State of the Environment
Rocky Shore Monitoring Report
2017-2019

Technical Report 2019-69

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Executive summary

Section 35 of the Resource Management Act 1991 requires local authorities to undertake monitoring of the region's environment, including land, air, marine and freshwater domains. The rocky shore component of the State of the Environment Monitoring (SEM) programme for Taranaki was initiated by the Taranaki Regional Council in the 1994-1995 monitoring year and has subsequently continued each year. This report covers the state and trends observed in intertidal hard-shore communities in Taranaki.

As part of the SEM programme, six representative reef sites are monitored twice a year (spring and summer surveys) using a fixed transect, random quadrat survey design. For each survey, a 50 m transect is laid parallel to the shore and substrate cover, algal cover and animal cover/abundance in 25 x 0.25 m^2 random quadrats are quantified. Changes in the number of species per quadrat (species richness) and Shannon-Wiener index per quadrat (diversity) have been assessed at the six reef sites throughout the 25 years of the SEM programme (spring 1994 to summer 2019). In this report, the results of aerial imagery based seagrass mapping carried out at one of the SEM sites, Orapa (near Waitara), are also presented.

Of the six sites surveyed, over the 25 years of monitoring, the intertidal communities at Manihi (West Taranaki) have been shown to be the most species rich and diverse. This is due to a low supply of sand, and the presence of pools that provided a stable environment with many ecological niches. The intertidal communities at Waihi (South Taranaki) are the least species rich and diverse, due to a high energy wave environment and resulting unstable habitat.

Sand deposition has been shown to have a profound effect on intertidal communities in Taranaki, with the sites at Orapa, Mangati and Greenwood Road (North Taranaki) being particularly prone to periodic sand inundation. Trend analysis shows that sand cover has increased at the four northern-most SEM sites. This is likely due to an increased sand supply from the mountain, combined with oceanographic conditions that shift this sand onshore. Although typically short lived, sand inundation events can result in significant reductions in species richness and diversity. Trend analyses suggest that inundation events at Greenwood Road have led to a declining trend in species richness and diversity over time.

The analysis also shows a declining trend in species richness and diversity at Waihi Reef that is unrelated to sand cover. It is possible that this declining trend is related to a change in wave exposure over time, however further investigation is required before this can be attributed as a causal factor.

In summary, natural environmental factors, in particular sand cover, wave exposure and habitat complexity appear to remain the dominant drivers of species richness and diversity at the six SEM reef sites.

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1 Introduction

1.1 State of the environment monitoring

The Resource Management Act 1991 (RMA) established new requirements for local authorities to undertake environmental monitoring. Section 35 of the RMA requires local authorities to monitor, among other things, the state of the environment of their region or district, to the extent that is appropriate to enable them to effectively carry out their functions under the Act.

To this effect, the Taranaki Regional Council (the Council) established a state of the environment monitoring (SEM) programme for the region. This programme is outlined in the Council's *State of the Environment Monitoring Procedures Document*, which was prepared in 1997. The monitoring programme is based on the significant resource management issues that were identified in the Council's *Regional Policy Statement for Taranaki* (1994).

The SEM programme is made up of a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these annual monitoring activities, summary reports are produced following the end of each monitoring year (i.e., after 30 June). Where possible, individual consent monitoring programmes have been integrated within the SEM programme to save duplication of effort and minimise costs. The purpose of annual SEM reports is to summarise regional environmental monitoring activity results for the year, and provide an interpretation of these results, together with an update of trends in the data.

Annual SEM reports act as 'building blocks' towards the preparation of the Regional State of the Environment report every five years. The Council's first, or baseline, *State of the Environment Report* was prepared in 1996 (TRC, 1996b), summarising the region's progress in improving environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003). Data spanning the ten year period 1995 to 2005 have been used in the preparation of a trend report (TRC, 2006). The third *State of the Environment Report* (for the period 1995 to 2007) was published (TRC, 2009a) and included trend reporting and the fourth report (for the 1995 to 2014 period) has been published (TRC, 2015a). The provision of appropriate computer software statistical procedures allows regular reporting on trends in the environmental quality over time, in relation to Council's ongoing monitoring activities, now that there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis of trends (i.e. minimum of 10 years).

This report summarises the results for the sites surveyed in the rocky shore SEM programme over the 2017-2019 monitoring period. Biological communities of the rocky reefs around the Taranaki coastline have been monitored since 1983 by the Taranaki Catchment Commission. A more comprehensive rocky shore monitoring programme was first implemented by the Taranaki Regional Council during the 1994-1995 spring as an on-going component of the SEM programme for the Taranaki region. However, this methodology was not implemented at all six sites until the 1995-1996 summer.

1.2 Taranaki rocky shore intertidal environment

1.2.1 Physical environment

Rocky reefs dominate the intertidal zone of the Taranaki coastline. Around the ring plain, the reefs are largely formed from lahar (volcanic derived) materials. The lahars consist of andesite cobbles and boulders bound within an ash type matrix. Selective erosion of the weaker matrix leaves the harder cobbles and boulders to form large platform reefs. These reefs are typically low in relief but can be considerable in extent e.g. the reefs off the Waitara coastline extend as far as 5 km offshore (TRC, 1991).

Taranaki reefs are exposed to high energy wave and wind conditions. Prevailing south westerly winds from the Tasman Sea, not weakened by land barriers or local irregularities of the coastline, can be persistent. The dominant wave direction is from the west, which results in considerable sand movement as waves strike much of the coast obliquely. The sand is supplied to the coast mainly from river/stream transport and cliff erosion, resulting in turbid conditions close to shore (TRC, 1991).

1.2.2 Biological communities

The organisms that live on the Taranaki rocky shore provide an important food source for humans, birds and fish and also form a significant component of marine biodiversity in the region. This ecological community is profoundly influenced by the physical characteristics of the region. The exposed weather and wave conditions, as well as the geomorphology of the shore largely determine the structure and composition of the marine communities found. However, these important geophysical factors do not uniformly influence rocky shore communities around the Taranaki coastline.

Due to the shape of the Taranaki headland, nearshore bathymetry and the prevailing wave climate, there is a gradient of wave energy which exists around the Taranaki coastline (Johnson et al., 2008; Crofskey, 2007). Wave energy is generally higher in western Taranaki, and decreases with distance in both directions around the coastline (north east towards New Plymouth and south east towards Hawera). This regional wave exposure gradient, combined with local geomorphological factors (e.g. reef slope and aspect), can result in considerable differences in rocky reef communities between sites, with more wave tolerant species prevailing at high energy sites.

Another factor which has a strong influence on some rocky reef communities in Taranaki is sand supply. Erosion events on Mount Taranaki have led to the transport of significant volumes of sand to the coast via the Hangatahua (Stony) River. Once at the coast, littoral drift transports this sand northeast, towards New Plymouth (Cowie, 2009). Under certain conditions, this sand can be deposited in the intertidal zone, burying rocky reef habitat as a result. Due to the direction that this sand is transported when it reaches the coast, rocky reefs south of the Stony River are less likely to be inundated as a result of such events (although these sites can still be affected by sand from other rivers and streams, or eroding cliffs [Matthews, 1977]). These different sand movement regimes have had different effects on rocky reef communities around the Taranaki coastline. However, heavy inundation events have consistently resulted in sharp declines in species diversity.

How wave exposure, sand movement, and other factors influence rocky reef communities in Taranaki will be discussed in more detail in Section 4 of this report, in light of the results of this monitoring programme.

1.2.3 Cultural significance

The reefs of Taranaki provide a valuable source of kaimoana/mātaitai for Maori. This kaimoana/mātaitai is of significant cultural value not only as a source of food, but also because it maintains tribal mana and standing (Waitangi Tribunal Reports, 1983; TRC, 2015).

The results of the Council's intertidal rocky shore surveys presented in this report are not suitable for providing robust assessment of kaimoana/mātaitai stocks, including paua, kina and kuku/kutae (mussels) because the sites are located higher on the shore than these species typically occur. Instead, the results of the rocky shore SEM programme provide a record of species richness, diversity and composition at representative reef sites around the region. These records can be used to assess the 'health' of the reef environment.

Around the Taranaki coastline, particular reefs are regarded as property of distinct hapu. Iwi and hapu associations with the six SEM reef sites are outlined in Figures 1 – 6.

2 Monitoring methodology

2.1 Site locations

2.1.1 Turangi Reef

Turangi Reef is the northern-most SEM rocky shore survey site, located near Motunui and the northern boundary of Taranaki's laharic coastline. The site is located approximately 7 km east from the Waitara River mouth, 47 km north east of the Stony River, and 59 km north east from Cape Egmont (the western-most point in Taranaki). This reef is within the rohe of local Iwi Te Atiawa and Ngati Rahiri hapu.

Site code: SEA900095 **NZTM:** 1713712 / 5684309

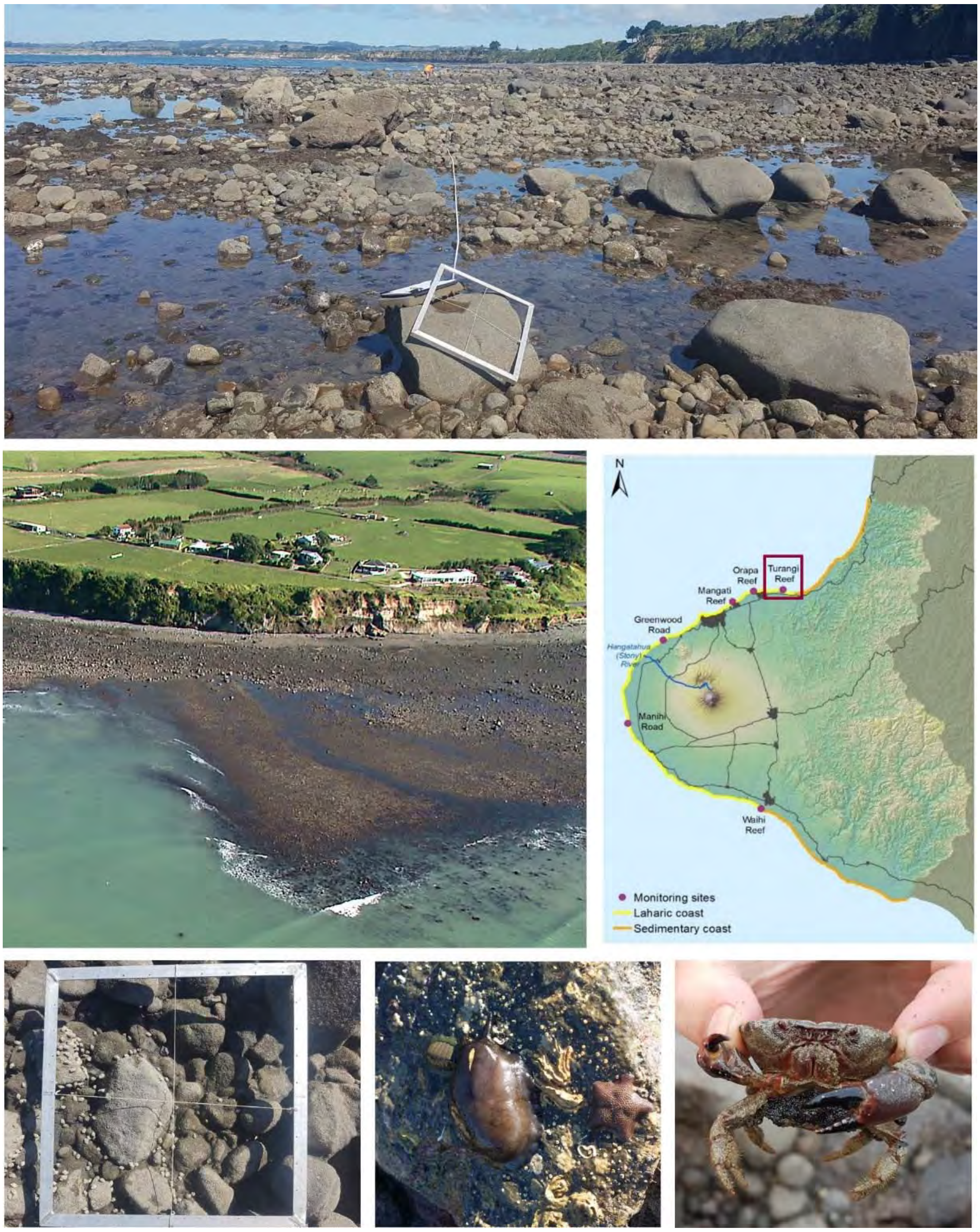

Figure 1 Turangi Reef SEM rocky shore survey site

2.1.2 Orapa Reef

Orapa Reef extends along the Waitara shoreline, in North Taranaki. The survey site is located 1.5 km west of the Waitara River mouth, approximately 40 km north east of the Stony River mouth, and 52 km north east of Cape Egmont. The reef is within the rohe of local Iwi Te Atiawa, and Otaraua and Pukerangiora hapu.

Site code: SEA901043 **NZTM:** 1704759 / 5683854

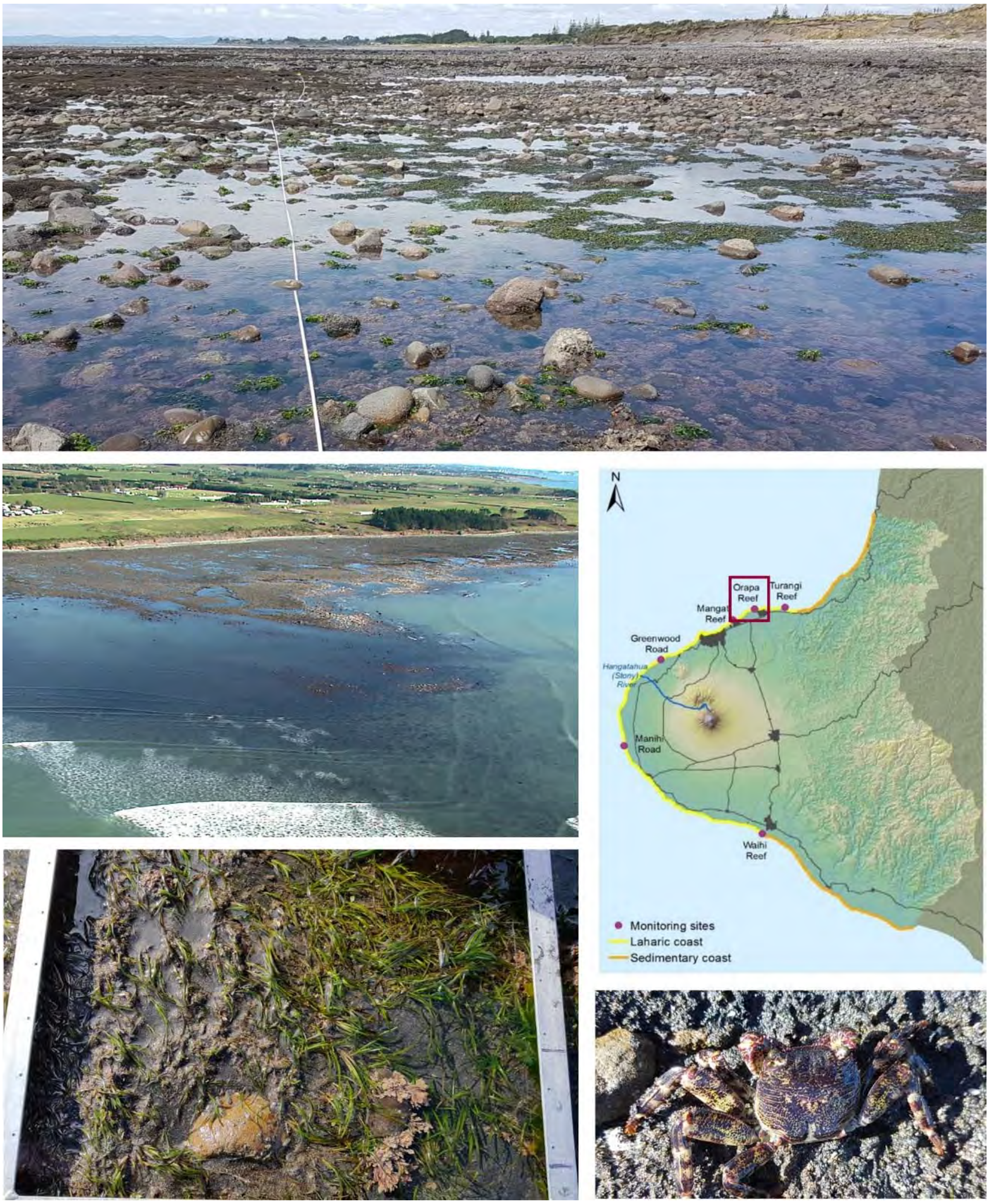

Figure 2 Orapa Reef SEM rocky shore survey site

2.1.3 Mangati Reef

Mangati Reef is found near Bell Block; just north of New Plymouth. It is positioned 3 km north east from the Waiwhakaiho River mouth, approximately 32 km north east of the Stony River mouth, and 44 km north east of Cape Egmont. This reef is within the rohe of local Iwi Te Atiawa, and Puketapu hapu.

Site code: SEA902005 **NZTM:** 1698314 / 5680510

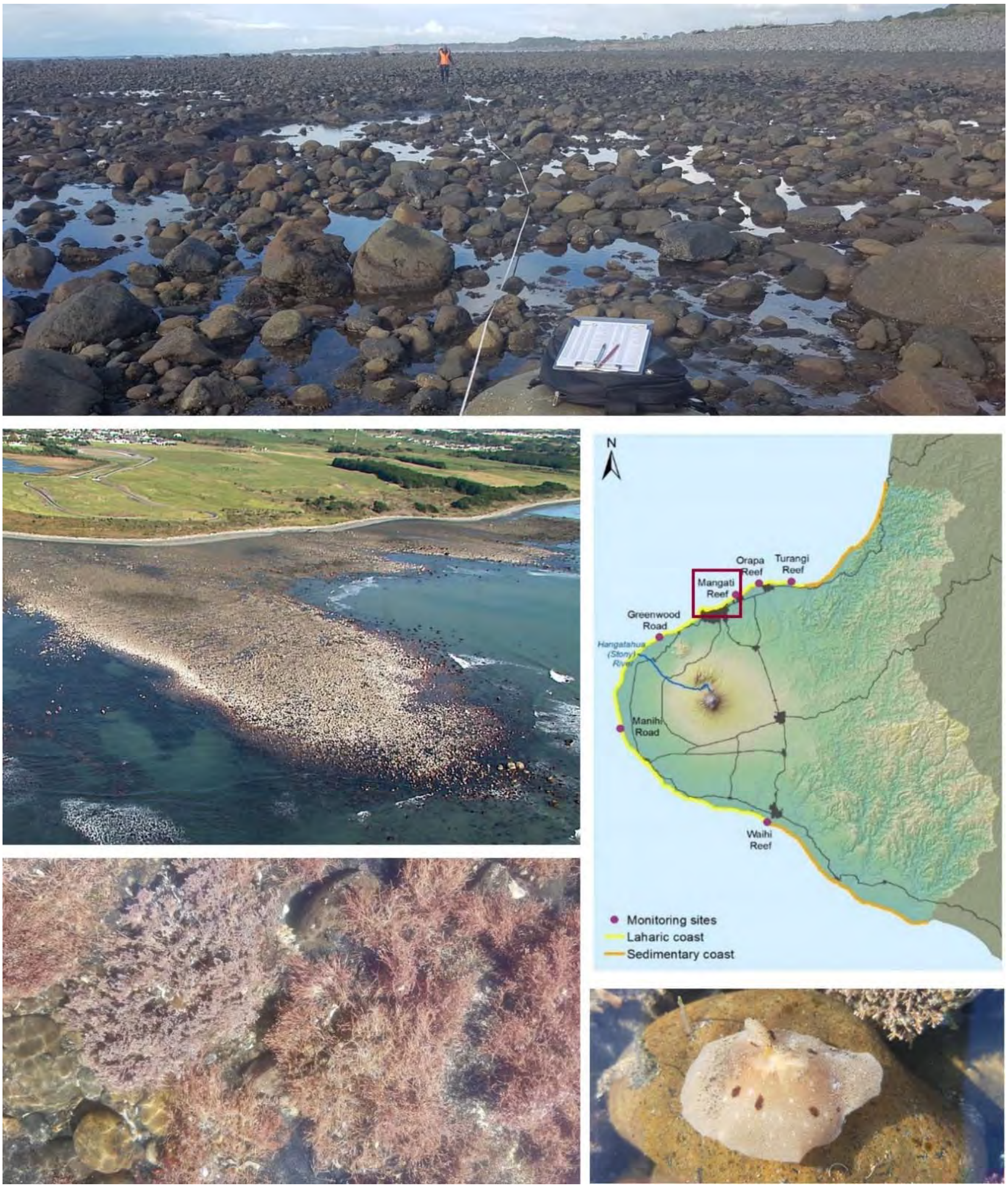

Figure 3 Mangati Reef SEM rocky shore survey site

2.1.4 Greenwood Road Reef

Greenwood Road Reef is found west of New Plymouth, near Oakura. It is located approximately 8 km north east of the Stony River mouth, and 21 km north east of Cape Egmont. This reef is within the rohe of local Iwi Taranaki, and Nga Mahanga-a-Tairi hapu.

Site code: SEA903070 **NZTM:** 1677185 / 5668284

Figure 4 Greenwood Road SEM rocky shore survey site

2.1.5 Manihi Road Reef

Manihi Road Reef is found just north of Oaonui and is the western-most SEM rocky shore survey site. It is located approximately 10 km south of Cape Egmont, and 22 km south of the Stony River mouth. This reef is within the rohe of local Iwi Taranaki, and Ngati Haupoto hapu.

Site code: SEA904065 **NZTM:** 1666415 / 5641780

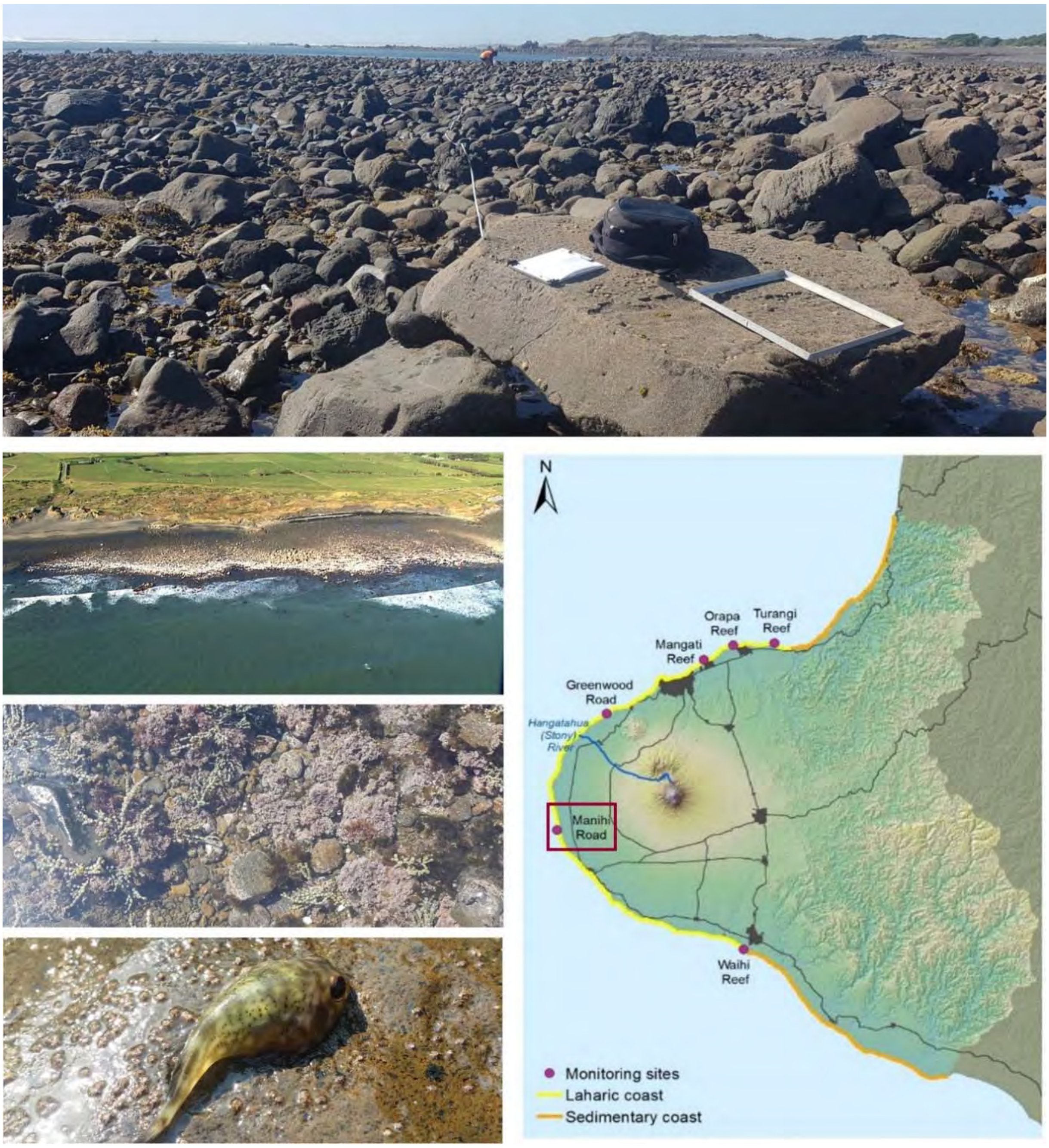

Figure 5 Manihi Road Reef SEM rocky shore survey site

2.1.6 Waihi Reef

Waihi Reef is located near Hawera, and is the southern-most SEM rocky shore survey site; positioned near the southern boundary of Taranaki's laharic coastline. Waihi Reef is located approximately 56 km south east of Cape Egmont. Immediately landward of this reef are tall, unstable cliffs reaching 20 m in height. Large sections of these cliffs frequently collapse, as the cliff toe is undercut by the sea. Waihi Reef is within the rohe of two local Iwi. Ngāruahine with Kanihi-Umutahi and Okahu-Inuawai hapu, and Ngati Ruanui with Hamua, Ngati Tanewai, Ngati Tupaea, Hapotiki, and Ngati Hawe hapu.

Site code: SEA906025 **NZTM:** 1707058 / 5614617

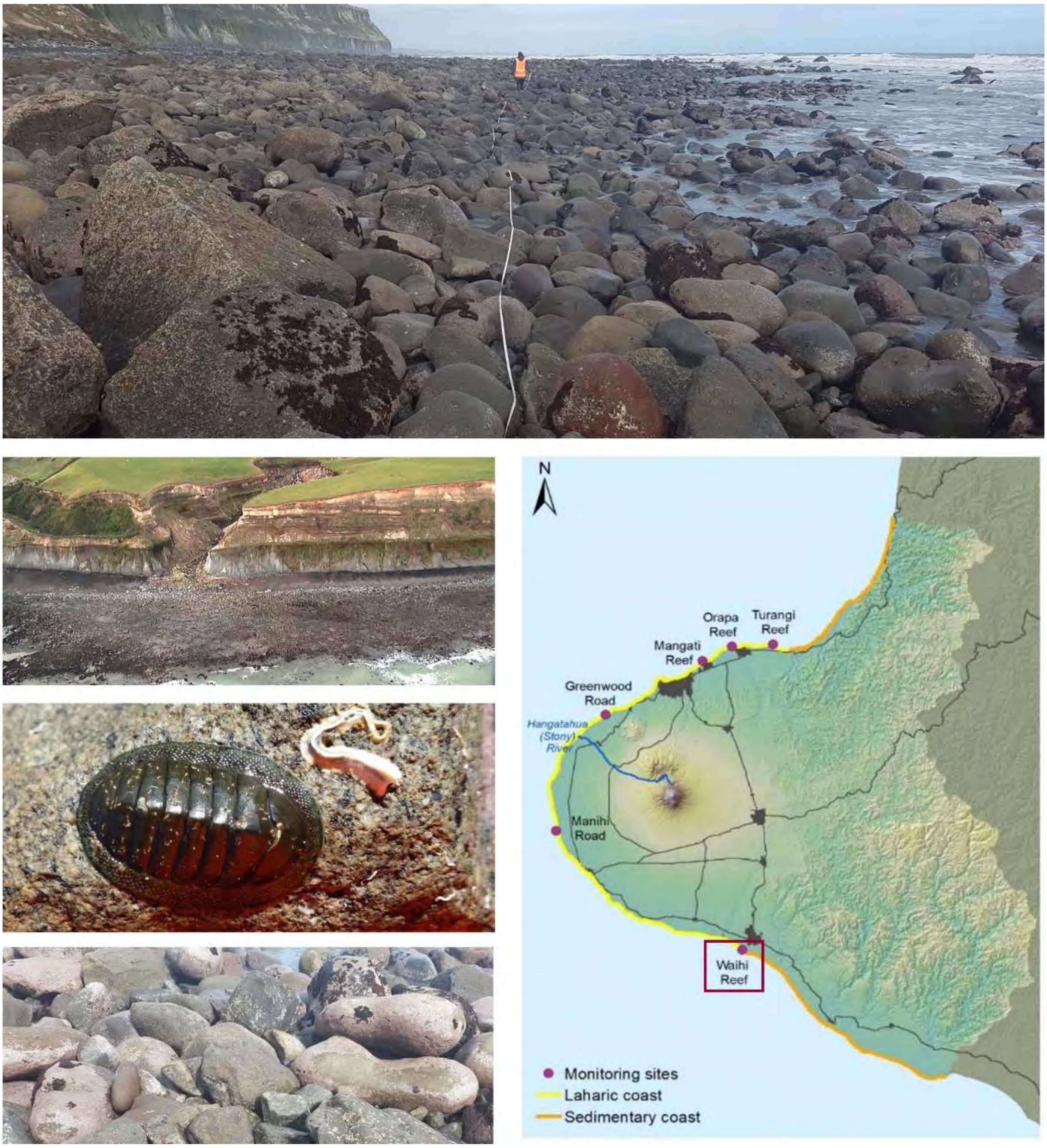

Figure 6 Waihi Reef SEM rocky shore survey site

2.2 Survey method

The six reef sites are monitored twice a year (spring and summer surveys) using a fixed transect, random quadrat survey design. The surveys are designed in a manner to provide sufficient statistical sensitivity to effectively detect change, while providing a realistic survey time in order to complete the survey within the low tide period (TCC, 1983; TCC, 1984).

At each site, the location of the transect is identified using GPS coordinates and photos (the start of most transects can be identified in relation to distinctive boulders and other landmark features). A 50 m transect is laid parallel to the shore, at a tidal height of approximately 0.6 m above chart datum. Five 5 m x 3 m blocks are then established along the transect. Within each block, five random 0.25 m^2 quadrats are laid, giving a total of 25 random quadrats per site. For each quadrat the percentage cover of algae and encrusting animal species is estimated using a grid. For all other animal species, individuals larger than 3 mm are counted. Under boulder biota are counted where rocks and cobbles are easily overturned.

2.3 Data analysis

The survey results are used to calculate two rocky shore community indices; species richness and the Shannon-Weiner diversity index. A species richness score is derived for each survey based on the mean number of species recorded in each quadrat. A Shannon-Weiner diversity index score is calculated the same way, but also factors in the relative abundance of each of the recorded species. Diverse ecological communities are comprised of a high number of species that are present in relatively even numbers, whereas communities that are comprised of a lower numbers of species, or where one species is disproportionately more abundant than the others, are considered less diverse. Diverse ecological communities generally include a high number of species within each functional group (e.g. primary producers, grazers, suspension feeders, predators, etc.) and as a result these communities are often more resilient when faced with stressors and disturbance. Higher levels of species diversity in rocky shore communities typically reflects optimal environmental conditions.

Long term trend analysis was undertaken of species richness (number of species per quadrat) and diversity (Shannon Wiener Index per quadrat) at each site using an adapted method of the water quality trend analysis first developed by Scarsbrook and McBride (2007) and later advanced by McBride (2014).

This analysis is based on two key measures. Firstly, a Mann-Kendall slope estimator (MKSE) is employed, with the median Sen slope used to estimate the magnitude of the trend. 95% credible limits are then used to qualify what the strength of evidence in the trend is. Statistically significant trends are determined to be those where the 95% credible limits do not include zero gradient.

It has previously been recognised that the statistical significance of a trend does not necessarily imply a 'meaningful' trend i.e. one that is likely to be relevant in a management sense. While the method of Ballantine and Davies-Colley (2009) is commonly used, (where a 'meaningful' trend is defined to be one which is found to be statistically significant, and that has a relative magnitude > 1 percent change per year), it has not been adopted in this report. While this method is useful and indicative when used to analyze a short, or initial, time period, it becomes less useful as the time series being studied grows longer. In fact, the rate of change which may be considered meaningful is specific to each unique site. As a consequence, while absolute and relative rates of change are calculated in this report, the interpretation of whether a trend is ecologically meaningful or not is made via professional judgment and scientific critique.

While the MKSE method is useful in investigating monotonic trends in a time series, it is insensitive to analyzing whether a change of trend has occurred. This can be an issue in longer time series, such as those analyzed in this report, particularly if a change in conditions has resulted in the long-term trend not being monotonic. A second key trend analysis method is thus employed, with the fitting of both Loess (locally weighted scatterplot smoothing) and GAM (generalised additive model) models to each time-series. This allows for a qualitative assessment of whether there has been a change in trends throughout time. Similarly, an inspection of residuals is undertaken to determine if there is any bias in them which may hint to a change in trend.

2.4 The effect of sand cover

The level of sand cover at a site can impact both species richness and diversity. While the reef community may be resistant to some level of sand cover, above a certain threshold the community becomes impacted. Once this threshold of sand cover is exceeded, the number of species declines, before eventually bottoming out at high percentages of sand cover. In many cases, the level of sand cover is the main driving force behind variability in species richness and diversity at a site.

To investigate the relative effect of sand cover and other driving factors on rocky shore communities at the six studied sites, an adjustment of both species richness and diversity by sand cover is made. To do this, the raw data at each site is adjusted to take the degree of sand cover into account. Trend analysis, as described in the previous section, is then undertaken on this adjusted dataset. A comparison of the trend analysis of the original and adjusted data sets allows for inferences to be made regarding the driving factors of variation in species richness and diversity at each site.

In order to make adjustments for sand cover, the sand cover percentage is plotted against species richness and diversity for each site. Loess and GAM models are fitted to the raw data using Time Trends software (version 6.30), with best professional judgement employed to compare the models and decide which is the more appropriate fit. Every data-point in the record is then adjusted depending on the value of percentage sand cover (adjusted value=raw value – modelled value + median value).

2.5 Seagrass habitat mapping

New Zealand's only species of seagrass (*Zostera capricorni*) is found on a number of the region's intertidal rocky reefs. Seagrasses are an important biogenic habitat and provide a number of ecosystem services ranging from primary productivity and nutrient cycling to habitat provision (Anderson at al., 2019). The conservation status of *Z. capricorni* in New Zealand is 'At Risk – declining' (de Lange et al., 2017), making it the only listed threatened species routinely monitored as part of the rocky shore programme.

Given the national importance of *Z. capricorni*, it was deemed necessary to map the current extent of seagrass in Taranaki. The region's largest seagrass patches are found on Orapa/Tauranga Reef, spanning approximately 2 km along the coast. Drone Technologies New Zealand Ltd were engaged to photograph and produce a geo-rectified, ortho-mosaic image and digital surface model (DSM) of the reef in order to trial the suitability and effectiveness of using an unmanned aerial vehicle (UAV) for mapping seagrass in Taranaki.

The imagery was captured using a UAV (DJI Phantom 4 Pro) with a 20 MP camera flown just after low tide between 2:50pm and 3:29pm on 17 May 2019. Low tide for Port Taranaki on this date was at 2.38 pm (0.4 m). The imagery was captured from an elevation of 70 m above ground. The resulting resolution of the DSM and ortho-mosaic was approximately (1 [cm/pixel]). Trimble ground control points were used to geo-reference the images.

Image classification was carried out by the Council using ArcGIS Pro. The first stage of this process involved manually identifying and designating the area on the reef that all seagrass occurred within. This step was necessary as the adjacent pastoral land reduced the accuracy of initial image classification attempts. Seagrass training samples were allocated to inform the image classification process. After performing the image classification, an accuracy assessment was undertaken using a random point methodology.

No structured ground-truth surveys were undertaken at the time that this imagery was captured. However, the resolution of the imagery was such that the seagrass could be readily and confidently identified by the viewer. Some of the other biogenic features on the reef could not be classified with the same level of confidence based on the imagery alone (e.g. sandy tube-worm colonies, little black mussel patches), therefore it was decided to limit the classification scope to seagrass only.

A reef 'walk over' was carried out before the survey in order to verify the spatial extent of the seagrass and ensure it was all included in the UAV flight path. The algal species *Ulva lactuca (*sea lettuce) was considered to be the most likely feature on the reef that could potentially be misclassified as seagrass. Sea lettuce cover at the Orapa Reef SEM survey site has been recorded as high as 9.2% during the late summer algal bloom period. However, sea lettuce cover was negligible at the time of the walk over and was considered unlikely to have had a meaningful effect on the classification accuracy.

It should be noted that these mapping outputs would be improved with more image classification training samples. Also, the random point accuracy assessment methodology is likely biased towards a higher accuracy assessment, given that there was a high proportion of the imagery that was left unclassified as seagrass was not present. Despite these limitations, the outputs are considered sufficiently accurate to assess the areal extent of seagrass on Orapa/Tauranga Reef. Furthermore, the image classification tool provided a far more efficient and accurate means of mapping compared to ground-based methods, especially given the large area and highly patchy distribution of the seagrass.

3 Results

3.1 Species richness and diversity

Figure 7 shows the mean number of species per quadrat (species richness) and Shannon-Wiener index per quadrat (diversity) at the six reef sites over the last two monitoring years. Both species richness and diversity were consistently highest at Manihi. Species richness and diversity was consistently lowest at Waihi. There has been an increase in species richness at a number of sites over the past two years, however, these increases have been most pronounced at the Manihi, Turangi and Waihi sites. The diversity results show a similar pattern, although with more variability.

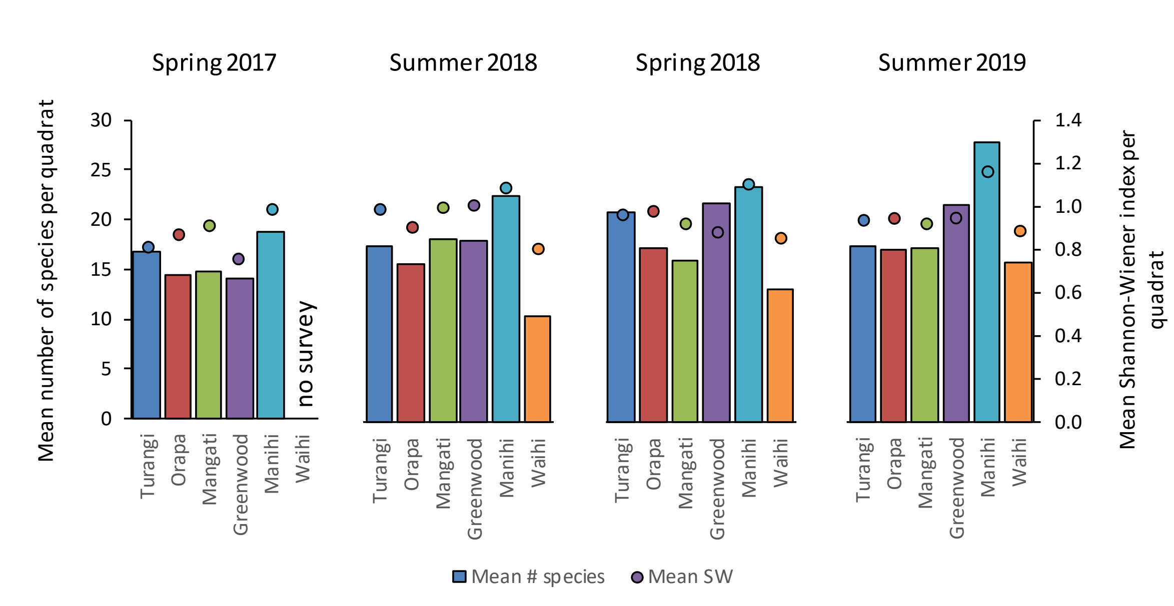

Figure 7 Species richness (bars) and diversity (points) at the six reef sites from spring 2017 to summer 2019

Summary statistics for species richness and diversity at the six reef sites, from the full 25 year record of SEM surveys, are provided in Table 1 (raw data in Appendix I).

Table 1 Summary statistics: species richness and diversity at six reef sites from 1994 to 2019

Site	Number of surveys	*Number of species per quadrat					*Shannon-Wiener index per quadrat				
		Mean	Median	Max	Min	SD	Mean	Median	Max	Min	SD
Turangi	54	16.0	16.3	20.9	11.7	1.98	0.89	0.89	1.03	0.68	0.07
Orapa	48	13.6	14.2	17.8	1.6	3.41	0.86	0.90	1.06	0.15	0.19
Mangati	46	13.6	14.0	18.2	3.4	3.08	0.86	0.91	1.05	0.28	0.16
Greenwood	50	15.9	16.6	23.8	0.2	4.44	0.89	0.92	1.15	0.02	0.18
Manihi	44	19.9	19.8	27.7	15.0	2.60	1.05	1.07	1.20	0.89	0.06
Waihi	53	11.4	11.6	17.0	4.8	2.04	0.85	0.85	1.03	0.40	0.10

*Values based on means for each survey, not individual quadrats

Comparisons of species richness and diversity at each site, for the first (1995-1997), previous (2015-2017), and most recent (2017-2019) SEM monitoring periods, are given in Figure 8 and Figure 9. It is notable that between the 2015-2017 and 2017-2019 monitoring periods, both median species richness and diversity has increased at all sites bar Orapa. Possible reasons for this are expanded on in the discussion section of this report. Species richness at each of the six sites is currently at a level similar to that recorded at the start of SEM monitoring (Figure 8), however there have been varying changes in species diversity at the different sites (Figure 9).

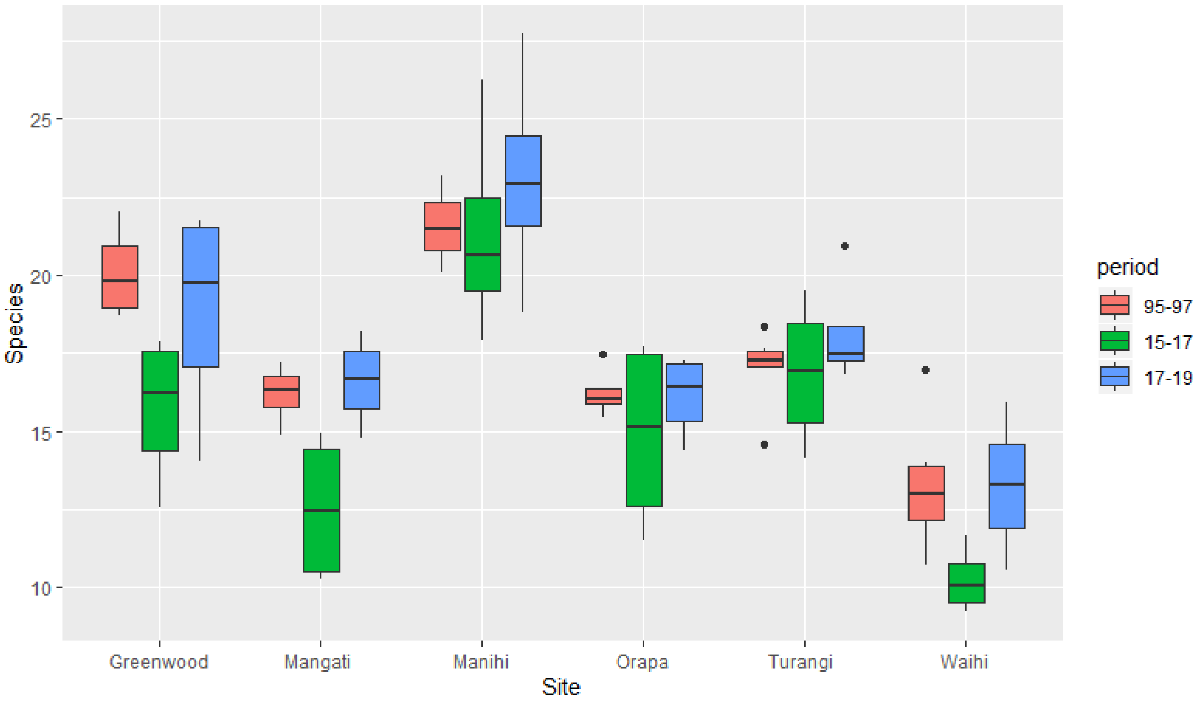

Figure 8 Box and whisker plot of number of species per quadrat (species richness) at the six reef sites for three monitoring periods: The first complete SEM monitoring period (95-97), last monitoring period (15-17), and current monitoring period (17-19)

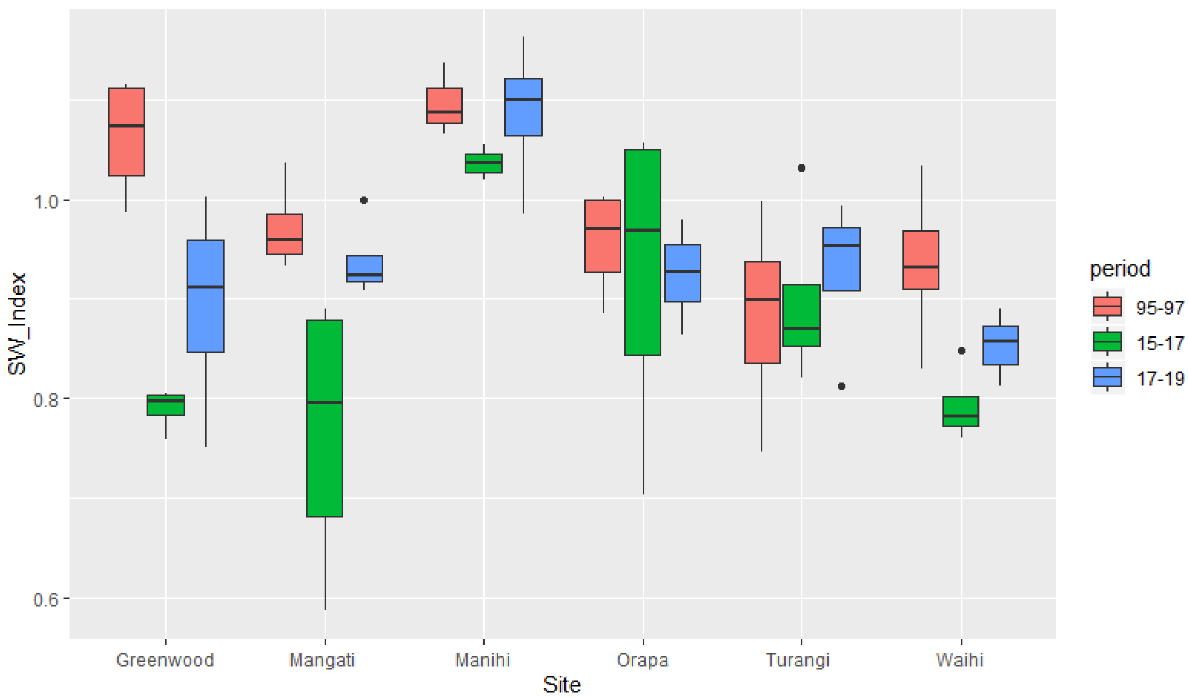

Figure 9 Box and whisker plots of Shannon-Wiener index per quadrat (diversity) at the six reef sites for three monitoring periods

In order to compare the nature of the rocky shore communities at the different sites, a non-parametric Mann Whitney U test was applied, using the full 25 year datasets. No evidence was found at the 0.05 p-level, for a difference in species richness between Turangi and Greenwood Road, or between Orapa and Mangati. Strong evidence was found for differences in species richness between all other sites.

Comparisons of SW Index records between the different sites found very strong evidence that Manihi has higher diversity than all of the remaining five sites ($p<10^{-8}$). There is also positive evidence for both Turangi and Greenwood being more diverse than Waihi. No evidence was found for a difference in diversity between other sites ($p > 0.05$). All tests were repeated using a P-value adjustment for false detection rates, with no significant change in results found between the two methods. The results of all Mann Whitney U tests can be found in Appendix II.

3.2 Long term trend analyses

Time series plots of species richness and diversity from spring 1994 to summer 2019 are shown in Figure 10 and Figure 11, respectively. Loess and GAM models are fitted to the time series in order to visually inspect for trends. In general, the Loess model tries to fit the data closer than the GAM model, however the main trends remain constant between the two models. Interestingly, at first inspection, species richness appears to increase from around 2010 at all sites, with the most pronounced increases observed at Turangi and Manihi. While this increase in richness is seemingly matched by an increase in diversity at some sites, at others, such as Waihi, there has been no apparent increase in diversity in recent years.

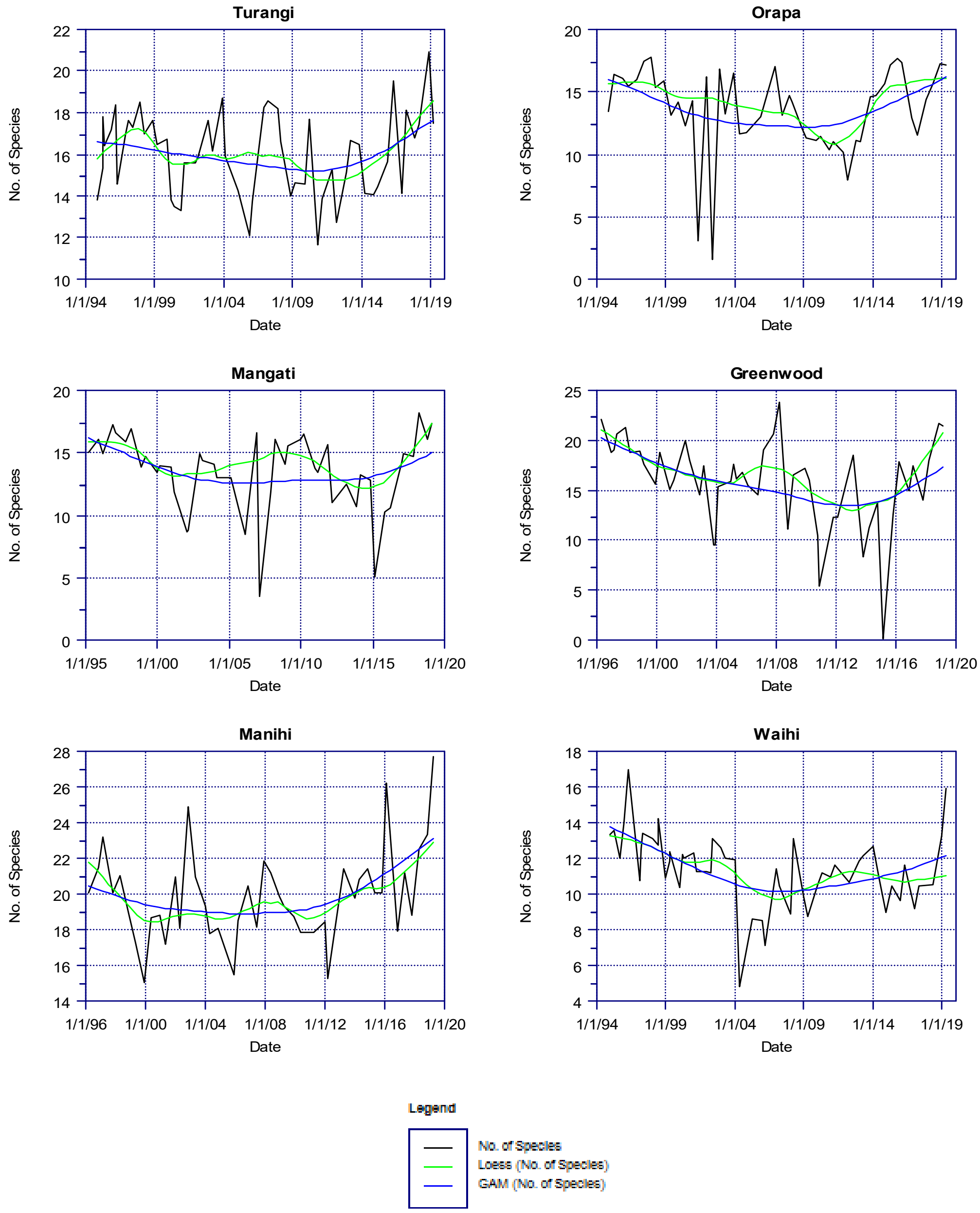

Figure 10 Mean number of species (richness) recorded per quadrat at each site, for all surveys undertaken between spring 1994 and summer 2019. GAM and LOESS models are fitted for the visual inspection of trends

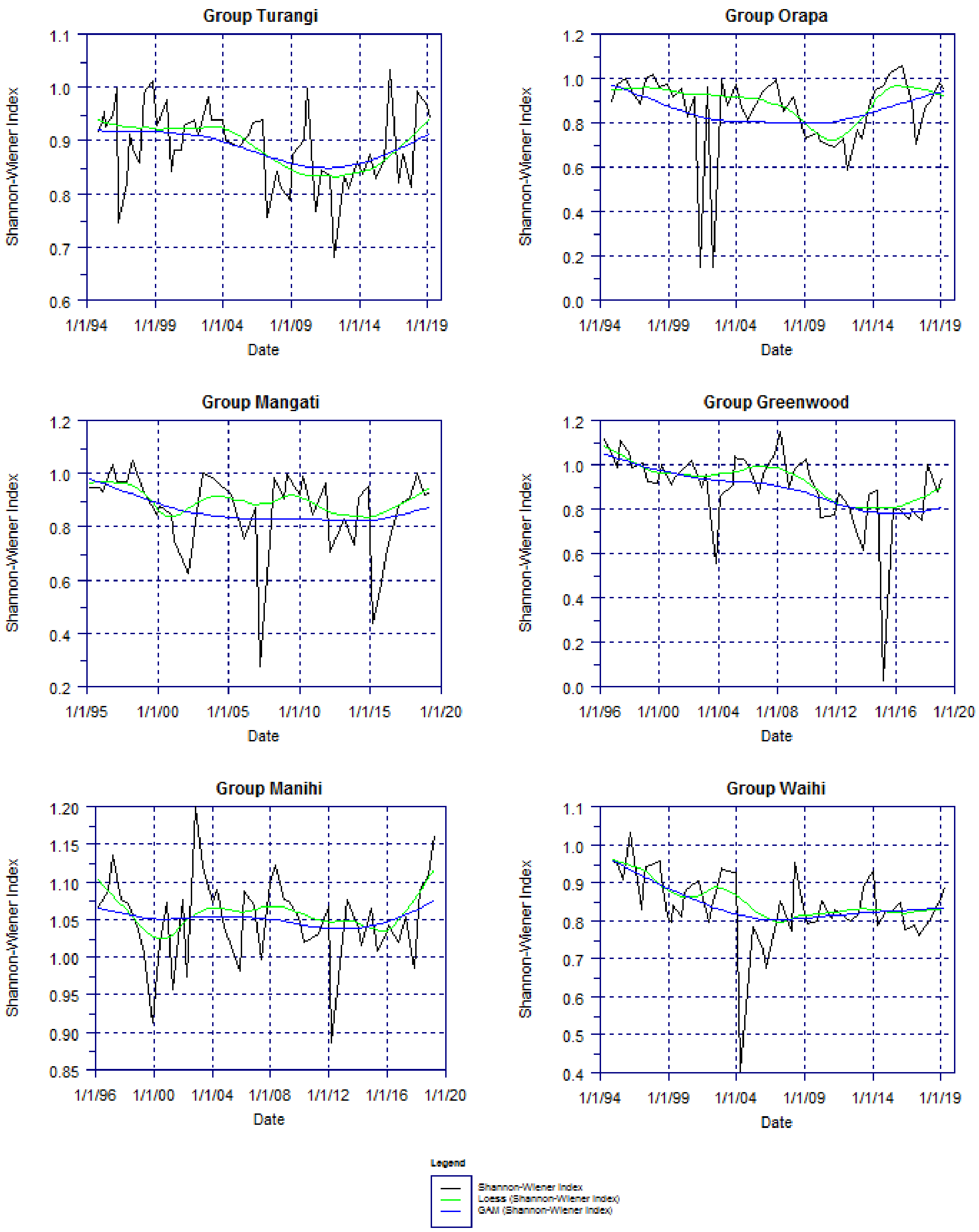

Figure 11 Time series of mean Shannon Wiener Index per quadrat, at each site, from spring 1994 to summer 2019. GAM and LOESS models are fitted for the visual inspection of trends

A comparison of sand cover with species richness and diversity (Figure 12) shows that over the 25 years of the monitoring programme, Orapa, Mangati, Greenwood and Waihi have experienced periodic sand inundation events. It is apparent that surveys undertaken in periods of high sand accumulation are associated with lower species richness and diversity (Figure 12). In addition to discrete sand inundation events, there may be long term changes in sand cover at some sites. GAM and Loess modelling of sand cover with time suggest that this could be the case at Orapa and Mangati (Figure 13).

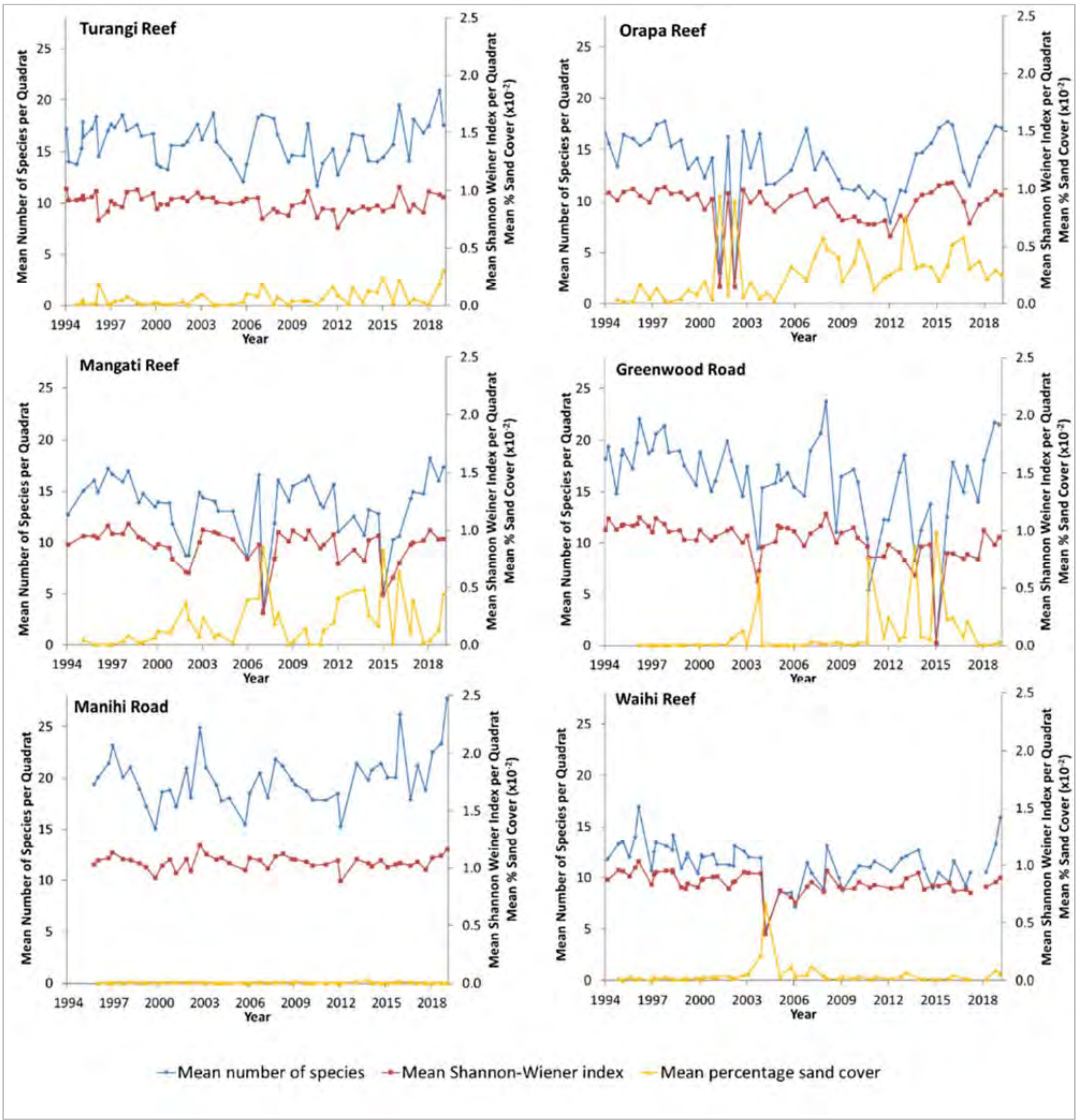

Figure 12 Number of species, Shannon-Wiener index and percentage sand cover at the six reef sites from spring 1994 to summer 2019

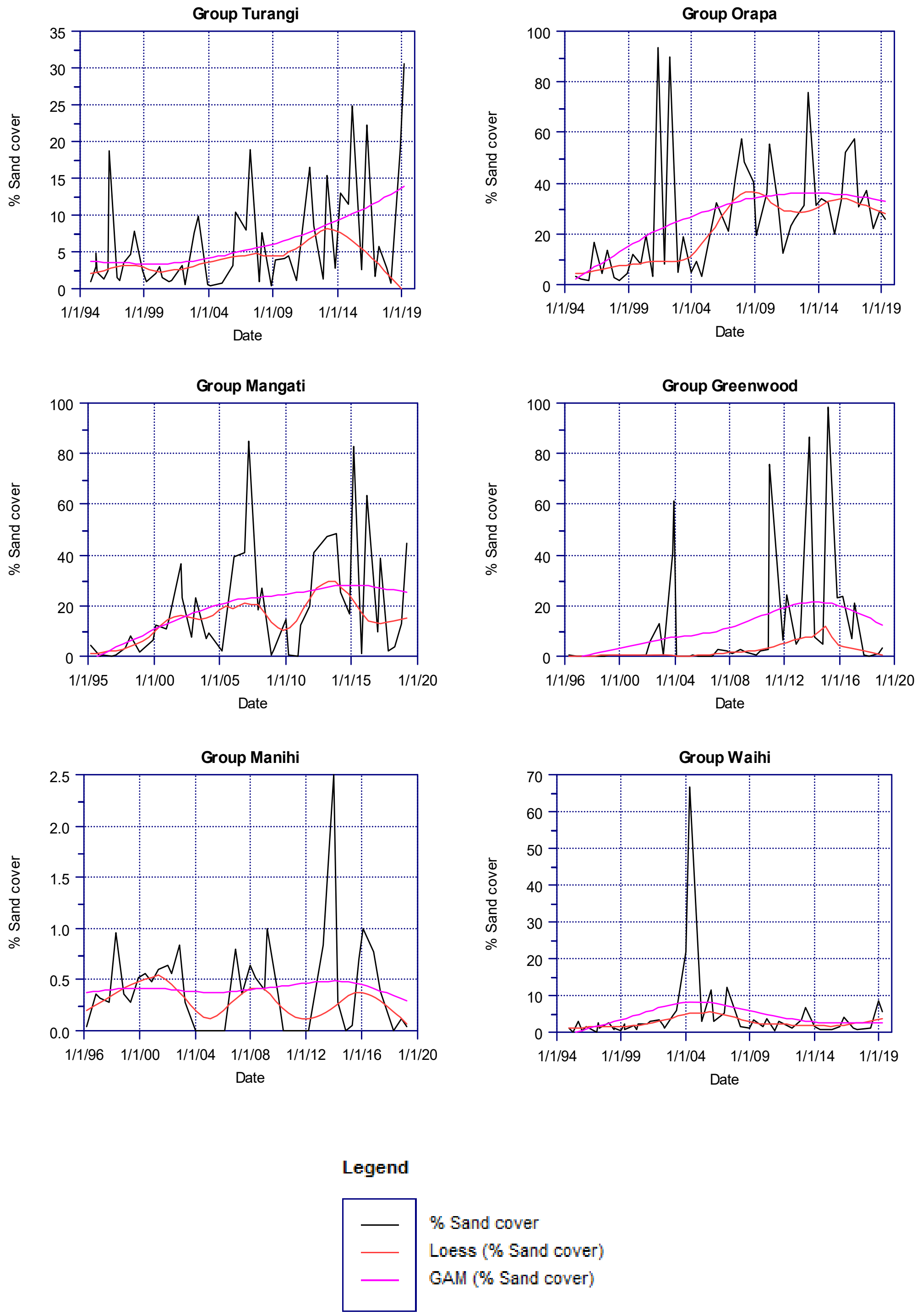

Figure 13 Time series of sand cover % at each site, between 1994 and 2019

The relationship between sand cover and species richness at each site is shown in Figure 14. As mentioned in Section 2.4, above a certain threshold of sand cover (which is different for each site), species richness is negatively impacted. While it appears this threshold has not been reached at the Turangi and Manihi sites, the other four sites show instances at which sand cover has impacted species richness. To investigate the relative impact of sand cover, compared to other drivers of change, the GAM models are used to calculate site specific, sand-cover-adjusted datasets, for species richness and diversity.

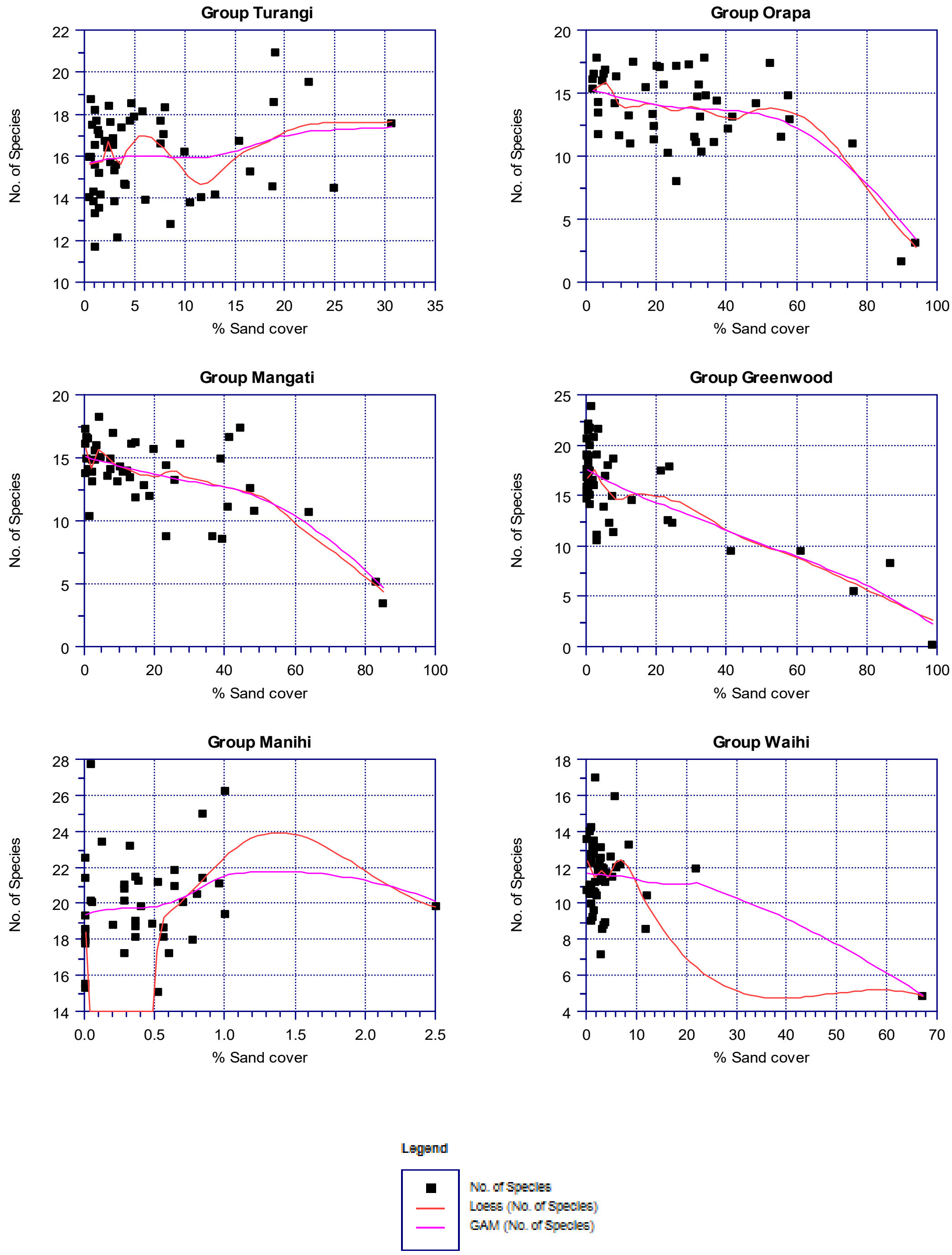

Figure 14 Sand cover vs mean number of species recorded per quadrat, at each site, for the full 25 years of monitoring. Loess and GAM models are used to estimate the relationship between the two variables at each site, and to adjust data for sand cover

The results of the Mann-Kendall trend analyses, undertaken on both the raw and sand adjusted datasets for each site, are given in Table 2. There is no unambiguous evidence for either an increasing or decreasing trend in species richness or diversity at Orapa, Mangati and Manihi Reefs, with the zero gradient trend included within the 95% credible intervals for all three of these sites (Table 3). A similar result was obtained for the sand adjusted data sets for these sites. At Turangi Reef there is very weak evidence for a negative overall trend in species diversity. Confidence for this trend is currently too low to reliably infer causality, however, further investigation may be warranted if future monitoring provides more evidence of a trend. In addition, while there is minimal to no evidence for a non-zero gradient long-term trends at these sites, there does appear to have been shorter-term variations (Figure 10 and Figure 11).

The consistent trend results between the original and sand adjusted records at these four sites indicate that sand cover is unlikely to have been a driving factor of any long-term (permanent) change for them. This is consistent with the modelled relationships between sand cover and number of species at these sites (Figure 14). At Turangi and Manihi sand cover has not reached a level at which it negatively impacts species richness. At Orapa and Mangati reefs, sand cover has only reached this threshold on a small number of occasions, linked to severe and short-duration sand inundation events (Figure 12).

There is strong evidence of a long-term declining trend in species diversity at Greenwood reef. However, there is only weak evidence for a declining long-term trend in the sand-adjusted dataset. This indicates that the decline in species diversity can likely be attributed to increases in sand cover. This result is supported by the weak evidence for a declining trend found in species richness, compared to the lack of evidence for such a trend in the sand adjusted dataset. An inspection of residuals, combined both with the lack of evidence for a monotonic non-zero long-term trend, and the GAM model of species richness with time (Figure 10), suggest that there may have been a change of trend in species richness at Greenwood in recent years, however further data is required to confirm this.

Weak evidence was found for a declining trend in species richness at Waihi Reef, both in the original and sand-adjusted datasets. This was matched by positive evidence for a declining trend in species diversity, both in the original and sand adjusted datasets. These results indicate that the decline in species richness and diversity over the past 25 years at Waihi Reef is likely due to a driving factor other than sand cover.

Long term trend analyses were also carried out for the level of sand cover at each site (Table 3). Evidence was found, of varying strength, for long-term increases in sand cover at Turangi, Orapa, Mangati and Greenwood reefs. The magnitude of this trend was found to be greatest at Orapa and Mangati reefs, where the median change in sand cover has been 1.32 and 0.95% per year over the last 25 years, respectively. While sand cover at these sites has not yet reached a level at which it negatively effects species richness, the long-term trend of increasing sand cover may be such that it becomes ecologically significant in the near future.

In contrast, there is positive evidence that there has been no long-term change in sand cover levels at Manihi or Waihi Reefs.

Table 2 Trend slopes and credible interval limits from Mann-Kendall trend analysis of species richness and diversity at the six reef sites between spring 1994 and summer 2019. Both unadjusted and sand adjusted trends are presented

Site	Variable	Mann-Kendall trend analysis					
		Unadjusted trend			Sand adjusted trend		
		Median slope (yr^{-1})	Median %AC	95% CrI	median slope (yr^{-1})	Median %AC	95% CrI
Turangi	No. species	-0.0111	-0.0680	-0.1013 to 0.0634	-0.0298	-0.1833	-0.1154 to 0.0432
	SW index	**-0.0031**	**-0.3436**	**-0.0057 to -0.0002**	-0.0027	-0.3045	-0.0052 to 0.0001
Orapa	No. species	-0.0422	-0.2966	-0.1702 to 0.0683	0.0323	0.2269	-0.0873 to 0.1164
	SW index	-0.0028	-0.3115	-0.0086 to 0.0015	0.0012	0.1289	-0.0041 to 0.0048
Mangati	No. species	-0.0660	-0.4698	-0.1744 to 0.0484	0.0259	0.1842	-0.0549 to 0.1188
	SW index	-0.0030	-0.3338	-0.0075 to 0.0007	0.0009	0.1003	-0.0028 to 0.0041
Greenwood	No. species	**-0.2065**	**-1.2410**	**-0.3670 to -0.0335**	-0.0780	-0.4687	-0.2065 to 0.0604
	SW index	**-0.0103**	**-1.1230**	**-0.0144 to -0.0062**	**-0.0043**	**-0.4698**	**-0.0086 to -0.0004**
Manihi	No. species	0.0737	0.3717	-0.0217 to 0.1866	0.0797	0.4019	-0.0242 to 0.1884
	SW index	-0.0006	-0.0599	-0.0029 to 0.0018	-0.0009	-0.0809	-0.0031 to 0.0018
Waihi	No. species	**-0.1039**	**-0.8957**	**-0.1582 to -0.0443**	**-0.1034**	**-0.8915**	**-0.1579 to -0.0469**
	SW index	**-0.0050**	**-0.5894**	**-0.0073 to -0.0022**	**-0.0048**	**-0.5688**	**-0.0073 to -0.0024**

% AC = % annual change (also RSKSE), CrI = Credible Interval

Table 3 Trend slopes and 95% credible interval limits of Mann-Kendall trend analysis of percentage sand cover at the six reef sites between spring 1994 and summer 2019

Site	Unadjusted trend	
	median slope (%yr^{-1})	95% Credible Interval Limits
Turangi	0.17758	0.023543 to 0.424731
Orapa	1.320302	0.842719 to 1.808126
Mangati	0.947182	0.228362 to 1.730878
Greenwood	0.210213	0.095244 to 0.425780
Manihi	0	-0.018881 to 0.006748
Waihi	0.044059	-0.014722 to 0.136841

3.3 Species composition and abundance

A full list of the species recorded during the SEM intertidal surveys between 2017 and 2019, including the percentage of quadrats each species was present in, is provided in Appendix III.

The encrusting algal species, *Corallina* sp. (paint) and *Ralfsia* sp., were among the most widespread primary producers recorded between 2017 and 2019 (present in the majority of quadrats at all sites). The geniculate algae, *Corallina* sp. (turf), was also widely found at all sites except for Waihi Reef. Notably fewer algal species were found at Waihi Reef compared with the other sites; no green algal species (Chlorophyta) were present in any of the surveys at this site. *Zostera capricorni* (seagrass) was only present at one of the survey sites; Orapa Reef.

The barnacle, *Chaemosipho columna*, and colonial tube worms *Neosabellaria kaiparaensis* (sand), and *Spirobranchus carniferus* (calcareous) were the most widespread sedentary filter feeding species across all six sites. *Isactinia olivacea*, was the only species of anemone present at all sites.

There were 41 species of mollusc identified across the six survey sites between 2017 and 2019; the most species of any animal phyla. Of these, the most widespread mobile grazers were two top shell species, *Lunella smaragda* and *Diloma aethiops* and the green chiton, *Chiton glaucus*. The oyster boring whelk, *Haustrum scobina*, was the most widely present predatory species.

Crustacea contained the second highest number of species (18) identified of all animal phyla. The filter feeding porcelain crab (*Petrolisthes elongatus*) was the most widespread mobile crustacean surveyed between 2017 and 2019.

Figure 15 provides the average cover data (or abundance data for mobile animals) from all SEM surveys for a number of the key species discussed above, along with sand cover.

Over all SEM surveys to date, the average cover of *Corallina sp.* (turf algae) has been comparable between five of the six sites, although a north to south pattern of decreasing cover is evident (Figure 15). The average cover of turf algae at Waihi Reef is considerably lower than at the rest of the sites. A similar north to south pattern of decreasing abundance is seen with the two top shells, *L. smaragdus* and *D. aethiops* and whelk *H. scobina* (with relatively high abundances of these species at Manihi being the notable exception).

In contrast to turf cover, the cover of *Corallina* sp. (paint) was over twice as high at Waihi than at any other site. Cover was lowest at the Orapa and Mangati sites. These two sites shared other notable results, including; having the lowest average abundances of *C. glaucus* and *P. elongatus,* having the highest average cover of sand and being the only two sites where *Z. capricorni* has been recorded. Average cover of *N. kaiparaensis* was significantly higher at Orapa than at any other site. These results are discussed further in Section 4.

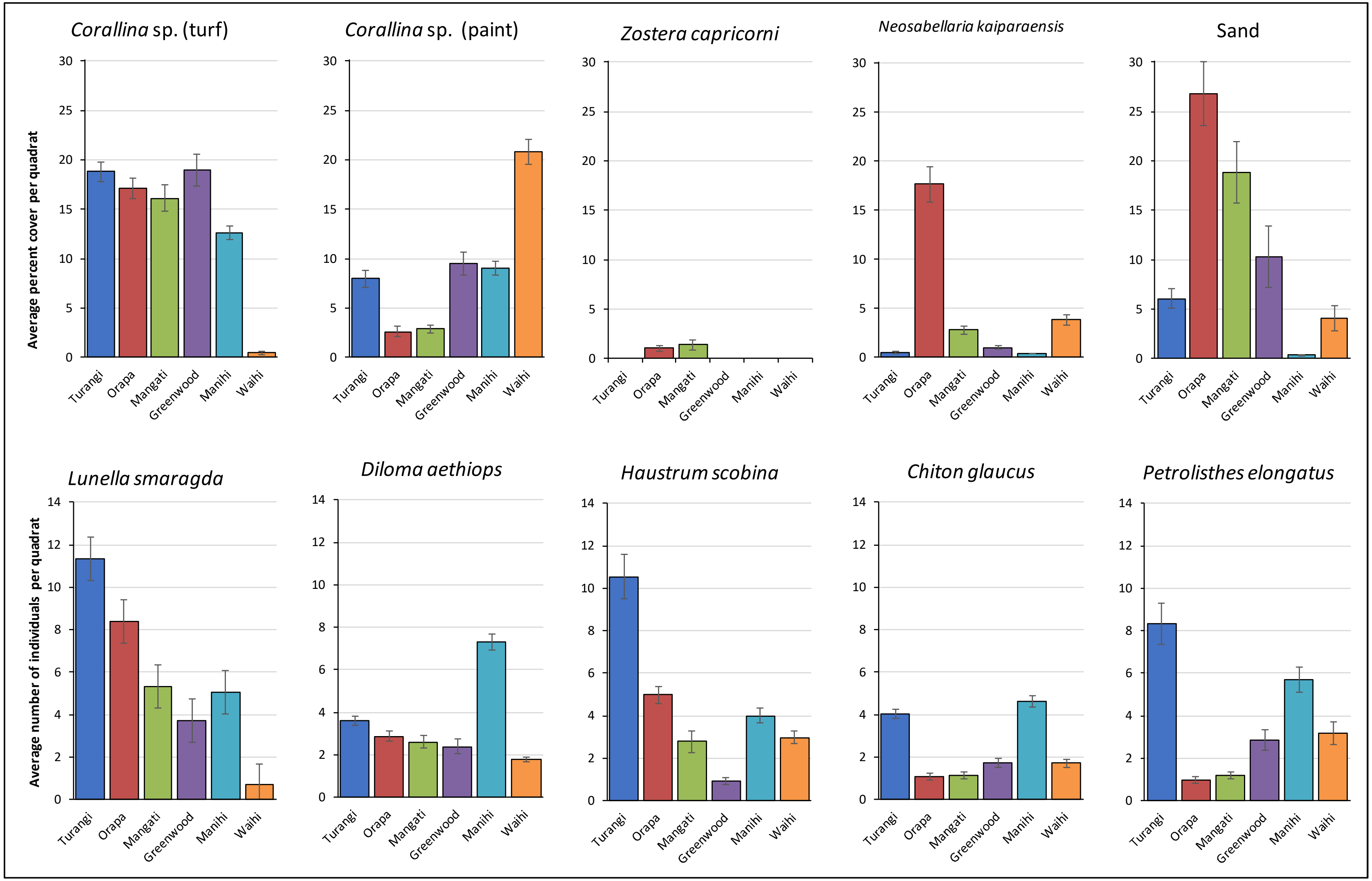

Figure 15 Average cover and abundance (±SE) of key species and sand at the six reef sites from all SEM surveys

3.4 Seagrass coverage and extent

Seagrass occurs in small patches at a number of rocky reef locations around the region, and also within the harbour at Port Taranaki. Seagrass is present on three SEM reefs (Manihi, Mangati and Orapa), however it has only been recorded within two of the survey sites; Mangati and Orapa. Seagrass has not been recorded at the Mangati survey site since the early 2000's, however, at the Orapa survey site seagrass has been frequently recorded since 2010. Average seagrass coverage at Orapa Reef over the last ten years is illustrated below in Figure 16. Because rocky reef seagrass patches are constrained to tidal pools and low lying areas, average seagrass cover is also presented in the Figure 16 as a proportion of suitable habitat (percent cover of seagrass as a proportion of the quadrat area with no rock or boulder).

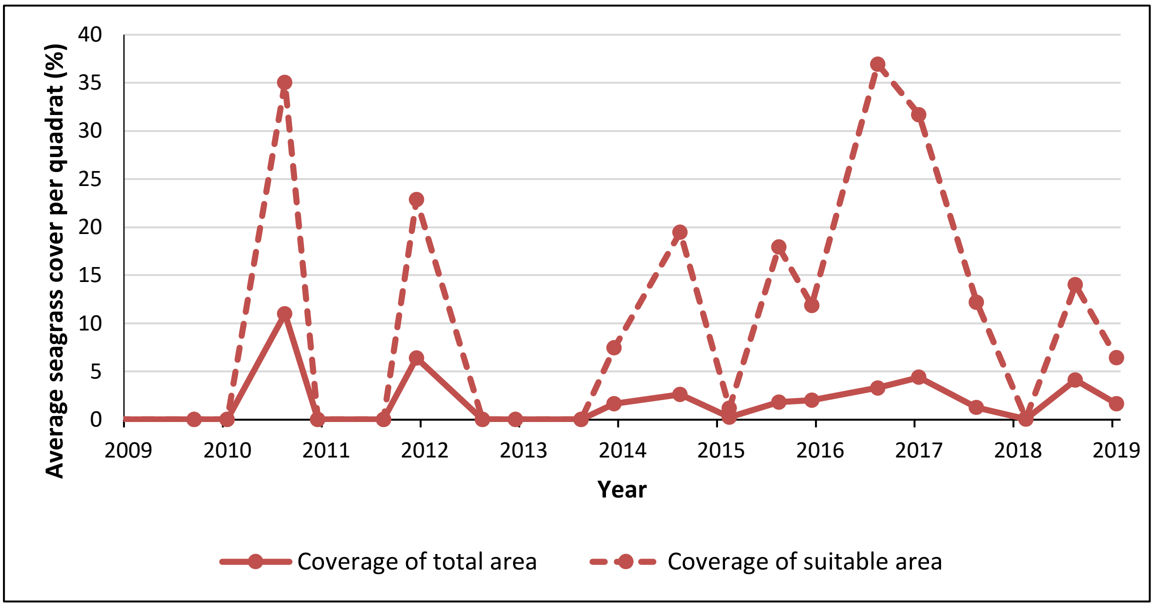

Figure 16 Average seagrass cover per quadrat over time at the Orapa Reef SEM site

Although this data is useful for monitoring seagrass cover within the survey site, the patchy distribution of seagrass on Taranaki reefs means that it may not accurately reflect wider changes in cover and extent. Habitat mapping surveys, utilizing high resolution aerial imagery can instead be more useful for gathering this type of broad scale information. The results of seagrass mapping, utilizing UAV imagery of Orapa-Tauranga Reef captured on 17 May 2019, are presented below in Figure 17 and Figure 18.

The imagery shows that the seagrass patches are not evenly distributed across the reef. Relatively dense seagrass patches were present towards the eastern and western boundaries of the surveyed area, whereas seagrass presence was sparse in the centre (including at the Orapa SEM survey site). Based on the results of the image classification analysis, total seagrass cover over the surveyed area was 1.4 ha (or 5.1% of the classified area). A random point accuracy assessment was performed on the image classification which produced an accuracy score of 97% (that is, seagrass presence or absence was correctly classified in 97% of instances). These results are discussed further in Section 4, whereas survey and analytical methods, including limitations, are described in Section 2.5.

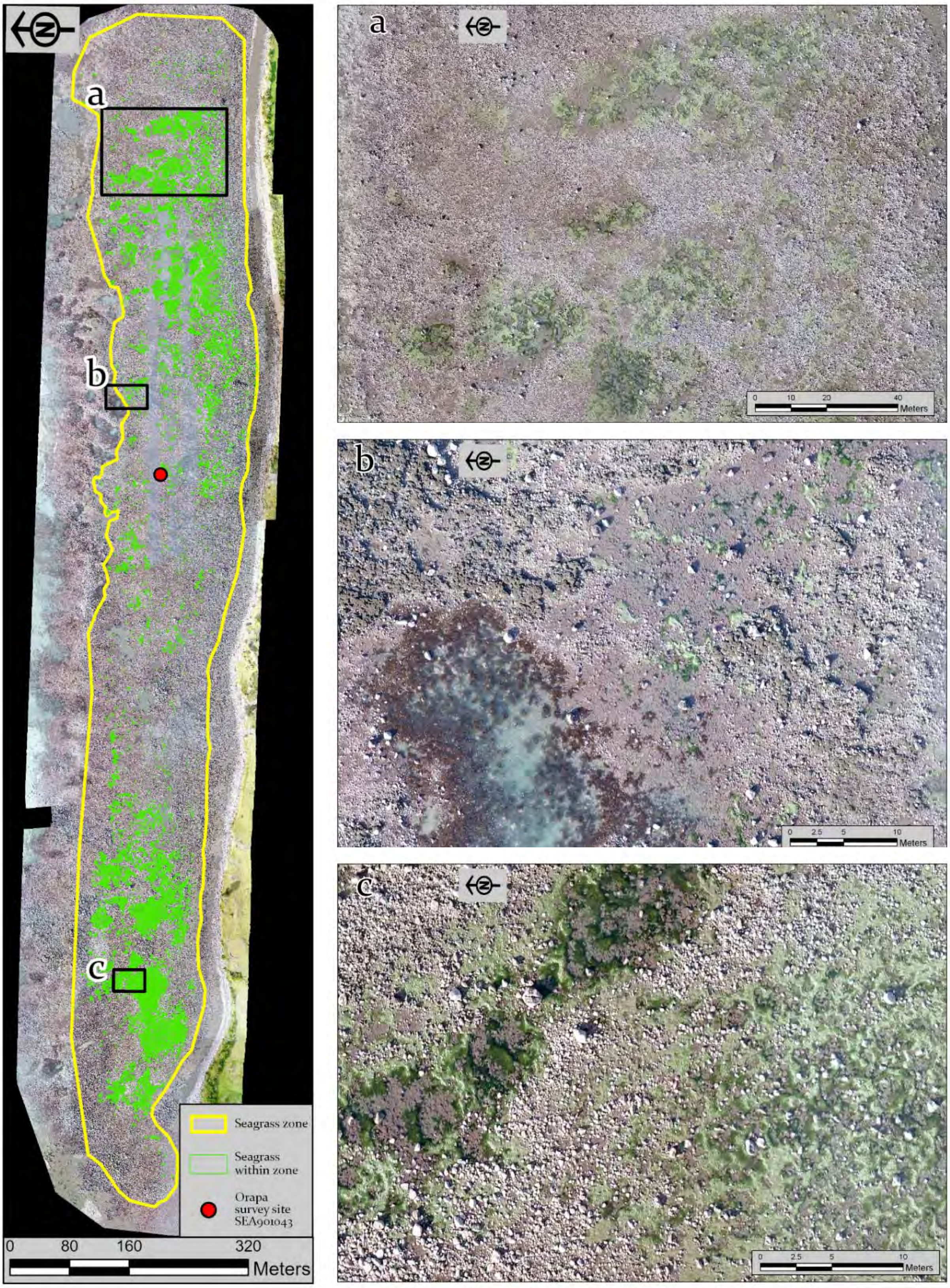

Figure 17 Orapa Reef seagrass patches, with classified areas highlighted green (left), and magnified sections of unclassified imagery (corresponding images on right)

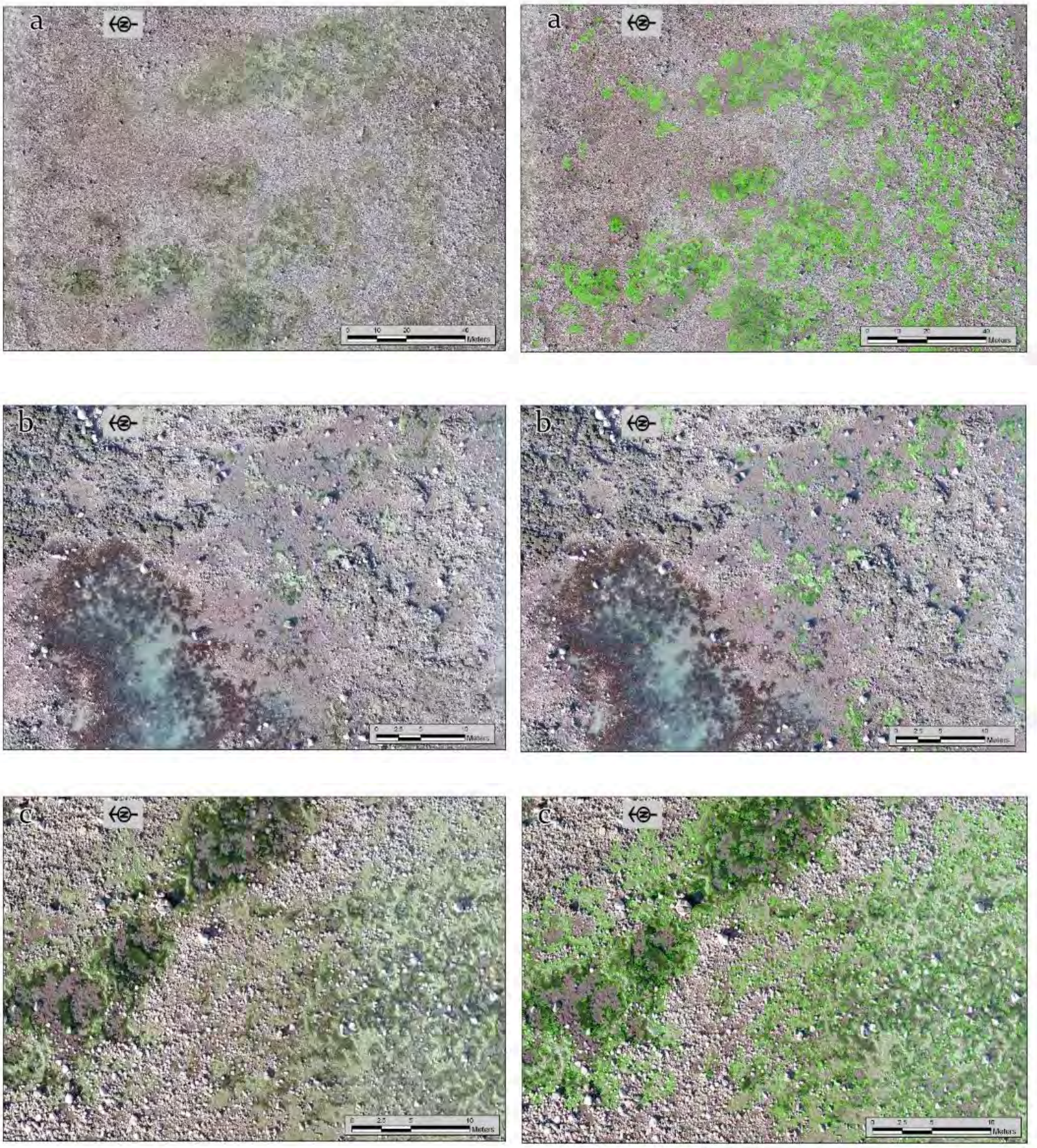

Figure 18 Orapa Reef seagrass imagery, pre-classification (left) and post-classification (right; with classified areas highlighted in green)

4 Discussion

The main findings from this report, which includes all SEM survey data collected up until the summer of 2019, are summarised below:

- The differences in species richness and diversity between sites during the 2017-2019 monitoring period reflected those seen over the entire duration of the monitoring programme. That is, Manihi Reef remained significantly more species rich and diverse than any other site, and Waihi Reef was significantly less species rich and diverse than any other site.
- Trend analyses found evidence of long term trends in species richness and diversity at Greenwood Road and Waihi Reef sites. At Greenwood Road, the analysis indicated that there was a declining trend in species richness and diversity that was likely related to sand coverage. A declining trend was also found at Waihi Reef, however, this appeared to be unrelated to sand cover.
- Trend analyses were also performed on sand cover data, which found increasing trends at the four northern most sites (Greenwood, Mangati, Orapa and Turangi). The median annual increase in sand cover was highest at the Orapa and Mangati sites.
- Analysis of coverage and abundance of key intertidal reef species highlighted differences between sites likely related to key environmental factors.
- Seagrass mapping provided an estimate of total areal cover at Tauranga/Orapa reefs and revealed the uneven distribution of the patches; highlighting the sparse coverage of seagrass at the SEM survey site, relative to other parts of the reef.

There are a number of factors, both abiotic and biotic, which can influence the diversity and composition of intertidal rocky reef communities. However, in this local context, it is a subset of these factors which appear to be significantly influencing patterns in intertidal communities across sites and over time. These factors are discussed in the following sections.

4.1 Sand

Sand deposition has been shown to have profound effects on intertidal hard-shore communities in Taranaki (Walsby, 1982). The presence of high quantities of sand results in reduced diversity due to sand scour and temporary sand burial (Walsby, 1982; Airoldi et al., 1996; Howes et al., 2000). Sand scour impacts on reef organisms causing removal from the substrate, physiological stress and increased metabolic demand (Airoldi et al., 1996; Howes et al., 2000). Sand inundation results in reduced light, oxygen and food availability (Airoldi et al., 1996; Howes et al., 2000). Manihi Reef, the SEM site with lowest average sand cover (<1%; Figure 12 and Figure 13), consistently had the highest species richness and diversity of all six reef sites (Figure 7, Figure 8 and Figure 9). In contrast, the Greenwood, Mangati and Orapa sites have all been

Photo 1 Greenwood Road Reef inundated with sand on 23 January 2015 (left) and with low sand cover on 30 September 2015 (right)

subjected to sporadic heavy inundation (Photo 1), which has resulted in dramatic short term effects on species richness and diversity (Figure 12 and Figure 13).

Encrusting and non-motile organisms are particularly susceptible to smothering and burial during heavy sand inundation, often resulting in death. Motile organisms are better designed to cope, with some species having been shown to escape heavy sand accumulation altogether. For example, paua escape heavy sand cover by moving into deeper waters (Howes et al., 2000). At the SEM survey sites, motile gastropods (including snails and limpets) have been observed aggregating on larger rocks which protrude above the sand (Photo 2). Such responses may aid rapid recovery of the reefs post sand inundation, with reefs typically recovering within a year or two providing sand accumulation is not persistent.

Photo 2 *Lunella smaragda* (left), and *Cellana radians* (right), aggregating on protruding rocks during sand inundation of the reef

Unlike at Greenwood Road, Mangati and Orapa typically retain higher levels of sand between the short-lived inundation events (Figure 12 and Figure 13). As a result, the average sand cover recorded at Orapa and Mangati is 27% and 19%, respectively, while it is just 9% at Greenwood (Figure 13). This persistent sand coverage has had demonstrable effects on the biota that occur at these sites. The green chiton, *C. glaucus* and porcelain crab, *P. elongatus* are two species which exist in the spaces beneath and between boulders rocks and cobbles. While *C. glaucus* grazes on the biofilms growing on rock surfaces, *P. elongatus* filter feeds from the water in the interstitial spaces. Of all six SEM sites, these two species are least abundant at Mangati and Orapa, and this is most likely due to sand filling the spaces beneath and between the hard substrates; reducing the amount of available habitat (Figure 15). Conversely, other species appear resilient to the elevated sand coverage. For example, Mangati and Orapa were two of four sites with the highest average coralline turf cover (Figure 15). Other species even appear to thrive on the increased sediment availability (Photo 3). Seagrass, (which relies on an optimal supply of sediment to form root mats) has only been recorded within the Mangati and Orapa survey sites, while the sandy tube worm, *N. kaiparaensis* (which also

Photo 3 Dense seagrass patches (left) and *N. sabellaria* colonies (right) on Orapa Reef

requires sediment for tube formation), has a significantly higher average cover at Orapa than at any other site (Figure 15).

The main sources of sand to the Taranaki coastline come from rivers, streams and eroding cliffs (Matthews, 1977; Cowie, 2009). In North Taranaki one source in particular has provided an increase in sand supply to the coastline since the late nineties. In 1998, a scarp at the headwaters of the Stony River collapsed, leading to a massive input of sand and gravel down the river and into the coastal system (Photo 4). Erosion has been ongoing since 1998, including another significant event which occurred in 2008. These erosion events have been linked to a possible increasing trend in storm intensity, based on increasing flood peaks observed in stream flow monitoring data (Betts et al., 2010). Prior to 1998, the coastline extending from Cape Egmont to Oakura was described as 'sand starved' being mainly comprised of cobble and boulder beaches and reefs. Since 1998, this influx of black sand derived from Mount Taranaki has been transported along the coast in a north easterly direction resulting in beach sediment nourishment. What were previously cobble and boulder beaches have now changed to sandy beaches (Cowie, 2009).

Boulder reefs along the North Taranaki coastline have also been affected by this increase in sand supply, with an increased chance of sand inundation. Large volumes of sand wash ashore at times when there are persistent long-period swells combined with prolonged calm periods with no storms (McComb pers. comm, 2015). Trend analyses suggest that an increase in these conditions, together with a greater sand supply from the mountain, have impacted reef species richness and diversity at certain sites (Figure 10 - Figure 14). Analysis of sand cover data found increasing trends at four sites, all located north of the Stony River (Table 3). The median annual increase in sand cover over the duration of the monitoring programme is 1.32% at Orapa, 0.95% at Mangati, 0.21% at Greenwood and 0.18% at Turangi Reef. The comparatively low increase in sand cover at Greenwood Road suggests that it is the frequency and magnitude of the discrete inundation events that is driving the decrease in species richness and diversity at this site, rather than a gradual accumulation of sand over time. Gradual accumulation of sand appears to be occurring at the Orapa and Mangati sites, however, the current levels of sand coverage at these sites have not yet reached the threshold at which significant declines in species richness and diversity occur (although this threshold has been temporarily exceeded during historic inundation events). It is important to note that just as natural processes deliver sand to intertidal reef habitats, the same processes are also responsible for taking it away. Therefore, sand supply and oceanographic conditions will continue to play an important role in shaping Taranaki's rocky reef communities into the future.

Photo 4 Pyramid Stream gully, at the headwaters of the Stony River: a major source of sand to the North Taranaki coastline

4.2 Wave exposure

On rocky shores in general, the extent of wave exposure can have a dramatic influence on species composition. Waves eliminate organisms that cannot withstand large accelerational forces, either by preventing settlement, or by limiting growth once settlement has occurred (Little *et al*., 2010). All six of the Taranaki SEM reef sites can be described as exposed and this is reflected in the community composition at these sites. Encrusting and geniculate coralline algal species (referred to as coralline paint and turf respectively) typically dominate at all of the Taranaki sites, with these species being more tolerant to drag forces and sedimentation compared to larger seaweed species. Herbivorous gastropod species, including *D. aethiops* and *L. smaragda*, are abundant, in part due to the low abundance of predators in exposed areas (Little *et al.*, 2010).

Differences in wave exposure between the Taranaki reef sites, related to the location and topography of each reef, can significantly affect the diversity of the communities at those sites. Due to the prevailing wave climate and nearshore bathymetry, wave energy is generally higher in western Taranaki, and decreases with distance in both directions around the coastline (north east towards New Plymouth and south east towards Hawera). In addition to location on the coast, reef topography can also be an important factor determining a site's level of wave exposure. Specifically, intertidal reef sites are exposed to higher wave forces when the angle of wave approach is direct, or 'head on', when the seaward reef slope is steeper, and when there are less obstacles in the path of the wave approach (Helmuth and Denny, 2003).

Given its location and relatively steep and short profile, Waihi Reef appears to be the most exposed of the six sites monitored. Photographic evidence indicates that relatively large boulders at this site shift in position from one survey to the next. Wave exposure is likely to be the main factor resulting in lower species richness at Waihi relative to other Taranaki reef sites. Community composition at this site reflects the exposed conditions with coralline paint and encrusting animals dominating (Photo 5, Figure 15). Trend analysis found statistically significant evidence of declining trends in both species richness and diversity at this site, unrelated to sand cover (Table 2). It is possible that this declining trend is related to a change in wave exposure over time, however, further investigation is required before this can be attributed as a causal factor.

Orapa Reef appears to be one of the least wave exposed sites, due to its location in North Taranaki, as well as the considerable seaward reef extent which effectively dissipates the incoming wave energy. This is reflected by the intertidal community that inhabits the reef, in particular, the presence of seagrass (Figure 17 and Figure 18). In addition to the sediment requirement mentioned in the previous section, seagrasses are also better suited to more sheltered environments, hence why in New Zealand they are most typically found in estuaries, harbours and embayments (Anderson et al., 2019). Therefore, the considerable extent of seagrass at Orapa suggests that the intertidal reef platform provides an adequate level of shelter.

Photo 5 Contrasting habitat between the exposed Waihi site (left) and stable Manihi site (right)

4.3 Other factors affecting habitat complexity

Habitat complexity is an important factor resulting in differences in diversity between the reef sites in Taranaki. Although it is intrinsically linked to sand cover and wave exposure, other geomorphological and biotic factors can also influence habitat complexity.

At Turangi, Orapa and Mangati, previously free rock and cobble has been found locked, or 'cemented', in place with sand and rubble. These cemented substrates do not provide under-boulder habitat, and this reduction in habitat complexity can result in decreased species richness and diversity. Moreover, interstitial sediments between the cemented substrates often become anoxic, rendering them unsuitable even to organisms that are otherwise adapted to these habitats (e.g. some worms and bivalves). Although substrates are not often cemented in place at Waihi Reef, the high proportion of large rocks and boulders may also lead to lower estimates of species diversity at the site. This is due to the fact that under-boulder biota can only be surveyed where the substrate is easily over turned; where there is a higher proportion of large rock and boulder, there may be more instances where those substrates cannot be overturned and surveyed. Conversely, the geomorphology of the Manihi Reef site comprises very little cemented reef, and a broad range of substrate sizes. This ultimately provides many different ecological niches for a large variety of species to occupy, with habitats including stable pools, under-boulder habitat and crevices within rocks (Photo 5).

Biotic factors have also been shown to have considerable effects on habitat complexity at Orapa. When large colonies of the sand tube worm *N. kaiparaensis* build up over the reef, the diversity of microhabitats available for other species can be significantly reduced (Photo 3). Although these tube worm mounds may provide cryptic habitat for small invertebrates between the tubes and mounds, this habitat provision does not compensate for the decrease in species diversity that occurs due to the reduction in under boulder, above boulder and pool habitat. Furthermore, any increases in species diversity that may be attributed to the tube worms can only be realized if the animals are visible and large enough to be recorded in the survey (>3 mm). Accordingly, increases in tube worm cover in recent years have corresponded to considerable declines in diversity at Orapa (Figure 19). Notably, the decline, increase, and subsequent decline in *N. kaiparaensis* cover between 2012 and 2018 corresponded to pronounced, contrasting changes in species diversity. For future analyses, multivariate statistics are recommended in order to objectively assess the proportional influence of sand tube worm colonies on species diversity at this site compared to other factors (e.g. sand cover).

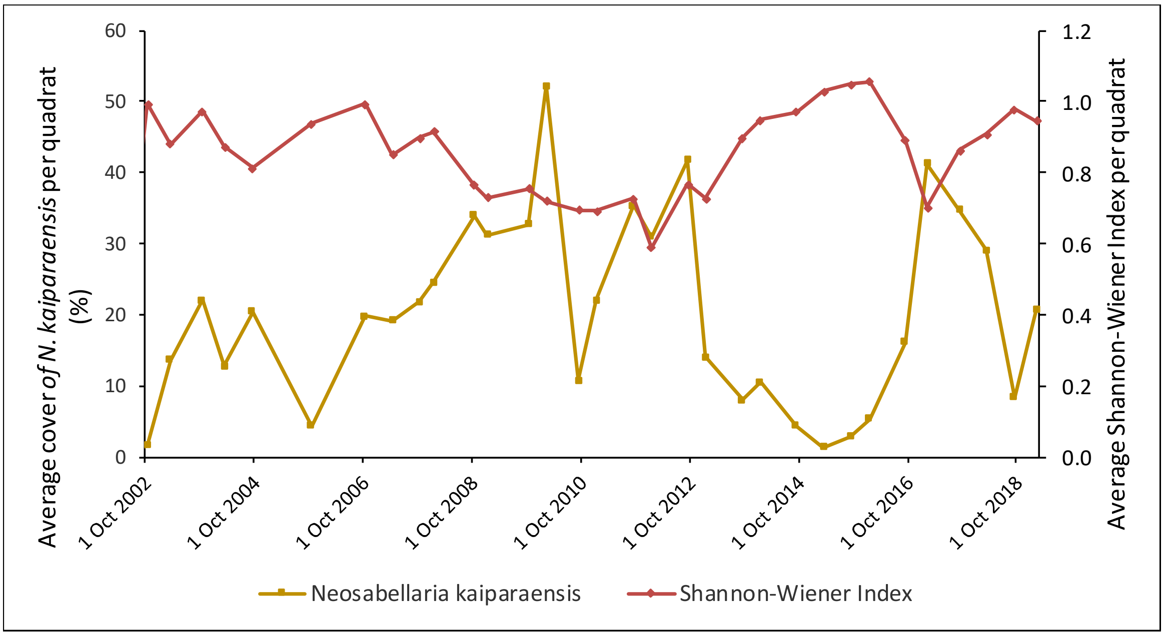

Figure 19 Average cover of N. kaiparaensis and average Shannon-Wiener Index over time at Orapa Reef

4.4 Anthropogenic factors

The diversity and composition of intertidal communities at the SEM reef sites are largely driven by the natural physical factors discussed thus far i.e. the effects of sand and sediment cover, wave exposure and geomorphology. As a result of these overriding natural drivers, underlying subtle ecological changes resulting from human activities can be difficult to detect (Clark *et al*., 2013). However, more noticeable impacts that may arise can be evident. For example, prior to 1997, dairy factory wastewater discharged through the nearshore outfall off the Hawera coastline was having significant adverse effects on the local intertidal community. This was clearly detectable in the results of the intertidal surveys undertaken as part of the consent compliance monitoring programme for the discharge (TRC, 2014). In 1997 the dairy company installed a long outfall to discharge the wastewater nearly 2 km offshore. This resulted in a stepwise improvement in intertidal species richness and diversity at the sites affected by the previous discharge. No such noticeable anthropogenic impacts have been detected at any of the SEM reef sites.

With the exception of Orapa and Mangati, the SEM reef sites are located outside of the influence of wastewater discharges (in the case of Orapa, the nearby wastewater outfall is now only used as a contingency option during rare, high rainfall events). Norovirus analysis of mussels collected from Orapa and (close to) Mangati indicate that previously these sites have had shoreline contact with wastewater discharged from the Waitara and New Plymouth wastewater treatment plants, respectively. Although there is evidence that these wastewater discharges have resulted in microbial contamination of shellfish at these sites, adverse impacts of the wastewater discharges on intertidal species richness and diversity have not been detected through the Council's Rocky Shore SEM programme.

Erosion on land increases the amount of fine sediment that is transported to the coast via rivers and streams. This sediment can have a range of adverse effects on the coastal environment, including effects on water quality and near-shore rocky reef communities. Since European settlement, increased land development has led to some catchments becoming more erosion prone, resulting in more sediment being transported to the coast. This holds true for Taranaki, with sediment loads in many of the region's larger rivers modelled to be two to six times higher than in their predicted natural state (Robertson, 2019).

The effects of fine sediment on coastal water quality vary throughout the region due to fundamental differences between river catchments (including size, geology and land class). In North Taranaki, a gradient of turbidity in coastal waters has been demonstrated, increasing from Cape Egmont to Waitara/Motunui (Crofskey, 2007). This gradient has been largely attributed to the high suspended sediment load that is delivered to the coast by the Waitara River. Analyses of suspended sediment and water clarity data collected monthly around the region between 1995 and 2018 generally show no significant trends over time (TRC, 2018). That is, for the majority of rivers, there is no statistical evidence to suggest that suspended sediment or water clarity has increased or decreased over the 23 year monitoring period. One exception to this is the Stony River, which has seen a significant decrease in water clarity and increase in suspended solids over time; evidence of the increased erosion occurring at the river's headwaters on Mount Taranaki. Although there is little that can be done to prevent natural erosion processes such as this, sustainable land management practises (e.g. riparian fencing and planting, and stabilizing steep hill country) are critical for limiting further erosion and sedimentation in the coastal environment.

Humans can also have localised impacts on intertidal rocky reef communities when exploring rock pools and collecting kaimoana species (i.e. paua and kina). Specifically, these communities can be adversely affected when rocks and boulders are overturned and not returned to their original position afterwards. Algal species are generally found attached to the top side of these substrates as they require light to photosynthesise, whereas many invertebrate species are found on the underside of rocks and cobbles in order to remain sheltered and avoid predation. Therefore, when exploring the reef, rocks must be turned back over to how they were found in order to preserve these intertidal communities. Although this issue has not been associated with the sites in this monitoring programme, it has been observed at various locations around Taranaki, typically lower down the intertidal zone where paua and kina are gathered.

The impacts of climate change on intertidal rocky reef habitats are also likely to increase in the future. In some instances, these impacts may exacerbate existing processes. For example, more frequent, intense rainfall events could accelerate erosion in the headwaters of the Stony River (and elsewhere in the region), introducing more sand to the coast, which may eventually be deposited on rocky reef habitat. Other facets of climate change may have a more selective effect on rocky reef communities, ultimately creating winners and losers. For example, the intertidal species that are most resilient to heat and desiccation stress may be better suited to cope with increasing ocean and atmospheric temperatures. Increased dissolved carbon dioxide associated with ocean acidification may potentially hold some benefit for photosynthesising seaweeds, whilst hindering calcification processes for shell forming molluscs, including mussels and paua. Eventually, intertidal reef habitat may be permanently reduced, and in some cases eliminated, in coastal areas with hard protection structures preventing landward shoreline migration in order to compensate for rising sea levels. With so many factors potentially affecting these important habitats, ongoing monitoring and management of the coastal environment will be critical for their protection. For more information on how climate change is predicted to effect New Zealand's coastal environment, see MfE & Stats NZ (2019) and PCE (2020).

5 General summary

Rocky reefs dominate the intertidal zone of the Taranaki coastline, particularly around the ring plain. In spring 1994, the Council began conducting biannual surveys of intertidal communities at six rocky reef sites as a part of its SEM programme. The information gained through these surveys is used to guide management decisions, enabling the Council to assess the influence of natural processes, and effectively take measures to mitigate the impacts of human activities on the coastal environment.

Natural environmental factors, in particular sand cover, wave exposure, and habitat complexity appear to be the dominant drivers of species richness and diversity at the six SEM reef sites. No noticeable anthropogenic impacts have been detected at any of the SEM reef sites to date, although subtle changes resulting from human activities can be difficult to identify due to the impact of dominant natural factors.

Of the six sites surveyed over the 25 year period of monitoring, the intertidal communities at Manihi are the most species rich and diverse due to the low supply of sand and the presence of pools that provide a stable environment with many ecological niches. The intertidal communities at Waihi are the least species rich and diverse due to a high energy wave environment and resulting unstable habitat. A summary of the main factors affecting diversity and species composition at the six reef sites is provided in Table 5.

Sand deposition from time to time has been shown to have a profound effect on intertidal communities in Taranaki, with the sites at Orapa, Mangati and Greenwood Road being particularly prone to periodic sand inundation. Trend analysis shows that sand cover has increased at the four northern-most SEM sites. This is likely due to an increased sand supply from the mountain, combined with oceanographic conditions that shift this sand onshore. Although typically short lived, sand inundation events result in significant reductions in species richness and diversity. Trend analyses suggest that inundation events at Greenwood Road have led to a declining trend in species richness and diversity over time.

Analysis also shows a declining trend in species richness and diversity at Waihi Reef that was unrelated to sand cover. It is possible that this declining trend is related to a change in wave exposure over time, however, further investigation is required before this can be attributed as a causal factor.

Table 4 Factors affecting diversity and species composition at the SEM reef sites

	Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
Sand cover	Sand cover low but increasing. Not prone to inundation.	High sand cover that is increasing. Occasional inundation.	Prone to periodic sand inundation: Increasing in frequency.	Prone to periodic sand inundation: Increasing in frequency.	Very low sand cover. Not prone to inundation.	Typically low sand cover. One inundation event previously.
Wave exposure	Moderately wave exposed.	Moderately wave exposed.	Moderately wave exposed.	Moderately wave exposed.	Moderately wave exposed.	Very exposed, high energy wave environment.
Reef substrate	Mix of different sized substrates.	Larger boulders and rocks less common.	Larger boulders and rocks less common.	Mix of different sized substrates.	Most diverse mix of substrates.	Rocks and boulders dominate.
Pools	Shallow pools.	Shallow pools.	Shallow pools.	Shallow and deeper pools when not inundated with sand.	Variety of shallow and deeper pools.	Fast draining site with few pools.
Under-boulder habitat	Rocks can become cemented to the substrate reducing the availability of under-boulder habitat.	Sand and cemented substrate can reduce the availability of under-boulder habitat.	Sand and cemented substrate can reduce the availability of under-boulder habitat.	Good availability of under-boulder habitat when not sand inundated.	Excellent availability and variety of under-boulder habitat.	Under-boulder habitat not stable due to high wave energy environment.
Tubeworm cover	Low tubeworm cover.	Large tubeworm colonies can cover reef at times, reducing habitat complexity.	Tubeworms present but not significantly impacting habitat complexity.	Tubeworms present but not significantly impacting habitat complexity.	Low tubeworm cover.	Occasional past high tubeworm cover.
Summary	Moderately diverse site. Under-boulder habitat can be reduced when rocks become cemented to the substrate. Sand cover typically low.	Sand cover and dense colonies of tubeworms can reduce biodiversity at this site.	Site is susceptible to sand inundation events, which may be increasing in frequency.	Diverse site when not inundated with sand. Sand inundation events may be increasing in frequency.	Most diverse SEM reef site due to low sand cover and high habitat complexity.	Least diverse SEM reef site, likely due to the high energy wave environment.

6 Recommendation

1. THAT monitoring of the six SEM reef sites is extended from that carried out in 2017-2019 to also include habitat mapping techniques in order to gather broad scale information on reef topography, sand coverage, seagrass and other key habitat forming species.
2. THAT further work is undertaken to investigate the declining trends in species richness and diversity that were found for the Waihi Reef SEM site, with particular emphasis on possible changes in wave climate and exposure around the region.

Glossary of common terms and abbreviations

The following abbreviations and terms may be used within this report:

Anthropogenic	Caused or produced by humans.
Biomonitoring	Assessing the health of the environment using aquatic organisms.
Community	An ecological unit composed of a group of organisms or a population of different species occupying a particular area, usually interacting with each other and their environment.
Gastropods	Snails and slugs within a large taxonomic class (Gastropoda) within the phylum Mollusca.
Intertidal	The intertidal zone, also known as the littoral zone, is the area of the foreshore and seabed that is exposed to the air at low tide and submerged at high tide, i.e. the area between tide marks.
Littoral	The intertidal zone.
Microhabitat	A habitat which is of small or limited extent and which differs in character from some surrounding more extensive habitat.
Niche (ecological)	An ecological niche is the role and position a species has in its environment; how it meets its needs for food and shelter, how it survives, and how it reproduces. A species' niche includes all of its interactions with the biotic and abiotic factors of its environment.
Physicochemical	Measurement of both physical properties (e.g. temperature, clarity, density) and chemical determinants (e.g. metals and nutrients) to characterise the state of an environment.
Population	A group of organisms of one species that interbreed and live in the same place at the same time.
Resource consent	Refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15).
Ring plain	On the Taranaki peninsula, a line of three cone volcanoes (Taranaki, Pouākai, and Kaitake) is surrounded by a ring plain of avalanche, lahar, and tephra deposits.
RMA	*Resource Management Act* 1991 and including all subsequent amendments.
Species	Regarded as the basic category of biological classification, composed of related individuals that resemble one another, are able to breed among themselves, but are not able to breed with members of another species.

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Appendix I

Species richness and diversity
Raw data & statistical summary

Turangi Reef

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
5 Oct 1994	13.80	0.918	0.84
2 Feb 1995	15.32	0.933	2.96
3 Mar 1995	17.84	0.956	4.88
18 Mar 1995	16.40	0.924	2.20
10 Oct 1995	17.20	0.947	1.32
21 Jan 1996	18.36	0.998	2.36
21 Mar 1996	14.56	0.746	18.64
28 Oct 1996	17.00	0.820	1.40
14 Jan 1997	17.64	0.911	1.16
8 Apr 1997	17.31	0.886	3.60
15 Oct 1997	18.52	0.858	4.59
31 Jan 1998	17.00	0.991	7.80
9 Oct 1998	17.60	1.010	2.48
18 Jan 1999	16.48	0.929	0.96
27 Oct 1999	16.72	0.977	2.00
25 Jan 2000	13.80	0.842	2.96
20 Apr 2000	13.52	0.881	1.40
17 Oct 2000	13.28	0.882	0.96
8 Jan 2001	15.56	0.929	1.04
19 Oct 2001	15.56	0.940	3.08
29 Jan 2002	15.92	0.912	0.60
9 Oct 2002	17.64	0.982	7.52
23 Jan 2003	16.16	0.939	9.88
25 Oct 2003	18.68	0.938	0.60
12 Jan 2004	15.92	0.901	0.40
16 Dec 2004	14.28	0.888	0.80
15 Oct 2005	12.08	0.909	3.20
5 Jan 2006	13.76	0.933	10.40
8 Oct 2006	18.28	0.939	7.92
21 Jan 2007	18.55	0.755	18.84
28 Oct 2007	18.20	0.842	1.00
24 Jan 2008	16.60	0.816	7.52
18 Oct 2008	14.00	0.787	0.40
11 Jan 2009	14.64	0.873	3.92
21 Oct 2009	14.60	0.902	4.08
31 Jan 2010	17.68	0.998	4.52
10 Sep 2010	11.68	0.766	1.04

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
21 Jan 2011	13.88	0.844	5.96
29 Sep 2011	15.24	0.834	16.44
24 Jan 2012	12.76	0.680	8.48
15 Oct 2012	15.16	0.833	1.33
14 Jan 2013	16.68	0.810	15.36
19 Sep 2013	16.48	0.861	2.84
3 Feb 2014	14.12	0.837	12.92
10 Sep 2014	14.04	0.873	11.52
20 Jan 2015	14.46	0.828	24.88
28 Sep 2015	15.68	0.864	2.52
22 Feb 2016	19.52	1.032	22.28
17 Oct 2016	14.12	0.821	1.60
31 Jan 2017	18.12	0.875	5.73
22 Sep 2017	16.80	0.812	2.76
30 Jan 2018	17.44	0.993	0.70
24 Oct 2018	20.92	0.965	19.00
22 Jan 2019	17.52	0.941	30.48
Mean	**16.02**	**0.89**	**6.19**
Median	**16.28**	**0.89**	**3.02**
Max	**20.92**	**1.03**	**30.48**
Min	**11.68**	**0.68**	**0.40**

Orapa Reef

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
6 Oct 1994	13.40	0.899	3.08
2 Mar 1995	16.44	0.975	1.96
7 Oct 1995	16.04	1.002	1.76
18 Mar 1996	15.40	0.941	16.80
26 Oct 1996	16.00	0.885	4.56
7 Apr 1997	17.44	0.998	13.20
14 Oct 1997	17.76	1.017	2.92
3 Mar 1998	15.32	0.960	1.40
19 Oct 1998	15.92	0.972	4.20
1 Apr 1999	13.16	0.913	12.08
29 Oct 1999	14.20	0.956	8.03
20 Apr 2000	12.32	0.824	19.23
14 Oct 2000	14.24	0.913	3.12
10 Apr 2001	3.08	0.149	93.76
17 Oct 2001	16.23	0.962	8.27
16 Mar 2002	1.60	0.148	89.76
7 Oct 2002	16.80	0.993	5.00
18 Mar 2003	13.28	0.880	18.60
24 Oct 2003	16.52	0.974	4.76
23 Mar 2004	11.64	0.872	9.19
29 Sep 2004	11.72	0.812	3.00
19 Oct 2005	13.04	0.939	32.40
7 Oct 2006	17.00	0.992	20.84
20 Apr 2007	13.08	0.851	41.24
26 Oct 2007	14.76	0.899	57.52
25 Jan 2008	14.16	0.916	48.20
16 Oct 2008	12.08	0.764	40.42
13 Jan 2009	11.28	0.729	19.24
19 Oct 2009	11.08	0.755	36.16
1 Feb 2010	11.48	0.719	55.20
7 Sep 2010	10.32	0.694	32.80
20 Jan 2011	11.00	0.693	12.28
28 Sep 2011	10.16	0.726	23.20
25 Jan 2012	7.96	0.588	25.60
19 Sep 2012	11.08	0.767	31.00
11 Jan 2013	10.96	0.726	75.60
23 Sep 2013	14.64	0.899	31.40

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
29 Jan 2014	14.76	0.948	34.00
11 Sep 2014	15.64	0.970	32.00
6 Mar 2015	17.12	1.029	19.80
14 Sep 2015	17.72	1.048	33.40
11 Jan 2016	17.36	1.057	52.00
20 Sep 2016	12.92	0.890	57.60
10 Feb 2017	11.52	0.703	30.72
18 Sep 2017	14.36	0.863	37.20
19 Mar 2018	15.68	0.908	21.84
27 Sep 2018	17.28	0.979	29.28
18 Feb 2019	17.12	0.946	25.68
Mean	**13.63**	**0.86**	**26.69**
Median	**14.22**	**0.90**	**22.52**
Max	**17.76**	**1.06**	**93.76**
Min	**1.60**	**0.15**	**1.40**

Mangati Reef

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
1 Feb 1995	15.04	0.950	4.40
26 Oct 1995	16.04	0.950	0.12
20 Jan 1996	14.88	0.933	0.28
27 Sep 1996	17.20	1.036	0.12
10 Jan 1997	16.64	0.969	0.48
15 Sep 1997	15.92	0.968	3.20
30 Jan 1998	16.96	1.052	8.11
20 Oct 1998	13.88	0.940	1.84
22 Jan 1999	14.75	0.921	2.62
8 Nov 1999	13.48	0.846	6.36
25 Jan 2000	13.92	0.878	12.12
30 Oct 2000	13.84	0.847	10.76
9 Jan 2001	11.80	0.747	14.40
3 Dec 2001	8.68	0.638	36.40
1 Feb 2002	8.76	0.625	22.96
22 Oct 2002	14.88	0.892	7.32
22 Jan 2003	14.36	1.002	23.24
30 Oct 2003	14.04	0.982	7.00
25 Jan 2004	13.04	0.967	9.19
13 Jan 2005	13.04	0.922	2.00
6 Jan 2006	8.48	0.752	39.20
9 Oct 2006	16.60	0.873	41.04
20 Jan 2007	3.44	0.277	85.00
24 Oct 2007	11.88	0.750	18.16
22 Jan 2008	16.08	0.984	27.04
14 Oct 2008	14.04	0.905	0.60
14 Jan 2009	15.52	0.995	2.76
16 Nov 2009	16.12	0.923	14.36
2 Feb 2010	16.48	0.993	0.64
6 Nov 2010	13.76	0.843	0.04
22 Jan 2011	13.40	0.870	12.56
1 Oct 2011	15.64	0.963	19.64
23 Jan 2012	11.04	0.707	40.80
30 Jan 2013	12.52	0.829	47.20
18 Oct 2013	10.71	0.733	48.40
1 Feb 2014	13.20	0.912	25.40
25 Sep 2014	12.80	0.954	16.80

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
19 Jan 2015	5.12	0.435	82.80
15 Sep 2015	10.28	0.587	1.00
9 Feb 2016	10.60	0.714	63.60
16 Nov 2016	14.28	0.876	9.80
11 Jan 2017	14.92	0.889	38.80
19 Sep 2017	14.76	0.908	1.96
28 Feb 2018	18.20	0.999	3.88
25 Sep 2018	16.04	0.921	13.04
20 Jan 2019	17.32	0.926	44.40
Mean	**13.57**	**0.86**	**18.95**
Median	**14.04**	**0.91**	**11.44**
Max	**18.20**	**1.05**	**85.00**
Min	**3.44**	**0.28**	**0.04**

Greenwood Road Reef

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
17 Mar 1996	22.04	1.115	0.36
25 Oct 1996	18.72	1.037	0.24
9 Jan 1997	19.04	0.987	0.12
6 Apr 1997	20.60	1.110	0.00
16 Oct 1997	21.36	1.056	0.20
28 Jan 1998	18.84	0.990	0.08
8 Oct 1998	18.96	1.004	0.12
21 Jan 1999	17.55	0.922	0.40
26 Oct 1999	15.64	0.918	0.52
24 Jan 2000	18.84	1.003	0.44
14 Oct 2000	15.04	0.912	0.68
12 Jan 2001	16.04	0.948	0.56
18 Oct 2001	19.92	1.001	0.80
28 Jan 2002	18.00	1.017	6.04
8 Oct 2002	14.56	0.894	12.76
22 Jan 2003	17.44	0.956	0.60
25 Sep 2003	9.48	0.555	41.12
23 Oct 2003	9.48	0.649	61.04
10 Jan 2004	15.36	0.860	0.00
12 Nov 2004	15.84	0.907	0.00
13 Jan 2005	17.60	1.041	0.00
14 Mar 2005	16.12	1.028	0.40
18 Aug 2005	16.80	1.024	0.00
4 Jan 2006	15.48	0.996	0.00
7 Sep 2006	14.60	0.869	0.00
23 Jan 2007	19.00	0.975	2.92
26 Sep 2007	20.68	1.042	2.00
23 Jan 2008	23.76	1.147	1.24
16 Sep 2008	11.08	0.895	2.64
12 Jan 2009	16.48	0.978	1.40
20 Oct 2009	17.16	1.025	0.46
30 Jan 2010	15.96	0.937	1.96
11 Sep 2010	10.48	0.865	2.76
7 Oct 2010	5.40	0.764	76.00
30 Sep 2011	12.28	0.775	6.36
11 Jan 2012	12.24	0.874	24.20
21 Sep 2012	16.92	0.812	5.08

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
13 Jan 2013	18.56	0.744	7.52
20 Sep 2013	8.29	0.612	86.40
2 Feb 2014	11.24	0.864	7.60
9 Sep 2014	13.80	0.881	4.92
23 Jan 2015	0.16	0.024	98.40
30 Sep 2015	12.56	0.805	23.04
12 Feb 2016	17.88	0.802	23.60
18 Oct 2016	14.96	0.758	7.16
13 Jan 2017	17.48	0.792	20.96
21 Sep 2017	14.04	0.751	0.79
31 Jan 2018	18.04	1.003	0.24
9 Oct 2018	21.72	0.879	0.88
21 Jan 2019	21.48	0.944	3.16
Mean	**15.90**	**0.89**	**10.76**
Median	**16.64**	**0.92**	**1.06**
Max	**23.76**	**1.15**	**98.40**
Min	**0.16**	**0.02**	**0.00**

Manihi Road Reef

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
23 Jan 1996	20.08	1.066	0.04
14 Oct 1996	21.48	1.087	0.36
12 Jan 1997	23.16	1.136	0.32
16 Sep 1997	20.07	1.077	0.28
12 Mar 1998	21.04	1.070	0.96
21 Oct 1998	18.96	1.037	0.36
31 Mar 1999	17.23	1.005	0.28
9 Nov 1999	15.04	0.913	0.52
19 Apr 2000	18.64	1.019	0.56
27 Oct 2000	18.84	1.073	0.48
26 Mar 2001	17.20	0.956	0.60
30 Nov 2001	20.96	1.076	0.64
15 Mar 2002	18.07	0.973	0.56
21 Oct 2002	24.92	1.200	0.84
17 Mar 2003	21.00	1.120	0.28
23 Nov 2003	19.32	1.073	0.00
22 Mar 2004	17.76	1.089	0.00
27 Sep 2004	18.04	1.041	0.00
18 Oct 2005	15.48	0.981	0.00
1 Feb 2006	18.52	1.088	0.00
6 Oct 2006	20.48	1.068	0.80
18 Apr 2007	18.12	0.997	0.36
25 Oct 2007	21.84	1.099	0.64
7 Apr 2008	21.16	1.122	0.52
15 Nov 2008	19.84	1.077	0.40
10 Feb 2009	19.36	1.074	1.00
6 Nov 2009	18.72	1.053	0.36
31 Mar 2010	17.88	1.019	0.00
22 Feb 2011	17.84	1.031	0.00
29 Nov 2011	18.48	1.066	0.00
9 Feb 2012	15.24	0.886	0.00
28 Feb 2013	21.40	1.076	0.84
4 Dec 2013	19.80	1.039	2.50
28 Feb 2014	20.80	1.016	0.28
10 Oct 2014	21.40	1.064	0.00
20 Mar 2015	20.04	1.008	0.05
29 Sep 2015	20.04	1.029	0.70

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
12 Jan 2016	26.24	1.042	1.00
19 Sep 2016	17.92	1.020	0.77
13 Mar 2017	21.20	1.054	0.38
20 Sep 2017	18.80	0.986	0.20
5 Mar 2018	22.52	1.090	0.00
8 Oct 2018	23.36	1.108	0.12
20 Feb 2019	27.72	1.162	0.04
Mean	**19.91**	**1.05**	**0.41**
Median	**19.82**	**1.07**	**0.36**
Max	**27.72**	**1.20**	**2.50**
Min	**15.04**	**0.89**	**0.00**

Waihi Reef

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
4 Nov 1994	13.32	0.958	1.24
15 Feb 1995	13.52	0.949	0.00
12 Jul 1995	12.00	0.907	2.96
24 Nov 1995	14.00	0.978	0.44
18 Feb 1996	16.96	1.033	1.64
10 Dec 1996	10.72	0.830	0.04
9 Feb 1997	12.52	0.921	2.68
25 Mar 1997	13.44	0.942	1.28
16 Nov 1997	13.12	0.951	2.68
14 Apr 1998	12.72	0.956	0.80
24 Apr 1998	14.20	0.938	0.96
2 Nov 1998	10.92	0.809	0.52
15 Feb 1999	11.84	0.796	2.12
16 Mar 1999	12.36	0.841	0.80
26 Nov 1999	10.40	0.809	1.96
18 Feb 2000	12.20	0.870	0.80
21 Mar 2000	12.00	0.883	2.36
15 Nov 2000	12.28	0.899	2.40
12 Feb 2001	11.28	0.903	2.96
17 Nov 2001	11.24	0.797	3.20
2 Mar 2002	11.16	0.853	1.80
26 Mar 2002	13.12	0.860	1.24
8 Nov 2002	12.58	0.939	4.62
19 Feb 2003	12.00	0.932	5.80
25 Nov 2003	11.92	0.928	21.80
8 Mar 2004	4.84	0.402	66.80
8 Feb 2005	8.56	0.782	3.00
3 Nov 2005	8.52	0.722	11.60
3 Feb 2006	7.12	0.673	2.80
6 Nov 2006	11.44	0.811	5.12
20 Feb 2007	10.44	0.853	12.12
26 Nov 2007	8.88	0.771	3.60
11 Feb 2008	13.12	0.954	1.36
13 Nov 2008	9.96	0.817	0.96
12 Feb 2009	8.76	0.791	3.24
3 Nov 2009	10.52	0.800	1.56
2 Mar 2010	11.16	0.852	3.52

Date	Number of species per quadrat	Shannon Wiener index per quadrat	Percentage sand cover per quadrat
8 Nov 2010	11.00	0.806	0.44
18 Feb 2011	11.60	0.828	2.91
11 Mar 2012	10.64	0.800	1.28
12 Nov 2012	11.88	0.817	3.44
27 Feb 2013	12.12	0.888	6.71
3 Dec 2013	12.68	0.932	1.38
15 Apr 2014	10.88	0.788	0.88
4 Nov 2014	8.96	0.824	0.76
19 Mar 2015	10.48	0.821	0.75
24 Nov 2015	9.60	0.848	1.44
9 Mar 2016	11.64	0.777	4.00
12 Dec 2016	9.20	0.787	1.08
27 Mar 2017	10.48	0.760	0.60
No Spring 2017 survey	-	-	-
29 Mar 2018	10.55	0.812	1.00
8 Nov 2018	13.27	0.857	8.42
21 Feb 2019	15.92	0.890	5.60
Mean	**11.43**	**0.85**	**4.22**
Median	**11.60**	**0.85**	**1.96**
Max	**16.96**	**1.03**	**66.80**
Min	**4.84**	**0.40**	**0.00**

Appendix II

Statistical analysis results

Mann Whitney U (Wilcoxon) test results for comparing species richness and diversity between the different sites. Values <0.05 indicate evidence for a difference between the sites indicated.

Pairwise comparisons of Number of Species at each site, over the full 25 years of records, using no p-value adjustment method.

	Greenwood	Mangati	Manihi	Orapa	Turangi
Mangati	0.00032	-	-	-	-
Manihi	1.50E-06	1.10E-14	-	-	-
Orapa	0.00081	0.83522	1.00E-14	-	-
Turangi	0.41419	2.30E-05	1.00E-11	0.00012	-
Waihi	2.80E-09	4.90E-06	< 2e-16	1.10E-05	4.80E-16

Pairwise comparisons of Number of Species at each site, over the full 25 years of records, using the Benjamini-Hochberg procedure to adjust p-values for false detection rates.

	Greenwood	Mangati	Manihi	Orapa	Turangi
Mangati	0.0004	-	-	-	-
Manihi	3.20E-06	4.10E-14	-	-	-
Orapa	0.00093	0.83522	4.10E-14	-	-
Turangi	0.44377	3.50E-05	3.00E-11	0.00017	-
Waihi	7.00E-09	9.30E-06	6.60E-16	1.90E-05	3.60E-15

Pairwise comparisons of Shannon Wiener index (species diversity) at each site, over the full 25 years of records, using no p-value adjustment method.

	Greenwood	Mangati	Manihi	Orapa	Turangi
Mangati	0.1395	-	-	-	-
Manihi	2.40E-09	2.90E-13	-	-	-
Orapa	0.1781	0.8917	5.90E-13	-	-
Turangi	0.159	0.8654	6.00E-15	0.8722	-
Waihi	0.0039	0.0559	6.10E-16	0.072	0.0103

Pairwise comparisons of Shannon Wiener Index at each site, over the full 25 years of records, using the Benjamini-Hochberg procedure to adjust p-values for false detection rates.

	Greenwood	**Mangati**	**Manihi**	**Orapa**	**Turangi**
Mangati	0.2092	-	-	-	-
Manihi	7.20E-09	1.40E-12	-	-	-
Orapa	0.2226	0.8917	2.20E-12	-	-
Turangi	0.2168	0.8917	4.50E-14	0.8917	-
Waihi	0.0098	0.1048	9.20E-15	0.1201	0.022

Mann-Kendall test results showing unadjusted and sand adjusted trends analysis for number of species per quadrat, Shannon Wiener index per quadrat and sand cover

Variable	# Samples	Sampling period	Mean	Max	Min	Median	Kendall statistic	Variance	Z	P	N (slopes)	Median Sen slope (annual)	% annual change	95% confidence limits for slope
Greenwood														
# Species	50	17/3/96-21/1/19	15.90	23.76	0.16	16.64	-271	14290	-2.26	0.023904	50	**-0.2065**	**-1.2410**	**-0.366971 to -0.033478**
# Species SC adjusted	50	17/3/96-21/1/19	"	"	"	"	-123	14292	-1.02	0.307485	50	-0.0780	-0.4687	-0.206493 to 0.060406
Shannon-Wiener Index	50	17/3/96-21/1/19	0.89	1.15	0.02	0.92	-486	14291	-4.06	0.00005	50	**-0.0103**	**-1.1230**	**-0.014390 to -0.006211**
S-W SC adjusted	50	17/3/96-21/1/19	"	"	"	"	-255	14292	-2.12	0.033614	50	**-0.0043**	**-0.4698**	**-0.008571 to -0.000396**
% Sand cover	50	17/3/96-21/1/19	10.76	98.40	0.00	1.06	487	14244	4.07	0.000047	50	**0.2102**	**19.8314**	**0.095244 to 0.425780**
Mangati														
# Species	46	1/2/95-20/1/19	13.57	18.20	3.44	14.04	-119	11151	-1.12	0.263805	46	-0.0660	-0.4698	-0.174392 to 0.048407
# Species SC adjusted	46	1/2/95-20/1/19	"	"	"	"	71	11155	0.66	0.507477	46	0.0259	0.1842	-0.054855 to 0.118751
Shannon-Wiener Index	46	1/2/95-20/1/19	0.86	1.05	0.28	0.91	-175	11153	-1.65	0.099434	46	-0.0030	-0.3338	-0.007473 to 0.000743
S-W SC adjusted	46	1/2/95-20/1/19	"	"	"	"	61	11155	0.57	0.569974	46	0.0009	0.1003	-0.002755 to 0.004088
% Sand cover	46	1/2/95-20/1/19	18.95	85.00	0.04	11.44	332	11154	3.13	0.001724	46	**0.9472**	**8.2796**	**0.228362 to 1.730878**
Manihi														
# Species	44	23/1/96-20/2/19	19.91	27.72	15.04	19.82	134	9773	1.35	0.178517	44	0.0737	0.3717	-0.021703 to 0.186610
# Species SC adjusted	44	23/1/96-20/2/19	"	"	"	"	144	9775	1.45	0.148082	44	0.0797	0.4019	-0.024155 to 0.188403
Shannon-Wiener Index	44	23/1/96-20/2/19	1.05	1.20	0.89	1.07	-43	9770	-0.42	0.670904	44	-0.0006	-0.0599	-0.002942 to 0.001846
S-W SC adjusted	44	23/1/96-20/2/19	"	"	"	"	-54	9775	-0.54	0.59192	44	-0.0009	-0.0809	-0.003087 to 0.001822
% Sand cover	44	23/1/96-20/2/19	0.41	2.50	0.00	0.36	-49	9587	-0.49	0.623971	44	0.0000	0.0000	-0.018881 to 0.006748
Orapa														
# Species	48	6/10/94-18/2/19	13.63	17.76	1.60	14.22	-95	12656	-0.84	0.403394	48	-0.0422	-0.2966	-0.170208 to 0.068337

Variable	# Samples	Sampling period	Mean	Max	Min	Median	Kendall statistic	Variance	Z	P	N (slopes)	Median Sen slope (annual)	% annual change	95% confidence limits for slope
# Species SC adjusted	48	6/10/94-18/2/19	"	"	"	"	62	12659	0.54	0.587701	48	0.0323	0.2269	-0.087311 to 0.116391
Shannon-Wiener Index	48	6/10/94-18/2/19	0.86	1.06	0.15	0.90	-151	12653	-1.33	0.182366	48	-0.0028	-0.3115	-0.008583 to 0.001490
S-W SC adjusted	48	6/10/94-18/2/19	"	"	"	"	54	12659	0.47	0.637594	48	0.0012	0.1289	-0.004081 to 0.004806
% Sand cover	48	6/10/94-18/2/19	26.69	93.76	1.40	22.52	468	12659	4.15	0.000033	48	**1.3203**	**5.8628**	**0.842719 to 1.808126**
Turangi														
# Species	54	5/10/94-22/1/19	16.02	20.92	11.68	16.28	-39	17959	-0.28	0.776749	54	-0.0111	-0.0680	-0.101339 to 0.063351
# Species SC adjusted	54	5/10/94-22/1/19	"	"	"	"	-98	17966	-0.72	0.469263	54	-0.0298	-0.1833	-0.115374 to 0.043165
Shannon-Wiener Index	54	5/10/94-22/1/19	0.89	1.03	0.68	0.89	-272	17960	-2.02	0.04316	54	**-0.0031**	**-0.3436**	**-0.005734 to -0.000228**
S-W SC adjusted	54	5/10/94-22/1/19	"	"	"	"	-250	17966	-1.86	0.063213	54	-0.0027	-0.3045	-0.005238 to 0.000128
% Sand cover	54	5/10/94-22/1/19	6.19	30.48	0.40	3.02	329	17959	2.45	0.014383	54	**0.1776**	**5.8801**	**0.023543 to 0.424731**
Waihi														
# Species	53	4/11/94-21/2/19	11.43	16.96	4.84	11.60	-400	16984	-3.06	0.002201	53	**-0.1039**	**-0.8957**	**-0.158232 to -0.044307**
# Species SC adjusted	53	4/11/94-21/2/19	"	"	"	"	-422	16993	-3.23	0.00124	53	**-0.1034**	**-0.8915**	**-0.157869 to -0.046856**
Shannon-Wiener Index	53	4/11/94-21/2/19	0.85	1.03	0.40	0.85	-449	16988	-3.44	0.000588	53	**-0.0050**	**-0.5894**	**-0.007339 to -0.002237**
S-W SC adjusted	53	4/11/94-21/2/19	"	"	"	"	-484	16993	-3.71	0.000211	53	**-0.0048**	**-0.5688**	**-0.007280 to -0.002375**
% Sand cover	53	4/11/94-21/2/19	4.22	66.80	0.00	1.96	197	16984	1.50	0.132588	53	0.0441	2.2479	-0.014722 to 0.136841

Appendix III

Species list

Algal and plant species identified during the July 2017 to June 2019 surveys (table values correspond to the percentage of quadrats each species was present in)

Phylum	Species	Presence in quadrats (%)					
		Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
Chlorophyta (green algae)	*Chaetomorpha aerea*	67	87	71	79	25	
	Cladophora sp.	4					
	Ulva intestinalis	1				14	
	Ulva lactuca	39	82	49	60	22	
Ochrophyta (brown algae)	*Carpophyllum maschalocarpum*					5	
	Colpomenia sp.	27	10	3	39	21	
	Cystophora torulosa					5	
	Dictyota sp.				1		
	Endarachne binghamiae	2	2		4	1	
	Hormosira banksii					86	
	Leathesia sp.				13	13	
	Myriogloea intestinalis	1					
	Notheia anomala					21	
	Ralfsia sp.	58	54	63	86	100	80
	Scytothamnus australis	4			26	12	
	Xiphophora gladiata		1				
Rhodophyta (red algae)	*Ballia* sp.	9		8			
	Ceramium sp.		1		1		
	Champia sp.	35	11	6	35	30	3
	Cladostephus spongiosus			1	10		
	Encrusting coralline spp. (coralline paint)	84	70	72	79	98	80
	Geniculate coralline spp. including *Corallina officinalis* (corraline turf)	93	98	100	97	94	5
	Echinothamnion sp.	1			9		
	Gelidium caulacantheum	67	5	22	35	10	43
	Gigartina spp.	9	35	1	23	18	11
	Hymenena sp.	3		2	24		3
	Jania sp.	12	9	70		2	
	Laurencia distichophylla	1	3			8	
	Laurencia thryisifera	28		2	22	25	3
	Porphyra columbina	9	8	6	2		
	Pterocladiella capillacea	6			25	1	
Unidentified algae	Unidentified algal species (at least eight different species)	19	35	22	44	34	1

Phylum	Species	Presence in quadrats (%)					
		Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
Tracheophyta (vascular plants)	*Zostera capricorni*		12				

Animal species identified during the July 2017 to June 2019 (table values correspond to the percentage of quadrats each species was present in)

Phylum	Class	Species	Presence in quadrats (%)					
			Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
Annelida	Polychaeta	Large sand tube-worm sp.	4	1	1	3	20	1
		Neosabellaria kaiparaensis	61	95	93	84	49	69
		Unidentified polychaete spp.	7	5	5	11	13	
		Scale worm spp.	6	3	4	9	13	
		Spirobranchus cariniferus	83	76	86	75	77	65
		Spirorbis sp.	43	66	10	43	72	4
		Smooth calcareous tube-worm sp.						5
Chordata	Tunicata	Unidentified tunicate spp.	16	5		7	12	
	Vertebrates	*Acanthoclinus littoreus*	2				3	
		Haplocylix littoreus					4	8
		Parablennius laticlavius						1
		Trachelochismus pinnulatus				1	3	3
		Triplefin spp. including *Forsterygion malcolmi* and *F. maryannae*				4	4	
		Unidentified fish spp.		1			2	
Cnidaria	Anthozoa	*Actinia tenebrosa*	4				1	
		Isactinia olivacea	44	49	54	33	52	11
		Oulactis magna				2		1
		Oulactis muscosa				5	12	9
		Unidentified anemone spp.					3	9
	Hydrozoa	Unidentified hydrozoan spp.						7
Crustacea	Malacostraca	*Alope spinifrons*	2		2	1	2	7
		Betaeus aequimanus	1				5	
		Biffarius filholi	1					
		Halicarcinus spp. including *H. cookii* and *H. whitei*	4	6	2	14	7	1

Phylum	Class	Species	Presence in quadrats (%)					
			Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
		Heterozius rotundifrons	3			3	10	5
		Leptograpsus variegatus		3	3	1		
		Metacarcinus novaezelandiae				1		
		Neohymenicus pubescens				2		
		Notomithrax sp.				1		
		Ozius truncatus	7		1	2	8	
		Pagurus sp.	29	5	26	16	18	4
		Palaemon affinis	2	1	4	1	9	5
		Petrolisthes elongatus	66	30	24	29	85	57
		Plagusia chabrus	4		2	3	4	
		Unidentified amphipod spp.	22	16	7	7	22	11
		Unidentified crab spp.	2					
		Unidentified isopod spp.	9	22	19	9	12	9
		Unidentified shrimp spp.				1	1	
	Maxillopoda	*Austrominius modestus*	3					63
		Chamaesipho columna	79	58	92	69	86	35
		Epopella plicata	2			1		
		Tetraclitella purpurascens	4	5		3	13	28
Echinodermata	Asterozoa	*Astrostole scabra*					1	
		Coscinasterias muricata	7				2	
		Ophionerias fasciata	2	2			33	
		Patiriella regularis	17	40	22	5	56	7
	Echinozoa	*Evechinus chloroticus*	28	2		1	2	
Mollusca	Bivalvia	*Borniola reniformis*	2			3	12	
		Perna canaliculus	9	1	3	5	2	
		Protothaca crassicosta	2	3	20	32	13	3
		Saccostrea glomerata				1		1
		Unidentified bivalve spp.						4
		Venerupis largillierti	1			3	3	
		Xenostrobus pulex	1	18	73	30	1	
	Gastropoda	*Alloiodoris lanuginata*					1	
		Atalacmea fragilis					13	
		Buccinulum sp.		1			1	

Phylum	Class	Species	Presence in quadrats (%)					
			Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
		Micrelenchus tesselatus	18	34	30	57	4	20
		Cellana ornata	5	2	3		40	
		Cellana radians	21	17	34	21	58	48
		Cominella maculosa	15	10	13	3	24	
		Dicathais orbita	3	2	1	16	1	3
		Diloma aethiops	77	67	75	67	92	52
		Diloma bicanaliculata	5	3	4	1	22	
		Diloma nigerrima			1	4		
		Diloma zelandicum		1	25	24	1	39
		Epitonium jukesianum			1		6	1
		Haliotis iris					1	
		Haustrum haustorium	7	11	5	39	56	17
		Haustrum scobina	71	63	25	21	63	36
		Jorunna sp.		2				
		Lunella smaragdus	87	94	86	69	66	19
		Margarella sp.	2		1	3	1	4
		Nodilittorina sp.	1					
		Notoacmea daedala	71	35	49	36	64	48
		Onchidella nigricans	10	5	1	1	28	
		Patelloida corticata		3	18	3	1	
		Phidiana milleri	2					3
		Scutus breviculus	4			1	4	
		Siphonaria australis		2	28	63	4	1
		Unidentified nudibranch spp.	1				2	
		Zeacumantus lutulentus		18			21	
		Zeacumantus subcarinatus		1	4	9		
	Polyplacophora	*Acanthochitona zelandica*	19	35	26	20	33	
		Callochiton crocinus	1					
		Chiton glaucus	73	43	45	27	87	60
		Ischnochiton maorianus	18	19	6	22	66	11
		Rhyssoplax aerea			1			
		Sypharochiton pelliserpentis	46	31	53	38	50	16
		Sypharochiton sinclairi	64	56	52	73	69	19
Nematoda		Nematode worm sp.		1	1		4	1

Phylum	Class	Species	Presence in quadrats (%)					
			Turangi	Orapa	Mangati	Greenwood	Manihi	Waihi
Nemertea		Nemertine worm spp.	12	1	1	6	6	5
Platyhelminthes	Turbellaria	Flatworm spp.	12	7	16	9	22	11
Porifera	Homosclero-morpha	*Plakina cf. monolopha*		6				
	Demospongiae	*Tethya* spp. (including *T. aurantium*)	2	2		1	1	
Sipuncula		*Sipunculid* spp.	5	1	1	11	4	