Auckland East Coast Subtidal Reef Marine Monitoring Programme: 2007 to 2013

January 2017

Technical Report 2017/002

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Technical Report 2017/002
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-0-9941450-2-4 (Print)
ISBN 978-0-9941450-3-1 (PDF)

This report has been peer reviewed by the Peer Review Panel.
Review submitted on 9 November 2016 Review completed on 23 January 2017 Reviewed by one reviewer
Approved for Auckland Council publication by: Name: Dr Lucy Baragwanath Position: Manager, Research and Evaluation (RIMU)
Name: Jacqueline Anthony Position: Manager, Environment Monitoring, Research and Evaluation (RIMU)
Date: 23 January 2017

Recommended citation

Shears, N (2017). Auckland east coast subtidal reef marine monitoring programme: 2007 to 2013. Prepared by the Leigh Marine Laboratory, Institute of Marine Science, University of Auckland for Auckland Council. Auckland Council technical report, TR2017/002

Auckland East Coast Subtidal Reef Marine Monitoring Programme: 2007 to 2013

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1.0 Executive summary

The Long Bay and Meola Reef Marine Monitoring Programmes were established in 1999 and 2001 respectively to investigate any potential impacts of urban development at Long Bay on adjacent reef assemblages, and to detect and document long-term trends in subtidal reef communities. The two programmes were combined in 2011 to form the basis of the more regional East Coast Subtidal Reef Monitoring Programme. The analysis and results presented in this report are restricted to the monitoring period from 2007 to 2013. This report presents data from annual sampling of shallow subtidal reef communities at Meola Reef, Campbells Bay, Torbay, Long Bay, Manly, Stanmore Bay and Waiwera. Monthly measurements of sedimentation were also taken at each site using sediment traps.

The reef community at all sites is dominated by a canopy of large brown macroalgae. The composition of this canopy varies in relation to the differing physical conditions among the seven locations. Overall canopy composition has remained relatively constant since 2007 among the different locations, with the exception of a relatively large increase in kelp *Ecklonia radiata* at a number of locations. The other major change in algal canopies over this period has been the introduction of the invasive kelp *Undaria pinnatifida* to Meola reef.

Mobile invertebrate assemblages also varied consistently among the seven locations and these patterns persisted over time. The catseye *Lunella smaragdus* is the numerically dominant mobile invertebrate across the locations. Densities of *Lunella* fluctuated in a consistent manner across all locations over the sampling period. General declines in *Trochus viridis* and *Cantharidus purpureus* also occurred. These fluctuations in the numerically dominant gastropod species were consistent across all locations and therefore likely reflect region-wide processes rather any than local-scale factors. The invasive Japanese paddle crab *Charybdis japonica* was recorded at Meola for the first time in 2010 and has been consistently recorded in low numbers since.

The encrusting assemblages beneath the algal canopy were highly variable among locations and over time. There appears to have been a shift in the encrusting assemblages over between 2009 and 2010, but this occurred at all locations and appears to be related to an increase in the number of benthic cover groups recorded since 2010. This change is therefore an artefact of increased sampling resolution rather than an actual change in the encrusting assemblage. Despite this, some changes in the dominant encrusting groups were evident. A clear increase in the cover of solitary ascidians was evident at Long Bay and Meola Reef, which coincides with and may be associated with the increase in *Ecklonia* at these locations. A large decline in the red encrusting algae *Hildenbrandia* sp. at Meola Reef may also be associated with increased *Ecklonia* density. Other changes of note were the arrival of the Mediterranean fanworm *Sabella spallanzanii* at Meola Reef in 2011 and at one site at Campbells Bay in 2013. The invasive ascidian *Styela clava*, first recorded at monitoring sites in 2006, is now present at all locations in low numbers.

The cover of sediment on the reef has fluctuated over time and is generally highest at the most sheltered locations (Meola and Manly). Temporal variation is likely driven by recent weather and wave conditions. Water clarity is lowest at Meola Reef, followed by the East Coast Bays locations, with highest water clarity at Waiwera and Stanmore Bay. Sediment trap rates were generally highest at the most exposed locations and lowest at the most sheltered locations (Meola and Manly). The percentage of fine sediments was inversely correlated with the higher proportion of fine sediments generally at the most sheltered locations. While sedimentation rates and the percentage of fine sediments were highly variable from month to month, there was some clear seasonal patterns among locations, but there was no evidence of any consistent long-term increasing or decreasing trends. Trap rates for fine sediments were particularly high in 2011 across locations. This was due to Cyclone Wilma which occurred in January 2011 bringing record high rainfall to the region and resulting in large numbers of slips and deposition of clay into the nearshore environment.

In summary, the biological communities on the reefs surveyed have been relatively stable since 2007, and overall species assemblages on the reefs remain similar to when the programme was established in 1999. Other than a general increase in invasive species there were no signs of degradation in reef ecosystems, and in particular no evidence of change at Long Bay in relation to the coastal development. Most changes observed over the sampling period were evident across locations and appear to be driven by regional-scale processes. The large increase in *Ecklonia* at some locations is notable, but the mechanisms responsible remain unknown and warrant further investigation.

The East Coast Subtidal Reef monitoring programme is the only long-term subtidal reef assemblage monitoring programme in New Zealand. This provides an important benchmark to understand changes associated with human impacts, such as the introduction of invasive species and their effects on native reef ecosystems, as well as documenting and understanding how climate change will impact on temperate reef assemblages in the future. Continuation of this programme is important given Auckland's rapidly growing population, increasing threats and demands on ecosystems and resources in the Hauraki Gulf, and the interacting effects of climate change on these ecosystems.

Table of contents

1.0 Introduction

Rocky reefs represent ecologically important and productive coastal marine habitats in New Zealand and worldwide. The wide variety of communities and species they harbour are also important from a commercial, recreational and customary perspective. In urban areas these reefs are subjected to a variety of anthropogenic factors such as terrestrial run-off of sediments and nutrients, as well as direct harvesting of a variety of species. Sediment deposition into the marine environment as a result of human activities on the land (e.g. coastal development and farming) can have a variety of effects on rocky coastal assemblages (Airoldi 2003) and is considered one of the major anthropogenic threats to coastal ecosystems in New Zealand's marine ecosystems (Morrison et al. 2009).

Shallow reefs in the Hauraki Gulf are characterised by canopies of large brown algae and provide important habitats for a variety of species (Grace 1983, Walker 1999, Shears and Babcock 2004). In general, the algal forests that characterise these sheltered reefs are considered to be more stable than those found on more exposed reefs of the outer Hauraki Gulf (Walker 2005), which are subject to larger wave disturbance and also greater grazing pressure due to higher abundances of the sea urchin *Evechinus chloroticus* (Choat and Schiel 1982).

The Long Bay Marine Monitoring Programme was established in 1999 to detect and document the impact of urban development at Long Bay on the subtidal marine environment (Ford and Pawley 2008, Shears 2010a). Earthworks for this development began in 2010 and houses are currently being built in the new subdivisions at Long Bay. The marine monitoring programme initially involved annual sampling of shallow subtidal reef communities at 30 rocky reef sites located between Campbells Bay and Waiwera, and monthly measurements of sedimentation at each site using sediment traps. However, monitoring at Waiwera and Stanmore Bay was discontinued in 2011 as the reef communities at these more exposed locations were distinct from those found in the more sheltered East Coast Bays locations (Shears 2010a). The Meola Reef monitoring programme was established by the Auckland Regional Council in 2001 and involves monitoring biological communities and sediment traps at six subtidal sites using the same methods as those employed in the Long Bay (Shears 2010b). The Meola monitoring programme is a State of the Environment (SOE) monitoring programme and was designed to determine trends in community change over time at and within sites at this location, compare community changes over time to those recorded at other sentinel locations within the Auckland region, interpret any community changes within the backdrop of two major threats to ecosystem health in the Auckland region, sedimentation from urban development and toxicity from urban discharges. In 2011, the Long Bay and Meola Reef monitoring programmes were combined to form the basis of a regional subtidal reef monitoring programme and the number of sites in the Long Bay region were reduced including the cessation of monitoring at Waiwera and Stanmore Bay.

A review of the Long Bay monitoring programme in 2006 suggested that observed changes in the reef assemblages during the early stages of the monitoring programme were an artefact of the movement of sites into deeper water (Haggitt and Mead 2006). In particular, this was proposed to explain the apparent change in the dominant canopy-forming algae from *Carpophyllum maschalocarpum* in the initial years, to *C. flexuosum* (Ford and Pawley 2008). *Carpophyllum* species have a clear depth zonation that has been well described in the inner Hauraki Gulf (Grace 1983, Shears and Babcock 2004), with *C. maschalocarpum* dominating the shallow subtidal fringe to depths of ~2m, below which *C. flexuosum* forests dominate. Analysis of the Long Bay monitoring data through until 2010 (Shears 2010a) confirmed that sites had moved into deeper water and this was the most likely explanation for the reported shift in reef communities. As recommended by the 2006 review, sites were permanently marked in 2006 and sediment trap bases were secured to the reef. Since this time sampling has been carried out at consistent locations using a consistent methodology and there has been a much higher return rate on monthly sediment trap collections (Shears 2010a). Consequently, this report only presents the results from the Long Bay and Meola Reef monitoring programmes spanning the period from 2007 to 2013 (earthworks at Long Bay began in 2010). While data from prior to 2007 are not considered directly comparable to subsequent data, broad comparisons with the earlier data are made in the discussion of this report in regard to the long-term stability of reefs in the Long Bay region.

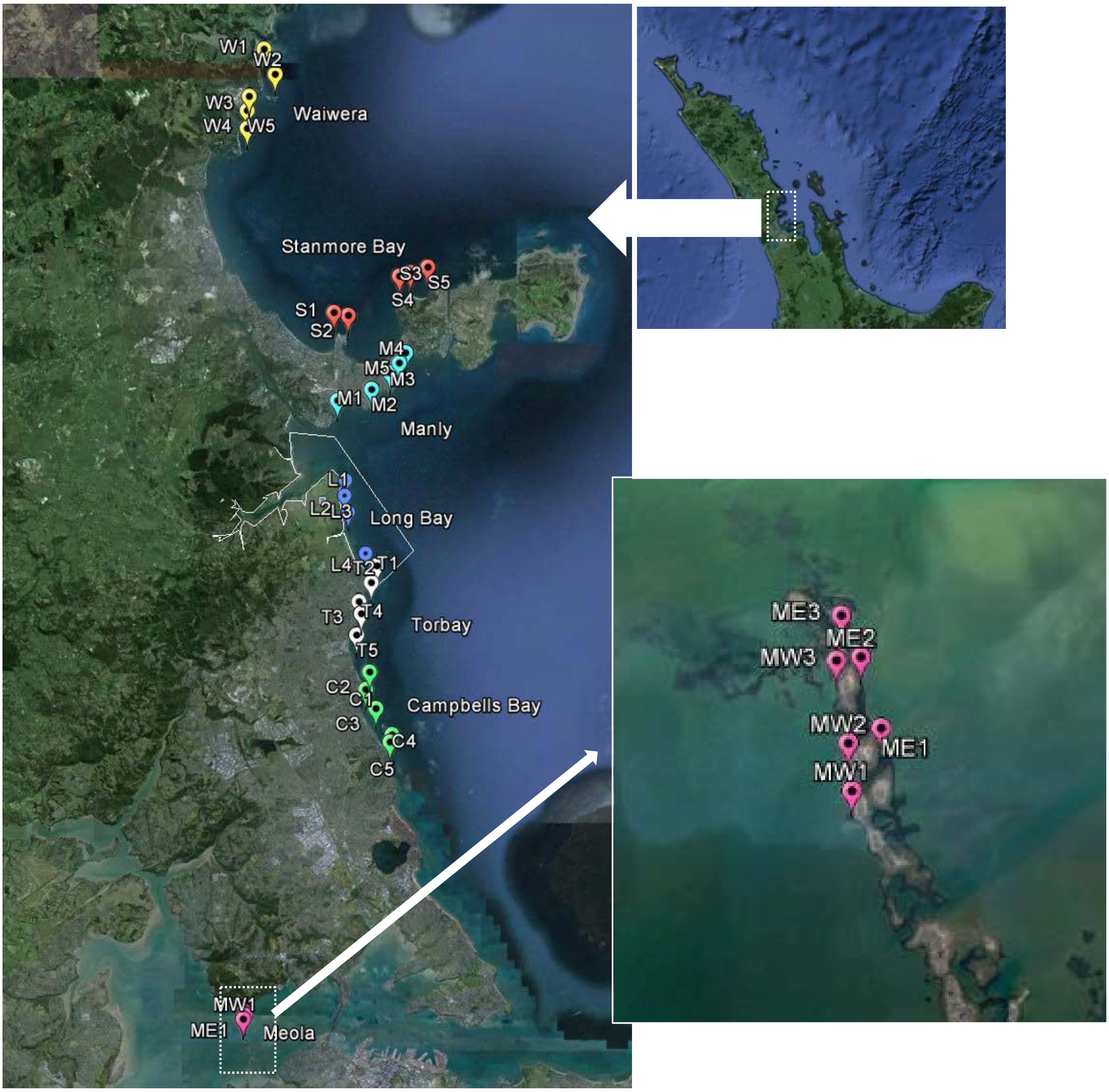


Figure 1. Location of Long Bay and Meola Reef monitoring sites. Five sites are located within each of the six open coast locations (Waiwera, Stanmore Bay, Manly, Long Bay, Torbay and Campbells Bay) and six sites are located within the Waitemata harbour at Meola Reef. White line indicates the boundary of the Long Bay-Okura Marine Reserve. Sampling at all Waiwera and Stanmore Bay sites was discontinued in 2011, and at T1 (Torbay) and C3 (Campbells Bay) in 2012. Inset maps show location of study area within northern New Zealand and zoomed in map of Meola Reef sites.

2.0 Methods

2.1 Site locations

Five sites were originally surveyed at Waiwera, Stanmore Bay, Manly, Long Bay, Torbay and Campbells Bay, as part of the Long Bay Marine Monitoring Programme and six sites at Meola Reef since 2001 (Figure 1,Table 1). In 2011 the programme was revised and sampling was discontinued at Waiwera and Stanmore Bay sites as well as one site at Torbay (T1) and one site at Campbells Bay (C3). Sites at Waiwera and Stanmore Bay were discontinued as these were considerably more exposed and therefore had distinct reef communities compared to the Long Bay sites (Shears 2010a). T1 and C3 were discontinued as they were located on low-lying and narrow finger of reef that was subjected to high sand abrasion, and therefore not comparable to the other East Coast Bays sites.

Sites are located on shallow rocky reef at depths of 1-2 m below the mean low water mark. All monitoring sites are marked with surface floats and surveys are carried out within 10 m of these markers. In most cases quadrats are placed haphazardly around the marker and generally within 5-10 m. However, at some sites, surveys are carried out on adjacent or inshore reef. Care is needed to ensure this is kept consistent from year to year.

2.2 Biological surveys

Subtidal surveys are carried out at each of the monitoring sites in February/March each year. Sampling methods are described in detail in Ford and Pawley (2008) along with details of changes in sampling methods over the monitoring period. In summary, the biological assemblages at each site (Figure 1) are surveyed annually using seven 1m^2 quadrats. All large brown algae and mobile macroinvertebrate species are counted in each quadrat and the percentage cover of turfing and encrusting algae, as well as sessile invertebrates, is estimated visually. The percentage cover of sand, sediment and bare rock are also estimated. Measurements of large brown algae and mobile macroinvertebrates (e.g. gastropods) are taken for all individuals in five of the quadrats.

2.3 Sedimentation monitoring

Sedimentation is monitored at each site using a single sediment trap (see Ford and Pawley 2008 for details). Traps are collected and replaced at each site on a monthly basis. Total sedimentation rate over each period is calculated on a per area basis ($g \cdot cm^2 \cdot day^{-1}$). The proportion of fine sediments (<63 µ) was estimated using a Galai laser particle analyser (see Ford and Pawley 2008 for details), but since 2011, wet sieving has been used to estimate the percentage of fine sediments. Since 2006 the steel bases were fixed to the reef using aluminium strapping and masonry nails. This has resulted in much more reliable and regular data collection, with very few sediment traps lost compared to before 2006.

Secchi depth has been measured at each site since 2010 to provide a measure of turbidity that can potentially be related to sedimentation rates. Secchi data has also been collected from sites at Leigh over this period for comparison.

2.4 Statistical analysis

2.4.1 Spatial and temporal variability in biological assemblages

Biological data were analysed as three data sets:

- Canopy forming algae – Counts of adult (>20 cm frond length) large brown algae.
- Mobile macro invertebrate assemblages - analysis of abundance data for mobile invertebrates, as well as some sessile invertebrates. This data set provides an assessment of the overall biological assemblages found at a site.
- Encrusting assemblages – Per cent cover of dominant substratum covers – analysis of per cent cover data provide information on overall community structure.

Multivariate analyses were carried out for each data set to explore overall patterns in biological assemblages (count data) and community structure (cover data) over time and among areas. All analyses were carried out in PRIMER v6 (Clarke and Gorley 2006). For all datasets multivariate analyses were completed using Bray-Curtis similarities and based on location means for each year. Canopy forming algae and mobile invertebrate data sets were log(x+1) transformed to account for high counts of certain species, whereas the encrusting assemblage data set (% covers) were square-root transformed. Principal Coordinates Analysis (PCO) was used to visualize patterns in community data among locations and years (the greater distance apart in the ordination means less similarity in community structure). In addition, correlations between PCO axes and dominant species/substratum types were presented as bi-plots to provide an exploratory analysis of the species contributing to the variation among areas and over time.

For each biological data set trends in the dominant species/substratum types were plotted over time for each location. PERMANOVA was used to test for variation in each data set over time (2007-2013) and between locations. The fixed factors Location and Year were used and the random factor Site (Location*Year). Waiwera and Stanmore Bay were excluded from these analyses because they were not monitored after 2010. These analyses were run on individual quadrat data and based on Bray-Curtis similarities. Quadrat data were log(x+1) transformed for canopy forming algae and mobile invertebrate data sets, and square-root transformed for the encrusting assemblage data set.

2.4.2 Spatial and temporal variability in sedimentation

Data are presented as rates of sedimentation that apply to the period between deployment and collection (rates are plotted against collection date for simplicity). Linear regression was used to test for changes in sedimentation rates from 2007-2013. Seasonal variation in sedimentation rates are also estimated by plotting long-term monthly averages.

Table 1. Site locations for Long Bay and Meola Reef monitoring sites

Site	Site Code	Latitude	Longitude	Comments
Waiwera	W1	36 32'11.15	174 43'02.02	Discontinued 2011
	W2	36 32'39.00	174 43'17.10	Discontinued 2011
	W3	36 33'03.60	174 42'40.90	Discontinued 2011
	W4	36 33'19.50	174 42'38.10	Discontinued 2011
	W5	36 33'39.56	174 42'38.19	Discontinued 2011
Stanmore Bay	S1	36 37'05.60	174 44'39.60	Discontinued 2011
	S2	36 37'08.90	174 44'59.60	Discontinued 2011
	S3	36 36'24.90	174 46'10.60	Discontinued 2011
	S4	36 36'20.90	174 46'26.00	Discontinued 2011
	S5	36 36'14.90	174 46'50.10	Discontinued 2011
Manly	M1	36 38'44.20	174 44'44.62	
	M2	36 38'31.57	174 45'31.76	
	M3	36 38'12.90	174 45'57.39	
	M4	36 38'2.46	174 46'10.55	
	M5	36 37'50.50	174 46'19.00	
Long Bay	L1	36 39'55.38	174 44'56.21	
	L2	36 40'12.77	174 44'55.36	
	L3	36 40'31.22	174 44'59.99	
	L4	36 41'17.37	174 45'24.63	
	L5	36 41'32.85	174 45'36.63	
Torbay	T1	36 41'48.48	174 45'39.69	Discontinued 2012
	T2	36 42'7.44	174 45'31.85	
	T3	36 42'28.51	174 45'14.99	
	T4	36 42'42.06	174 45'17.89	
	T5	36 43'05.94	174 45'11.40	
Campbells Bay	C1	36 43'47.23	174 45'29.59	
	C2	36 44'06.71	174 45'24.18	
	C3	36 44'28.40	174 45'38.02	Discontinued 2012
	C4	36 44'57.25	174 46'01.25	
	C5	36 45'05.34	174 45'58.02	
Meola	ME1	36 50'10.41	174 42'36.06	
	ME3	36 50'02.68	174 42'32.86	
	ME2	36 50'05.74	174 42'34.43	
	MW1	36 50'14.87	174 42'33.85	
	MW2	36 50'11.38	174 42'33.23	
	MW3	36 50'05.94	174 42'32.35	

3.0 Results

3.1 Biological assemblages

3.1.1 Large brown algal canopy

The reef at all of the monitoring sites was structurally dominated by a canopy of large brown algae, which typically consists of a mix of species. *Carpophyllum maschalocarpum, C. flexuosum* and *Ecklonia radiata,* were typically the dominant canopy components, and their relative importance varies among locations (Figure 2). *C. plumosum, Cystophora retroflexa* and *Sargassum sinclairii* were locally common at some locations, and the introduced kelp *Undaria pinnatifida* is now common at Meola Reef.

Overall canopy composition varied considerably among locations (Figure 2, Table 2). The canopy at Waiwera, Stanmore and Campbells Bay was dominated by a mix of *Carpophyllum maschalocarpum, C. flexuosum* and *Ecklonia radiata,* whereas at Long Bay and Torbay the canopy was primarily dominated by *C. maschalocarpum* and *Ecklonia*. *Cystophora* was also common at these locations and *C. plumosum* was abundant at some of the Long Bay sites. Manly is the most sheltered of the open coast locations and has a distinct canopy (Figure 2), with a high abundance of *C. flexuosum, Cystophora* and *Sargassum,* and comparatively low abundance of *Ecklonia* and *C. maschalocarpum.* The canopy at Meola was somewhat distinct in that it is typically dominated by *Ecklonia, C. maschalocarpum and C. flexuousum*, while *C. plumosum and C. retroflexa* were absent (Figure 2-4).

PERMANOVA indicated a non-significant ($p=0.11$) change in macroalgal canopy composition over time across all locations (Figure 2, Table 2). Analysis of individual locations also indicated no significant variation over time for all locations except Meola. The canopy at Meola Reef has changed substantially over the past seven years. Initially it was dominated by a mix of *C. maschalocarpum* and *C. flexuosum,* but these two species have since declined (Figure 3) and *Ecklonia radiata* (>6 adult plants m^{-2}) and *Sargassum sinclairii* now dominate (Figure 4).

While canopy composition generally remained relatively stable at the other locations there was some variation in some of the dominant species (Figure 3 and Figure 4). *Carpophyllum flexuosum* does appear to have increased at Manly sites since 2007.

Ecklonia abundance has remained stable at Campbells, Torbay and Manly, but has increased at Waiwera, Stanmore and Long Bay (Figure 5). *Cystophora* has remained relatively stable, but decreased at Manly and increased at Long Bay and Torbay in 2013. *Sargassum* is a relatively opportunistic species and shows similar fluctuations at the open coast sites over time, but had a large increase at Meola in 2011 and 2012, but has since declined in 2013.

Undaria pinnatifida was only present at Meola Reef, where it was first recorded in 2011 in relatively low numbers (Figure 5). The majority of *Undaria* plants recorded were recruits (<20 cm) as expected during summer surveys. In 2011, when sampling could not be carried out until July (due to logistical reasons), individuals up to 70 cm in length were recorded.

Table 2: PERMANOVA results for macroalgal canopy composition, based on log(x+1) transformed quadrat data from 2007 to 2013, excluding Waiwera and Stanmore Bay

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Year	6	38159	6359.8	1.45	0.111	997
Location	4	2.97E+05	74361	16.9	0.001	998
Year*Location	24	79433	3309.7	0.8	0.916	997
Site(Year*Location)	145	6.38E+05	4398.2	6.3	0.001	998
Residual	719	4.98E+05	693.27			
Total	898	1.56E+06				

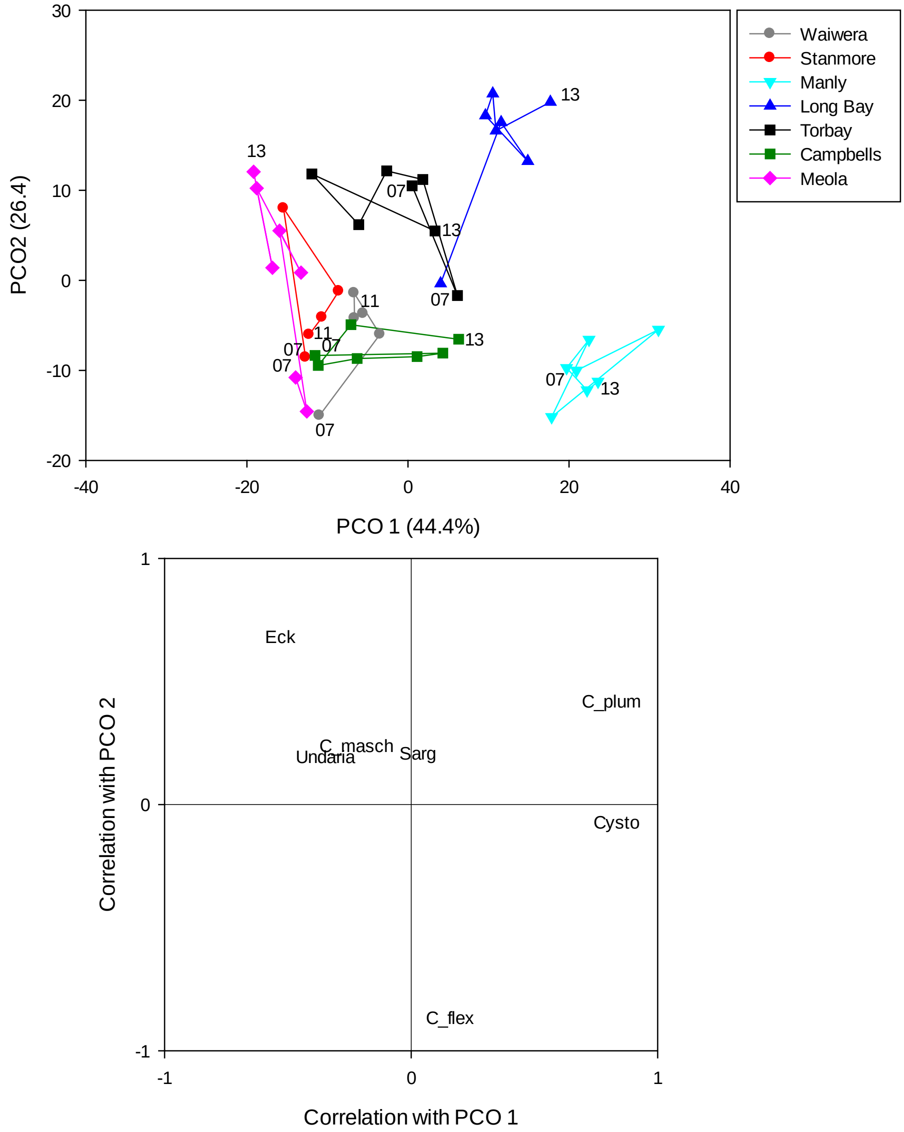


Figure 2: Location-level variation in large brown macroalgal canopy composition from 2007-2013. Principal coordinates analysis based on log(x+1) transformed adult abundance data of seven large brown algal species.

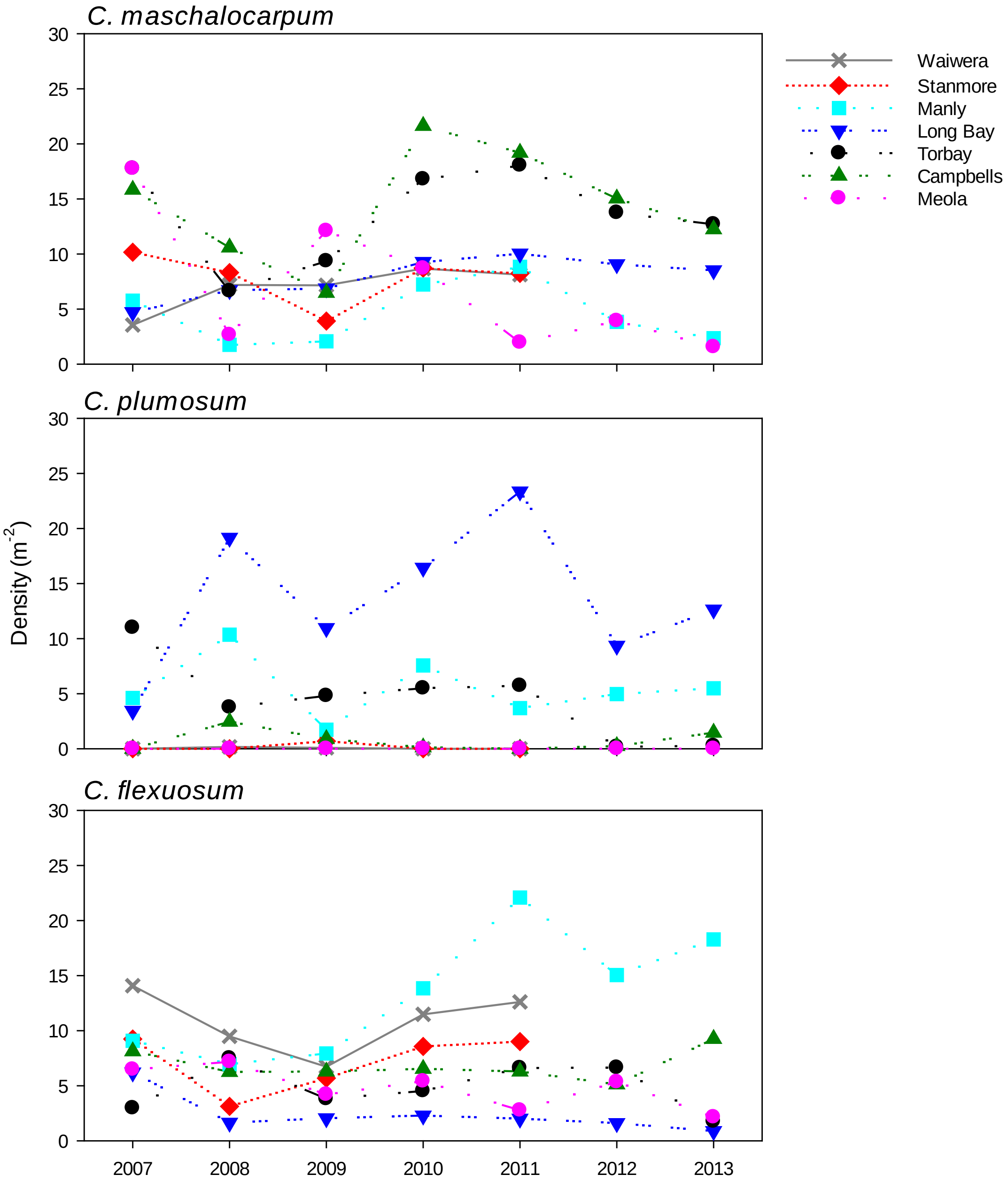


Figure 3: Location-level variation in the density of *Carpophyllum* species between 2007 and 2013. Densities are for adult plants (> 20 cm frond length) to remove the effect of large number of recruits on mean densities).

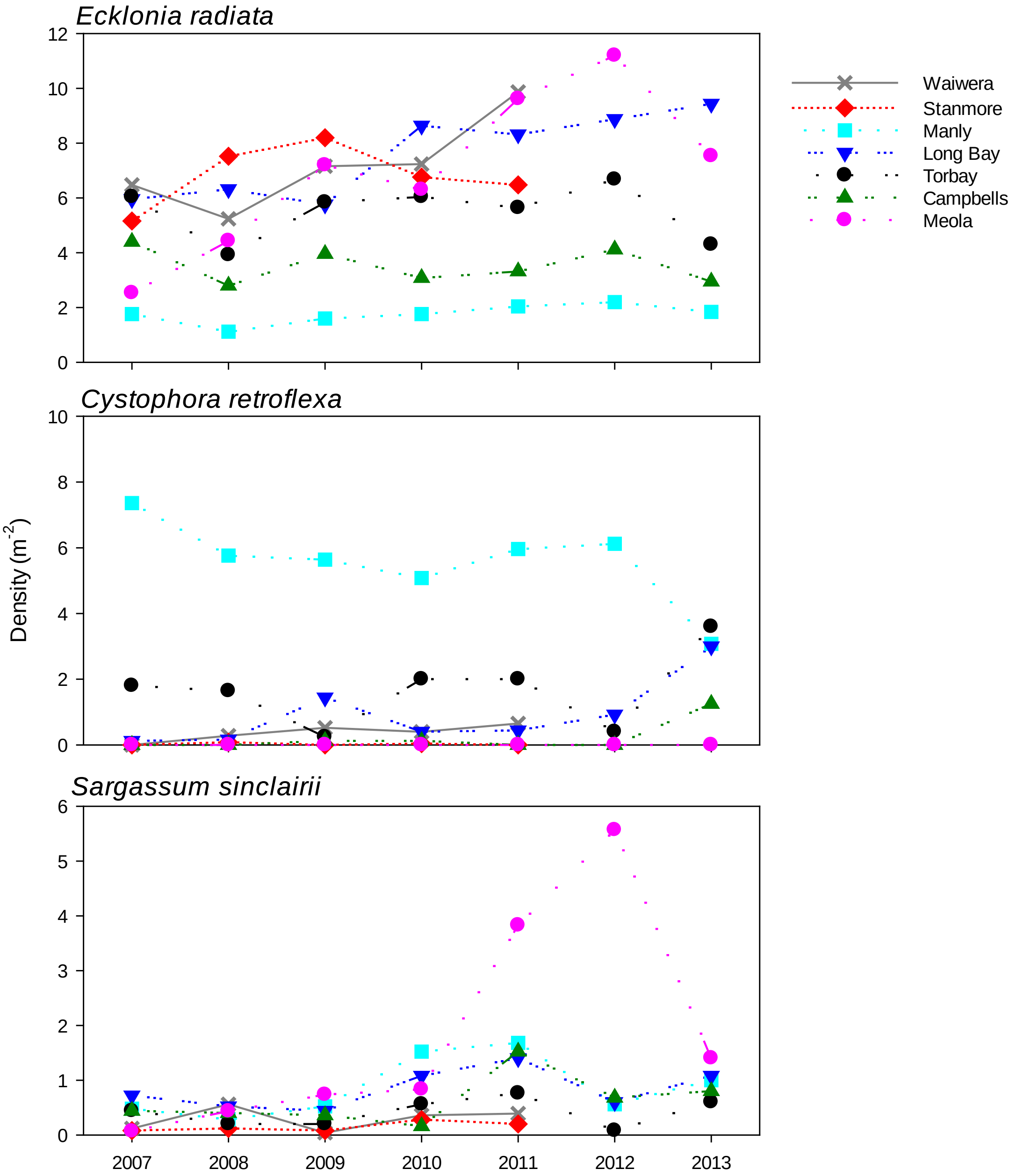


Figure 4: Location-level variation in the density of *Ecklonia radiata*, *Cystophora retroflexa* and *Sargassum sinclairii* between 2007 and 2013. Densities are for adult plants (> 20 cm frond length) to remove the effect of large number of recruits on mean densities).

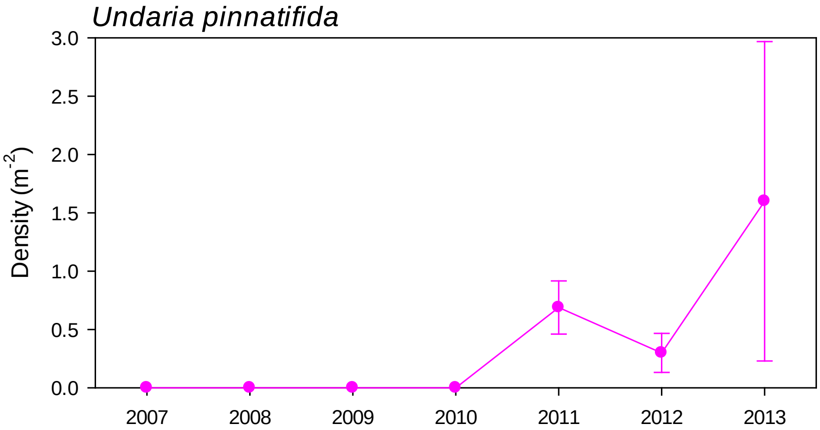


Figure 5: Density of *Undaria pinnatifida* at Meola Reef between 2007 and 2013. Densities are for all plants recorded, as this is an annual species.

3.1.2 Mobile macro-invertebrates

A variety of mobile macro invertebrate species occur on the reef substratum and in the algal canopy (Table 3). The catseye *Lunella smaragdus* (formerly *Turbo smaragdus*) was the numerically dominant mobile invertebrate across all locations, followed by *Trochus viridis,* except at Meola where *Patiriella regularis* was the second-most common species. The total abundance of mobile invertebrates has declined across most locations (Figure 6), which was largely driven by the observed declines in *Lunella*, *Trochus* and to a lesser extent *Cantharidus* (Figure 8). Species richness and evenness has been relatively stable across all locations since 2007. Both species richness and evenness were lowest at Meola, followed by Manly, and was similar among the remaining locations.

Mobile invertebrate assemblages varied significantly among the seven locations and these patterns were consistent over time (Figure 7, Table 4). The mobile invertebrate assemblages at Meola were distinct from those at the open coast locations (Figure 7). *Lunella smaragdus* was the most common mobile invertebrate at Meola, followed by *Patiriella regularis* and *Cryptoconchus porosus*. Two species, *Scutus breviculus* and *Charybdis japonica*, were unique to Meola, whereas a number of species that were common at the open coast locations were rare or absent at Meola, e.g. *Trochus*, *Cantharidus*, *Cookia* and *Cominella virgata* (Table 3).

Mobile invertebrate assemblages also exhibit some consistent differences among the other locations in relations to wave exposure (Figure 7). Waiwera, Stanmore Bay and to a lesser extent Campbells Bay are the most wave exposed locations and typically have a higher abundance of *Trochus, Cantharidus*, *Micrelenchus* and *Stegnaster inflatus*. Manly is the most sheltered open coast location and has the highest abundance of *Lunella* and *Maoricolpus*, and comparatively low numbers of *Trochus, Cantharidus* and *Cookia.* The mobile invertebrate assemblage on reefs at Long Bay and Torbay were intermediate between Manly and the more exposed localities. Overall abundance was comparatively low at Long Bay and Torbay with low numbers of *Lunella*, compared to Manly, and relatively low numbers of other species, compared to the more exposed locations.

The overall assemblages remained relatively constant over time and there was no significant difference between years (Figure 7, Table 4). The largest temporal variation occurred at Torbay (Figure 7), which appears to be driven by fluctuations in *Trochus* and *Maoricolpus*, the latter of which has a highly patchy distribution. The six most common species fluctuated over time (Figure 8 and Figure 9), but these fluctuations were consistent among the locations suggesting region-wide patterns. For example, the trend in *Lunella* abundance across the open coast locations was a general decline since 2007, with a small increase in 2010 (Figure 8). At Meola, *Lunella* generally declined over time but has increased slightly over the past 2 years. *Trochus* exhibited a similar pattern across the open coast locations with a peak in 2009 followed by a general decline.

The invasive paddle crab *Charybdis japonica* was first recorded at Meola in 2010. It has now been recorded at all of the Meola sites except MW1. The densities are relatively low, with between 1 and 4 individuals being recorded during each survey since 2010.

Table 3: Mean density of the 25 most common mobile macroinvertebrate species for each location from 2007-2013

Location	Waiwera	Stanmore	Manly	Long Bay	Torbay	Campbells	Meola	*Grand Average*
Total abundance of all species	*26.68*	*28.78*	*27.79*	*15.37*	*19.38*	*28.44*	*14.19*	*22.52*
Species								
Lunella smaragdus (Lunel)	10.58	13.20	18.21	7.99	10.37	13.80	12.50	*12.42*
Trochus viridus (Trohus)	4.47	8.51	1.24	1.95	3.29	8.78	0.03	*3.82*
Cantharidus purpureus (Canth)	5.92	1.97	0.13	0.26	0.81	1.08	0.01	*1.23*
Maoricolpus roseus (Maori)	0.28	0.28	4.82	0.85	1.97	0.60	0.00	*1.34*
Patiriella regularis (Patir)	1.10	1.03	0.39	0.36	0.69	0.68	0.88	*0.70*
Cominella virgata (C_virg)	0.04	0.38	1.14	0.75	0.37	1.53	0.00	*0.64*
Buccinulum lineum (B_line)	0.59	0.71	0.56	1.45	0.76	0.60	0.02	*0.67*
Cookia sulcata (Cookia)	0.78	1.24	0.68	0.14	0.32	0.22	0.01	*0.44*
Evechinus chloroticus (Evech)	0.30	0.53	0.14	0.65	0.22	0.11	0.10	*0.28*
Coscinasterias muricata (Cosci)	0.17	0.31	0.31	0.38	0.21	0.24	0.09	*0.25*
Stegnaster inflatus (Stegn)	0.27	0.21	0.06	0.05	0.09	0.42	0.01	*0.15*
Cryptoconchus porosus (Crypto)	0.13	0.34	0.08	0.29	0.13	0.15	0.28	*0.20*
Micrelenchus sp.	1.58	0.02	0.00	0.11	0.09	0.12	0.00	*0.23*
Haustrum haustorium	0.42	0.02	0.01	0.14	0.01	0.11	0.00	*0.09*
Dicathais orbita	0.07	0.04	0.00	0.00	0.00	0.02	0.01	*0.02*
Cominella adspersa	0.02	0.01	0.00	0.01	0.02	0.01	0.08	*0.02*
Stichopus mollis	0.02	0.03	0.02	0.02	0.02	0.02	0.01	*0.02*
Cabestana spengleri	0.01	0.02	0.02	0.04	0.02	0.01	0.04	*0.02*
Dendrodoris citrina	0.00	0.00	0.02	0.00	0.00	0.00	0.05	*0.01*
Scutus breviculus	0.00	0.00	0.00	0.00	0.00	0.00	0.09	*0.02*
Muricopsis octogonus	0.00	0.01	0.02	0.00	0.03	0.00	0.00	*0.01*
Penion sulcatus	0.02	0.01	0.01	0.00	0.00	0.01	0.00	*0.01*
Ceratosoma amoena	0.02	0.02	0.01	0.01	0.00	0.02	0.00	*0.01*
Charybdis japonica	0.00	0.00	0.00	0.00	0.00	0.00	0.04	*0.01*
Amblyneustes elevatus	0.00	0.00	0.01	0.00	0.01	0.00	0.00	*0.01*

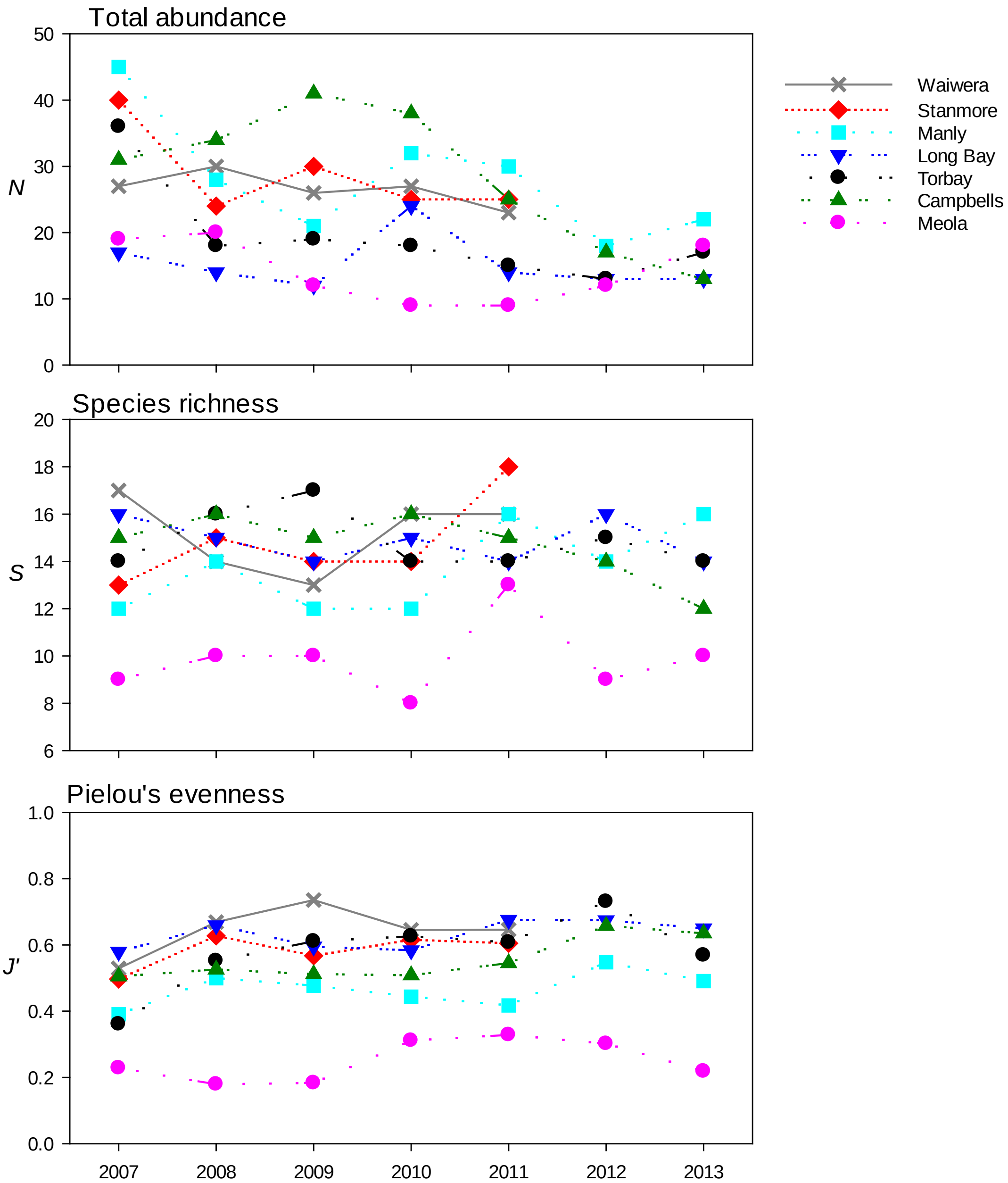


Figure 6: Location-level variation in the numerical abundance, richness and evenness of mobile macroinvertebrates between 2007 and 2013

Table 4: PERMANOVA results for mobile macroinvertebrate assemblages, based on log(x+1) transformed quadrat data from 2007 to 2013, excluding Waiwera and Stanmore Bay

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Year	6	45441	7573.5	1.2	0.224	999
Location	4	5.02E+05	1.26E+05	20.2	0.001	995
Year*Location	24	72611	3025.5	0.5	1.000	998
Site(Year*Location)	145	9.06E+05	6249.3	5.6	0.001	990
Residual	1057	1.17E+06	1109.2			
Total	1236	2.70E+06				

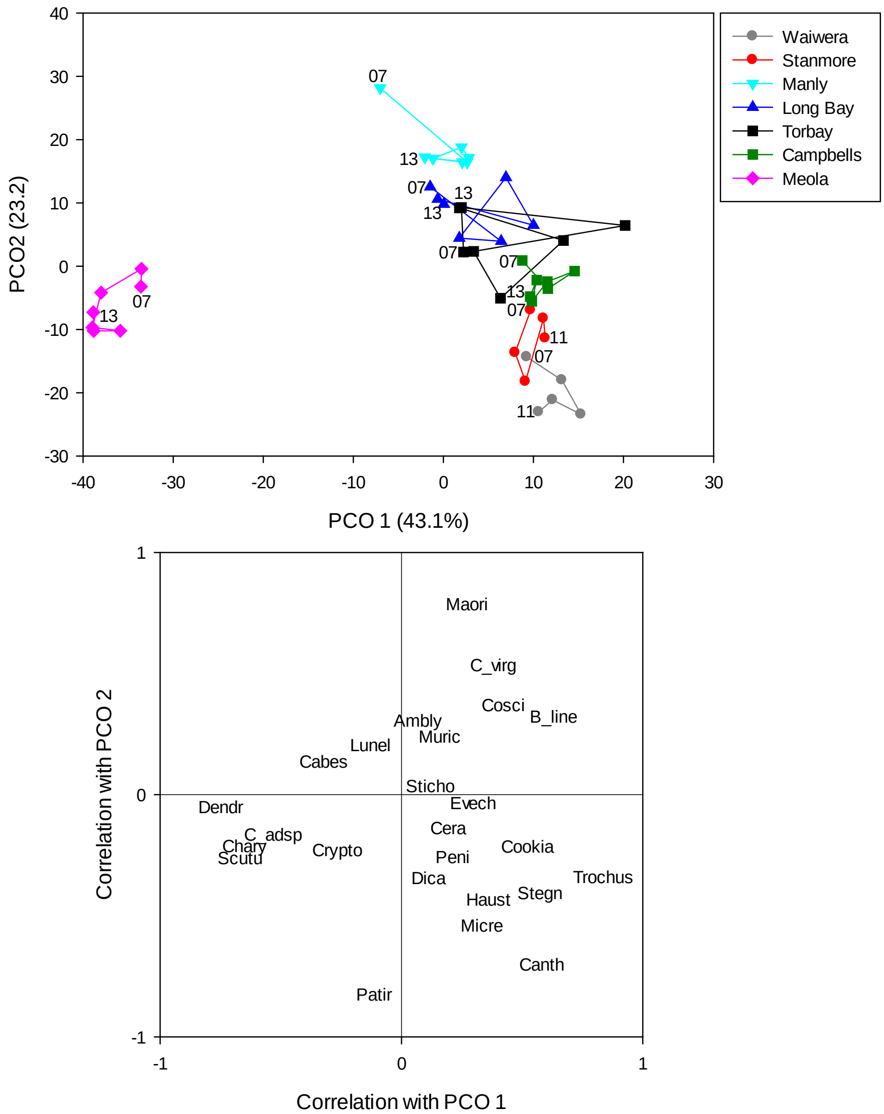


Figure 7: Location-level variation in mobile macroinvertebrate assemblages from 2007-2013. Principal coordinates analysis based on log(x+1) transformed abundance data of 25 macroinvertebrate species. Bi-plot shows correlation between PCO axes and each species (see Table 3) for species names).

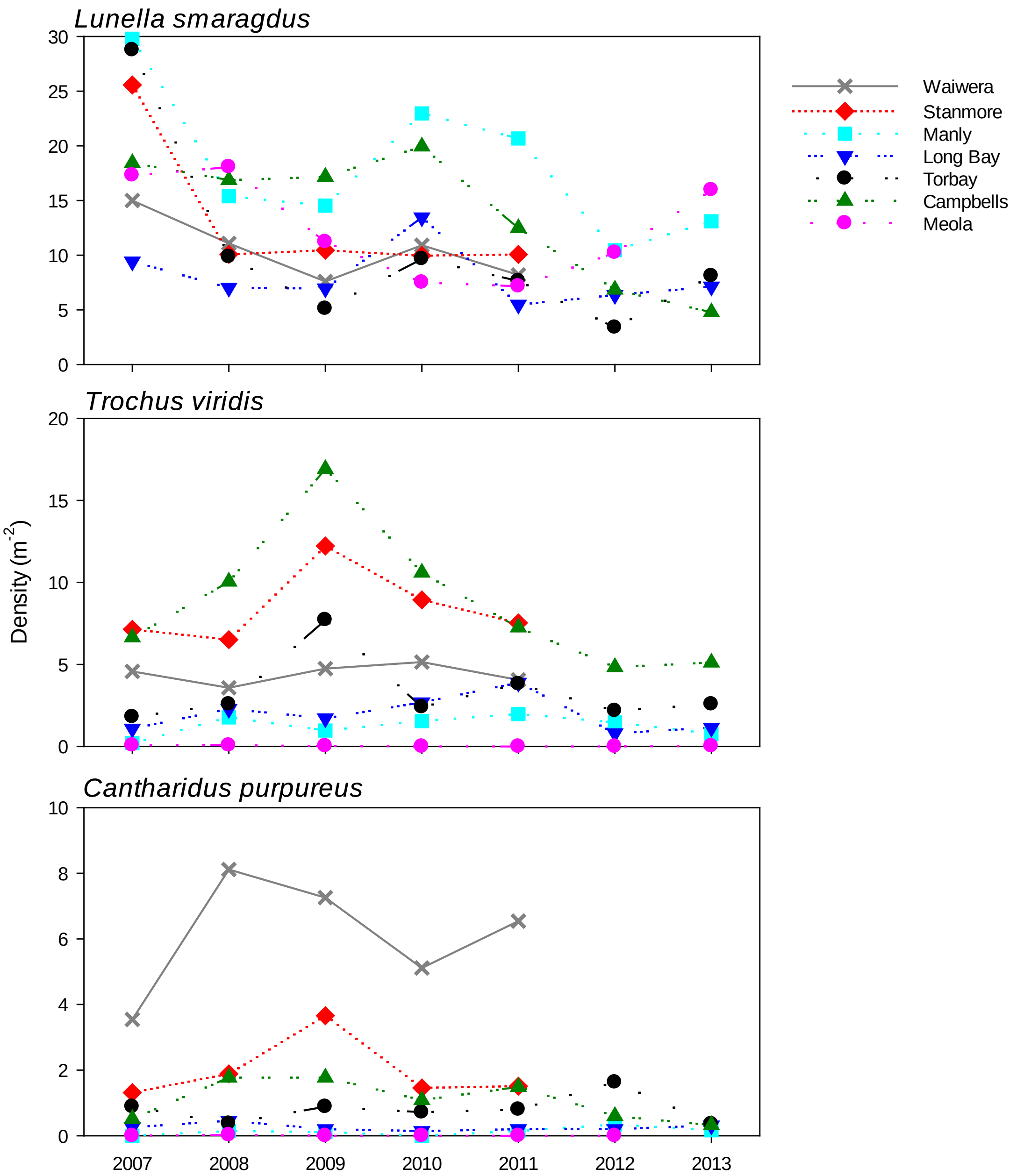


Figure 8: Location-level variation in the density of the dominant herbivorous gastropod species between 2007 and 2013.

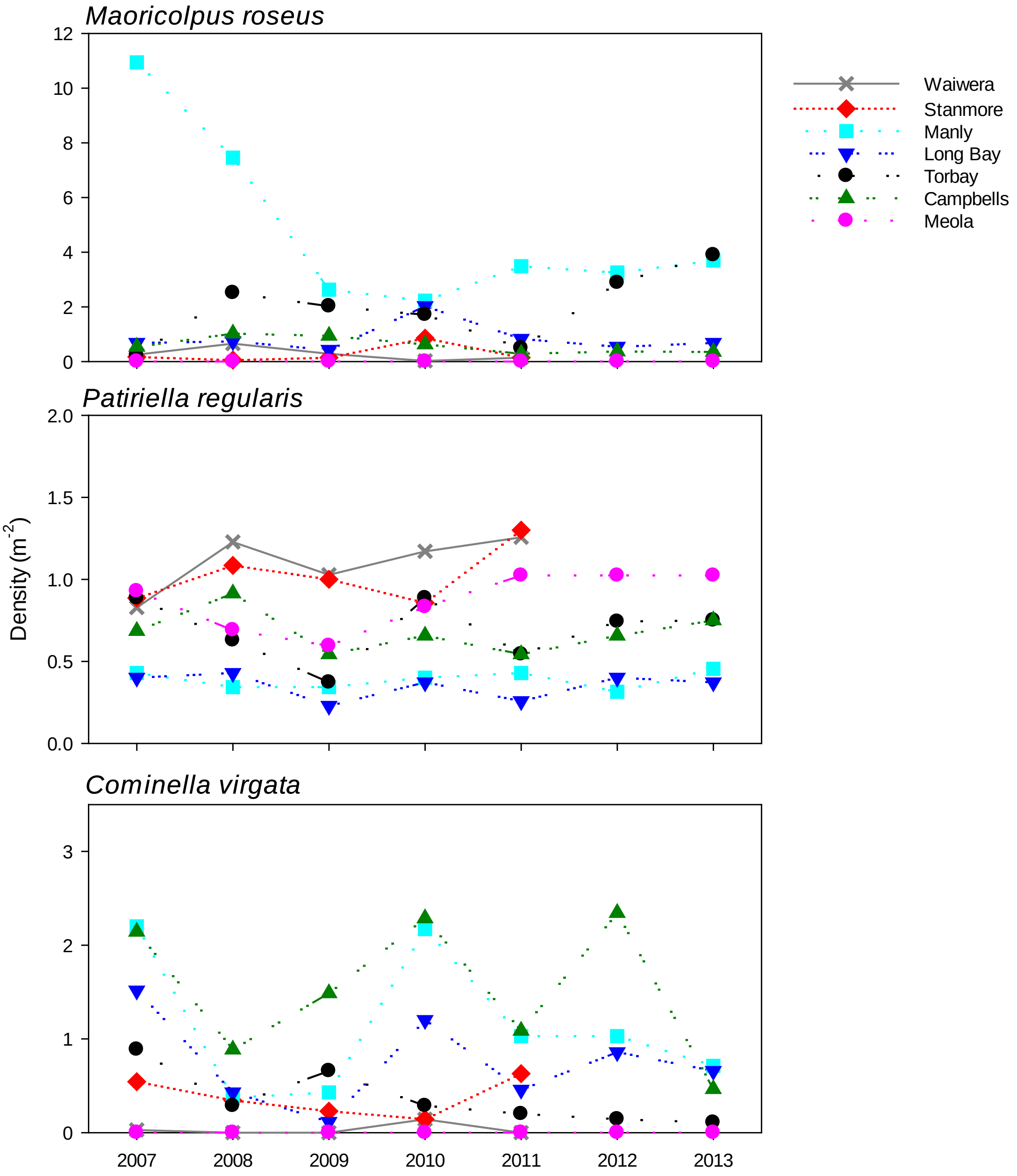


Figure 9: Location-level variation in the density of the turret shell *Maoricolpus roseus*, the cushion star *Patiriella regularis* and *Cominella virgata* between 2007 and 2013.

3.1.3 Benthic encrusting assemblage (covers)

The rocky substratum beneath the algal canopy was covered by a mix of encrusting and foliose algae, and a variety of sessile invertebrates (Table 5). Crustose coralline algae was the dominant cover at all locations except Meola, where it typically only covers about 10% of the substratum. The holdfasts of canopy forming algae cover on average about 5% of the substratum. The other dominant algal groups were encrusting algae (predominantly *Ralfsia* sp. at open coast locations and

Hildenbrandia sp. at Meola) (~2% cover), the small brown algae *Zonaria turneriana* (~3%), articulated coralline turf *Corallina officinalis* (~1%) and the short green turfing alga *Cladophora herpestica* (0.6%). Encrusting sponges were the dominant encrusting invertebrate group followed by solitary ascidians (0.4%). *Tethya* species, predominantly *T. bergquistae*, were also common. The substratum also has a substantial coverage of sediment at all locations, ranging from ~15-40% (Table 5, see Section 3.2.1). Sand fills crevices and depressions on the reef making up about 6% and a small proportion of the reef was typically bare (1-3%).

The number of encrusting categories recorded (species richness) was similar among the seven locations, whereas evenness was notably higher at Meola Reef (Figure 10). There was an apparent increase in richness between the periods of 2007-2009 and 2010 onwards. This is likely due to observer variability and divers recording a number of additional benthic invertebrate categories from 2010 onwards.

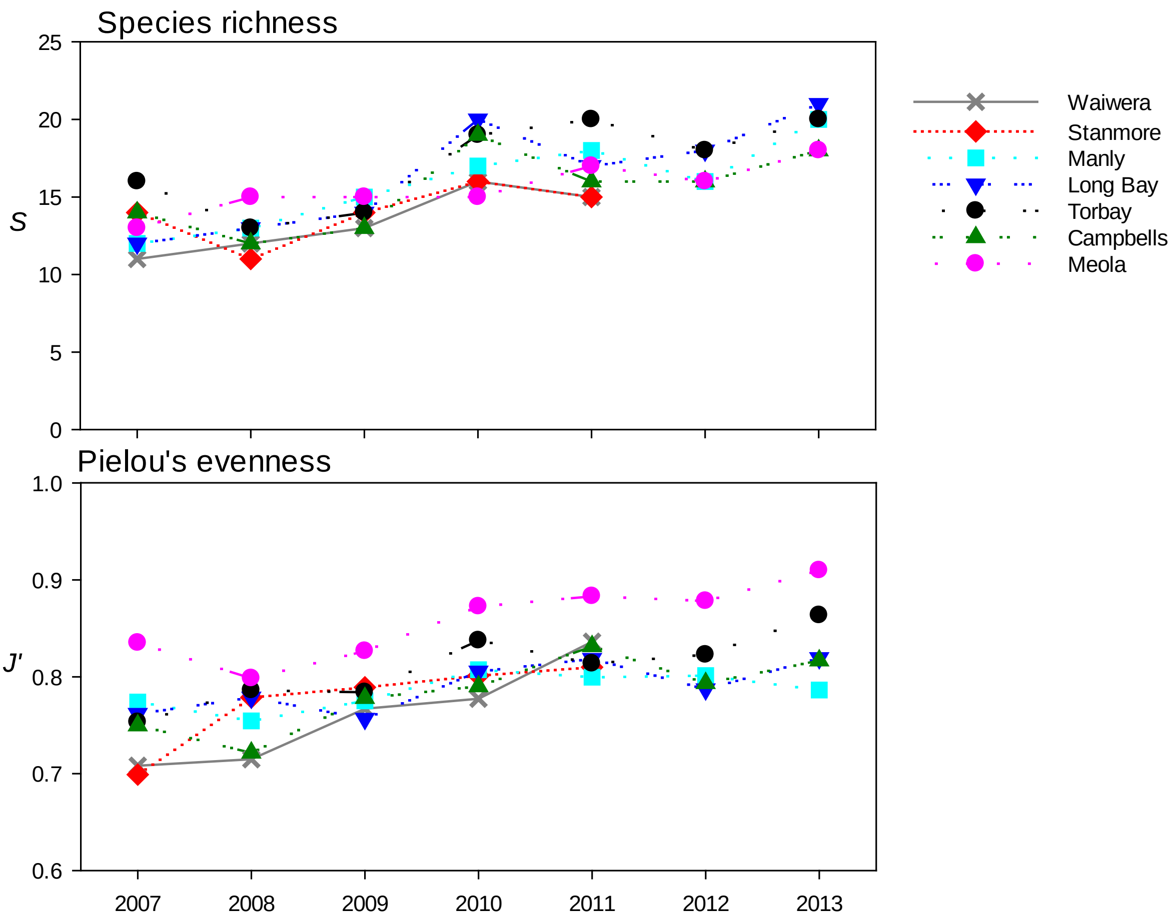


Figure 10: Location-level variation in the richness and evenness of encrusting assemblages between 2007 and 2013. Note: these indices are based on encrusting categories not individual species.

Table 5: Mean cover of dominant encrusting groups or species for each location from 2007-2013

Location	Waiwera	Stanmore	Manly	Long Bay	Torbay	Campbells	Meola	*Grand Average*
Category/Species								
Crustose coralline algae (CCA)	60.5	47.64	42.23	45.33	41.42	47.09	9.67	*39.91*
Canopy algae (holdfast)	4.95	4.37	3.56	4.96	5.02	4.21	4.49	*4.49*
Encrusting algae (Ralfsia)	1.82	0.74	1.5	1.89	3.83	1.19	10.82	*3.51*
Encrusting sponge	5.48	5.42	1.34	2.46	1.91	3.22	4.11	*3.27*
Zonaria turneriana	2.45	0.87	0.88	1.97	1.84	2.55	0.01	*1.44*
Cladophora herpestica	0.49	1.07	1.74	0.39	0.52	1.36	1.45	*1.04*
Corallina officinalis	0.01	0	0.64	0.17	1.7	0.1	2.81	*0.9*
Ascidian (solitary)	0.2	0.29	0.72	0.97	0.56	0.58	1.44	*0.74*
Red fleshy algae	0.15	0.36	0.18	0.88	0.88	0.82	0.46	*0.55*
Barnacles	0.59	1.1	0.11	0.33	0.65	0.34	0.08	*0.41*
Tethya spp.	1	0.81	0.11	0.29	0.31	0.36	0.28	*0.41*
Chaetopterus sp.	0.06	0.08	0.3	0.43	0.25	0.14	0.01	*0.18*
Hydroids	0.19	0.08	0.06	0.08	0.09	0.06	0.28	*0.12*
Encrusting bryozoa	0.07	0.11	0.03	0.13	0.17	0.13	0.14	*0.11*
Crassostrea gigas	0	0	0	0	0.01	0	0.59	*0.11*
Ascidian (colonial)	0.16	0.11	0.02	0.04	0.16	0.11	0.11	*0.1*
Styela clava	0.01	0.01	0.06	0.06	0.06	0.02	0.01	*0.03*
Colpomenia sinuosa	0.01	0	0.03	0.05	0.07	0.05	0.02	*0.03*
Halopteris funicularis	0	0.02	0.07	0.02	0.04	0.01	0.01	*0.02*
Anemones	0.01	0.02	0.02	0.03	0.03	0.03	0.01	*0.02*
Codium fragile	0	0	0.01	0.01	0.01	0	0.05	*0.01*
Perna canaliculus	0	0	0.01	0	0.01	0	0.05	*0.01*
Sabella spallanzanii	0	0	0	0	0	0.01	0.03	*0.01*
Culicea rubeola	0.01	0	0.01	0.01	0.01	0	0	*0.01*
Physical variables								
Sediment	15.05	26.79	35.88	29.63	22.83	24.83	40.88	*29.05*
Sand	3.69	5.49	3.61	4.24	8.82	4.9	10.07	*6.06*
Shell	2.05	2.85	2.95	2.26	3.69	3.83	9.29	*4.13*
Gravel	0.01	0.33	0.34	0.19	0.54	0.54	0.04	*0.28*
Bare rock	1.25	1.3	3.28	2.73	3.23	2.61	1.16	*2.26*

Encrusting assemblages varied among years and locations, and there was a significant interaction between year and location (Figure 11,

Table 6). The encrusting assemblage at Meola Reef was distinct from that at the open coast locations (Fig. 11). Meola has a number of encrusting species that were absent or rare at the other localities, e.g. *Perna canaliculus, Crassostrea gigas,* and *Sabella spallanzanii* (Table 5). Meola also has a very low cover of crustose coralline algae and a higher cover of encrusting algae (predominantly the red encrusting alga *Hildenbrandia* sp.) (Figure 12), and *Zonaria,* which was common at the open coast locations, was absent at Meola (Fig 13). The cover of sponges and solitary ascidians was also relatively high at Meola (Fig. 14).

There was some consistent variation in the encrusting assemblages among the open coast locations (Figure 12). The encrusting assemblage at Manly was distinct to the other open coast locations, with a relatively low cover of crustose coralline algae, canopy algae holdfasts, and sponges, and a relatively high cover of *Cladophora herpestica* and *Corallina officinalis* compared to the other open coast locations. At Waiwera and Stanmore Bay, which are the most exposed locations, there was a relatively high cover of encrusting sponges and Tethya and a low cover of solitary ascidians (Figure 14) and *C. officinalis* (Figure 13).

The significant effect of year (Table 6) was evident in the shift in encrusting assemblages at all locations between 2009 and 2010 (Figure 11). This change was largely driven by an increase in the number of encrusting categories recorded, but some changes in the dominant covers were also observed (Figure 12 to Figure 14). SIMPER analysis suggested the main species groups contributing to a difference between the periods 2007-2009 and 2010-2013, were a decline in CCA, an increase in the cover of red algae, *Zonaria* and canopy algae holdfasts, and an increase in both colonial and solitary ascidians. Of particular note is the decline in encrusting algae at Meola Reef (Figure 12) and the large increase in the cover of solitary ascidians at Meola and Long Bay Figure 14).

Notable invasive sessile invertebrate species recorded at the monitoring sites were the clubbed ascidian *Styela clava* and Mediterranean fanworm *Sabella spallanzanii. Styela* was first recorded in the monitoring programme in 2006 and is now found in low numbers (<1 m^{-2}) at all locations. *Sabella* was first recorded at Meola Reef in 2011 and was also recorded at one Campbells Bay site (C1) in 2013. The cover of *Sabella* is presently very low (<0.5%).

Table 6: PERMANOVA results for encrusting assemblages, based on square root transformed quadrat data from 2007 to 2013, excluding Waiwera and Stanmore Bay

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Year	6	77854	12976	8.7	0.001	996
Location	4	2.75E+05	68765	46.2	0.001	998
Year*Location	24	59892	2495.5	1.7	0.001	998
Site(Year*Location)	145	2.16E+05	1488.9	3.8	0.001	994
Residual	1081	4.26E+05	394.48			
Total	1260	1.06E+06				

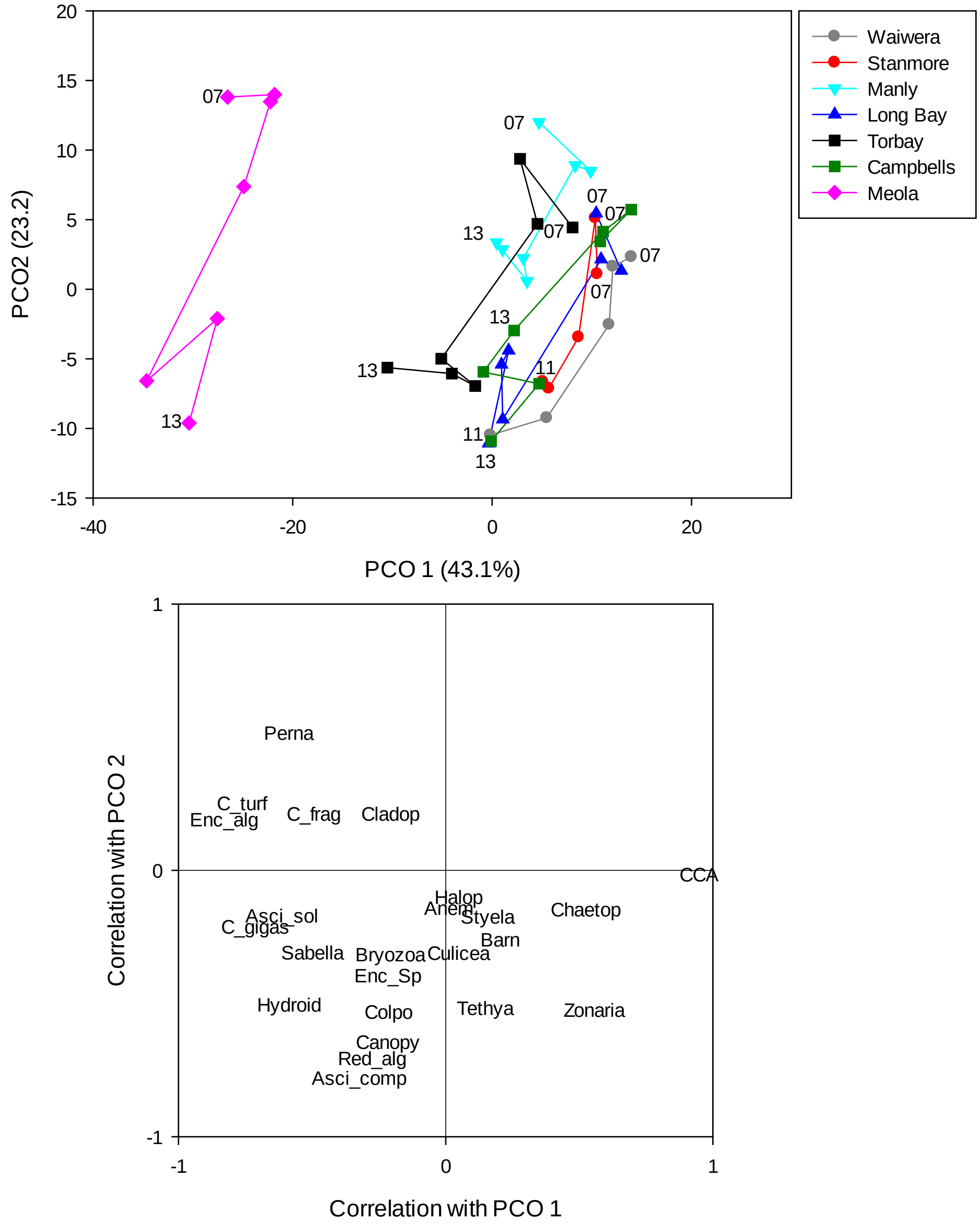


Figure 11: Location-level variation in encrusting assemblages from 2007-2013. Principal coordinates analysis based on square root transformed abundance data of 24 encrusting categories. Bi-plot shows correlation between PCO axes and each species (see Table 5).

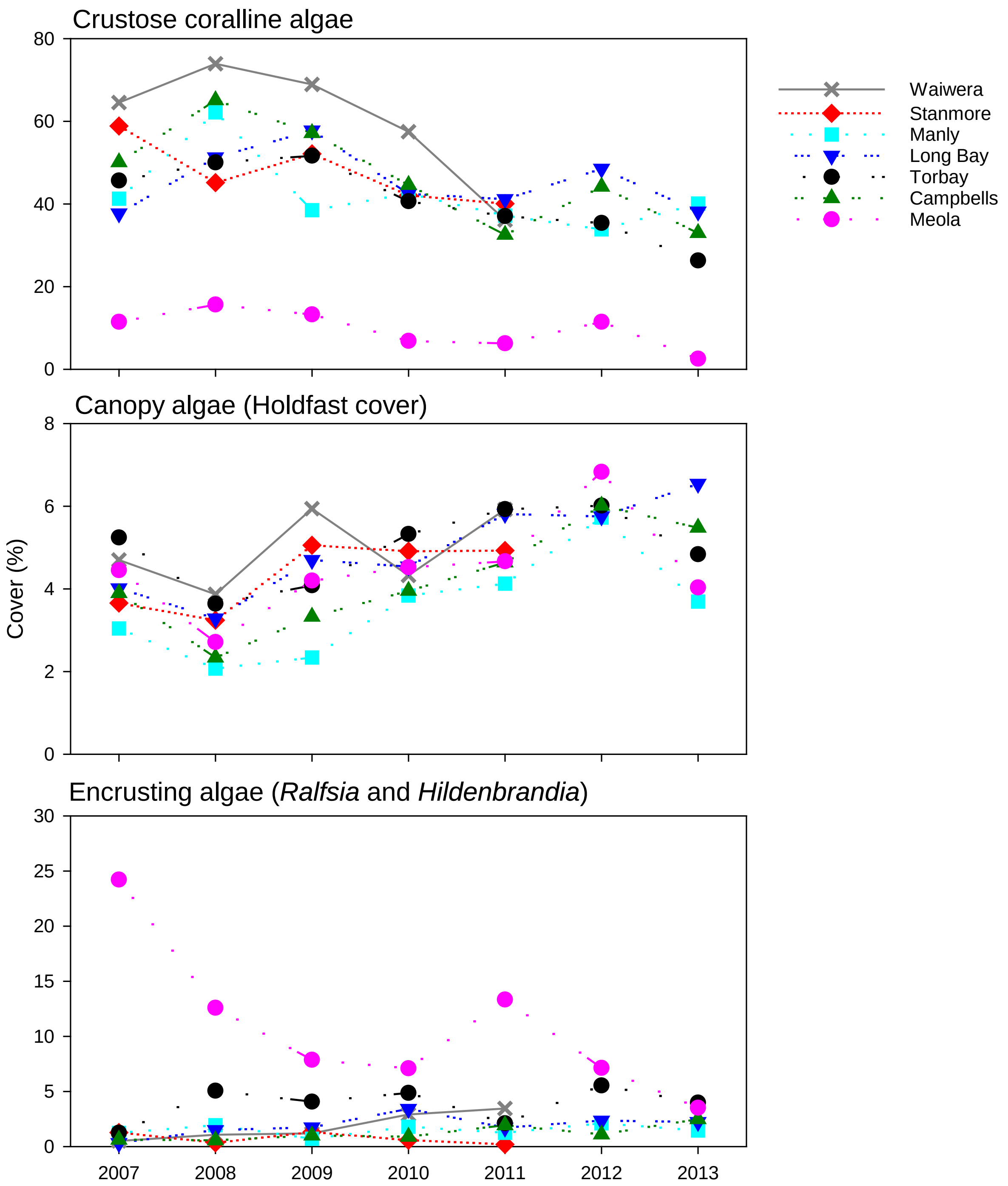


Figure 12: Location-level variation in the cover of the crustose coralline algae, canopy holdfasts and encrusting algae between 2007 and 2013.

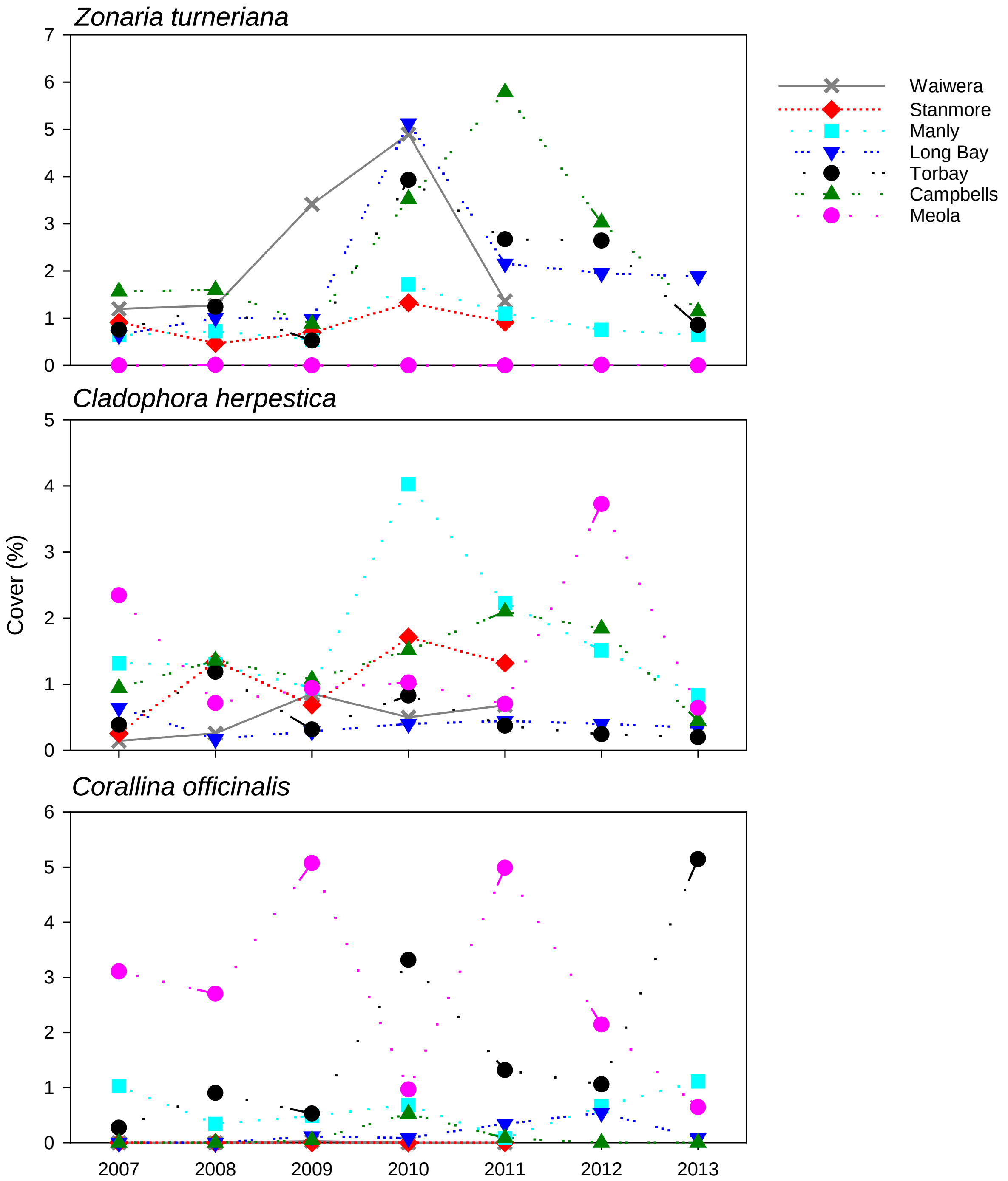


Figure 13: Location-level variation in the cover of the *Zonaria turneriana*, *Cladophora herpestica* and *Corallina officinalis* between 2007 and 2013.

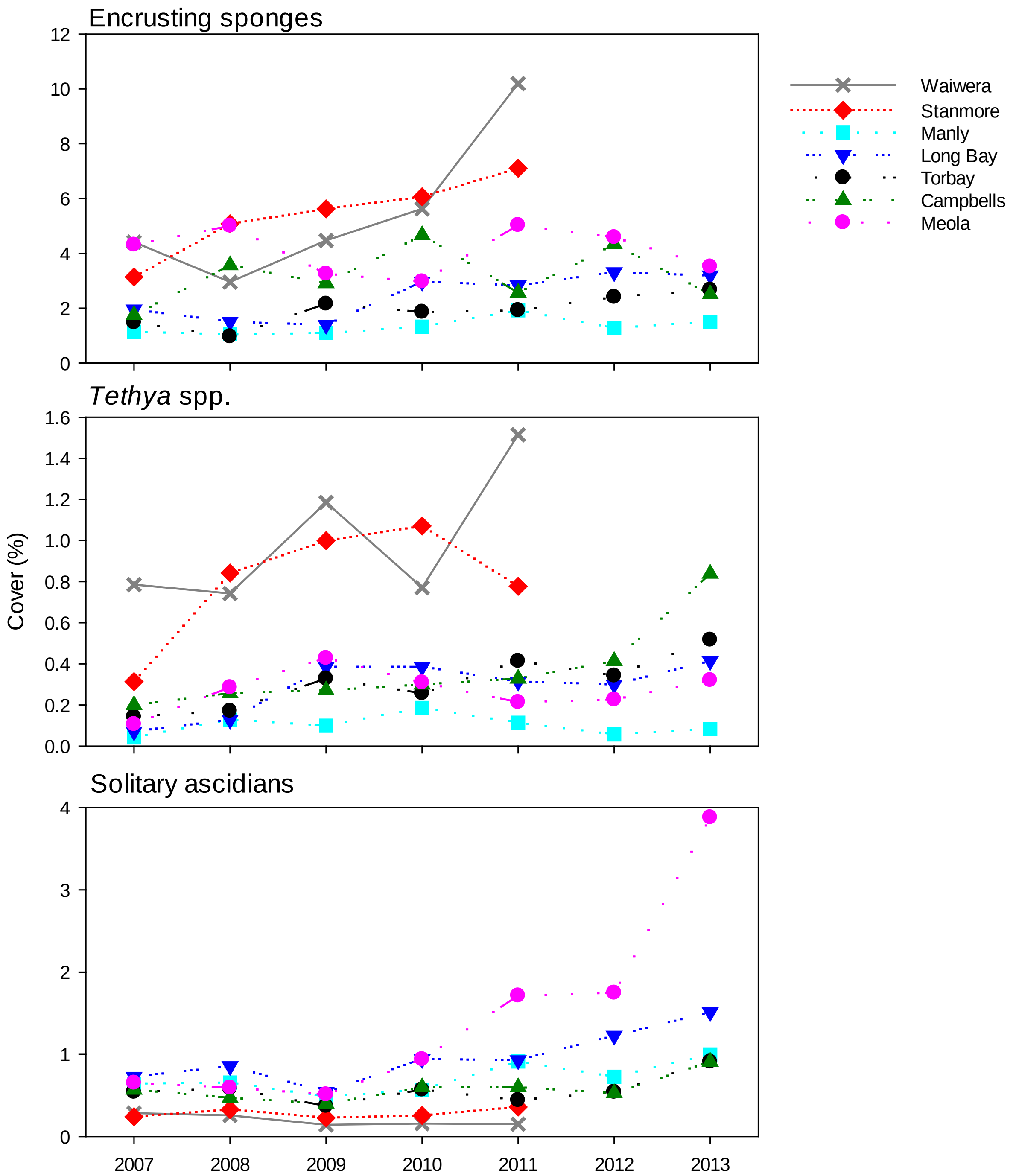


Figure 14: Location-level variation in the cover of encrusting sponges, *Tethya* spp. and solitary ascidians between 2007 and 2013.

3.2 Sediment characteristics

3.2.1 Sediment cover

The cover of sediment on the reef varied among the seven locations (Figure 15, Table 3). Sediment cover was typically highest at the more sheltered locations (e.g. Meola and Manly) where ~40% of the reef was covered in sediment, and lowest at Waiwera, the most exposed location. The cover of sediment at Long Bay is generally very similar to that at Torbay and Campbells Bay. There was considerable variation in sediment cover over time. With the exception of Manly, the open coast locations followed a similar pattern with a decline between 2007 and 2009, followed by an increase and then relatively constant levels in recent years. Sediment cover at Meola tended to increase between 2007 and 2010, and remain stable in recent years.

The cover of sand and shell hash was highest at Meola and generally similar among the remaining locations (Figure 15, Table 3). Sand cover was relatively stable across years, except for low cover of sand across locations in 2010.

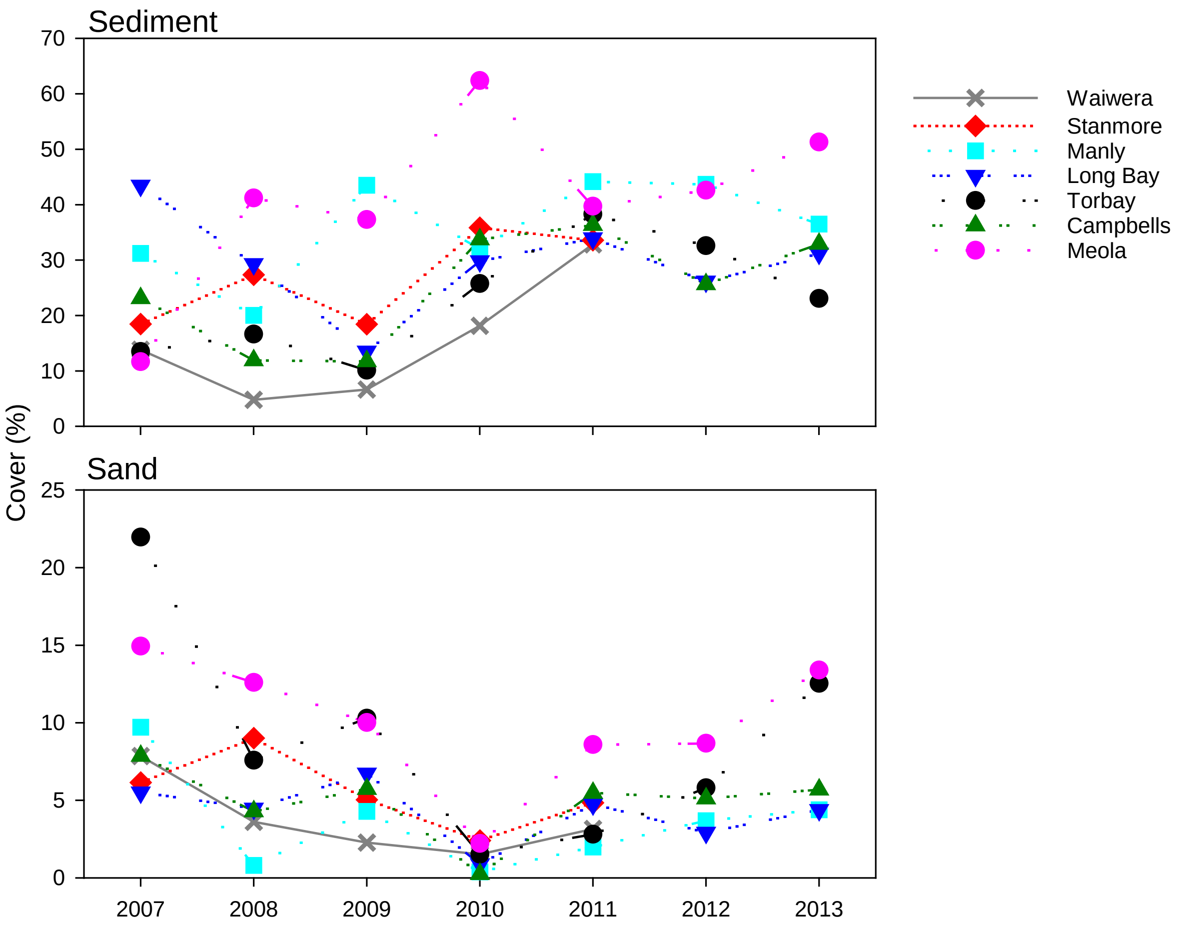


Figure 15: Location-level variation in the cover of sediment and sand between 2007 and 2013.

3.2.2 Sediment traps

Trends in annual sediment trap rate are shown in Figure 16. Large differences in overall trap rates, the percentage of fine sediments and the trap rate for fine sediments were apparent among the seven regions. Overall trap rates were inversely related to the percentage of fine sediments, meaning that locations with high trap rates have a lower percentage of fine sediments, i.e. trapped sediments were predominantly coarse, whereas sites with low overall rates have higher per cent fines. For example, Meola Reef has the lowest trap rate but the highest percentage of fine sediments, with approximately 80% of trapped sediment being <63 microns. In contrast, Waiwera and Long Bay have the highest rates and have the lowest percentage of fine sediments. Both of these variables have generally been constant from 2007 to 2013. However, the trap rate at Torbay was considerably higher in 2007.

There was considerably variation in overall trap rates from month to month and among sites within each location (see the Appendix for site-level time series, and Fig. 1 for site positions). In general, sites within each location follow a similar temporal trend, but the magnitude of trap rate did vary considerably among sites within some locations. For example, there was one site at each of Waiwera (W1), Long Bay (L3) and Campbells Bay (C3) that had considerably higher trap rates than the other sites within those locations. There was no evidence of any consistent trends in trap rates across sites within locations between 2007 and 2013, although some sites had significant trends. Significant declines in trap rate were observed at T3 (p=0.002) and T5 (p=0.087), whereas trap rate increased at C1 (p=<0.001). There was also a marginally significant increase at C3 (p=0.087) and MW1 (p=0.058). At Meola there was a general positive trend among the sites, but this was not significant and appears to be driven by particularly high trap rates in November 2012.

The trap rate for fine sediments varied in a similar manner as total sediment trap rate among locations (Figure 16). Campbells Bay typically had the highest trap rates for fine sediments, followed by Waiwera and Long Bay, whereas the most sheltered locations (Manly and Meola) had the lowest rates. Overall, the trap rate for fine sediments remained relatively constant over time, with a small increase in 2011, which occurred across all of the locations. Temporal patterns in trap rate for fine sediments at the site level (Appendix) were similar as for overall trap rate, with significant or marginally significant increases at C1 (p=<0.001), C3 (p=0.036), L3 (p=0.011), T1 (*p*=0.059) and MW1 (*p*=0.049), and a significant decline at T5 (*p*= 0.016).

There was clear seasonal variation in trap rates for total sediment and fine sediments, as well the percentage of fine sediments across locations (Figure 17). The open coast localities all followed a similar pattern with a small peak in trap rates in summer (January-March) and a larger peak in winter (June-July), with lowest trap rates in spring (October-November). In contrast, the percentage of fine sediment was lowest in winter and peaked in spring. The seasonal patterns in trap rates for open coast locations were more variable but generally lowest in spring. There was strong seasonal variation at Meola Reef with the highest trap rates in summer (January and February) and in spring (September-November) and lowest trap rates in winter. The majority of trapped sediments was fine (<63) so the trap rate for fine sediments and the percentage fines at Meola followed a similar seasonal pattern.

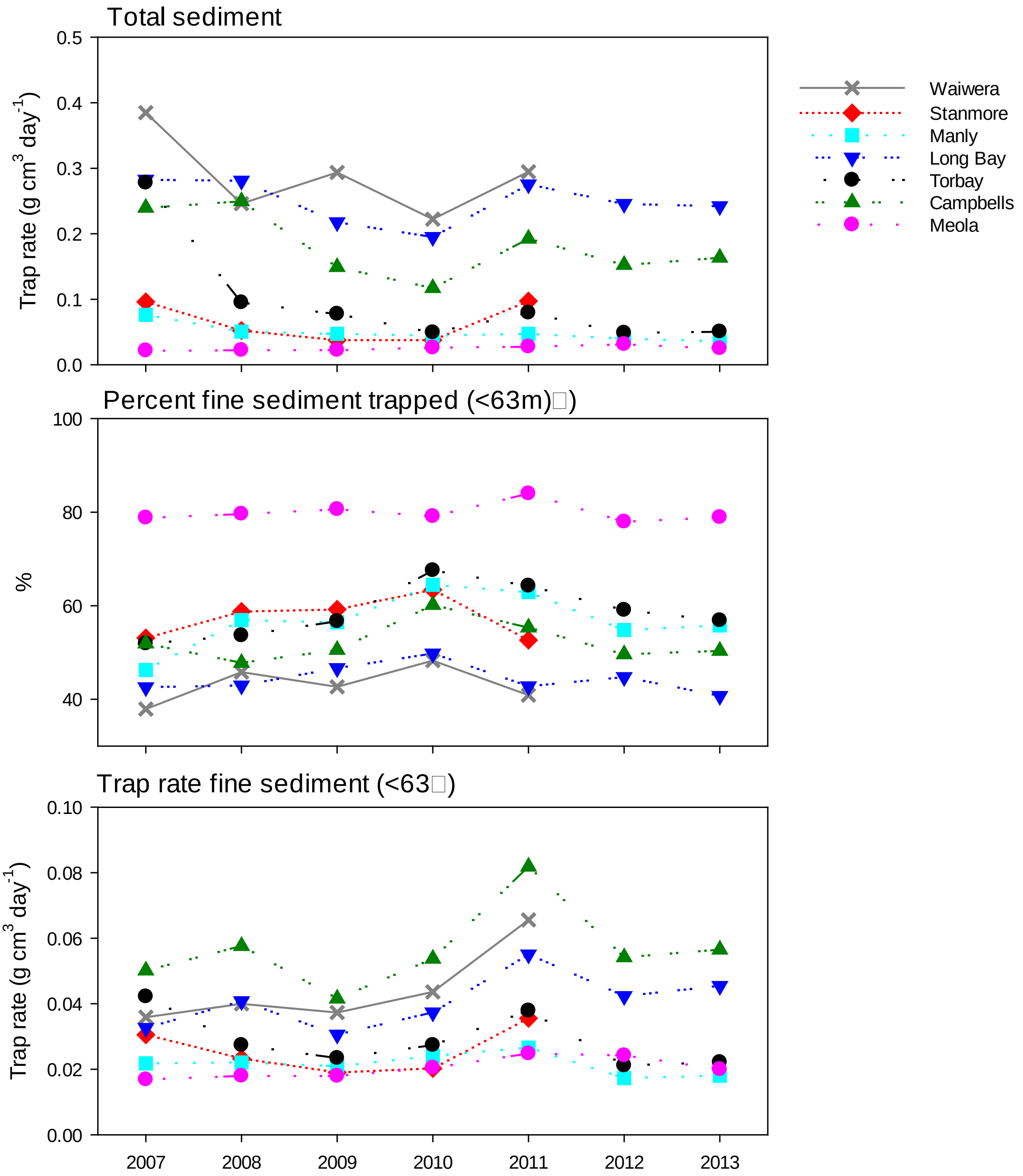


Figure 16: Location-level variation in sediment trap rates and the percentage of fine sediments from 2007-2013.

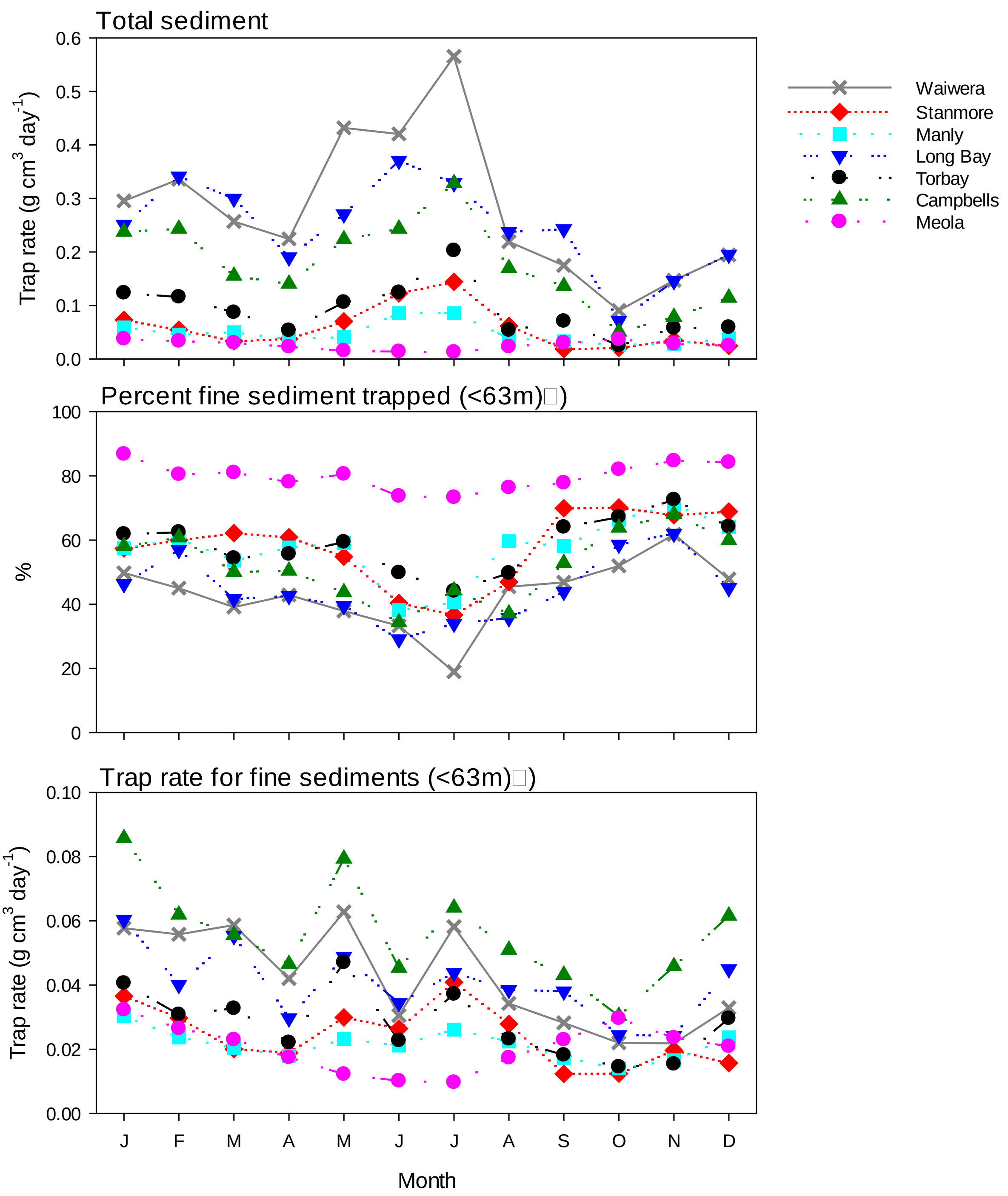


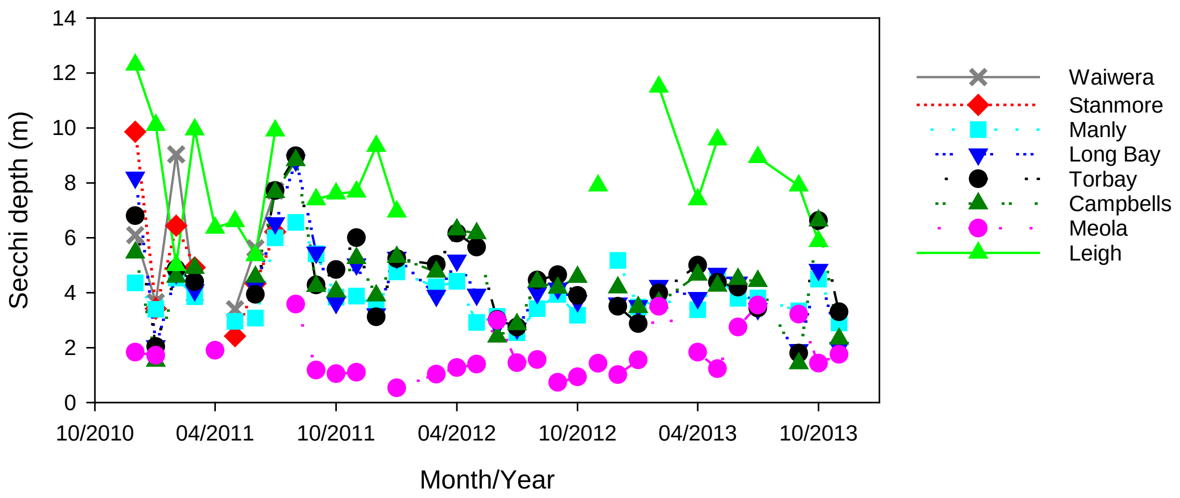
Figure 17: Seasonality in sediment trap rates and percentage fine sediments among locations.

3.2.3 Turbidity (Secchi)

Turbidity, as measured by Secchi depth, varied considerably among locations and over time (Figure 18 A and B). There was insufficient time series to detect long-term changes, but clear differences in turbidity were evident among the locations. Meola consistently had the lowest secchi readings (highest turbidity), followed by Manly.

Leigh typically had the highest secchi readings followed by Waiwera and Stanmore Bay. Secchi depth at Long Bay was generally similar to Campbells Bay and Torbay and marginally higher than Manly. There was some evidence of seasonality at Meola with the highest secchi readings (clearest water) occurring in the winter (June-August) (Figure 18A). At open coast locations there was no clear evidence of any seasonality in water clarity.

A



B

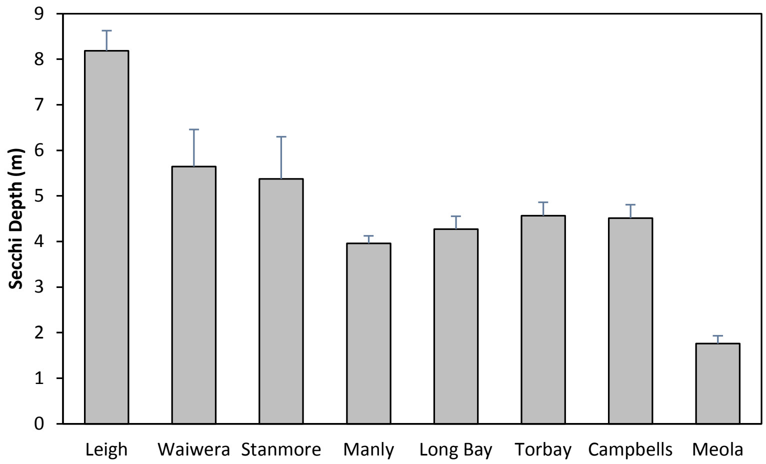


Figure 18: Variation in Secchi depth over time (A) and overall mean secchi depth (+ SE) among locations (B). Data from Leigh are included for an outer Hauraki Gulf comparison. Locations in (B) are arranged from north to South.

4.0 Discussion

The Long Bay and Meola Reef Marine Monitoring Programme represents a nationally unique monitoring programme for subtidal rocky reefs, due to its longevity and the large number of sites that are sampled on an annual basis. The primary aim of this programme is to detect changes in subtidal reef communities that identify potential impacts, particularly in relation to land use change.

4.1 Macroalgal canopies

The programme centres on relatively sheltered shallow reefs in the inner Hauraki Gulf that are dominated by canopy-forming large brown algae (Figure 19), particularly the large fucoids *Carpophyllum maschalocarpum* and *C. flexuosum* (Shears and Babcock 2004). These communities are generally considered stable compared to more exposed locations in the Hauraki Gulf where the kelp *Ecklonia radiata* dominates, and wave action as well as grazing by sea urchins can cause large changes in algal assemblages (Walker 2005). Algal canopy composition has remained relatively stable at all locations (except for Meola Reef) since 2007. While there have been some changes in the relative abundance of dominant species, the reefs at the open coast locations remain dominated by a mixed canopy of *C. maschalocarpum*, *C. flexuosum*, *Ecklonia radiata*, and to a lesser extent *C. plumosum*, *Sargassum sinclairii* and *Cystophora retroflexa*. This is largely consistent with earlier data from these sites (Shears and Babcock 2004, Walker 2005, Ford and Pawley 2008, Shears 2010a) and demonstrate that, while the relative dominance of species may vary, these sheltered reefs are characterised by a relatively stable large brown algae canopy.

At Meola Reef located within the Waitemata Harbour there has been a significant change in canopy composition over time. This primarily involved a large increase in the abundance of kelp *Ecklonia,* which now dominates the reef at these sites, and a decline in *C. maschalocarpum* and *C. flexuosum*, which dominated previously. The increase in kelp and decline in *Carpophyllum* species is contrary to expectations based on the highly urbanised nature of the Waitemata Harbour catchment, high turbidity and high nutrients. Worldwide kelp has been lost from urbanised reefs as a result of pollution (Connell et al. 2008). The reef at Meola is shallow (~1m depth at MLW), and therefore presumably subject to sufficient light to support *Ecklonia,* despite the high turbidity. The increase in *Ecklonia*, does however appear to reflect a region-wide trend with increases in *Ecklonia* also observed at Long Bay, Stanmore Bay and Waiwera sites. This is particularly evident when compared with earlier data from the monitoring programmes (Figure 20). Unlike *Carpophyllum maschalocarpum* and *C. flexuosum,* which exhibit strong zonation in density with depth, *Ecklonia* abundance is similar across depths at these sites (Shears 2010a). Therefore, the data from prior to 2007 for *Ecklonia* can be considered useful in assessing long-term change despite sampling now being carried out deeper than when the programme was established.

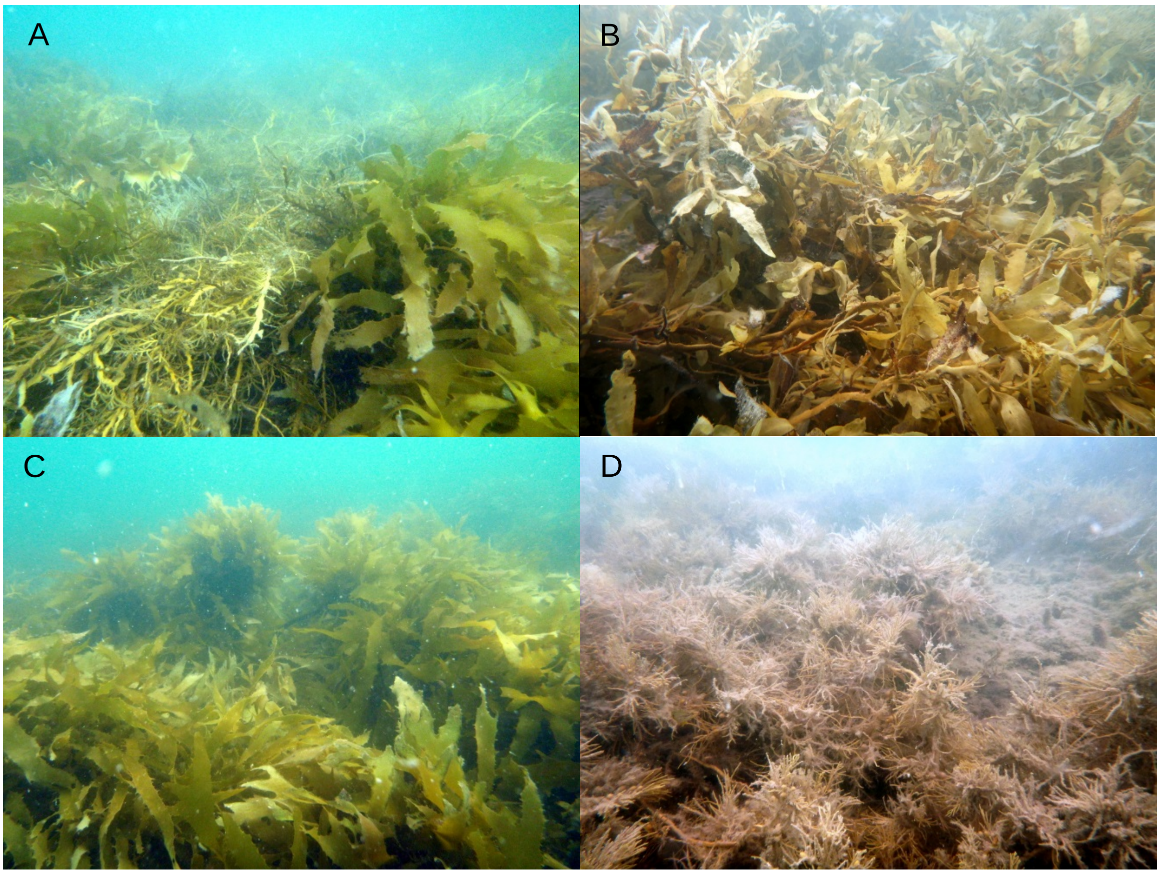


Figure 19: Examples of the variation in macroalgal canopies at the monitoring sites. (A) Canopy dominated by *C. maschalocarpum* and *Ecklonia radiata*, (B) *C. flexuosum* dominated canopy at M5, (C) *Ecklonia* dominated canopy at L5, and (D) canopy dominated by *Cystophora retroflexa* at M3. Open patches dominated by coralline turf are also evident in (D) with *Styela clava* present.

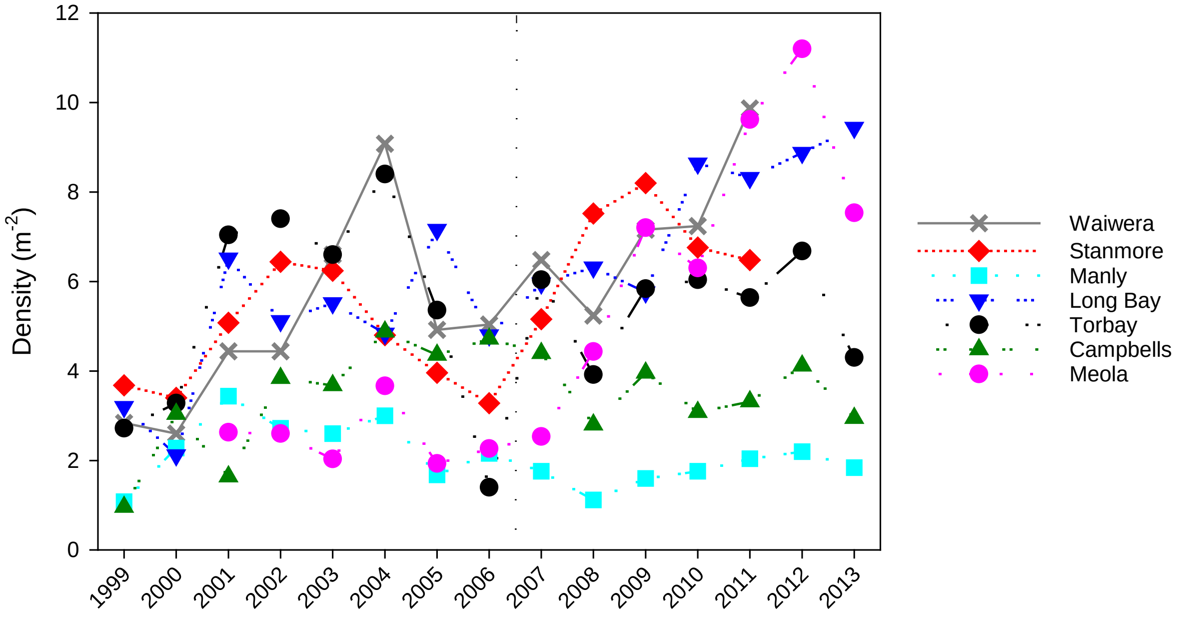


Figure 20: Long-term trends in *Ecklonia radiata* (adult plants) for the Long Bay and Meola Monitoring Programmes. Note: Data from prior to 2007 are included as *Ecklonia* density estimates will have been less affected by movement of sites compared to other species (Shears 2010a).

The mechanism responsible for the increase in *Ecklonia* across these locations is unknown and given the reasonably large-scale of these changes may reflect large-scale climatic variation and a shift to conditions more favourable for *Ecklonia*. Kelps in general are cool water species and *Ecklonia* is vulnerable to warming conditions (Wernberg et al. 2013). However, there are no obvious trends in sea temperatures or the Southern Oscillation Index over this period (Figure 21). When the programme was started in 1999, this was a relatively strong La Nina period with particularly warm temperatures, following on from the strong El Nino and cooler temperatures in 1997 and early 1998. Temperatures were also cooler in 2004 and 2006, associated with El Nino conditions, but since then have generally been within 1^{o} of long-term means. The strong La Nina conditions in 2011 and 2012 did not correspond to particularly warm sea surface temperature. Maximum summertime temperatures at the monitoring locations around Long Bay are generally warmer than at Leigh and typically about 23^{o}C (N. Shears unpubl. data 2010-2013). This is similar to maximum summertime temperatures along much of Western Australia, where *Ecklonia* predominates (Wernberg et al 2010), but below the temperatures (25-28^{o}C) that caused large-scale mortality of kelp in the northern parts of Western Australia (Wernberg et al 2013). Long-term changes in temperature have been shown to influence the composition of algal communities on intertidal reefs in New Zealand

(Schiel et al. 2004). It is currently unknown how particular temperature, light or nutrient conditions in the Hauraki Gulf might differentially favour *Ecklonia* or the dominant fucoid species (*C. maschalocarpum* and *C. flexuosum*). Continued monitoring at these sites will likely provide insights into how variation in SST, and ENSO, affect algal communities in the Hauraki Gulf.

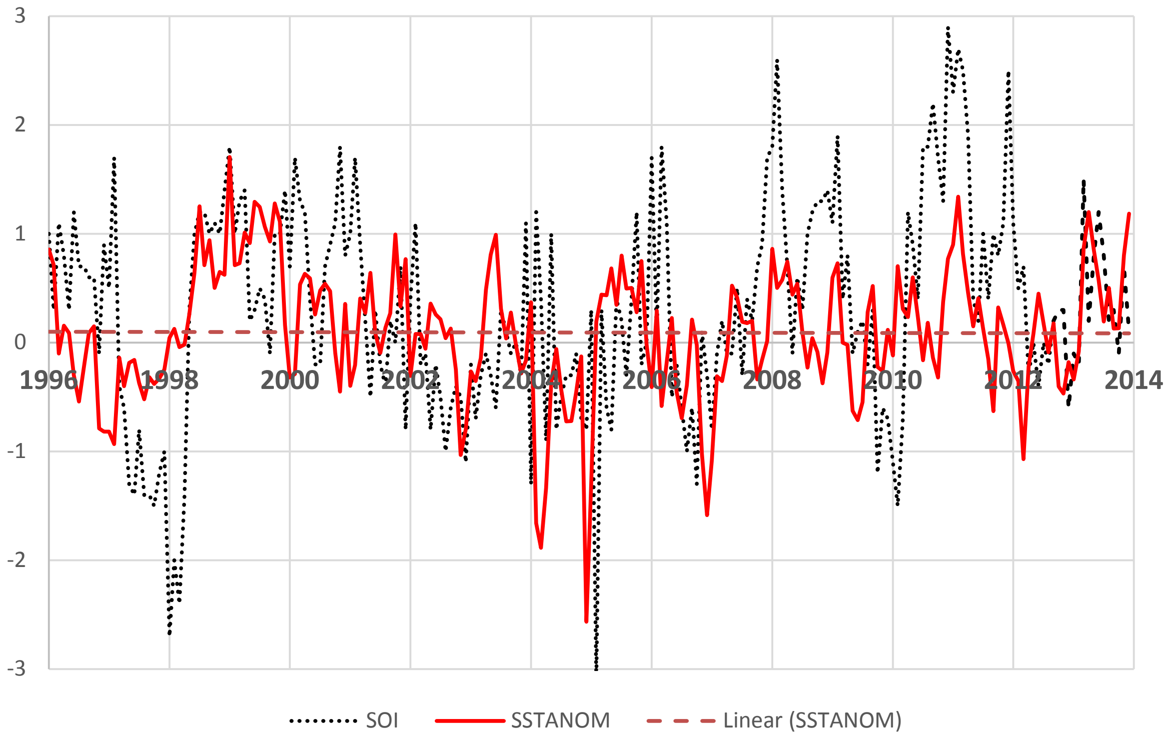


Figure 21: Monthly sea surface temperature anomaly (°C) at the Leigh Marine Laboratory, and the Southern Oscillation Index, from 1996-2013. SST anomalies are calculated from long-term monthly means based on the long-term time series at Leigh (1967-2013). Dashed red line indicates linear regression line through SSTANOM.

4.2 Encrusting assemblages

The increase in *Ecklonia* at many of the locations does have implications for the associated community found on the reef. *Ecklonia* being stipitate and erect, compared to the fucoid species that generally lay more prostrate on the reef, support a different understory encrusting fauna with more solitary and compound ascidians. The cover of solitary ascidians has increased at a number of sites, in particular at locations where *Ecklonia* has increased.

A general change in encrusting assemblages and an increase in overall benthic encrusting diversity was observed between the periods 2007-2009 and 2010-2013. This change is, however, more likely an artefact of changes in observers, as more categories have been recorded since 2010 including hydroids and compound ascidians, which are relatively common on the reefs. This is the most likely explanation for the consistent change in encrusting communities across all locations. There are inherent difficulties associated with estimating per cent covers of encrusting communities, which can be highly patchy and diverse (Figure 22), especially while diving and often under turbid and rough conditions. While other methods such as using photoquadrats may provide an improvement, allowing for greater accuracy and taxonomic resolution, the current method is relatively efficient and provides a broad measure of overall encrusting assemblage structure and diversity. Furthermore, the trends in diversity and overall community composition are consistent among the locations.

Analyses of the main categories over time, such as the cover of sponges are reliable and generally suggest the overall benthic encrusting assemblage structure at the locations is relatively stable. The widespread decline in crustose coralline algae is likely an artefact of more accurate estimates being made in recent years that take into account the cover of other groups that had not previously been recorded. Articulated coralline turf (*Corallina officinalis*) is highly patchy and overall only covers a small fraction of the reef. However, at some sites, particularly those with flat shelving reefs at Torbay, Long Bay and Manly, the algal canopy is lacking from patches of reef, which are dominated by coralline turf, the small brown algae *Zonaria turneriana* and sediment. In many temperate regions worldwide macroalgal forests have been lost from coastal reefs and replaced by turfing assemblages that trap sediments and are not amenable to macroalgal recruitment (Copertino et al. 2005; Mangialajo et al 2008; Wernberg et al 2013). Currently, these areas of turfing algae, and conversely the surrounding algal canopies, appear to be relatively stable at the locations sampled. However it is important that monitoring these communities continues to provide information on the state of these reef ecosystems and provide early detection should canopy loss begin to occur in the Hauraki Gulf.

Figure 22: An example of a representative understory encrusting community beneath the macroalgal canopy at Long Bay demonstrating the diversity, patchiness and complexity of the community. This area of reef, approximately 15 x 15 cm, has at least four species of sponge, a hydroid, barnacles, crustose coralline algae, small Zonaria turneriana plants, areas covered by filamentous algae, sediment and shell hash and *Ecklonia* holdfasts. Quantifying this community accurately with visual estimates using a 1m^2 quadrat is not possible.

4.3 Mobile macroinvertebrate assemblages

Mobile macroinvertebrates are known to be highly variable among sites and over time on northern New Zealand reefs (Choat and Andrew 1986). General differences in mobile macroinvertebrate assemblages among locations are consistent with their physical setting in the Hauraki Gulf (Shears and Babcock 2004). Meola Reef, being the most sheltered location and situated within the Waitemata harbour, lacked many of the species common on the open coast, e.g. *Cookia sulcata* and *Cantharidus purpureus*, but supported more invasive species such as the Japanese paddle crab *Charybdis japonica*. Among the open coast locations assemblages varied in relation to wave exposure, with the more exposed locations (Waiwera, Stanmore Bay and Campbells Bay) having higher densities of *Cantharidus*, *Trochus viridis*, *Patiriella regularis*, *Micrelenchus* sp. and *Stegnaster inflatus*, whereas the most sheltered open coast location Manly had higher densities of *Lunella* and *Maoricolpus* and comparatively low numbers of *Trochus, Cantharidus* and *Cookia*.

Macroinvertebrate assemblages generally remained stable over the monitoring period. A number of the common species did exhibit some interesting patterns over time, that were largely evident across all of the open coast locations. *Lunella* is the numerically dominant species on sheltered reefs in the Hauraki Gulf (Walker 2005, Shears and Babcock 2004). The abundance of *Lunella* fluctuated over the monitoring period in a consistent manner at the open coast locations, with peaks in density in 2007 and 2009. These patterns likely reflect variable levels of recruitment over time, which is a common feature of the life histories of many molluscan species (Creese 1988). *Trochus viridis* and to a lesser extent *Cantharidus purpureus* exhibited similar fluctuations across locations with a peak in abundance in 2009 and subsequent declines. These trends appear to reflect region-wide processes.

4.4 Sedimentation

Sedimentation, due to runoff from the land, is considered one of the major impacts on the Hauraki Gulf (Kelly 2011), and was considered one of the likely impacts of the development at Long Bay. Extensive sediment controls, including multiple retention ponds, limiting open earthworks areas, progressive stabilisation, diversion drains, baffles and flocculation, have been put in place to manage sediment runoff during the development. The current monitoring programme utilises sediment traps to measure sedimentation levels on the coastal reefs, and more recently (since 2010) turbidity has also been measured monthly at the monitoring sites using secchi disc measures. The shallow reefs monitored in this programme are relatively flat and the reef-sand border is at relatively shallow depths (~3m below MLWS). Sites with the highest trap rates are generally in close proximity to the sand and most of the sand collected in the traps is coarse sand that has been resuspended by wave action. Therefore, it is more informative to examine trends in the trap rate for fine sediments (<63 microns).

Over the period from 2007-2013 the trap rate for fine sediments appears to increase, with the highest rates occurring in 2011. This peak was apparent at all of the open coast locations in 2011 and was likely due to high rainfall associated with Cyclone Wilma (29th January 2011, Figure 23). Cyclone Wilma was the first tropical cyclone on record to hit New Zealand, while still being classified as a tropical storm/cyclone. At the Leigh Marine Laboratory, where daily rainfall has been recorded since 1967, there was 194 mm of rain on January 29th, making it the wettest day on record. There was also 151 mm of rain a week earlier on January 23rd, which was the third wettest day on record. Consequently, January 2011 was the second wettest month since

1967 and by far the wettest month over the course of the current monitoring programme monitoring (Figure 23). These two large rainfall events resulted in a large number of slips around much of the coast where monitoring is carried out (Figure 24) and around Leigh (pers. obs.). In many cases, clay and debris associated with these slips was present along the shore for months after the cyclone and sediment was observed to be continually dispersed by spring tides and easterly swells. Weather conditions throughout 2011 and early 2012 were La Nina with frequent easterly storms. The highest trap rates for fine sediment in 2011 were recorded in June and associated with a large easterly storm and relatively low rainfall. It is therefore highly likely that the higher rates of fine sediment in 2011 are due to continued resuspension and dispersal of sediments that were deposited along the coast and in the nearshore environment by Cyclone Wilma. Overall, the patterns in sedimentation observed at Long Bay were reflective of the other monitoring locations and did not appear to differ as a result of the development. Furthermore, turbidity at the Long Bay sites (as measured by secchi disc) was generally comparable to surrounding locations. Turbidity was marginally higher at Manly, which is perhaps more strongly influenced by discharge from the Okura and Weiti Rivers.

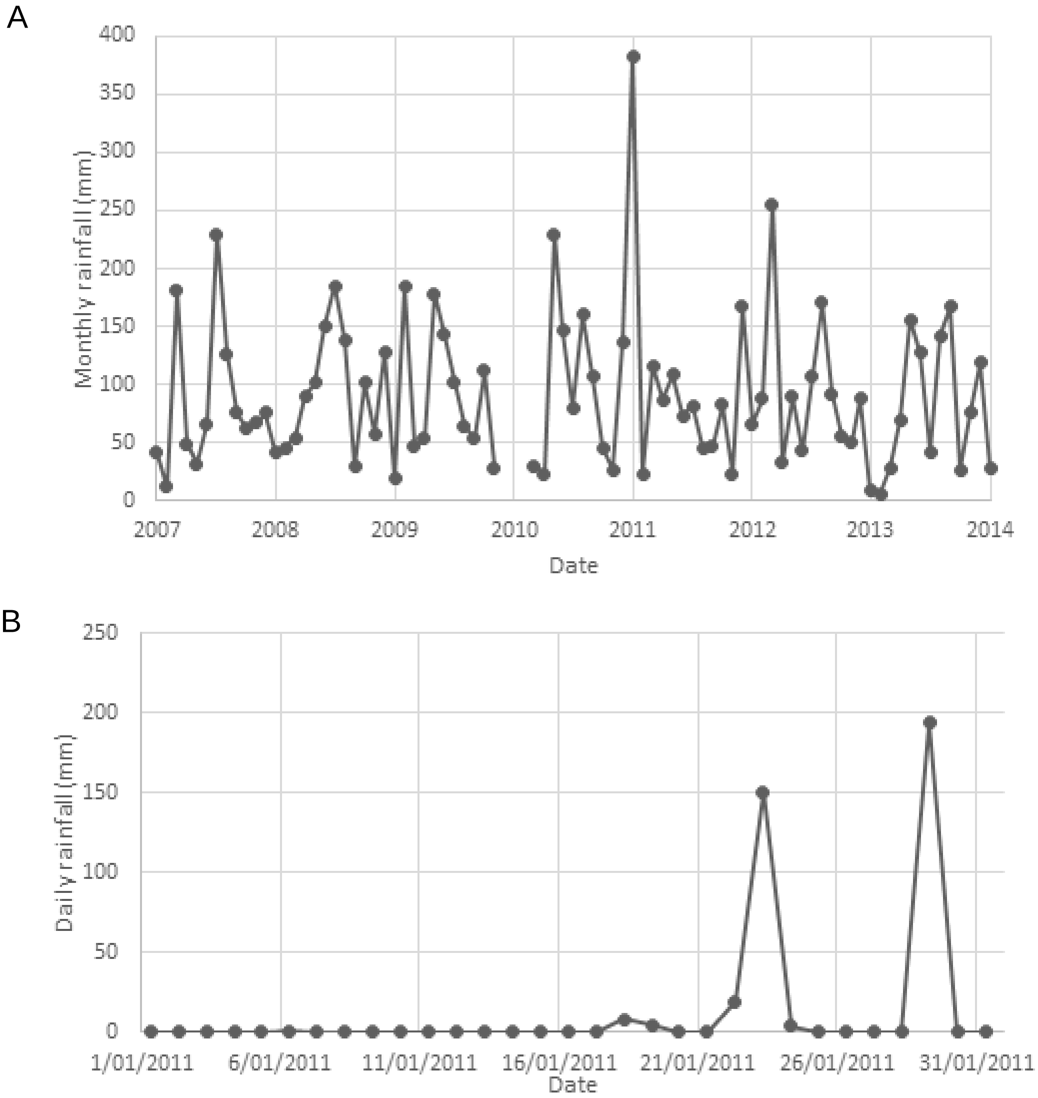


Figure 23: Rainfall data from the Leigh Marine Laboratory; (A) Total monthly rainfall from 2007-2013 and (B) Daily rainfall in January 2011 (Cyclone Wilma January 29th 2011).

Figure 24: Cliff subsidence and accumulation of clay on the foreshore of the Long Bay-Okura Marine Reserve adjacent to subtidal monitoring sites. These slips occurred as a result of heavy rains associated with Cyclone Wilma, January 28th 2011. Photos taken 17th February 2011.

4.5 Invasive species

Perhaps the greatest change in reef assemblages over the last seven year is the appearance of, and increase in abundance of invasive species (Fig. 25). Consequently, the monitoring programme provides important information on the spread of invasive species, the rate of increase in populations on the reefs, and their potential impacts on native flora and fauna. Since the last report on these monitoring programmes (Shears 2010a and 2010b), two new invasive species have been recorded at Meola Reef, the Japanese kelp *Undaria pinnatifida* and the Mediterranean Fanworm *Sabella spallanzanii.* In 2013, *Sabella* was also recorded at Campbells Bay (C1) indicating that it has begun to spread beyond the Waitemata Harbour. Both of these species are widespread invaders on temperate reefs and can have a variety of impacts on native reef flora and fauna (Thompson and Schiel 2012; Holloway and Keough 2002). *Sabella* was first recorded in Lyttelton Port and the wider Waitamata Harbour in 2008 (Read et al. 2011), and has more recently been reported in Whangarei Harbour (www.biosecurity.govt.nz)**.** *Styela clava* was first recorded at the Long Bay sites in 2006.

Undaria was first recorded at Meola in 2011. The surveys in 2011 were carried out in July, which is later in the year than normal due to poor weather over the summer associated with La Nina conditions. In the Hauraki Gulf *Undaria* has a winter-annual lifecycle (K. James Unpublished data), therefore it was of concern that it may have been present in earlier years, but not at the time when surveys were carried out (February). However, subsequent surveys in February have recorded juvenile *Undaria* sporophytes on the reef. Therefore, it is likely that *Undaria* became established around 2010. *Undaria* is now found throughout New Zealand from the far north (James et al 2014) down to the Snares Islands (www.biosecurity.govt.nz). It was first found in the Waitemata Harbour in 2004 and is now found throughout the harbour. It is also known to occur at Great Barrier Island, the Coromandel Peninsula, and was also seen on the end of Whangaparaoa Peninsula in 2012 (J. Walker pers. comm.). Therefore it is highly likely that *Undaria* will spread to other monitoring sites in the coming years. The impact of *Undaria* on native flora and fauna in northern New Zealand is unknown. The current monitoring programme will provide important information on the continued spread of *Undaria,* but also on the habitats in which it occurs and the potential impacts on reef assemblages.

The abundance of a number of other invasive species has also increased throughout the monitoring programme. The parchment worm *Chaetopterus* sp. was first recorded at Long Bay in 2002 and generally increased across most bays until 2008. While it is found at most sites, it typically covers <1 % of the reef and does not appear to impact on the native reef communities. The clubbed tunicate *Styela clava* was first recorded in 2006 (one individual at M1) and has generally increased since. Twenty individuals were recorded in 2010 and these were found at 7 sites (C3, L2, M1, M5, S5, T3 and T4). While only occurring at low densities now (<1 m2), this species appears to spreading throughout the Hauraki Gulf and can achieve very high densities on aquaculture structures overseas (Locke et al. 2007). The potential threat of this species to the indigenous reef community is unknown and continued monitoring will shed light on this.

Figure 25: Invasive species that have become established at monitoring sites during the course of the Long Bay and Meola monitoring programmes (clockwise from top left, the invasive kelp Undaria and the Mediterranean fanworm *Sabella spallanzanii*; close-up of *S. spallanzanii*; the Japanese paddle crab *Charybdis japonica*; the clubbed ascidian *Styela clava*.

4.6 Implications and application

The reefs monitored in the East Coast Subtidal Monitoring Programme can largely be characterised as urban reefs and water quality in these areas is likely influenced by activities on the land. In many temperate ecosystems worldwide, e.g. in the Mediterranean, South Australia and California, macroalgal canopies have been lost from such urban reefs due to a range of local stressors including sedimentation and nutrient pollution (Copertino et al. 2005; Mangialajo et al. 2008; Foster and Schiel 2010). Furthermore, research has indicated that such local stressors will interact synergistically with climate change and exacerbate canopy loss on temperate reefs worldwide (Russell et al 2008). Large-scale canopy loss has been seen in parts of Western Australia as a result of warming temperatures (Wernberg et al. 2013). To date, such changes have not been observed on the reefs monitored in the East Coast Subtidal Monitoring Programme. Other than the increased prevalence of introduced species on shallow reefs, the monitoring programme has revealed little change in reef assemblages that can be attributed to environmental degradation, over the current monitoring period (2007-2013) and also compared to the historic data dating back to 1999 (Shears 2010). The reefs remain dominated by large brown algal canopies, support a variety of mobile macroinvertebrate species and a relatively diverse encrusting assemblage beneath the canopy.

The Hauraki Gulf is under increasing pressure with a rapidly growing population in Auckland and ever increasing demands on marine ecosystems for resources and recreation. The 2011 State of Environment Report on the Hauraki Gulf (Kelly 2011) “suggest that the Gulf is experiencing ongoing environmental degradation, and resources are continuing to be lost or suppressed at environmentally low levels.” The major problems identified were overexploitation of ecologically important species and runoff of comtaminants, sediment and nitrogen into various parts of the Gulf. Little has been done since this report to safeguard the ecosystems within the Hauraki Gulf and the more recent 2014 State of Environment indicates continued decline in many ecosystem health metrics (Kelly et al. 2014).

Macroalgal assemblages on coastal reefs provide a variety of important ecosystem services, yet our general understanding of these is poor. The importance of the macroalgal dominated shallow reefs in the inner Hauraki gulf in terms of providing habitat, food and and contributing to the coastal foodweb is poorly understood. Recent research has demonstrated that net primary productivity can be estimated for rocky reef algal assemblages using a simple model based on the photosynthetic parameters of macroalgal species present, macroalgal biomass and light levels at a given site (Miller et al. 2013). Therefore, by combining biomass and light data collected from the monitoring sites, with existing photosynthetic parameters (Shears and Babcock 2004), it will be possible to estimate productivity of these shallow reef assemblages. Furthermore, recent development of habitat maps of shallow reefs in the Hauraki Gulf based on satelite imagery and aerial photos, provides a means of scaling up the in-situ monitoring data to estimate overall productivity of shallow reefs in the Hauraki Gulf and their wider contribution to coastal production. Combining both of these methods, i.e. traditional in-situ sampling and contempary habitat mapping techniques based on imagery, will also provide a powerful monitoring tool for monitoring reefs and other coastal habitats at large spatial scales.

Given the ever increasing pressures on the Hauraki Gulf and the impending threat of climate change it is essential that monitoring be continued to document changes and inform management of potential links with anthropogenic stressors so that actions can be taken to understand and mitigate these impacts.

4.7 Recommendations

Some additions and changes to the sampling methods are recommended to increase the information available to interpret trends, but also to improve the taxonomic resolution of the monitoring programme.

- Additional estimates of the percentage cover of algal canopies should be taken. At some sites there has been a potential reduction of the canopy cover with more open space on the reef, but these changes are not easily distinguishable based on density data. Per cent canopy is easily measured and is widely used in other studies of temperate reefs. Habitat mapping based on regular satelite or aerial imagery may also provide important insights into changes in the extent of algal canopies.
- To improve the taxonomic resolution and accuracy of sampling benthic encrusting assemblages it is recommended that photoquadrats be trialled. This is particularly important in determining overall species diversity as well as increasing the chances of documenting any invasive species. There is a relatively large diversity of encrusting sponges and ascidians that are not currently being sampled. Photoquadrats also provide a long-term record, but their application in these dense algal forests needs to be tested.

- Temperature and light loggers have been in place since 2010 at one site at Torbay (T2). It is recommended that loggers be deployed at a selection of sites (one site per location). Information on temperature and light combined with nutrients from regional water quality monitoring programmes may provide insights into interannual variation in key species.
- Ongoing monitoring is recommended at Long Bay and surrounding areas, as the Long Bay development is still in a relatively early stage and other developments are being proposed in adjacent catchments. The programme should also be expanded to include areas that are beyond the influence of any new developments.

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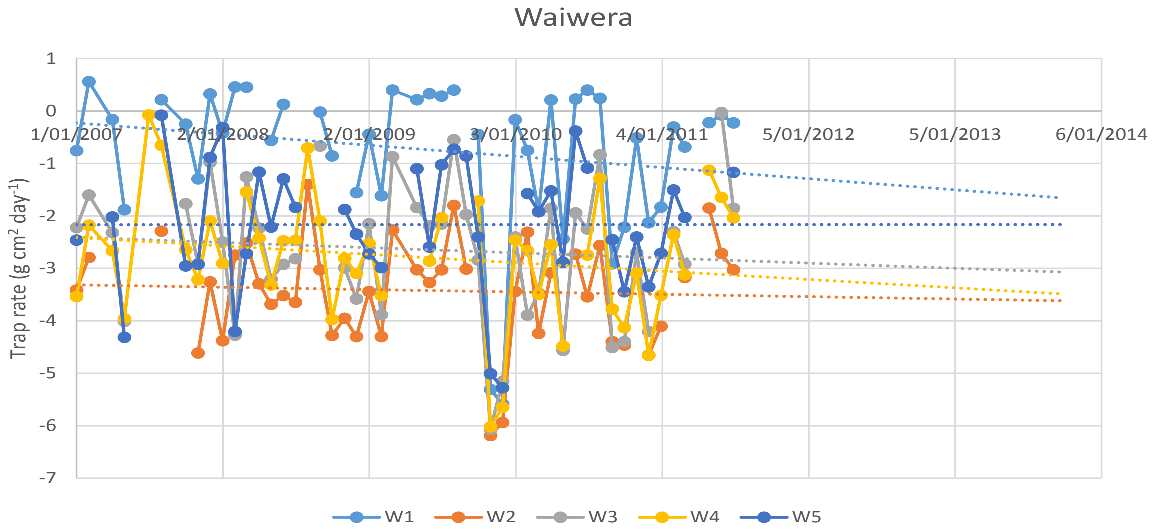
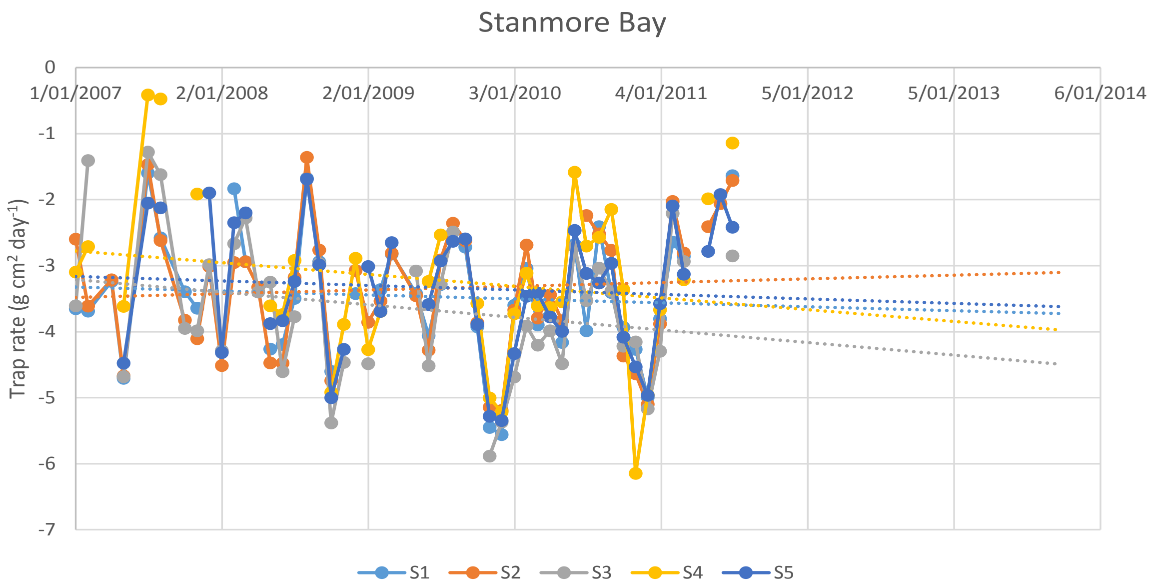
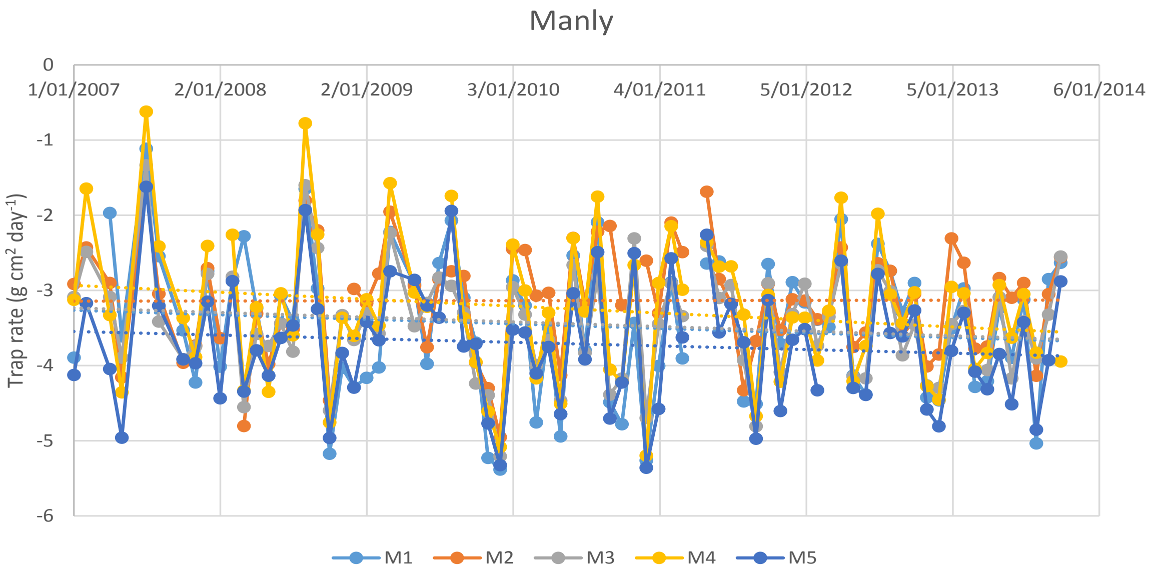
6 Appendix

A. Site-level variation in sediment trap rates (natural log, linear regression)






Manly
0
-1
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-3
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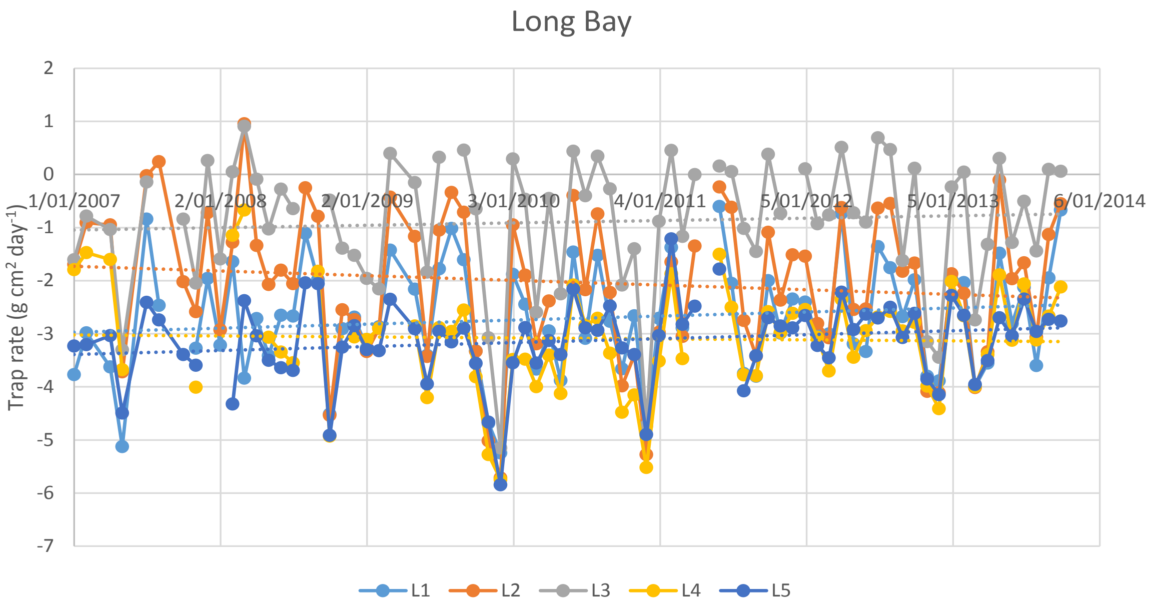
-5
-6
1/01/2007
2/01/2008
2/01/2009
3/01/2010
4/01/2011
5/01/2012
5/01/2013
6/01/2014
Trap rate (g cm² day⁻¹)
M1
M2
M3
M4
M5


Long Bay
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-2
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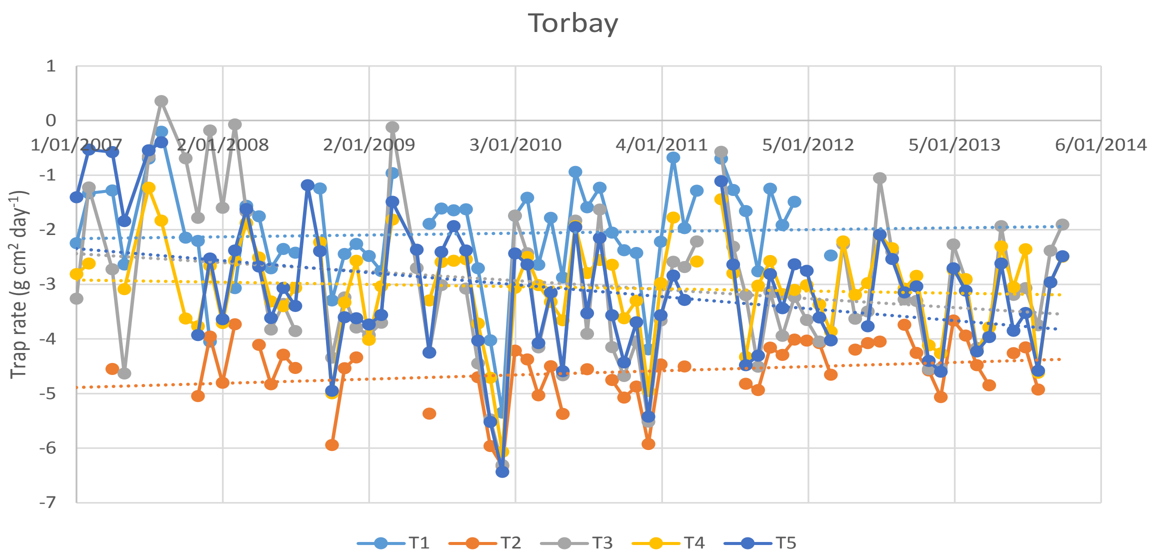
2/01/2008
2/01/2009
3/01/2010
4/01/2011
5/01/2012
5/01/2013
6/01/2014
Trap rate (g cm² day⁻¹)
L1
L2
L3
L4
L5


Torbay
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4/01/2011
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Trap rate (g cm² day⁻¹)
T1
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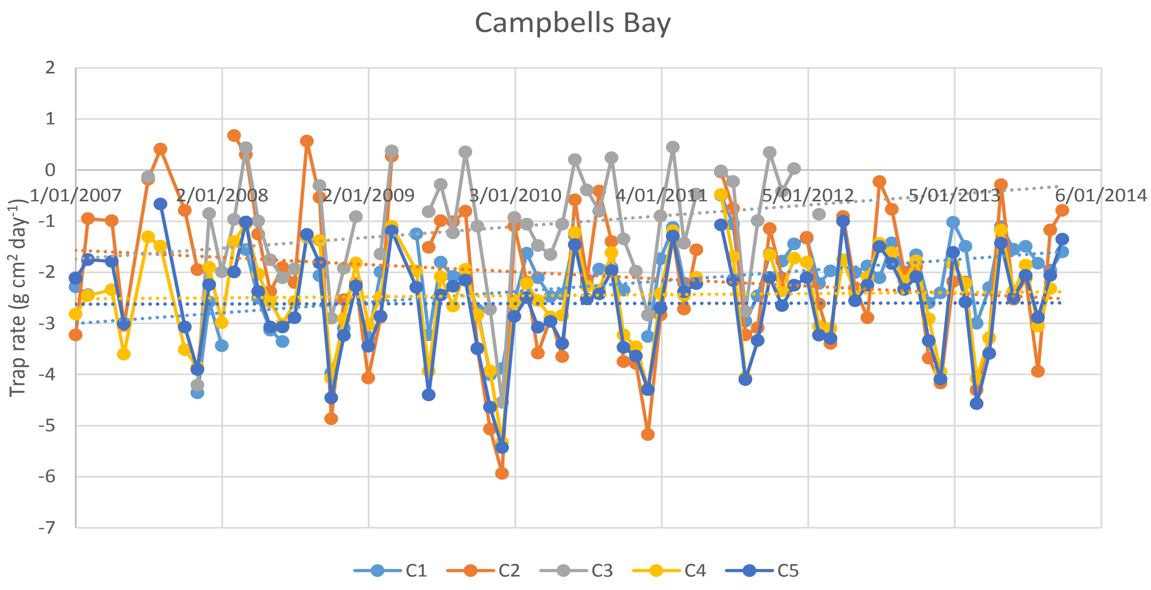
T4
T5


Campbells Bay
Trap rate (g cm² day⁻¹)
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-2
-3
-4
-5
-6
-7
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2/01/2008
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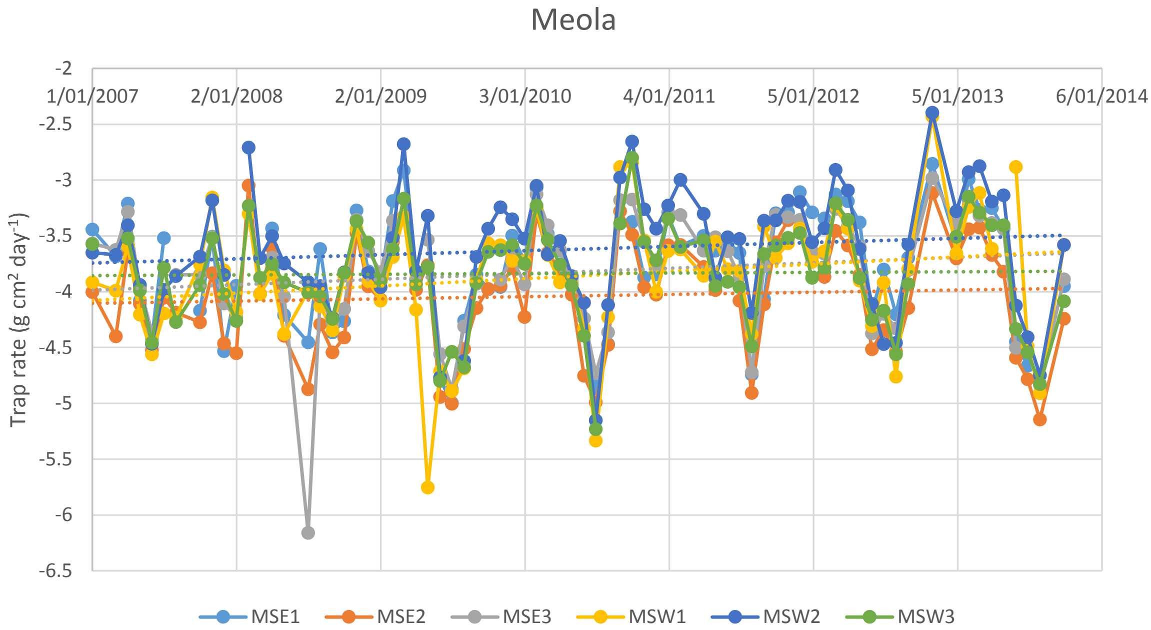
C2
C3
C4
C5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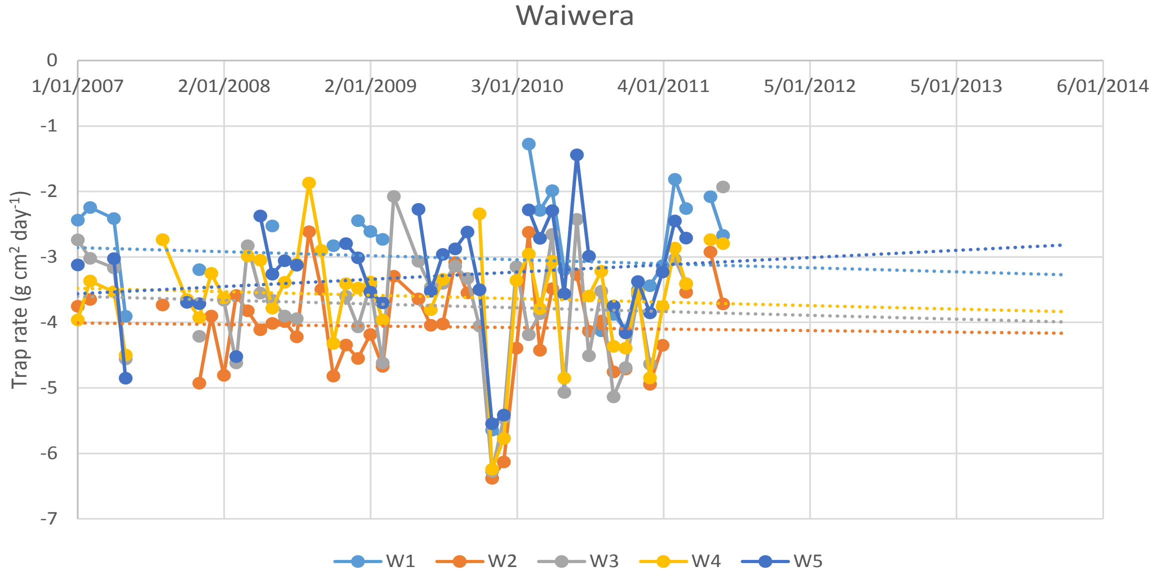
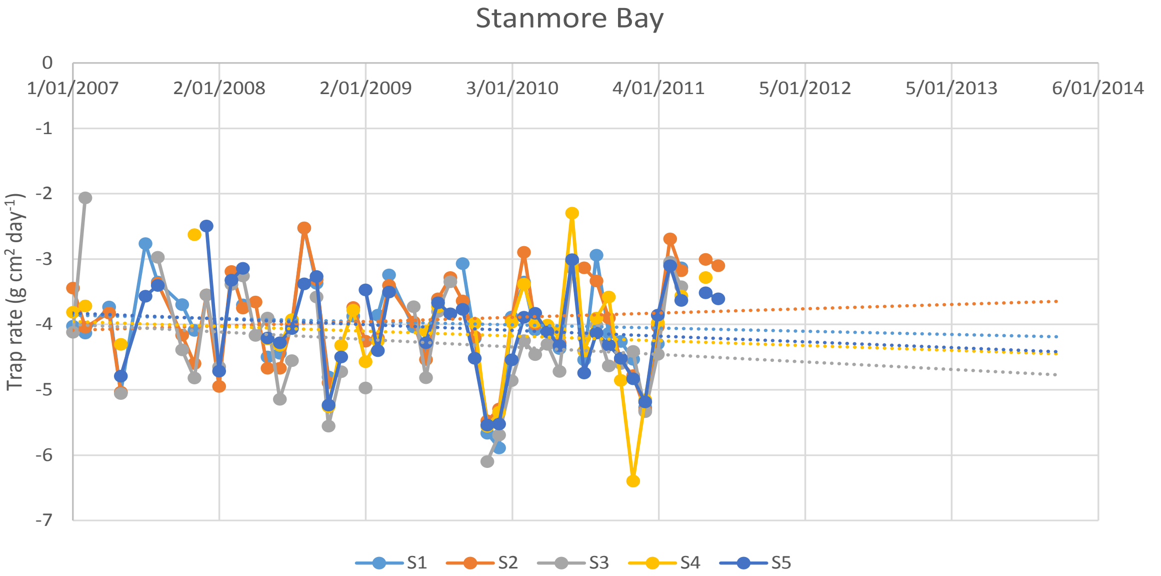
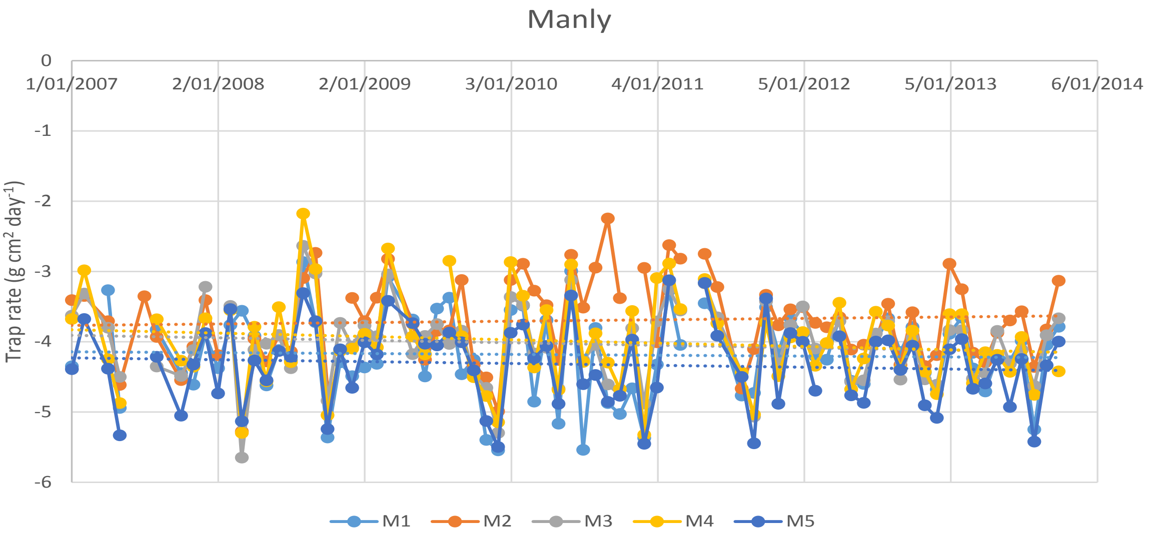
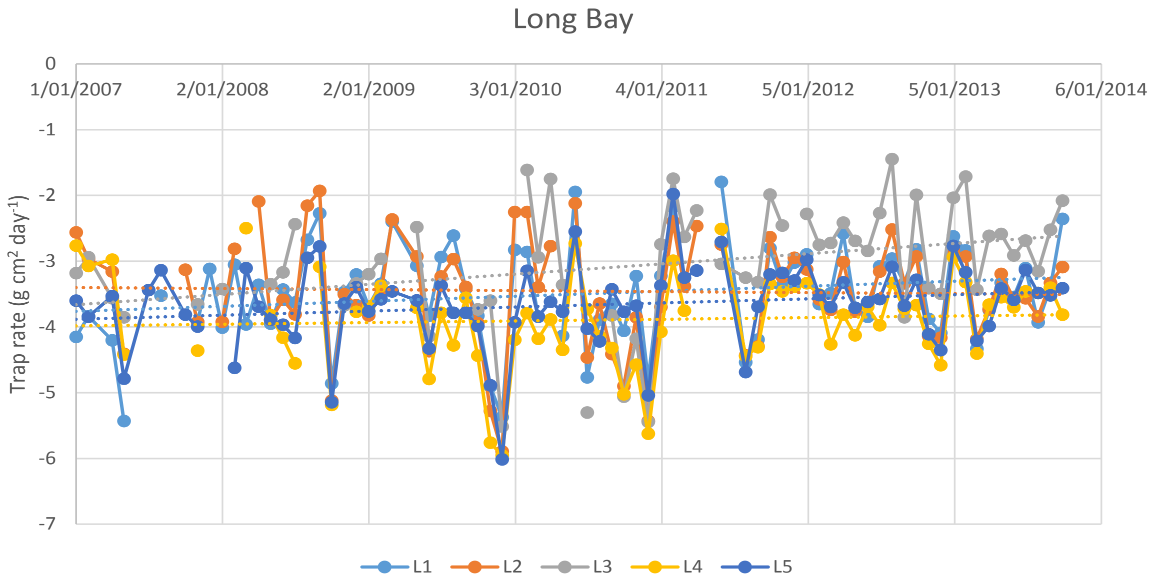
-4.5
-5
-5.5
-6
-6.5
1/01/2007
2/01/2008
2/01/2009
3/01/2010
4/01/2011
5/01/2012
5/01/2013
6/01/2014
MSE1
MSE2
MSE3
MSW1
MSW2
MSW3

B. Site-level variation in sediment trap rates for fine sediment (natural log, linear regression)








Long Bay
Trap rate (g cm² day⁻¹)
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1/01/2007
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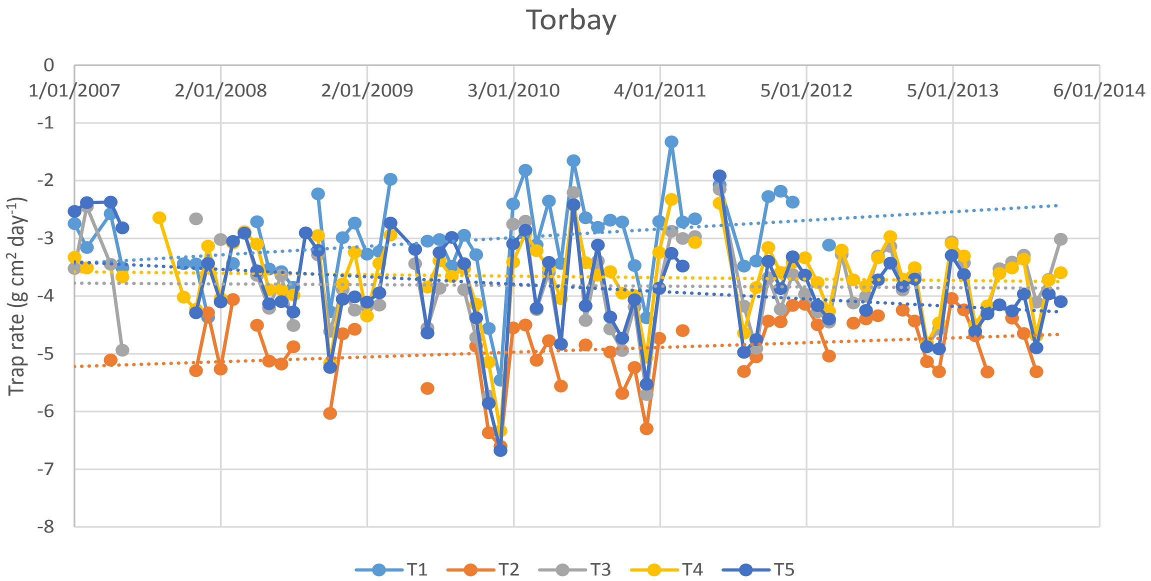
Torbay
Trap rate (g cm² day⁻¹)
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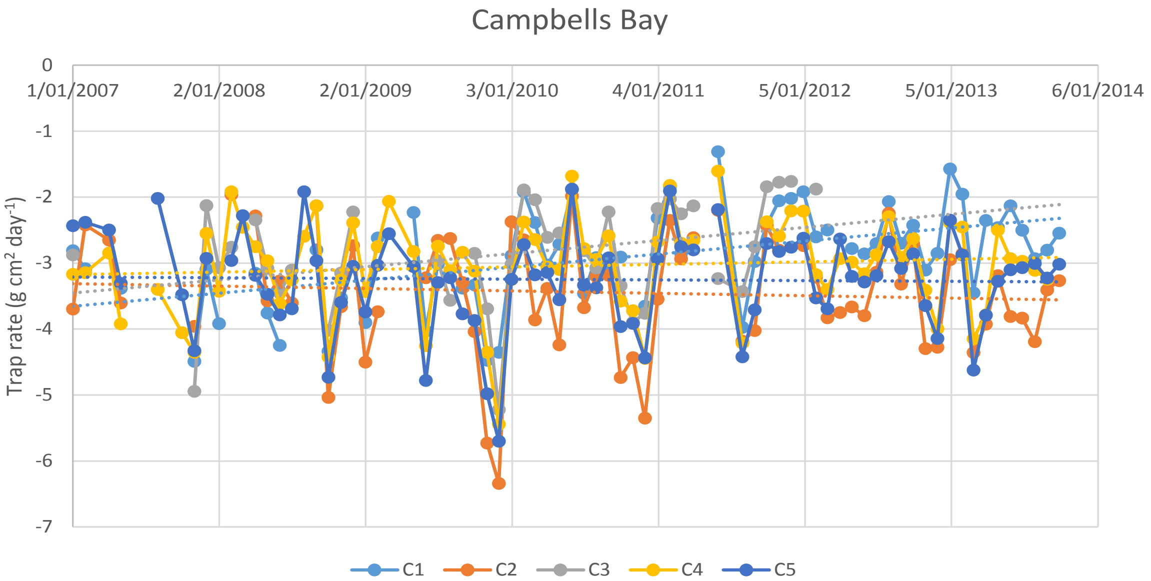
Campbells Bay
Trap rate (g cm² day⁻¹)
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-4
-5
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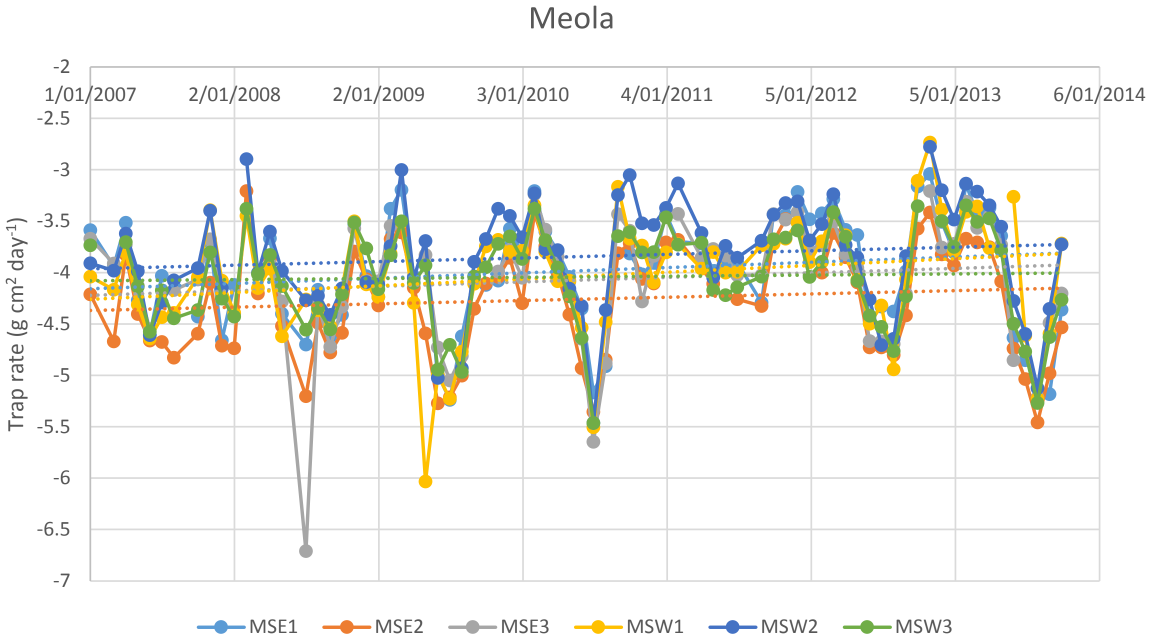
-7
1/01/2007
2/01/2008
2/01/2009
3/01/2010
4/01/2011
5/01/2012
5/01/2013
6/01/2014
C1
C2
C3
C4
C5


Meola
Trap rate (g cm2 day-1)
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
-6.5
-7
1/01/2007
2/01/2008
2/01/2009
3/01/2010
4/01/2011
5/01/2012
5/01/2013
6/01/2014
MSE1
MSE2
MSE3
MSW1
MSW2
MSW3

Find out more: phone 09 301 0101, email rimu@aucklandcouncil.govt.nz or visit aucklandcouncil.govt.nz and knowledgeauckland.org.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau