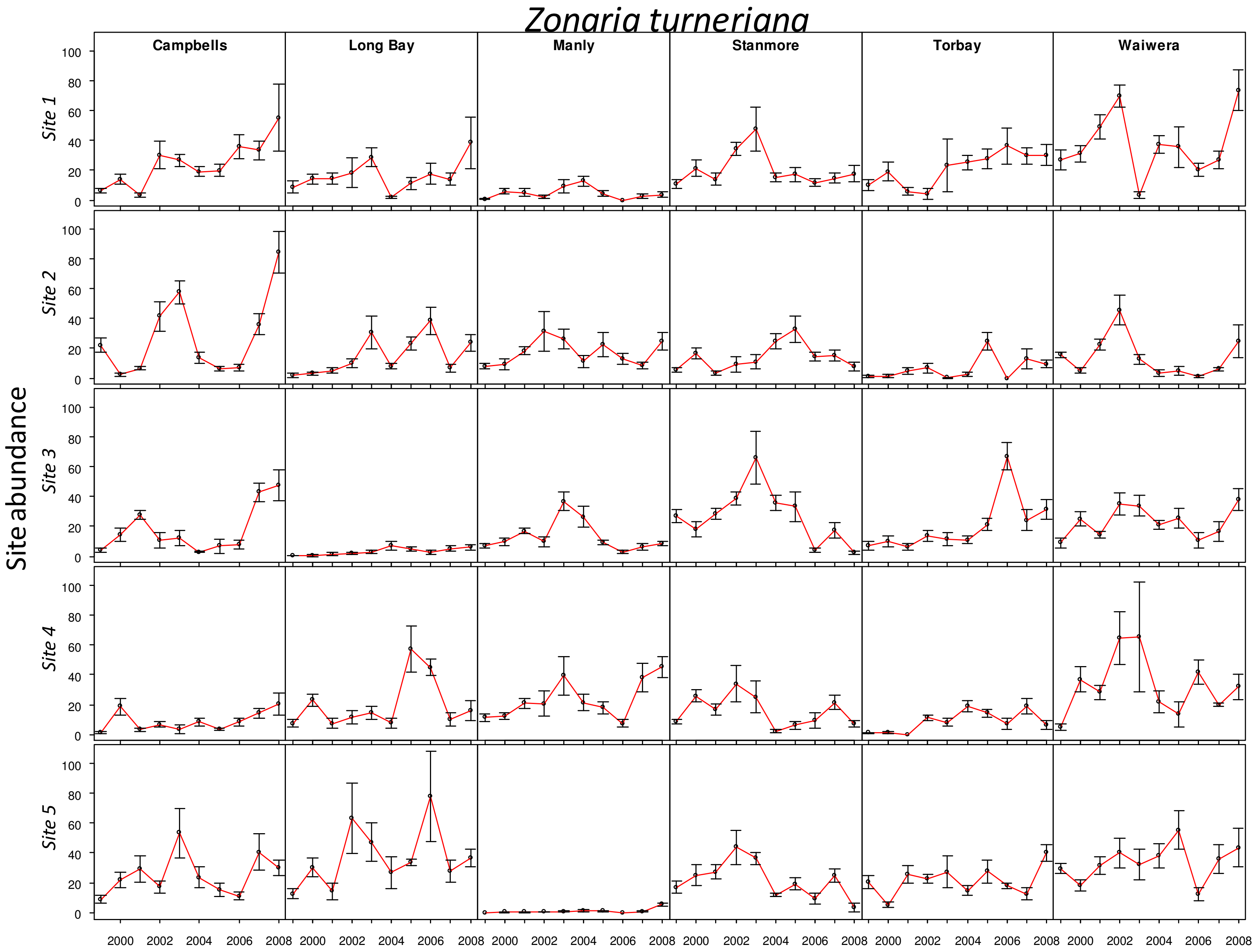


7.8 Appendix H. Mean abundance of dominant reef species

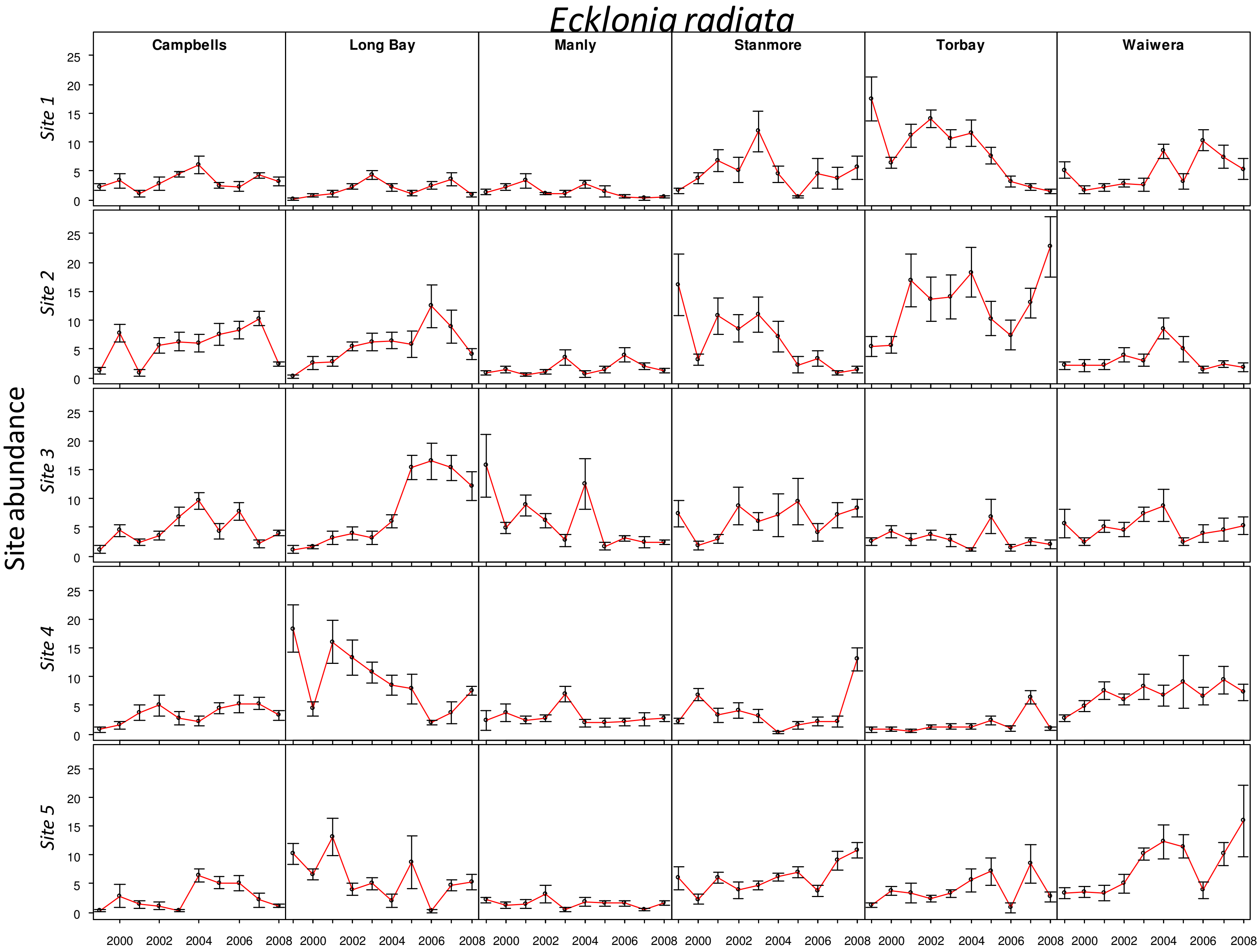



C. flexuosum
Campbells
Long Bay
Manly
Stanmore
Torbay
Waiwera
Site 1
Site 2
Site 3
Site 4
Site 5
Site abundance
0
10
20
30
40
50
2000
2002
2004
2006
2008

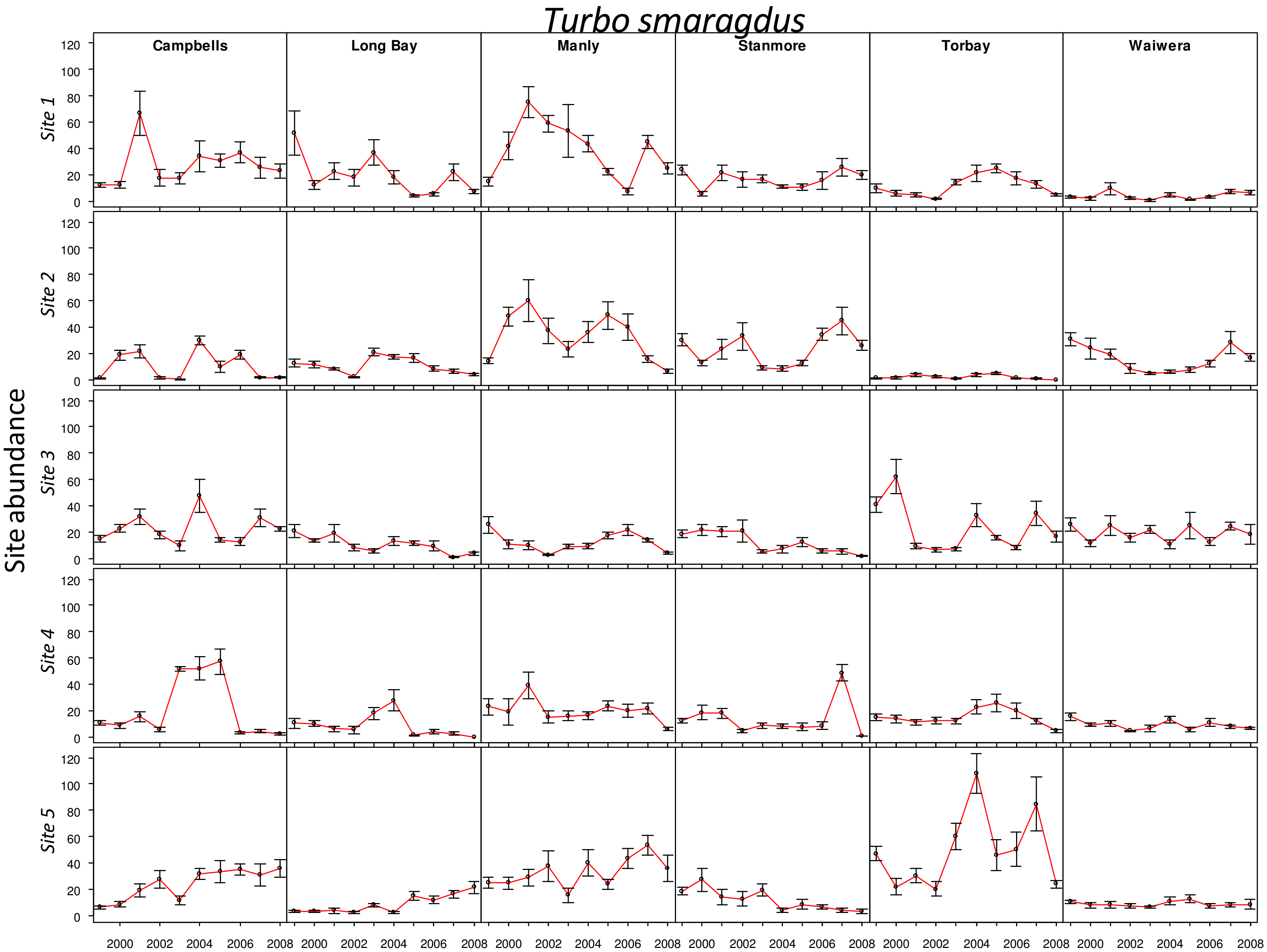

C. plumosum
Campbells
Long Bay
Manly
Stanmore
Torbay
Waiwera
Site 1
Site 2
Site 3
Site 4
Site 5
Site abundance
0
50
100
150
2000
2002
2004
2006
2008

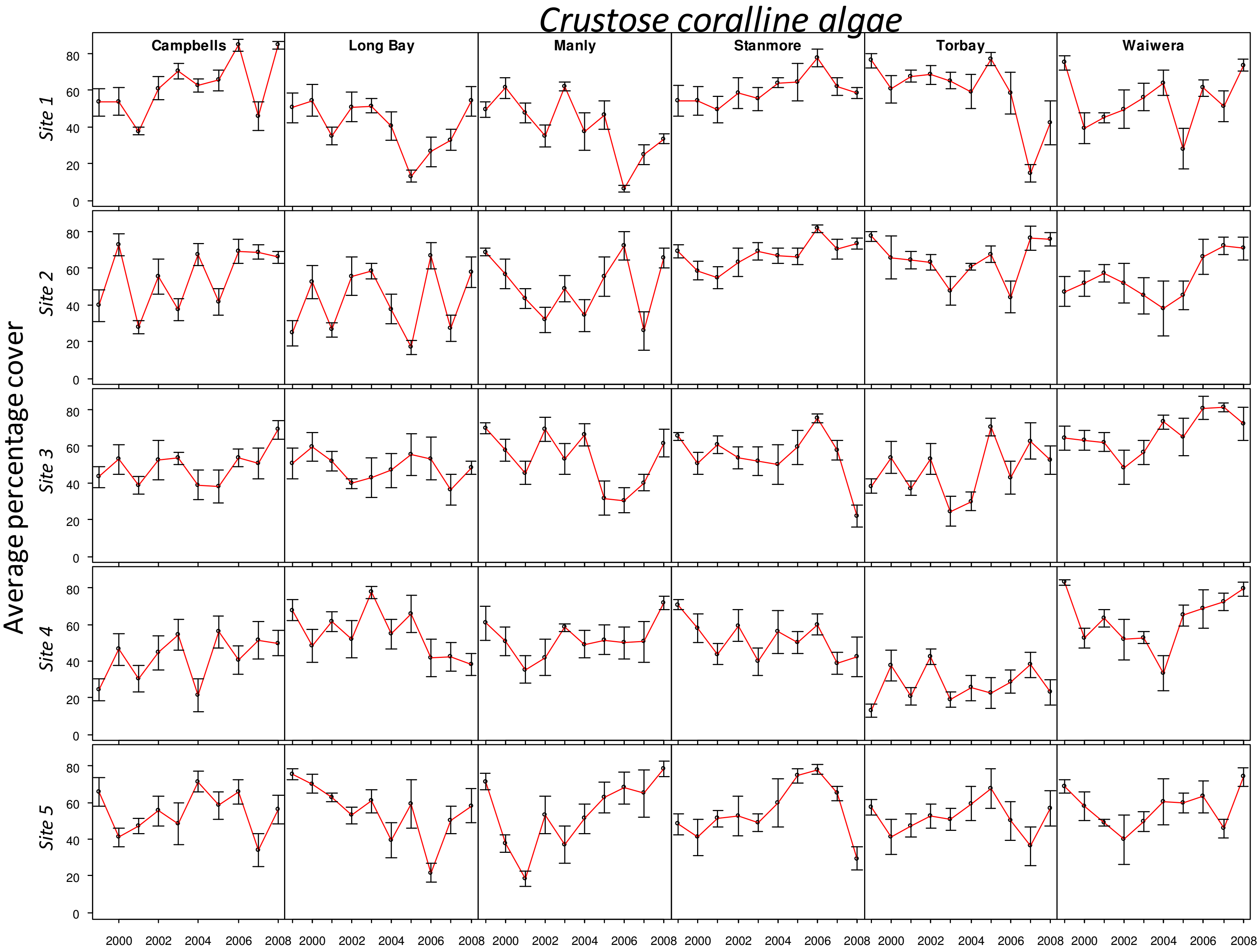


Zonaria turneriana
Campbells
Long Bay
Manly
Stanmore
Torbay
Waiwera
Site 1
Site 2
Site 3
Site 4
Site 5
Site abundance
0
20
40
60
80
100
2000
2002
2004
2006
2008



Ecklonia radiata
Campbells
Long Bay
Manly
Stanmore
Torbay
Waiwera
Site abundance
Site 1
Site 2
Site 3
Site 4
Site 5
0
5
10
15
20
25
2000
2002
2004
2006
2008


Turbo smaragdus
Campbells
Long Bay
Manly
Stanmore
Torbay
Waiwera
Site 1
Site 2
Site 3
Site 4
Site 5
Site abundance
0
20
40
60
80
100
120
2000
2002
2004
2006
2008


Crustose coralline algae
Campbells
Long Bay
Manly
Stanmore
Torbay
Waiwera
Site 1
Site 2
Site 3
Site 4
Site 5
Average percentage cover
0
20
40
60
80
2000
2002
2004
2006
2008

7.9 Appendix I. Environmental effects on univariate abundances

Table 19
GLMM model results showing the effect of Climate (ENSO) on (i) indices (ii) count abundance and (iii) cover data (after accounting for year and depth effects). Values indicate the 95% confidence interval of the estimated change per MEI unit.

Counted biota	*Campbells*	*Torbay*	*Long Bay*	*Manly*	*Stanmore*	*Waiwera*
Trochus viridus				-(11-48)%		(32-166)%
Cantharidus purpureus			(150-615)%	(40-390)%	(180-540)%	
Solitary ascidians				(60-254)%		(26-260)%
Cystophora sp.					(23-237)%	(190-1100)%
Tethya burtoni					(30-350)%	
Evechinus chloroticus		(0-49)%				

Table 20
GLMM model results showing the effect of depth on (i) indices (ii) count abundance and (iii) cover data (after accounting for year and climate effects). *NL* indicates a non-linear change with depth (not shown in this report). Values indicate the 95% confidence interval of the estimated change in abundance per meter.

Counted biota	*Campbells*	*Torbay*	*Long Bay*	*Manly*	*Stanmore*	*Waiwera*
Trochus viridus	*NL*				*NL*	
Cantharidus pupureus	*NL*					
Solitary ascidians						
Cystophora sp.						-(20-91)%
Tethya burtoni						*NL*
Evechinus chloroticus						

Table 21

GLMM model results showing the effect of the rate of trapped fines on abundance (after accounting for year, depth and climate effects). Values indicate the 95% confidence interval of the estimated change in abundance (or index value) given a change in rate of 1 g per cm^2 per day.

Counted biota	*Campbells*	*Torbay*	*Long Bay*	*Manly*	*Stanmore*	*Waiwera*
Trochus viridus						
Cantharidus purpureus					-(1-4)%	
Solitary ascidians						
Cystophora sp.		-(1-7)%				
Tethya burtoni					-(1-8)%	
Evechinus chloroticus						