

Biodiversity and habitat assessment of subtidal reefs at the Mercury Islands, northeastern New Zealand

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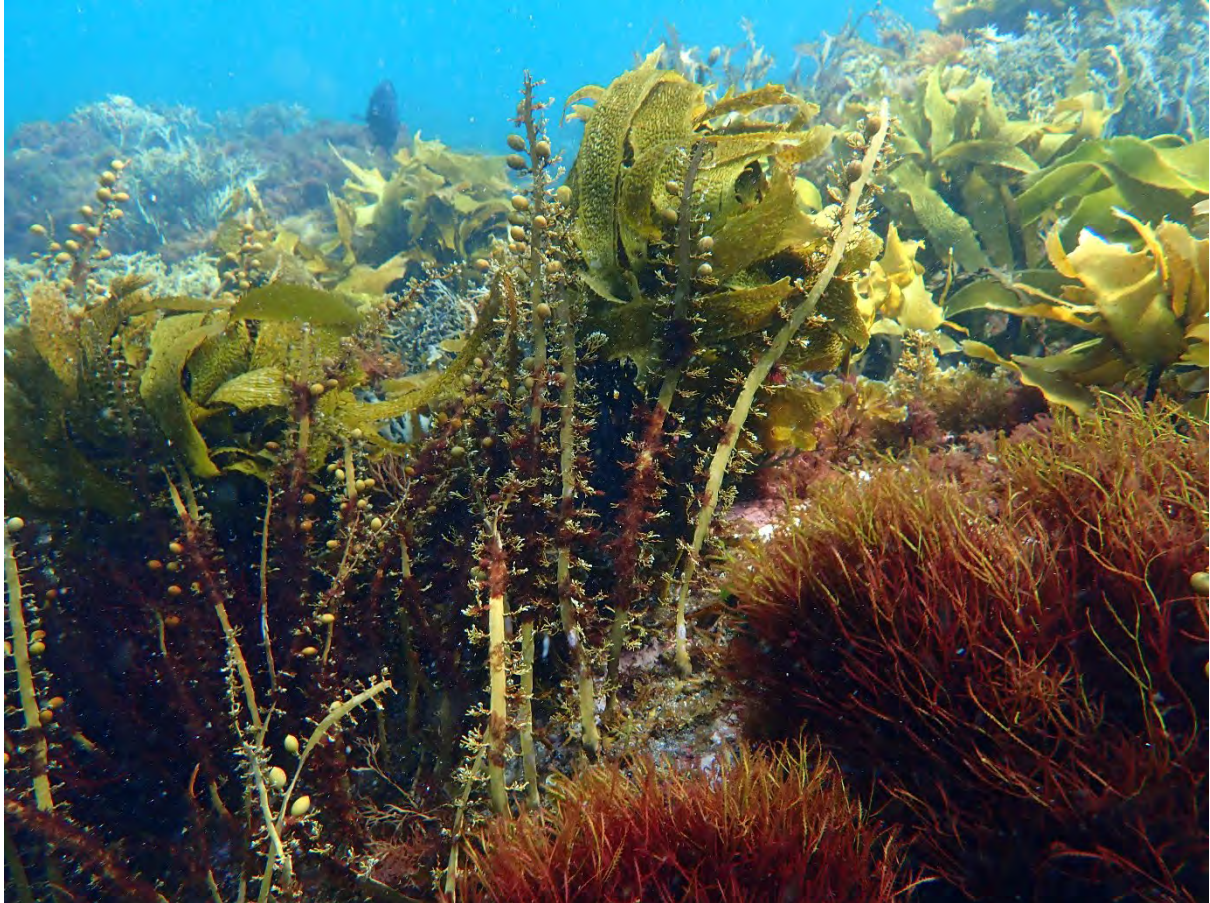
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Biodiversity and habitat assessment of subtidal reefs at the Mercury Islands, northeastern New Zealand



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Abstract

With growing pressure on the marine environment there is an urgent need to understand the health of coastal reef ecosystems in order to inform marine managers on the state of the environment and support marine spatial planning. To date, very limited information exists on the biodiversity and health of rocky reef ecosystems at the Mercury Islands, northeastern New Zealand. To address this knowledge gap, reef fish and benthic community surveys were carried out at nine sites spanning the island group in 2021/2022. In addition, targeted surveys for key reef invertebrates (red rock lobster *Jasus edwardsii*, long-spined urchin *Centrostephanus rodgersii*) were carried out at seven of these sites.

The rocky reef communities at all sites were generally dominated by macroalgal forests and mobile macroinvertebrate densities were low. The sea urchin or kina, *Evechinus chloroticus*, occurred in relative low densities and kina barrens were generally rare and patchy at the survey sites. However, some large areas of kina barrens (100-1000 m²) were observed via drop camera near to the survey sites. *Jasus edwardsii* abundance was low (~2 per 500 m²) and the population was dominated by sublegal individuals. *Centrostephanus rodgersii* was only observed in low numbers and did not form barrens as seen in other offshore islands in northeastern New Zealand. Reef fish communities were typical of northeastern New Zealand, dominated by several schooling planktivores. In general, there were low numbers and small sizes of heavily targeted species such as snapper, kingfish, trevally. There was also a low diversity and abundance of subtropical and vagrant species (e.g., tropical wrasses) indicating a more coastally influenced fish assemblage, compared to other offshore island groups.

Overall, the reef assemblages of the Mercury Islands appear healthy with no invasive species recorded on the reefs and extensive and diverse algal forests covering much of the reef. However, the islands are heavily fished, and this was evident in reef fish and rock lobster surveys. Large reef predators such as *J. edwardsii* and snapper were rare, and the presence of kina barrens likely reflects an indirect effect of fishing these ecologically important predators. However, the occurrence of barrens was highly variable among sites reflecting the complex topography and underwater seascape of the islands. This study provides the first island-wide assessment of reef biodiversity and habitats at this island group and serves as a reference point for future management of the Mercury Islands.

1 Introduction

Coastal rocky reefs provide many ecosystem services including providing habitats for numerous species that are culturally, recreationally and commercially important. With increasing stressors on our coastal environment there is a growing need to understand the health of these ecosystems and inform initiatives aimed at better managing and safeguarding their biodiversity. Assessing and monitoring community structure, biodiversity, and the spatial distribution and abundance of species over time is an integral part of such coastal management. Valuable information in this regard can be achieved by a detailed assessment of the coverage and complexity of the reef habitats. Furthermore, detailed biodiversity assessments are necessary to first know what is there, and second, to give an indication of the health of the ecosystem. Documenting these habitats and species suites is required to monitor any change over time and elucidate the mechanisms that may be behind any potential change. This is particularly pertinent in nearshore regions in northeastern New Zealand, which are potentially affected by a range of stressors including over-exploitation, sedimentation and nutrient enrichment from land-based activities, invasive species, and increasingly climate-related disturbances.

Shallow subtidal reefs in northeastern New Zealand are typical of temperate rocky reefs globally, being naturally dominated by macroalgal forests - mainly kelp (order Laminariales) and fucoids (order Fucales) - that form three-dimensional habitats and support a diverse ecosystem (Shears and Babcock 2004). The main human impacts identified for these forests are sedimentation and overfishing. Elevated turbidity associated with sedimentation has been shown to lead to a shallowing and reduced productivity of kelp forests (Blain et al. 2021), whereas overfishing of large sea urchin predators (red rock lobster, *Jasus edwardsii* and snapper, *Chrysophrys auratus*), can lead to an increase in sea urchins and loss of kelp forest (*Ecklonia radiata*) and their associated biodiversity at intermediate depths (Shears and Babcock 2002). The common sea urchin or kina (*Evechinus chloroticus*) can form extensive areas of reef devoid of large brown algae (called “kina barrens”), but the depth distribution and extent of this habitat varies in relation to several environmental factors, such as wave exposure (Shears et al. 2008). Notably long-term protection of predators within marine reserves has been shown to promote the recovery of kelp forests within urchin barrens (Shears and Babcock 2003).

To date, there is limited evidence to suggest invasive species and climate change, which are often major stressors on marine ecosystems, have impacted on shallow reef ecosystems in northeastern New Zealand. However, recent events in this region suggest these ecosystems may be becoming increasingly vulnerable to such impacts. For example,

in 2022 the exotic seaweeds *Caulerpa brachypus* and *Caulerpa parvifolia* were found in waters at Great Barrier Island (Aotea) and Great Mercury Island (Ahuahu). Additionally, a large marine heatwave in 2022 resulted in the necrosis and bleaching of sponges on rocky reefs at several locations across New Zealand, including the Hauraki Gulf (Bell et al. 2023). There is also emerging evidence that the subtropical long-spined sea urchin (*Centrostephanus rodgersii*) is increasing in abundance with warming temperatures and forming barrens at offshore islands in northeastern New Zealand (Balemi & Shears 2023). This species has also increased in Tasmania with warming temperature, where it has been shown to have a number of deleterious effects on the reef ecosystem (i.e., barren-forming) (e.g. Tasmania; Ling & Keane 2018).

To our knowledge, limited information exists on the biodiversity and impacts on subtidal reef habitats and associated species at the Mercury Islands. Grace & Grace (1976) provide descriptions of several closely situated rocky reef sites located in the western bay of Ahuahu (Great Mercury Island), and Grace (1972a) describes two sites on the western side of Whakau (Red Mercury Islands), including some fish data.

Furthermore, Grace (1973) provides some further information on fish fauna at Whakau (Red Mercury Island). These studies documented a healthy reef ecosystem in the 1970's, but the current state of the reef ecosystems is unknown. Given region-wide declines in the abundance and size of key predator species such as rock lobster and snapper (LaScala-Gruenewald et al. 2021), this area is likely to have subsequently seen the establishment of kina barrens since the early 1970's. Furthermore, the offshore location of the Mercury Islands may mean this area has seen increases in *C. rodgersii* abundance and associated impacts in recent decades. To address this knowledge gap, we use a range of methodologies for surveying reef invertebrate and algal communities and reef fishes that are widely used on rocky reefs inside and outside northeastern New Zealand marine reserves, including the Leigh, Tāwharanui, Hahei and Poor Knights Islands Marine Reserves (e.g. Shears & Babcock 2004, Haggitt 2011). This will provide a baseline to detect future changes and allow quantitative comparisons with other parts of northern New Zealand. The biodiversity assessment will incorporate representative, spatially limited surveys, aiming to encompass the breadth of the island's subtidal rocky reef habitat types and associated marine life.

The combination of benthic community analyses, fish visual censuses, targeted surveys of key invertebrates and abiotic and biogenic habitat information will provide a broad understanding of the state of the subtidal environments at the Mercury Islands. Overall,

this is the first island-wide biodiversity and habitat assessment of this nature to be undertaken at this island group.

2 Materials and Methods

2.1 Survey sites

Nine sites were surveyed spanning the main islands of the Mercury Islands, in the northern part of the group. Sites were chosen based on knowledge of reef habitats, nautical charts and satellite imagery, covering a diversity of subtidal rocky reef habitats and exposure aspects (embayments, points, offshore-facing, inshore-facing etc.). An attempt was made to survey a representative coverage of the subtidal habitats and marine life across the island group, but weather conditions influenced the final selection of sites. Four sites were surveyed at Ahuahu (Great Mercury Island), two at Whakau (Red Mercury Island), and one each at Green Island, Kawhиту and Moturehu (Double Island) (Figure 1). The site names were (with abbreviations): Sister Rocks (SisR), Cathedral Rock (Cath), Coralie Bay (Cora), Te Whanga Bay (TeWh), Green Island (GrnI), Kawhиту (Kawh), Moturehu (Motu), Roger's Spot (Rogr), and Von Luckner's Cove (Luck) (Figure 1). Sister Rocks and Roger's Spot correspond to sites from the previous studies of Grace & Grace (1976) and Grace (1972b), respectively.

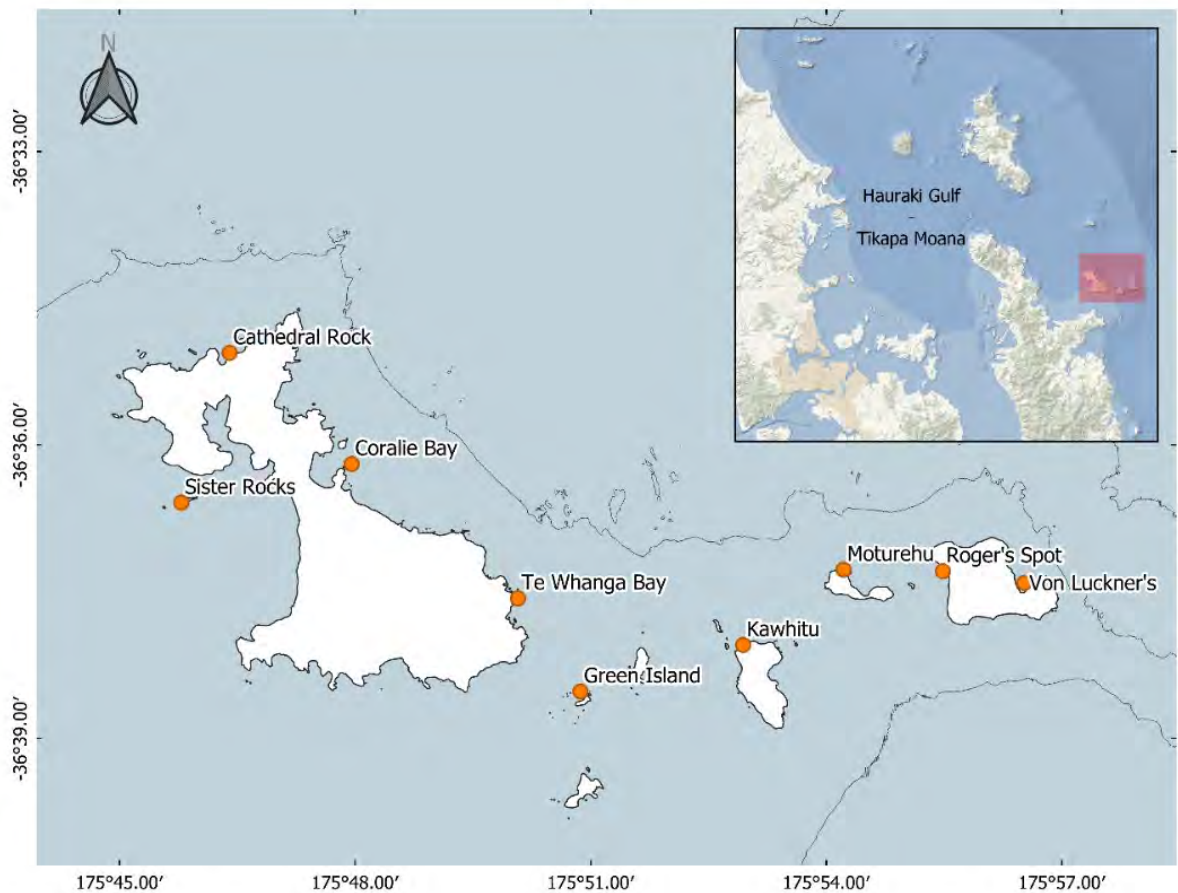


Figure 1. Survey locations around the Mercury Islands, from the westernmost Ahuahu (Great Mercury Island) to the easternmost island, Whakau (Red Mercury Island). Site names: Sister Rocks, Cathedral Rock, Coralie Bay, Te Whanga Bay, Green Island, Kawhиту (Stanley Island), Moturehu (Double Island), Roger's Spot, Von Luckner's Cove. Lines indicate 50 m isobath. Inset map shows Mercury Islands location (red box) relative

to the Hauraki Gulf/Tikapa Moana and greater Auckland and Coromandel, North Island New Zealand.

Table 1. Site positions, fetch and survey details. Sites listed in order of exposure from most sheltered to most exposed.

Site	Latitude	Longitude	Total fetch (km)	Benthic	Fish	Lobster /Centro	Reef Profiles	Georeferenced Habitat Photos
Sister Rocks	-36.610	175.716	472	Jul-21*	Jul-21**	X	Jul-21	No
Roger's Spot	-36.622	175.925	769	Jul-21	Jul-21	X	Jul-21	No
Cathedral Rocks	-36.584	175.773	1295	Jul-21	Mar-22	Mar-22	Jul-21	Yes
KawhITU North	-36.634	175.882	2276	Mar-22	Mar-22	Mar-22	Mar-22	Yes
Green Island	-36.642	175.848	2711	Jul-21	Mar-22	Mar-22	Jul-21	Yes
Te Whanga	-36.626	175.835	2955	Jul-21	Mar-22	Mar-22	Jul-21	Yes
Von Luckner's Cove	-36.624	175.942	3005	Jul-21	Mar-22	Mar-22	Jul-21	Yes
Moturehu	-36.621	175.904	3311	Mar-22	Mar-22	Mar-22	Mar-22	Yes
Coralie Bay	-36.603	175.799	3634	Jul-21	Mar-22	Mar-22	Jul-21	Yes

* Only shallow depth range sampled due to lack of deeper reef.

**Three additional fish transects were undertaken at the westernmost island of Sister Rocks, ~350 m to the SW of this benthic site, but where deeper reef habitat exists.

2.2.1 Reef Profiles and Habitat Distribution

The reef profile and distribution of major habitat types was recorded at each site using a line transect that was run down the reef, from low tide to the reef edge (or a maximum depth of 15 m). The depth, main substrate and biological habitat types (using categories from Shears et al. 2004) were recorded at 5 m intervals along the transect. This provides an easily interpretable metric of the extent of major habitats at each site (e.g., kina barrens or kelp forests) that will complement habitat mapping.

Table 2. Description of habitat types used to classify the reef in this study (based on Shears et al. 2004).

Reef habitat type	Typical depth range (m)	Description
Shallow <i>Carpophyllum</i> forest	<3	Dominated by high abundances (>20 adult* plants m ⁻²) of <i>Carpophyllum maschalocarpum</i> , <i>C. plumosum</i> , <i>C. angustifolium</i> and in some cases <i>Xiphophora chondrophylla</i> . <i>Ecklonia radiata</i> , <i>Sargassum sinclairii</i> and the red algae <i>Pterocladia lucida</i> , <i>Osmundaria colensoi</i> , and <i>Melanthalia abscissa</i> also common. Sea urchin <i>Evechinus chloroticus</i> occurs in low numbers and usually occupies crevices.
Mixed algal forest	2-10	Mixture of large brown algal species including <i>Lessonia variegata</i> . No clear dominance of one particular species, with >50% canopy cover (typically >4 adult plants m ⁻²) and urchins may also occur at low numbers (<2 exposed urchins m ⁻²).
Urchin barrens	3-12	Very low numbers of large brown algae present (<4 adult plants m ⁻²), substratum typically dominated by crustose coralline algae. Usually associated with grazing activity of <i>Evechinus</i> (>2 exposed urchins m ⁻²), which leaves the substratum relatively devoid of macroalgae. <i>C. flexuosum</i> and <i>Sargassum sinclairii</i> may occur.
Turfing algae	3-12	Substratum predominantly covered by turfing algae (e.g., articulated corallines and other red turfing algae) (>50% cover). Low numbers of large brown algae (<4 adult plants m ⁻²) and urchins may be common.
<i>Ecklonia</i> forest	>5	Generally monospecific stands of mature <i>Ecklonia</i> with >50% canopy (typically >4 adult plants m ⁻²), occasional <i>C. flexuosum</i> plants. Urchins at low numbers and usually occupy crevices.
<i>Carpophyllum flexuosum</i> forest**	3-12	<i>C. flexuosum</i> plants dominate (>4 adult plants m ⁻²), on sheltered reefs plants are large and associated with high levels of sediment. On more exposed reefs plants are short and generally associated with <i>Evechinus</i> .
Deep reef***	>12	Deep reef with sparse <i>Ecklonia</i> (<4 adult plants m ⁻²) and sponges visually dominant, high cover of sediment. Usually occurs on the reef-sand interface.
<i>Caulerpa flexilis</i> mats****	8-12	Dense mats of <i>Caulerpa flexilis</i> over the substratum (>40%). Usually occurs on the reef-sand interface. Urchins and large brown algae rare.
Encrusting invertebrates	2-15	Usually vertical walls, substratum predominantly covered by community of encrusting ascidians, sponges, hydroids, and bryozoans. Large brown algae are rare.

* Adults >25 cm; Juveniles <25 cm.

** Not recorded at survey sites but does occur on some sheltered reefs (~10 m depth) at the Mercury Islands (N.S. pers. obs.).

*** Analogous to Sponge Flats in Shears et al. (2004).

**** The invasive *Caulerpa* species were not observed during these surveys.

2.2.2 Benthic Community Quadrats

The macroalgal and benthic invertebrate assemblage (i.e., sessile and small mobile invertebrates) were recorded at each site using depth-stratified 1 m² quadrats. In order to be comparable to similar surveys in northeastern New Zealand, the methods followed those of Shears and Babcock (2004), which are used for monitoring reef communities inside and outside marine reserves in northeastern New Zealand for the Department of Conservation (e.g. Shears et al. 2008b). The benthic community was surveyed using five haphazardly placed quadrats in each of the two sampled depth zones: 4-6 (shallow) and 10-12 m (deep) (below MLWS). Note that the reef at the Sister Rocks site only extended to ~6 m depth and thus the benthic community was only surveyed in the shallow depth range at this site. Sampling locations at each depth were GPS marked to ensure accurate relocation for future monitoring. Care was taken to ensure all quadrats were independent of each other (e.g., not along the same crack/crevice). In each quadrat, the abundance of mobile macro invertebrates (≥ 10 mm), size of sea urchins (test diameter), density of macroalgae by size class (adult, juvenile), and percent cover of macroalgae, encrusting invertebrates and substrate were recorded on pre-printed data sheets. A digital photograph of each quadrat was taken. Additionally, photographs were taken of anything that could not be confidently identified underwater, for later identification.

2.2.3 Rock Lobster and *Centrostephanus rodgersii* Transects

In addition to the benthic quadrats (2.2.2), targeted transect surveys for *Centrostephanus rodgersii* and rock lobster (*J. edwardsii*) were carried out at seven of the sites in March 2022 (Table 1). These consisted of 50 m belt transects, which were laid out at three depth zones: deep (15+ m), mid (8-15 m) and shallow (<8 m). Long-spined urchins (*Centrostephanus rodgersii*) were recorded 1 m either side of the transect line in 5 m sections, giving counts over 10 m². Additionally, their behaviour was also recorded as cryptic or exposed. All rock lobster were counted, sexed and measured (carapace length) on 5 m either side of the transect (50 x 10 m total area) using the same methods for monitoring lobster populations in northern NZ marine reserves (LaScala-Gruenewald et al. 2021).

2.2.4 Reef Fish Surveys

Divers surveyed the benthic-pelagic reef fish community using visual census methodology. Three transects were surveyed in each of two depth zones: 5-10 m and 12-

18 m (below MLWS). For each transect, the diver affixed a transect tape to kelp or rock, then, to avoid sampling diver positive fish whilst setting up, swam 5 m before commencing counts. The diver then swam at a constant slow speed whilst unwinding the tape until 30 m, counting all fishes within a strip estimated 2.5 m either side and 5 m above the centre of the tape, and recording them on a pre-printed data sheet. A total reef area of 125 m² was covered by each transect (625 m³ volume of water). Sizes were estimated to the nearest 5 cm for species of particular interest (e.g., common recreational/commercial targeted species). Care was taken not to duplicate counts (i.e., for fish that overtake or swim in and out of range). Cryptic species (e.g., blennioids, scorpionfishes, small groupers) were not included, likewise nor were schooling fishes that could not reliably be counted without surveying under the canopy and/or looking in caves and underhangs (e.g., oblique-swimming triplefins, bigeyes, slender roughies). Additionally, start/end depths and broad habitat variables—substrate, major biological habitat, were recorded as percent covers across the whole transect. This methodology is the same as that used to monitor reef fish communities inside and outside northeastern New Zealand marine reserves, including the nearby Te Whanganui a hei (Hahei) and Poor Knights Islands Marine Reserves (e.g. Haggitt 2011, Allard 2020). Any unique species noticed outside the transects (or during benthic quadrats) were also recorded for presence but were not included in quantitative assessments. Approximately five to ten minutes at the end of each dive was also allocated for unique species searching.

2.2.5 Georeferenced habitat photos

At all but two of the sites (Sister Rocks and Roger's Spot) a series of georeferenced photos were haphazardly taken by divers at the site to provide a broader spatial assessment of the main reef habitats over a wider area than that quantitatively sampled. Divers towed a float with GPS and took photos approximately every 5 seconds as they swam over the reef, ensuring the GPS float was directly above when taking each photo. Each photo was geotagged based on the GPS track using the Benthic Photo Survey software¹. The reef habitat type in each photo was classified according to the broad categories outlined in Table 1. Image positions and habitat types are presented in Appendix 1 and used to inform general site descriptions.

¹ http://jkibele.github.io/benthic_photo_survey/

2.3 Statistical Analysis

2.3.1 Wave Exposure

The wave exposure of each site was approximated using an index of potential wind fetch, which can be defined as the area of ocean surface over which waves are generated by wind with a constant direction and speed. Total wind fetch was calculated for each site using the windfetch web app (Seers 2021), with vectors at 10-degree intervals, distances truncated at 300 km, and summed for all 36 vectors (Table 1).

2.3.2 Multivariate Analyses

To explore the spatial variation in the reef benthic community, Bray-Curtis similarity was calculated for all site-depth combinations based on the square-root transformed taxa abundance data. For the benthic community analysis, percent cover and density data were analysed separately to ensure the interpretability of the results. Analysis was performed on the macroalgal community (% cover), sessile invertebrate community (% cover), mobile invertebrate community (density, i.e., indiv. m⁻²), and for the benthic-pelagic fish community. For the mobile invertebrate community, Bray-Curtis similarity was calculated with an added dummy variable with a value of one. This was done to ensure that relatively denuded samples containing single species in low abundance do not fluctuate between very high similarity to dissimilarity due to the identity of the species present. For instance, two quadrats containing a single individual can fluctuate between 0-100% similarity depending on the species identity (Clarke & Gorley 2015). Similarity calculation for the benthic-pelagic reef fishes community was based on dispersion weighted density data to dampen the potential effects of high-density aggregations of some schooling fish species on dis/similarity of various sites and depths (9999 perms; Clarke & Gorley 2015). To visualise the variation in the community, nMDS ordinations were plotted using Bray-Curtis similarity matrices of the means of the quadrats sampled at each site and depth. Vectors depicting the species most correlated with the nMDS coordinates were laid over the ordination. To visualise similarities between sites and depth strata, samples were clustered using similarity profile by permutation analysis (Type I SIMPROF, 9999 perms, $\alpha=0.05$; Clarke & Gorley 2015). SIMPER (Clarke & Gorley 2015) was done on Bray-Curtis similarity data of the species' site-depth abundance means to determine the species relative contribution to the within group similarity and between groups dissimilarity. For the SIMPER analysis within and between clusters, the factor obtained by the SIMPROF analysis was used.

To explore potential effects of depth and site on the reef benthic communities and benthopelagic fish assemblage, a multivariate analysis of variance by permutation was done (PERMANOVA, 9999 perms, type III SS; Anderson et al. 2008). This analysis used the fixed factor 'depth' and the random factor 'site' and their random interaction 'site * depth', and was run on Bray-Curtis similarity matrices calculated at the quadrats or transects level similar to those described above. Because Sister Rocks (East) lacked the deep level of the factor 'depth' it was excluded from the analysis.

To explore the relationship between wave exposure and depth with the benthic reef community, multivariate multiple regression by permutation was performed (DistLM; 9999 perms; Anderson et al. 2008) using total wind fetch (km) and the true depth (below MLWS; corrected according to the tide) as predictors. The analysis was run on the Bray-Curtis similarity matrices as mentioned above, using a specified model selection with an R^2 model criterion.

3 Results

3.1 Reef Habitats and Site Descriptions

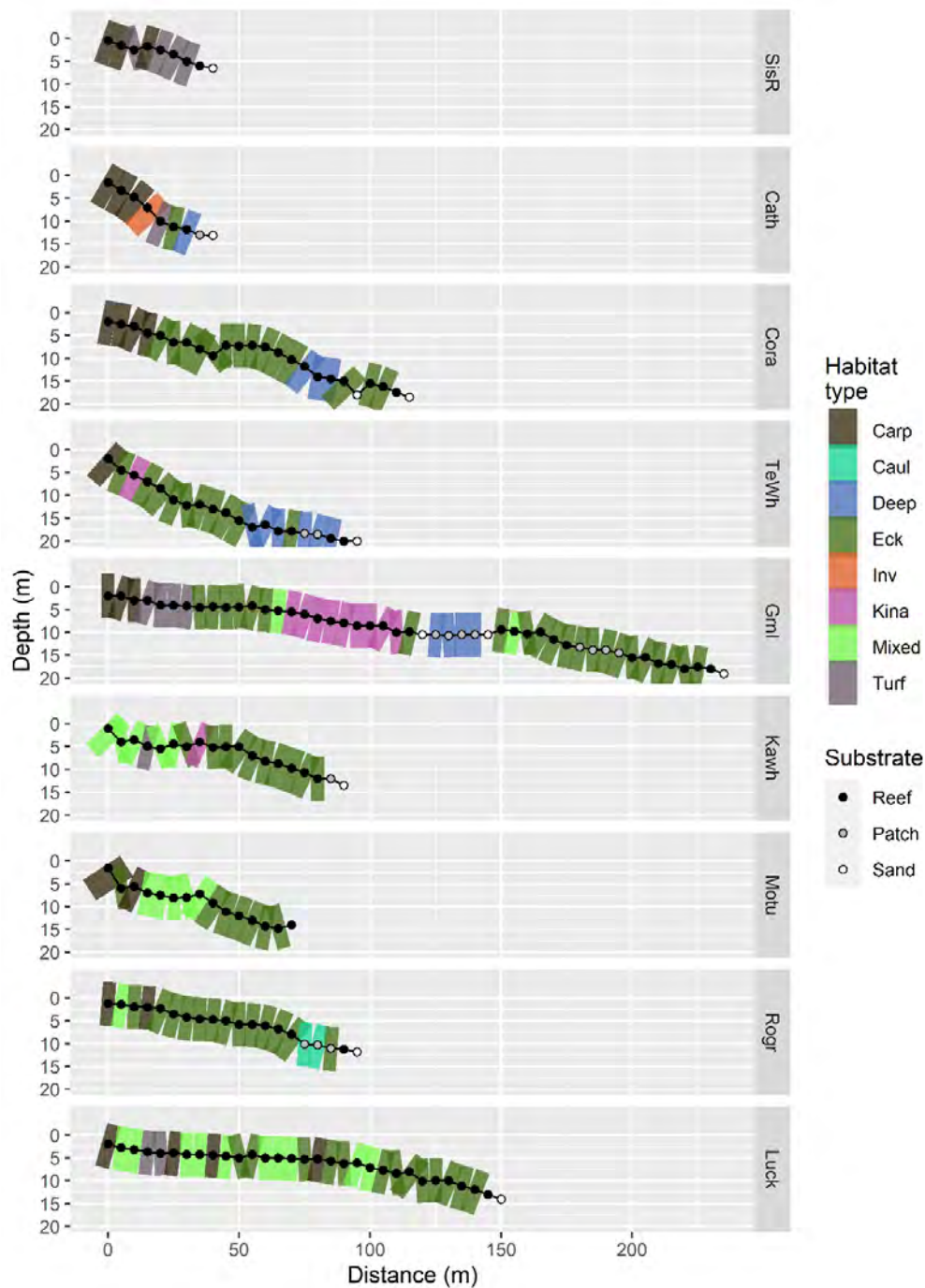


Figure 2. Reef profiles for the nine sites surveyed at Mercury islands, with dominant substrate and main biotic habitat at each 5 m interval. See methods for site abbreviations. Depth and distance were measured from the low tide mark. Black circles indicate hard reef substrate, grey circles patchy reef/sand substrate, white circles sand. Abbreviations: Kina = Kina barrens, Turf = Turfing algae, Carp = Shallow *Carpophyllum* forest, Mix = Mixed macroalgae forest, Eck = *Ecklonia radiata* forest, Inv = Encrusting invertebrates, Caul = *Caulerpa flexilis* mats, Deep = Deep reef with sparse *Ecklonia radiata* (often with sponges).

3.1.1 Sister Rocks

Sister Rocks is located on the western side of Great Mercury Bay and consists of two main islets, which we refer to as east and west (Fig. 1; Appendix 1a). The majority of the surveys (reef profile, benthic, most of the fish, urchins) were carried out at the east islet, and hereafter Sister Rocks refers to that islet, unless otherwise stated. Sister Rocks is the most sheltered site surveyed, and also the shallowest (Table 1), with the reef only extending to ~6 m depth (Fig. 2). *Carpophyllum maschalocarpum* dominated the shallow subtidal fringe (<2 m deep). The reef from ~2-6 m was dominated by coralline turf and the cover of large brown macroalgae was sparse, with *Ecklonia radiata*, *Cystophora retroflexa* and *Xiphophora chondrophylla* being the most common (Fig. 3a). To the southeast of the site (southern side of Sister Rock), an *E. radiata* forest was present, but there was evidence of recent kelp die-off over an area of reef of ~30 x 100 m (Fig. 3b). Large numbers of dog cockles (*Tucetona laticostata*) were present on the adjacent sand indicating a nearby dog cockle bed.

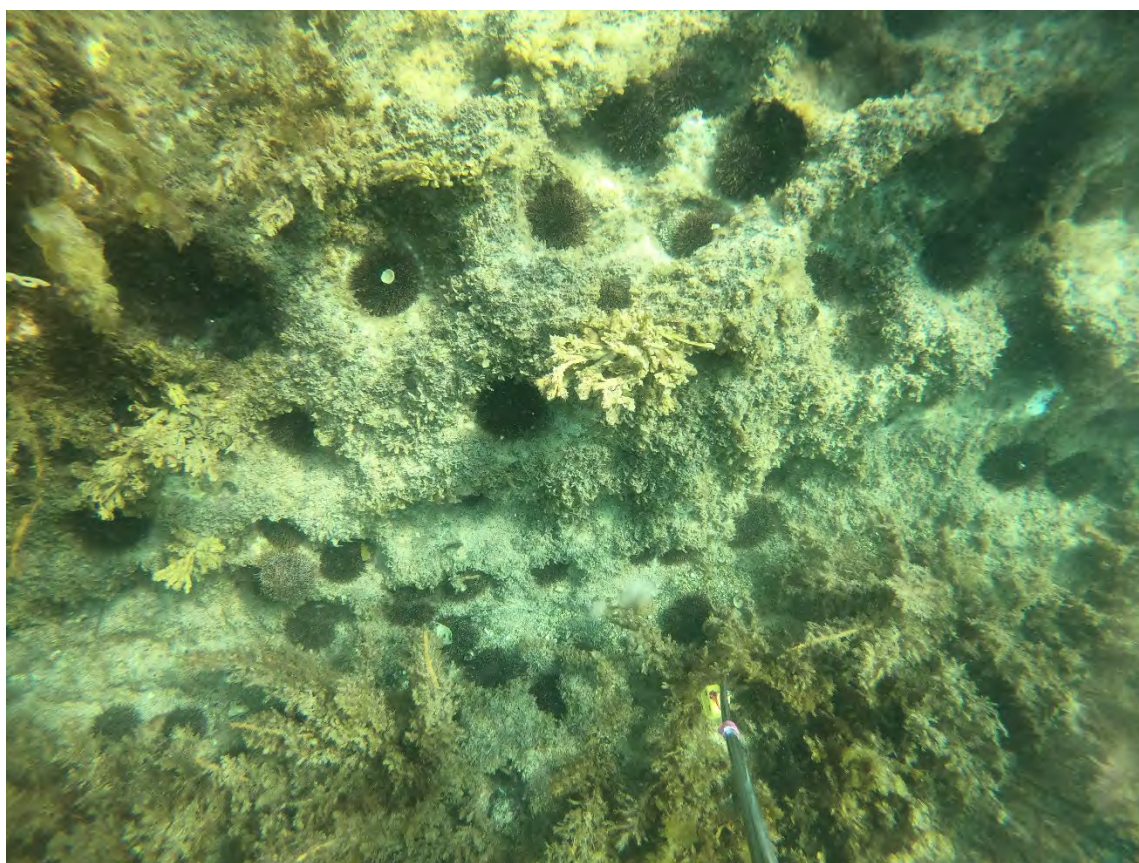


Figure 3a. Shallow reef habitat indicating sheltered environment, showing turf, filamentous algae, *Xiphophora chondrophylla* and *Carpophyllum plumosum*. Also note the kina are embedded in depressions in the soft sandstone substrate. Sister Rocks, ~5 m deep.



Figure 3b. *Ecklonia radiata* die-off. ~5 m deep, Sister Rocks.

Three additional fish transects were performed at Sister Rocks west, an islet situated ~350 m to the southwest of the main Sister Rocks. Here the reef topography is steep, sloping steeply around the islet to the sand at ~17 m. Uniform *E. radiata* forest was present on the sloping reef, with *C. maschalocarpum* in the shallow subtidal fringe (Fig. 3c).



Figure 3c. Uniform thick and tall *Ecklonia radiata* forest, home to a large number of fishes, including these goatfish (*Upeneichthys lineatus*). Sister Rocks (west), ~15 m deep.

3.1.2 Cathedral Rock

The Cathedral Rock site is located in a semi-enclosed bay at the northern end of Ahuahu (Great Mercury Island) and is relatively sheltered from the east (Fig. 1, Appendix 1b). The centre of the bay is sand with a margin of reef around the bay extending to depths of ~12 m. The profile at the monitoring site was relatively steep-sloping, and very compressed laterally (e.g., only ~40 m from low tide mark to the reef/sand edge). *Carpophyllum maschalocarpum* dominated the immediate subtidal, and a shallow shelf to about 6 m with a mixed algal composition of mostly *C. maschalocarpum* and *E. radiata*. Seaward of this shelf is a steep drop off of several metres, the near-vertical wall covered in encrusting invertebrate life, which then reaches a patchy reef substrate with sparse kelp, much of it with tall stipes (Fig. 4a).

Across the wider bay, the immediate subtidal and the deep reefs are the same as the reef profile above (i.e., subtidal fringe *C. maschalocarpum*, *E. radiata* forests > 10 m, respectively). However, much of the intermediate depths are gradual sloping and typically dominated by a mix of urchin barrens and turfing algae. In March 2022 there was a high cover of seasonal filamentous algae and *C. flexuosum* was also common in urchin barrens (Fig. 4b).



Figure 4a. Boulder substrate with mixed turfing algae and urchin barrens, *Carpophyllum flexuosum* and covered in seasonal filamentous algae. Cathedral Rock, ~8 m deep.

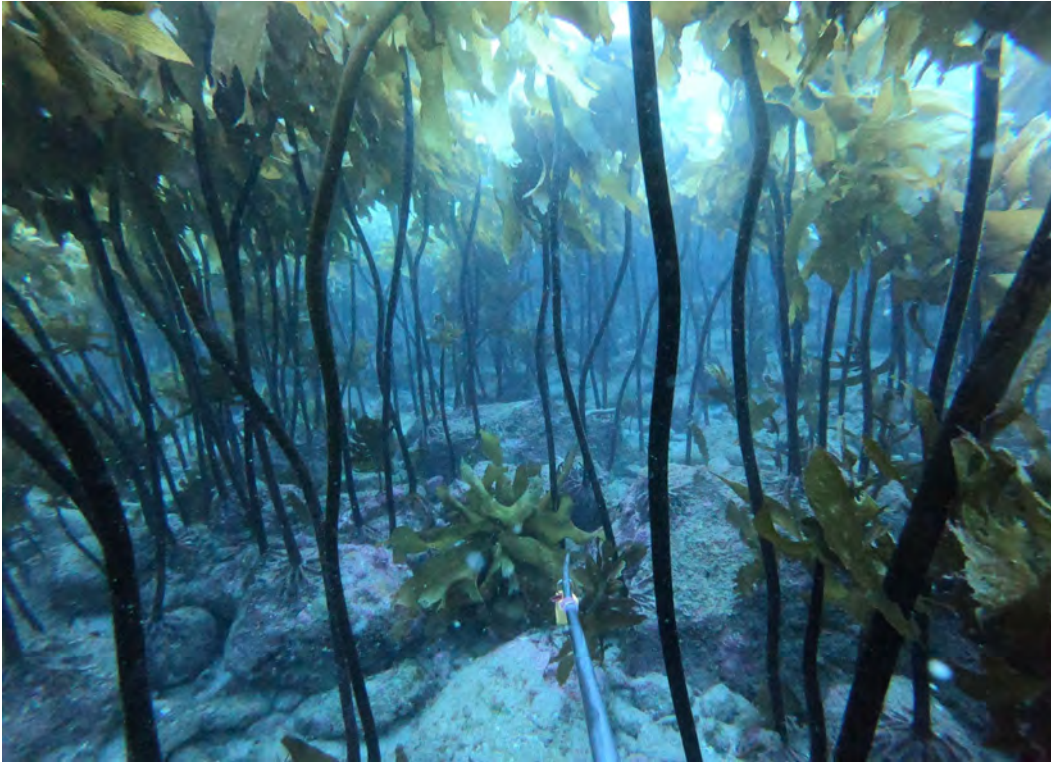


Figure 4b. Tall *Ecklonia radiata* forest. Cathedral Rock, ~14 m deep.



Figure 4c. Die-back of tall *Ecklonia radiata* forest at Cathedral Rock, ~10 m deep. March 2022.

3.1.3 Coralie Bay

Coralie Bay is situated on the northeastern side of Ahuahu (Great Mercury Island), very exposed to oceanic swell and has high wind fetch (Fig. 1, Table 1). The reef profile is one of complex, rugose bedrock substrate full of cracks and crevices, with flat and gentle gradients punctuated by sudden vertical drops (Fig. 2). The biotic habitat consisted of thick *C. maschalocarpum* and *C. angustifolium* in shallow (<2 m), mixed algal composition (e.g., *E. radiata* and *C. maschalocarpum*) dominating the mid-depths (2-7 m – see Fig. 5), and thick kelp *E. radiata* coverage from approximately 7 m to the reef/sand edge ~19 m (Fig. 2). Some dense kina clusters were present in small patches throughout. North of the survey site is a sandy bay, where large areas of shallow reef (~2-5 m depth) were dominated by turfing algae and urchin barrens (see Appendix 1c).



Figure 5. Rugose bedrock substrate with shallow mixed algal community including *E. radiata*, *C. maschalocarpum* and the *C. angustifolium*/*C. maschalocarpum* hybrid in centre top of image (see discussion). Coralie Bay, ~3 m deep.

3.1.4 Te Whanga Bay

Te Whanga Bay is located on the eastern side of Ahuahu (Great Mercury Island), very exposed to the oceanic swells and wind fetch from north through east (Fig. 1, Table 1, Appendix 1d). The reef profile is moderately complex and rugose, a mix of boulders and bedrock, and with a moderate slope which levelled off at the deeper reef area (Fig. 2). The biotic habitat consisted of *C. maschalocarpum* and *C. angustifolium* (including the *Carpophyllum* hybrid) in the subtidal fringe, with some discrete areas of kina barrens and *C. flexuosum* (Fig. 6). *Ecklonia radiata* dominated the mid and deeper depths, thick in mid-deep zones, becoming sparser and interspersed with sponges amongst patch reef the deeper the profile went, typical of many deeper reefs that reach 20 m in depth (Fig. 2). The site is situated in the middle of a 2.5 km stretch of similar aspect of offshore facing coast.

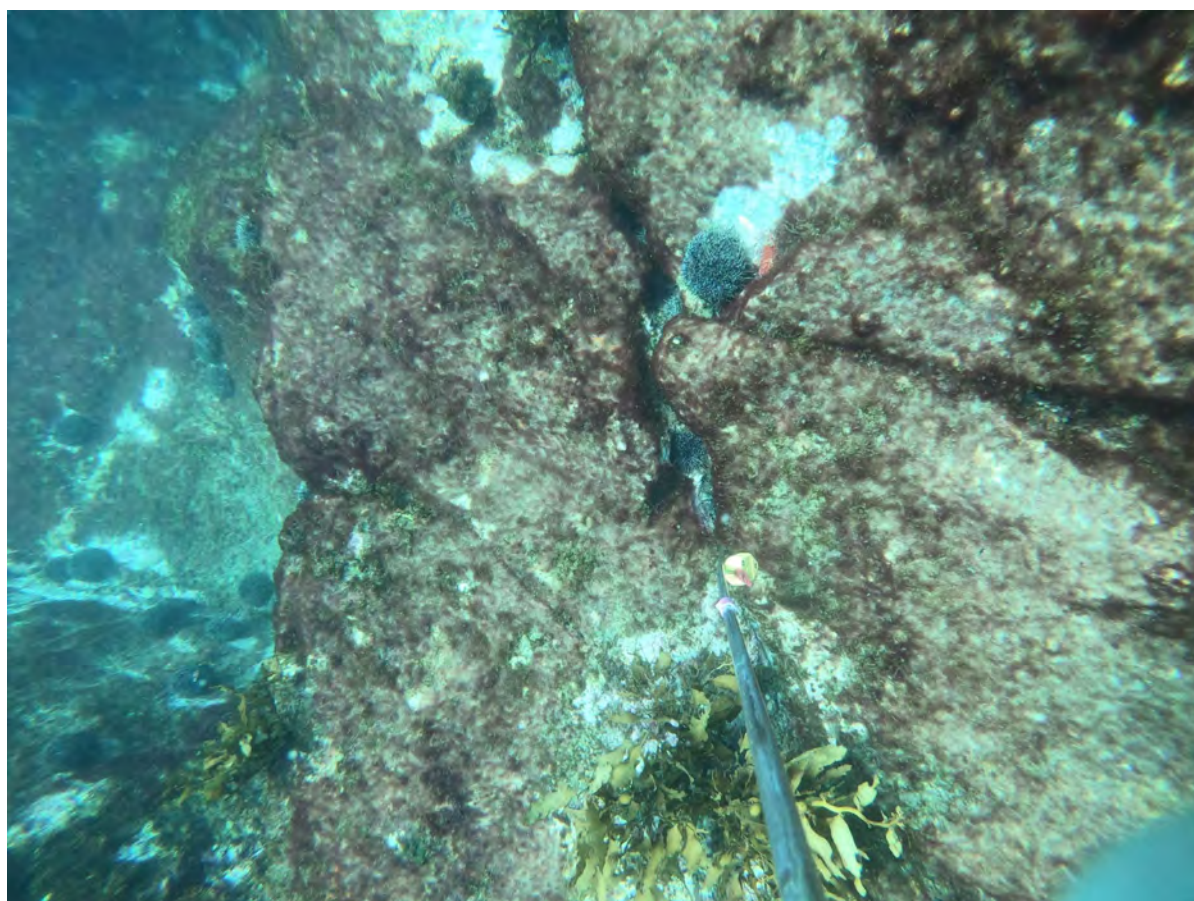


Figure 6. Kina barrens with a high cover of seasonal red filamentous algae. Note the presence of *Carpophyllum flexuosum*, which can be a common seaweed in kina barrens. Te Whanga Bay, 7 m deep.

3.1.5 Green Island

Green Island is the smallest of the seven main northern islands in the Mercury Island group (Fig. 1, Appendix 1e). The survey site was located on the northern side of this island, exposed to the oceanic swell and wind fetch from the north and north east (Fig. 1, Table 1). The reef profile represents the shallowest gradient of the nine sites, sprawling across 235 m of reef habitat before reaching the sand at approximately 19 m deep (Fig. 2). This site consisted of a diverse and patchy distribution of biotic habitats, with turf complexes in shallow to about 4 m, good coverages of *C. plumosum*, a band of *E. radiata* forest growing on boulders, before a mix of semi-extensive urchin barrens areas sparse kelp and further thicker kelp forests deeper (Fig. 2). High covers of seasonal red filamentous algae and the dinoflagellate *Ostreopsis siamensis* were present during the March surveys, especially in the barrens habitats (Fig. 7). Due to the makeup of the broken rocks and islets around Green Island, there were several rocks that breached the surface, and sand channels running through the reef areas.



Figure 7. A high cover of the seasonal red filamentous algae and *Ostreopsis siamensis*, abundant *Carpophyllum flexuosum*, and some evidence of small, perhaps regenerating *Ecklonia radiata* plants. Green Island, ~7 m deep.

3.1.6 Kawhitu

The survey site was on the northside of Kawhitu (Stanley Island) and highly exposed to the north and northeast (Fig. 1, Table 1, Appendix 1f). The reef profile is as other exposed sites: with lush mixed algal forest dominating the shallow to mid-areas above ~8 m, a few small, isolated patches of kina barren (<10 m²), and *E. radiata* forest extending deep to the reef edge (Fig. 2), particularly rich in understory red and brown foliose algae. The substrate consisted mostly of large boulders.

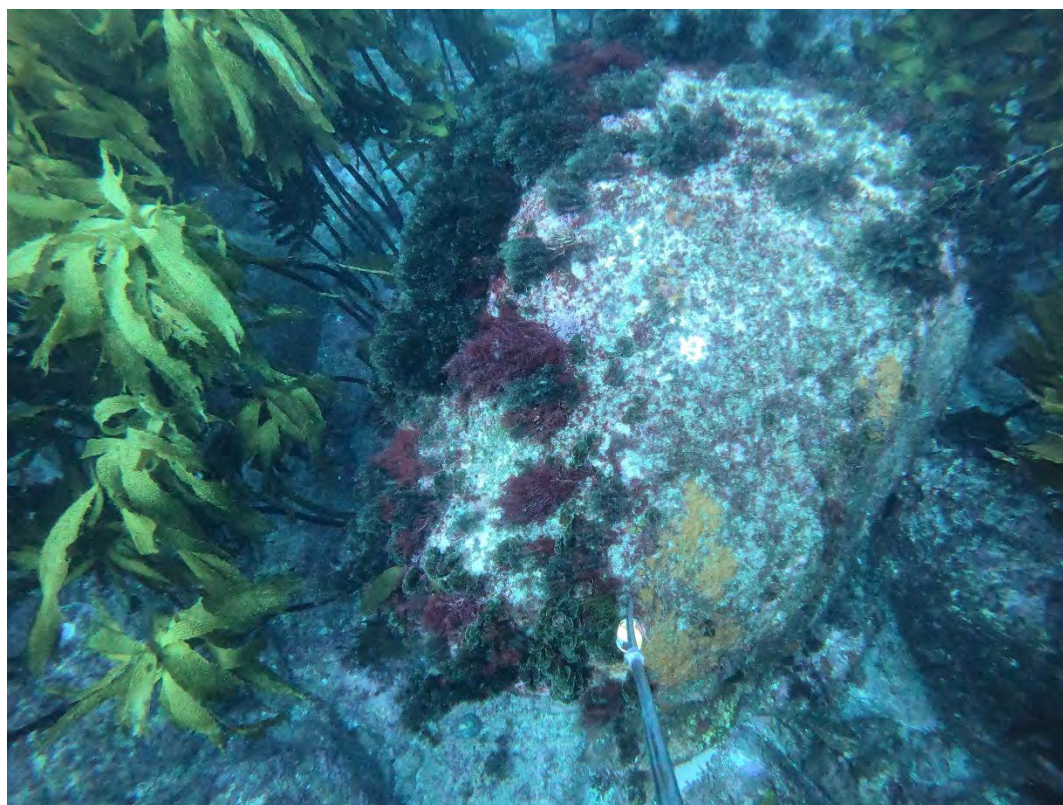


Figure 8. The Kawhitu site consisted mostly of boulder substrate, with a notably high covers of red and brown algal understory algae, such as *Zonaria aureomarginata* and *Plocamium* spp. as seen on a boulder above. Kawhitu, ~7 m deep.

3.1.7 Moturehu

Moturehu (Double Island) is a very exposed north-facing site, open to the north through east-northeast (Fig. 1, Table 1, Appendix 1g). The reef profile is relatively compressed, spanning 70 m from the low tide mark to the reef/sand edge. Large boulders throughout the site were covered in shallow by a mosaic of mixed algae, with small patches of turf and/or kina barrens. There was a notable gradient change (i.e., drop off) between the shallow mixed algal community and the *E. radiata* forest between about 7-9 m (Fig. 2). Again, there was a particularly rich understory of red and brown foliose algae at this site.



Figure 9. The Moturehu site consisted mostly of boulder substrate, with high large brown algal cover and occasional patches of kina and turfing algae. Moturehu, ~6 m deep.

3.1.8 Roger's Spot

Roger's Spot is on the western side of Whakau (Red Mercury Island) (Fig. 1, Appendix 1h). This is the second most sheltered site, protected from the E and NE (i.e., oceanic) swell and wind fetch (Fig. 2, Table 1). The reef profile at the survey site represents a moderate gradient and distance from shore (95 m to sand at 12 m depth), with fairly uniform reef habitat consisting of big boulders and *E. radiata* coverage (Fig. 2). This kelp is particularly tall and thick on the deeper areas of this reef (Fig. 10a). There were some isolated patches of kelp die-off in the shallows (<5 m). Additionally, there were very discrete clusters of kina, often isolated to single rocks among otherwise lush kelp (Fig. 10b). This site is approximately in the vicinity of the site named Rolypoly Bay from Grace (1972b), and here we named it in the memory of the late Roger Grace, who was among the few to carry out subtidal research at the Mercury Islands, including this general site.

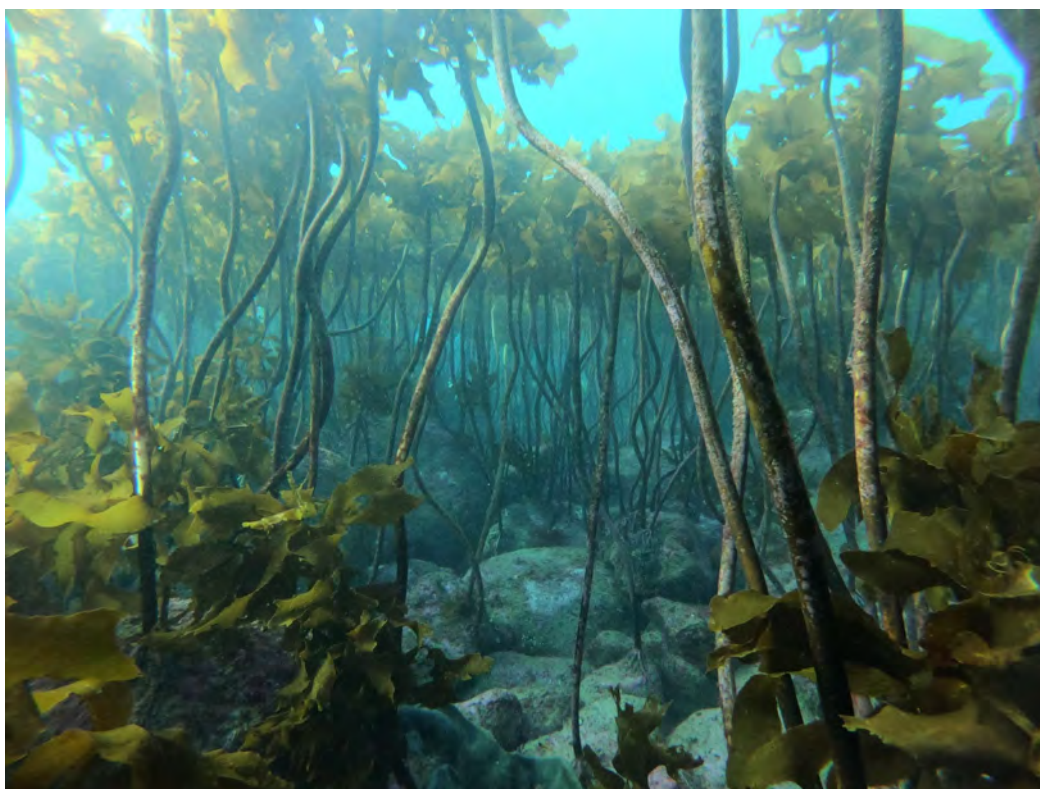


Figure 10a. Tall, thick *Ecklonia radiata* forests on boulders. Roger's Spot, ~10 m deep.



Figure 10b. Dense kina clusters amongst *Ecklonia radiata* forests on boulders. Roger's Spot, ~10 m deep.

3.1.9 Von Luckner's Cove

Von Luckner's Cove is the easternmost site across the surveys, and very exposed to the oceanic swells and wind fetch (Fig. 1, Table 1). The reef profile consisted of a gentle gradient that covered 150 metres from the low tide mark to the reef/sand edge at approximately 14 m deep (Fig. 2, Appendix 1i). Large boulders are covered in a diverse assemblage of algae, especially in the shallow and mid depth zones, which consisted of *C. angustifolium*, *C. maschalocarpum* and *C. plumosum*, *Lessonia variegata*, *E. radiata*, a host of smaller red, green and brown algae in amongst the larger macroalgae, and small patches of turf in shallower depths (Figs. 2, 11a). Deeper areas of the reef consisted mostly of moderately dense stands of *E. radiata* interspersed with a few other species of macroalgae, such as *L. variegata* and *C. plumosum*.

Outside of the survey area, in particular the reef below the steep cliffs to the south of the survey site, there were moderate areas of kina barren (Fig. 11b, Appendix 1i). Additionally, the deep patch reefs extend >200 metres out from shore, interspersed with sand channels.

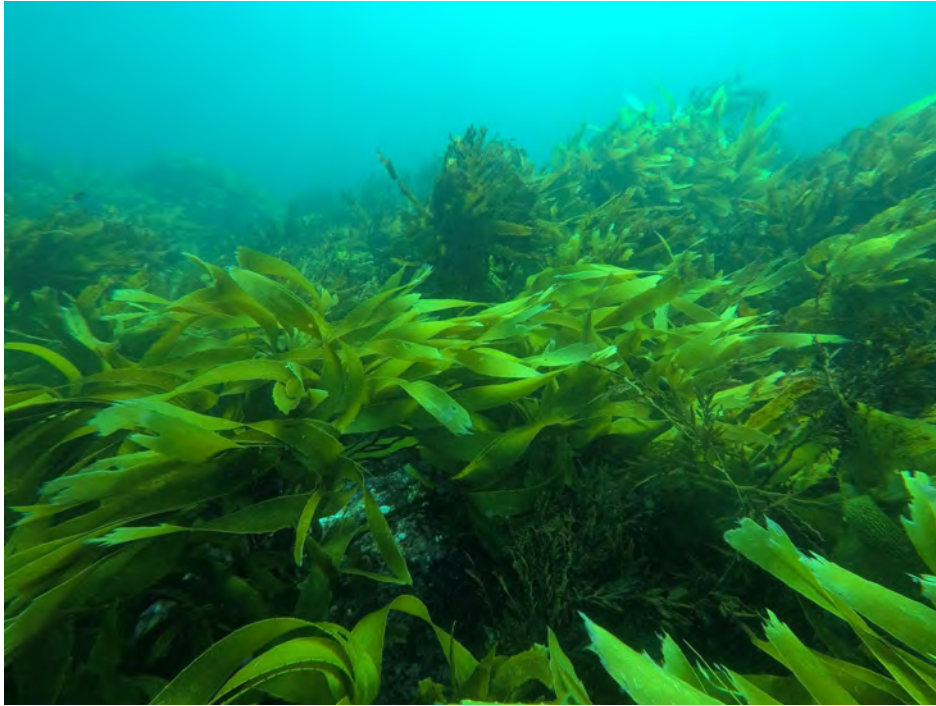


Figure 11a. Dense mixed algal beds, including high coverage of the strap kelp *Lessonia variegata*, indicative of offshore islands. Von Luckner's Cove, ~5 m deep.



Figure 11b. Presence of *Centrostephanus rodgersii* in kina barrens habitat on the steep reef slope. Eastern point of Whakau (Red Mercury Island), SE of Von Luckner's Cove, ~8 m deep.

3.2 Reef Community Composition

3.2.1 Macroalgal Communities

Variation in macroalgal communities was significantly related to depth and wave exposure, but overall, these factors only collectively explained a small portion of the total variation ($R^2=0.15$; Table 2). In general, wave exposure predicted a slightly larger proportion of the variation compared to depth. Additionally, the macroalgal communities varied between the two depth zones, but the effect of depth varied among sites (Fig. 12; Table 3). Sister Rocks clustered separately from other sites, likely due to the low *Ecklonia radiata* and high coralline turf cover (note there was no deep reef at this site). The remaining sites clustered together and there was a general division in macroalgal assemblages between shallow and deep. Shallow depths were generally characterised by higher cover of crustose coralline algae, brown encrusting algae, *C. maschalocarpum* and the *C. maschalocarpum/C. angustifolium* hybrid (hereafter *C. angustifolium* hybrid). There was less variation in macroalgal communities among sites in the deeper strata, which was typically dominated by *Ecklonia radiata* and the cover of other large brown algae was low.

Table 2. Multivariate multiple regression results to explore the relationship between the predictors depth and wave exposure with the benthic reef communities using DistLM. The table shows the marginal and sequential tests of the predictors.

	Variable	MARGINAL TESTS			SEQUENTIAL TESTS				
		Pseudo-F	P	Prop.	R^2	Pseudo-F	P	Prop.	Cumul.
Macroalgae	Depth	4.51	<0.001	0.051	0.052	4.51	<0.001	0.051	0.051
	Wave exposure	7.63	<0.001	0.084	0.15	8.99	<0.001	0.094	0.15
Sessile Invertebrates	Depth	3.52	<0.001	0.041	0.041	3.52	<0.001	0.041	0.041
	Wave exposure	2.5	0.006	0.029	0.072	2.76	0.003	0.031	0.072
Mobile Invertebrates	Depth	5.4	<0.001	0.061	0.061	5.4	<0.001	0.061	0.061
	Wave exposure	2	0.09	0.021	0.087	2.36	0.05	0.026	0.087

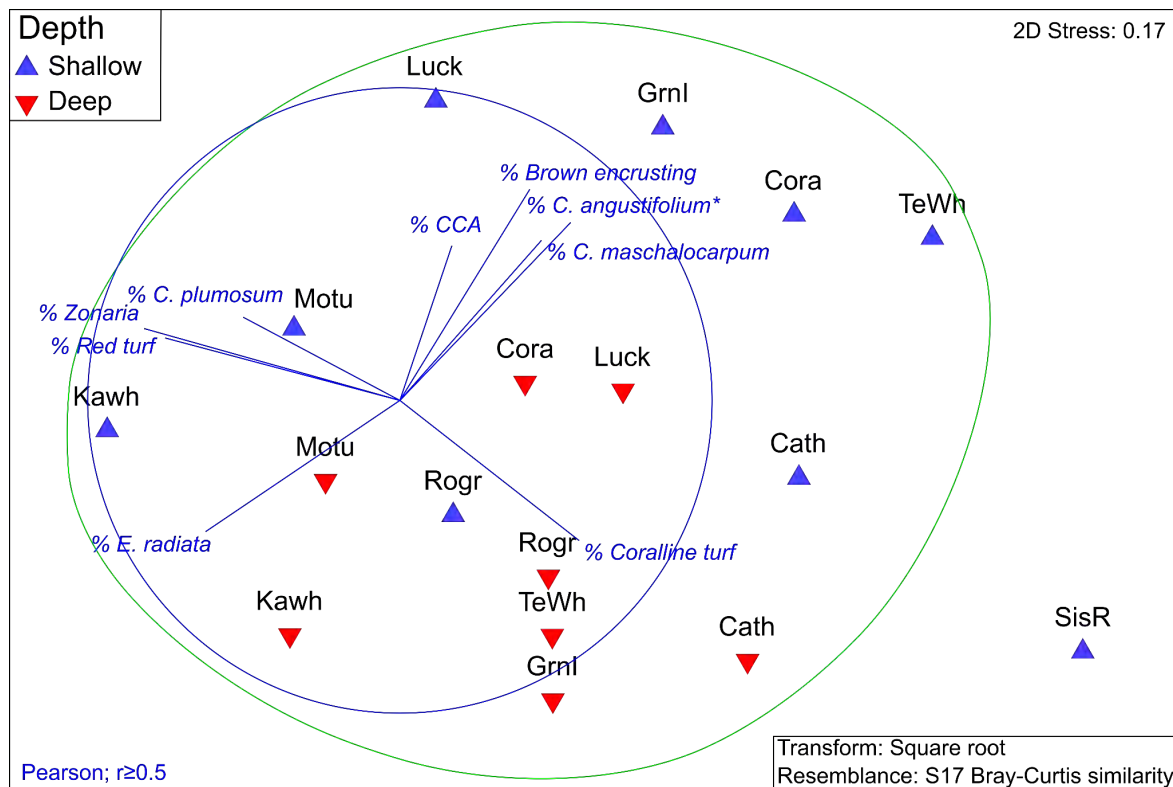


Figure 12. Non-Metric MDS ordination showing variation in macroalgal communities between the two depth strata across sites. Based on Bray-Curtis similarities of square-root transformed percent cover data for 18 dominant species and algal groups averaged for each site and depth using quadrat data. The green line depicts the clustering of the various samples according to similarity profile by permutation (Type I SIMPROF, 9999 perms). The overlaid vectors show the Pearson correlation ($r \geq 0.5$) of taxa abundance with the nMDS coordinates. The * next to *Carpophyllum angustifolium* indicates the hybrid variety.

Table 3. Results on analysis of variance by permutations (PERMANOVA, 9999 perms, SS Type III) of the effects of the fixed factor 'Depth range (DR)', random factor 'Site (Si)', and their interaction 'DR*Si' on the examined reef communities.

	Fixed		Random	
	Depth range (DR)		Site (Si)	DR*Si
Macroalgae (% cover)	$F_{1,64}=2.94, P=0.039$	$F_{7,64}=8.36, P<0.001$	$F_{7,64}=3.79, P<0.001$	
Sessile invertebrates (% cover)	$F_{1,64}=2.37, P=0.042$	$F_{7,64}=2.70, P<0.001$	$F_{7,64}=1.85, P<0.001$	
Mobile invertebrate (density)	$F_{1,64}=3.85, P=0.034$	$F_{7,64}=3.01, P<0.001$	$F_{7,64}=1.57, P=0.047$	
Fish community	$F_{1,33}=4.92, P=0.006$	$F_{8,33}=2.61, P<0.001$	$F_{8,33}=1.59, P=0.015$	

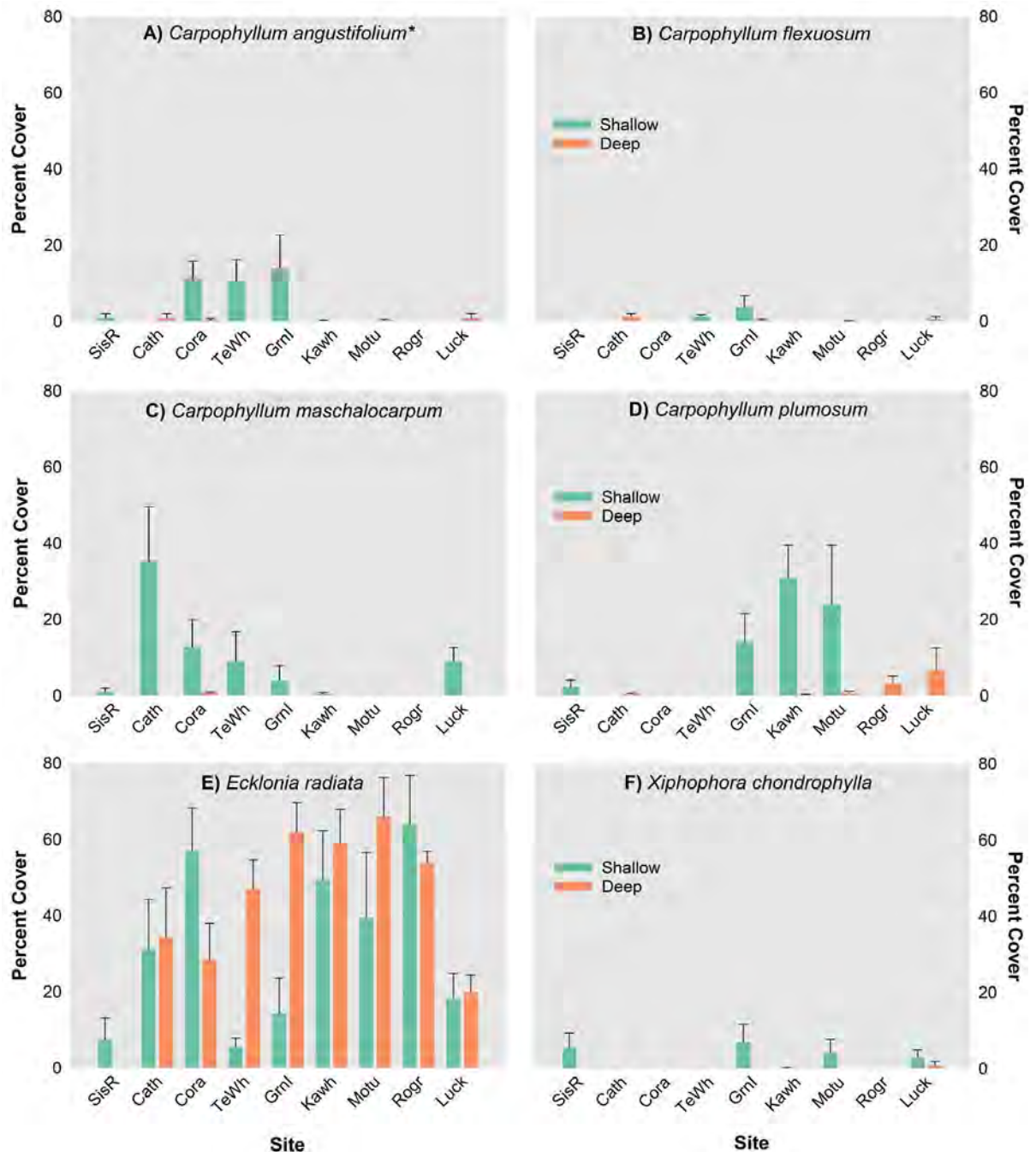


Figure 13. Mean percent cover of the main macroalgal species at each site for: A) *Carpophyllum angustifolium**, B) *C. flexuosum*, C) *C. maschalocarpum*, D) *C. plumosum*, E) *Ecklonia radiata*, and F) *Xiphophora chondrophylla*. Data is from the benthic quadrat surveys. Note: *Lessonia variegata* was not included here due to only being recorded in Von Luckner's shallow sites in the quadrat data. Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove), see methods for site abbreviations. Bars represent the standard error of the means. *includes the hybrid of *C. angustifolium* and *C. maschalocarpum*.

Ecklonia radiata was the dominant canopy forming algae at all sites (excluding Sister Rocks), and across both depth strata (Fig. 13). *Ecklonia radiata* dominated the deeper zone forming monospecific forests at Te Whanga, Green Island, Kawhitu, Moturehu and Roger's Spot, but cover was lower at Cathedral Rocks, Coralie Bay and Von Luckner's

Cove (Fig. 13e). In the shallow zone, *E. radiata* dominated at Coralie Bay and Roger's Spot. The *Carpophyllum* species and to a lesser extent *Xiphophora chondrophylla* had highest cover in the shallow zone and generally formed part of a mixed algal forest with *E. radiata*. The prevalence of the different *Carpophyllum* species varied among the sites, and of note was the presence of the *C. angustifolium/maschalocarpum* hybrid (sensu Hodge et al. 2010) at Coralie Bay and Te Whanga.

The smaller and/or understory algal communities were dominated by the crustose coralline algae (Fig. 14a), which was abundant in most surveys (and to a lesser extent brown encrusting algae, not plotted here), essentially covering the hard substrata where macroalgae and invertebrates were not. Coralline turf, which was principally *Corallina officianalis*, had a varied distribution, with no real patterns in abundance based on exposure, depth, or distance offshore (Fig. 14b). Other red turfs and the brown *Zonaria aureomarginata* were only common at the four easternmost sites, with a notable hotspot for *Z. aureomarginata* at Kawhitu (Fig. 14c, e). Red foliose algae included species such as *Vidalia colensoi*, *Plocamium* spp. and *Pterocladia lucida*, and became more abundant the further eastward was sampled, with the highest abundance at the easternmost site Von Luckner's Cove (Fig. 14d). The remaining other brown foliose algae were collectively not that abundant, making up less than 2% of quadrats in general; the exception being at Sister Rocks, where *Cystophora retroflexa* and *Sargassum sinclairii* were common amongst the turf complex (Fig. 14f).

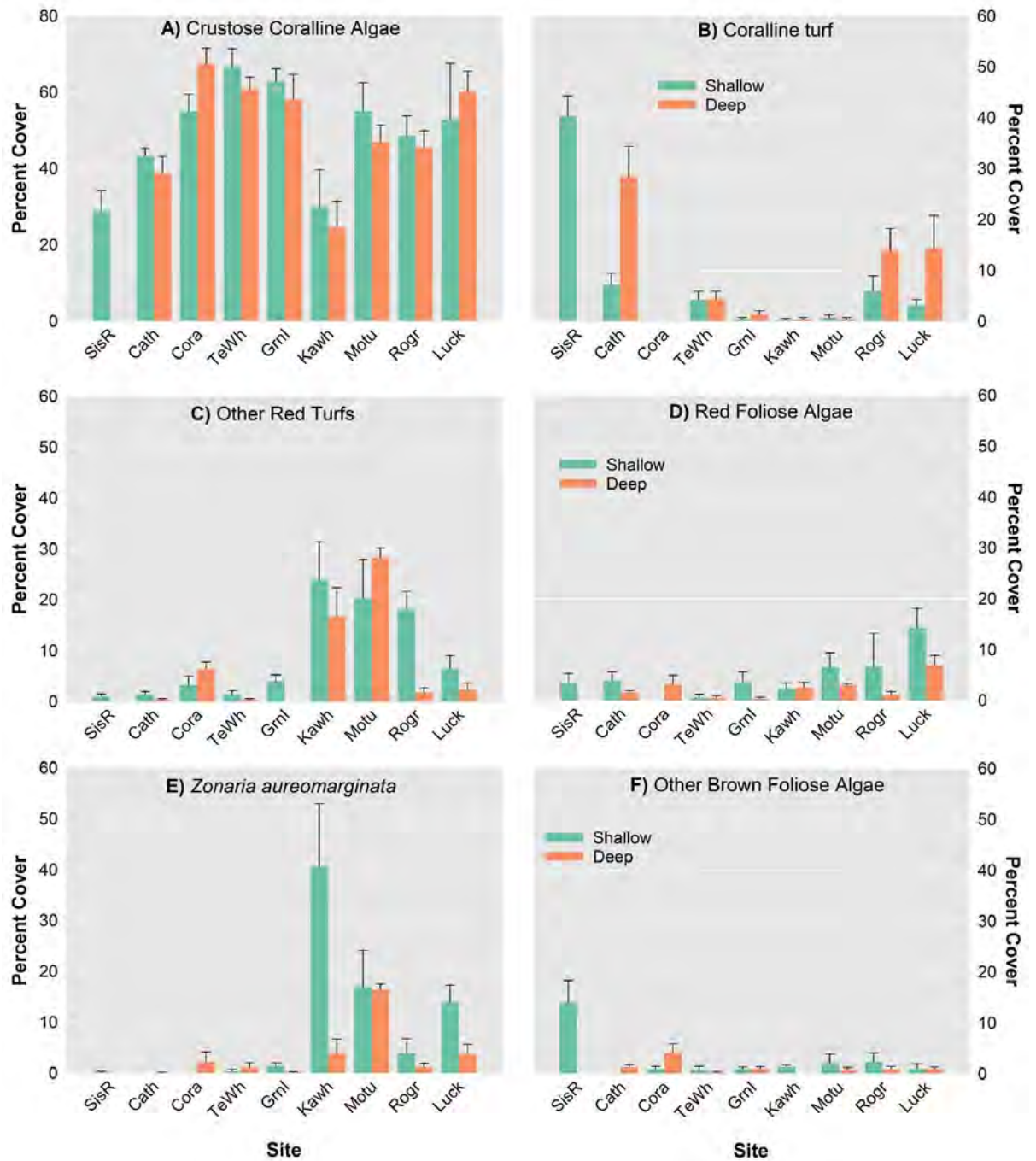


Figure 14. Mean percent cover of main smaller/understory algal species at each site for: A) crustose coralline algae, B) coralline turf, C) other red turfs, D) red foliose algae, E) *Zonaria aureomarginata*, and F) other brown foliose algae. Note the difference in y-axis scale of for A). Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove), see methods for site abbreviations. Bars represent the standard error of the means.

3.2.2 Mobile Invertebrates

Mobile macroinvertebrates occurred at relatively low densities at the monitoring sites. Overall, the mobile invertebrate community was significantly affected by depth and wave exposure, but predicted only a small portion of the overall variation ($R^2=0.09$; Table 2). Moreover, wave exposure was only significant once depth was included in the model (Table 3). There was not a clear separation of sites based on mobile invertebrate communities (Fig. 15). In general, the shallow zone was separated from the deeper zone due to a higher abundance of the two most common species, *Cookia sulcata* and *Evechinus chloroticus*.

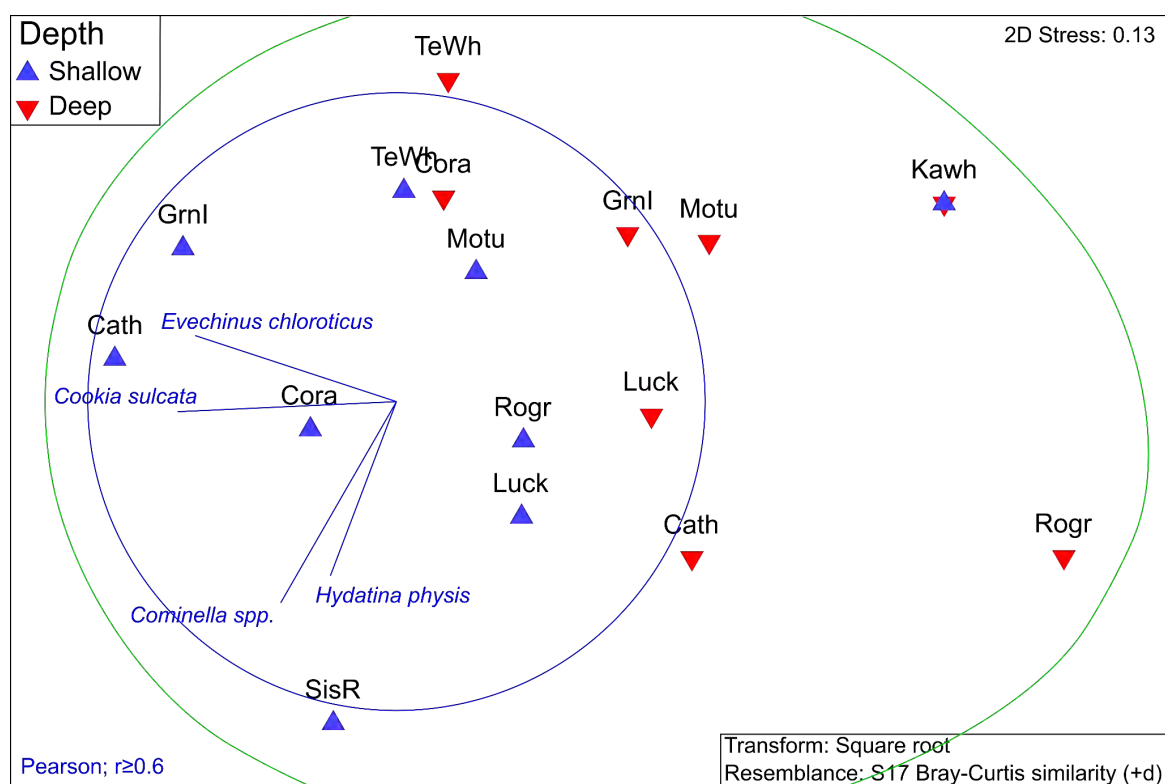


Figure 15. Non-Metric MDS ordination showing variation in the mobile invertebrate community between the two depth strata across sites. Based on Bray-Curtis similarities of square-root transformed density data (i.e., number of indiv. m^{-2}) for 18 mobile invertebrates and a dummy variable with a value of 1. The green line depicts the clustering of the samples according to similarity profile by permutation (Type I SIMPROF, 9999 perms). The overlaid vectors show the Pearson correlation ($r \geq 0.6$) of taxa abundance with the nMDS coordinates.

In terms of individual species of interest, Cook's turban shell (*Cookia sulcata*), the large grazing gastropod, was the most abundant mobile invertebrate recorded in the benthic surveys, found on average $0.97 \pm 0.25 m^{-2}$ ($\pm SE$). It was distributed throughout the

islands, demonstrating a preference for shallow areas of the reef (Fig. 16a). All other gastropods made up a small fraction of the mobile invertebrate community, and pooled together, consisted of generally less than two individuals per square metre (Fig. 16b). See species inventory (Appendix 3) for a list of those gastropods present.

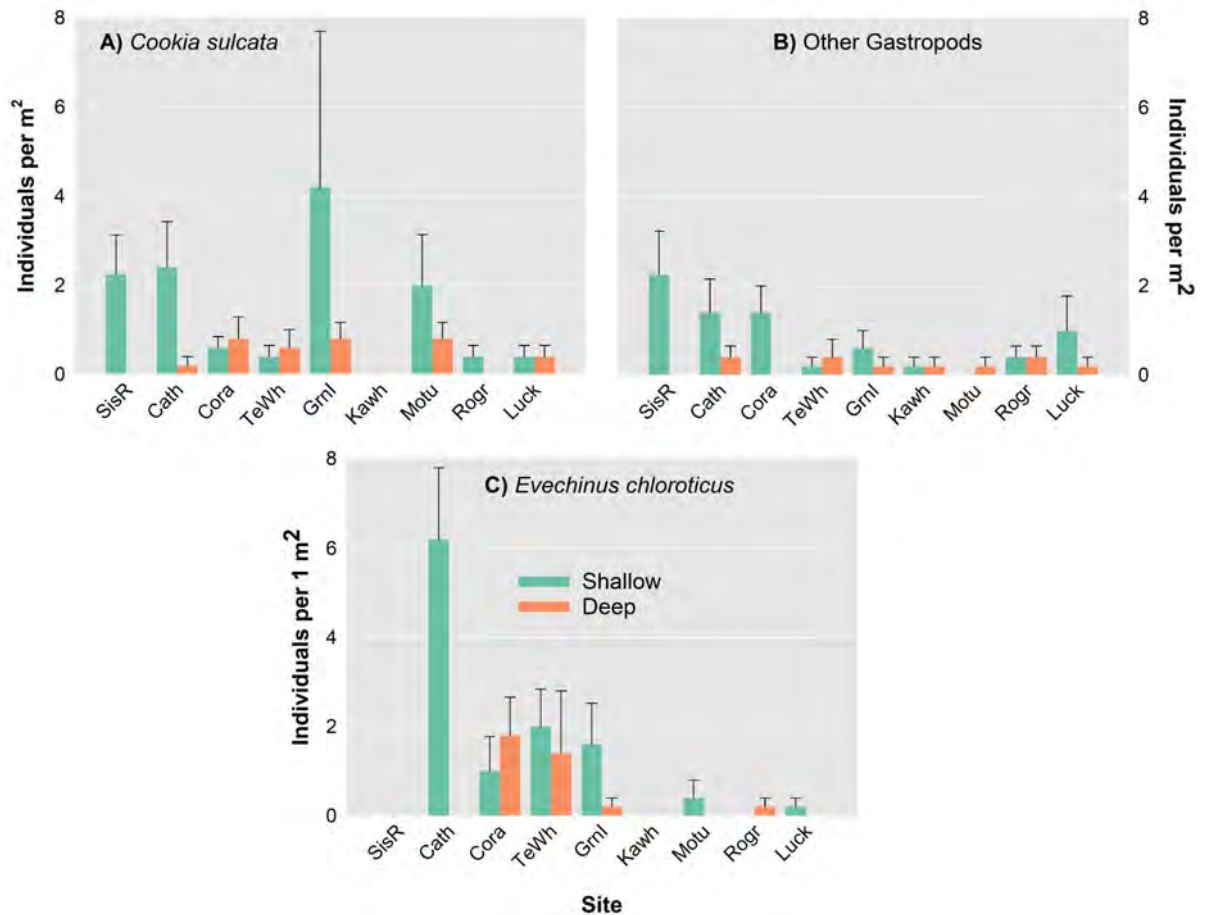


Figure 16. Mean density of A) *Cookia sulcata*, B) all other gastropods, and C) *Evechinus chloroticus*, stratified by depth zone at each site at the Mercury Islands. Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove), see methods for site abbreviations. Bars represent the standard error of the means.

The overall mean density of kina was 0.81 ± 0.13 kina m⁻² (\pm SE) (Fig. 16c). There was a significant difference in the densities of kina between depth zones ($U=4819$, $n_1=105$, $n_2=125$, $P<0.001$), with higher densities in shallow areas (1.4 m⁻²) than in deep areas (0.3 m⁻²), equating to nearly 80% of the kina being recorded in the shallow areas. The highest densities were recorded in the shallow zone at Cathedral Rocks, but these were largely cryptic and interspersed amongst shallow mixed algae. From these diver survey data, only at Te Whanga shallow and Coralie deep did kina appear to limit macroalgal abundance in some quadrats (i.e., form barrens). Kina size structure was left-skewed, with a median

test diameter of 90 mm (Fig. 17). Furthermore, there was a significant difference in kina size between shallow and deep areas of the reef ($U=259$, $n_1=17$, $n_2=58$, $P=0.003$), with mean size of shallow kina 81.7 mm (\pm SEM 2.7 mm), versus deep kina 97.9 mm (\pm SEM 4.4 mm). Behaviourally, the majority (70%) of kina were found out in the open (i.e., exposed), with only 30% situated in cracks and crevices (i.e., cryptic).

Blackfoot pāua (*Haliotis iris*) were found in very low abundance throughout the islands, except for the easternmost site, Von Luckner's Cove. This site constituted a patchy distribution (small counts within quadrats, but denser patches encountered). A small number of the Von Luckner population were sub-sampled for size ($n=50$) exhibiting a mean shell size of 113.9 mm (\pm SEM 0.98), with three at 125 mm.

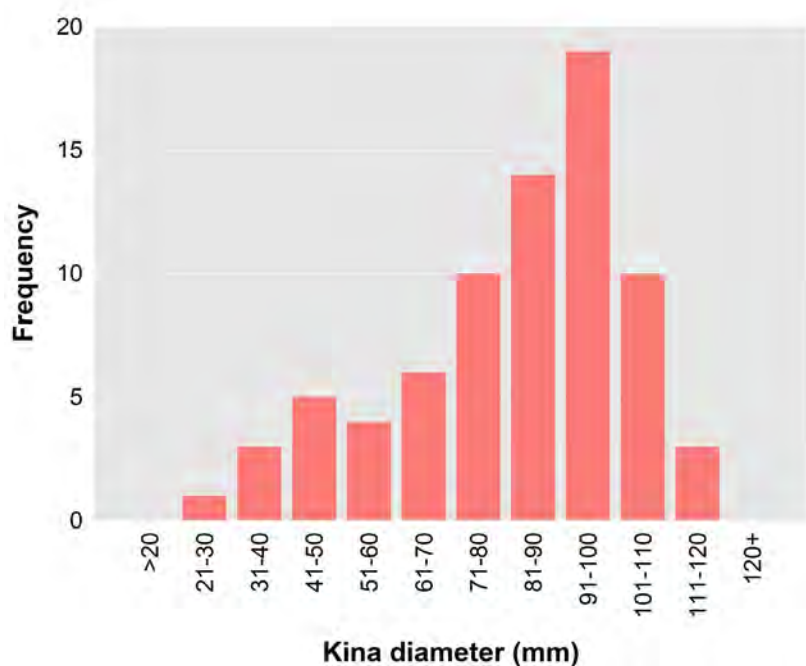


Figure 17. Size-frequency distribution of kina (*Evechinus chloroticus*) across the Mercury Islands.

3.2.3 Sessile Invertebrates

Depth and wave exposure had a significant effect on sessile invertebrate communities (Fig. 18), and jointly these variables predicted a small portion of the variation in the community ($R^2=0.07$; Table 2). This varied among sites however (Table 3). The sessile communities were distinct at Sister Rocks and at Moturehu shallow, compared to the other sites, due to a very low cover of sessile invertebrates at Sister Rocks and a high cover of wool bryozoans at Moturehu (Fig. 19).

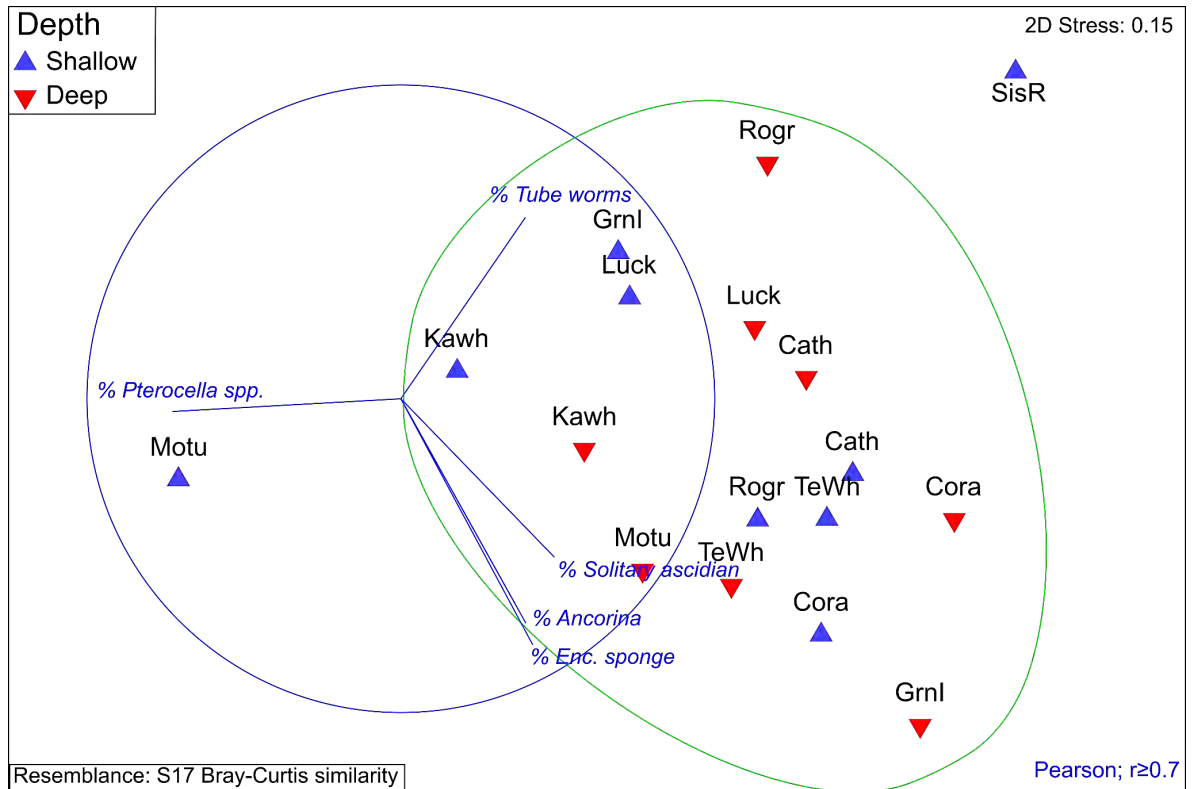


Figure 18. Non-Metric MDS ordination showing variation in the sessile invertebrates community between the two depth strata across sites. Based on Bray-Curtis similarities of raw percent cover data for 38 sessile invertebrate species and groups. The green line depicts the clustering of the samples according to similarity profile by permutation (Type I SIMPROF, 9999 perms). The overlaid vectors show the Pearson correlation ($r \geq 0.7$) of taxa abundance with the nMDS coordinates.

Sponges were the dominant sessile invertebrate group (Fig. 19a), with the most abundant coverage by encrusting sponges; but in general there was a high diversity of sponges across all sponge morphologies (not plotted here in that level of detail, but see Appendix 3 for species recorded). The next highest coverage of sessile invertebrates were ascidians, the large majority of those being encrusting or colonial species (Fig. 19b, Appendix 3). Interestingly, hydroids were relatively dense at one shallow site (Coralie Bay) and one deep site Green Island) (Fig. 19d). Likewise for bryozoans, principally the wool bryozoans such as *Cribricellina cribraria*, shallow at Moturehu and deep at Coralie Bay (Fig. 19e).

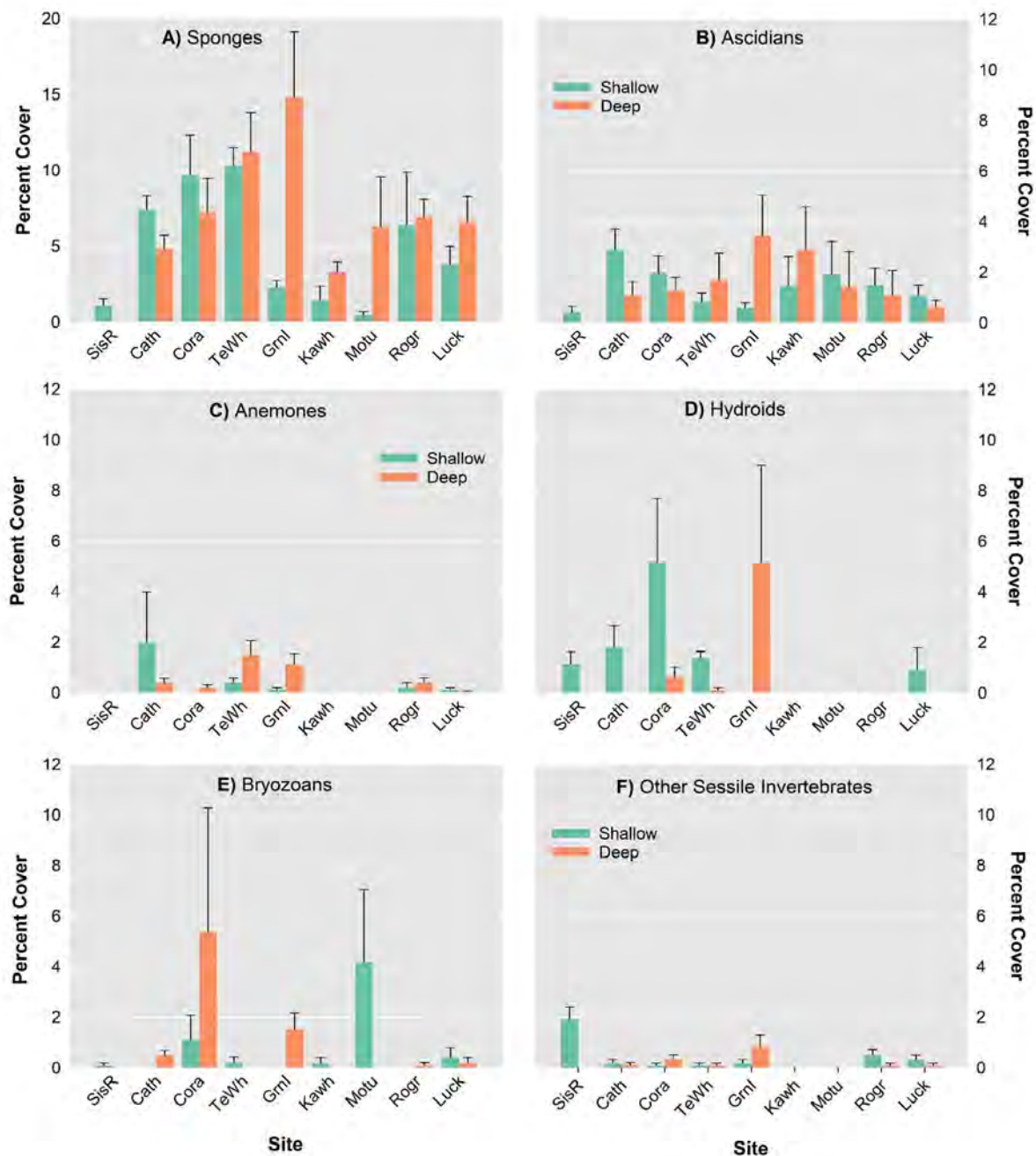


Figure 19. Mean percent cover of the main encrusting invertebrate groups at each site for: A) Sponges, B) ascidians, C) anemones, D) hydroids, E) bryozoans, and F) all other sessile invertebrates (e.g. brachiopods, tube worms) Data is from the benthic quadrat surveys. Note the different y-axis scale for A). Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove), see methods for site abbreviations. Bars represent the standard error of the means.

3.3 Rock Lobster and Long-Spined Urchin Surveys

Red rock lobster (*Jasus edwardsii*), or crayfish, were also recorded with targeted surveys. The highest abundances were found at Coralie Bay, with low abundances at all other sites (Fig. 20a). There was a preferred depth for lobsters during the surveys, with 79% recorded in the shallower transects (<10 m), however there were no significant differences in mean size between shallow and deep transects ($U=144.0$, $n_1=9$, $n_2=38$, $P=0.465$; Fig. 20b).

Mean size of lobsters overall was 79.04 mm carapace length (± 3.2 SEM). Lastly, the gregarious behaviour of the lobster was recorded, with 60% of the lobsters recorded being in shared dens (i.e., with two or more lobsters), distributed evenly between sexes. The largest den accommodated six individuals (at Coralie Bay).

Carapace length of each lobster was estimated visually to avoid handling of the lobsters. This meant that legal size (tail width) could not be recorded. However, based on conversions of carapace length to tail width, it estimated that ~95 mm carapace length for females and males would be considered the minimum legal size limit (Hanns 2021). Fifteen individuals were estimated as being 95 mm and four males were ≥ 100 mm carapace length. Therefore, it is estimated that nineteen of the 48 recorded lobsters were at or above catch size limits.

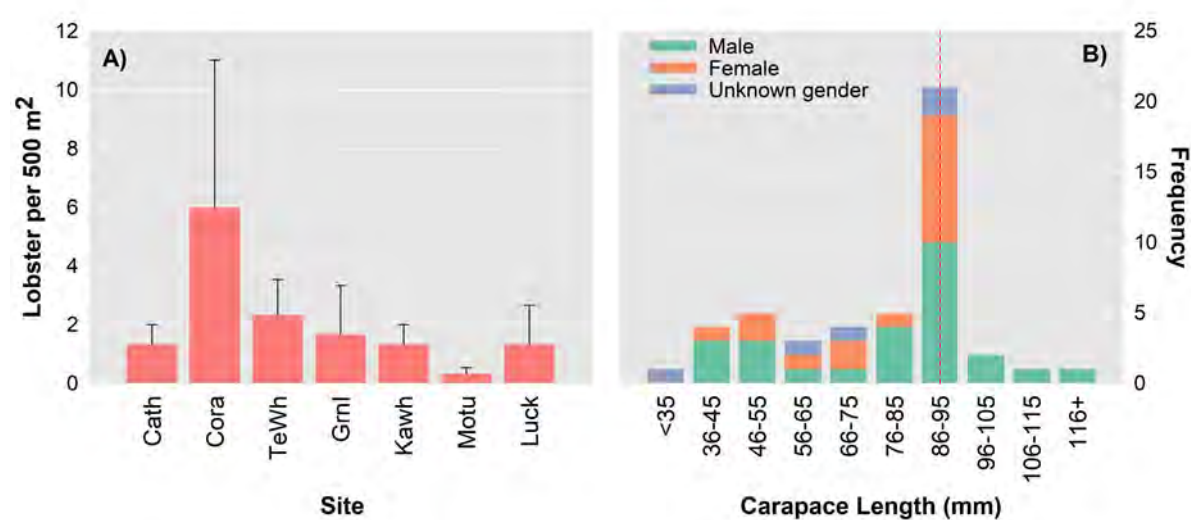


Figure 20. A) Density of red rock lobster (*Jasus edwardsii*) at each site, with sites arranged from west (Cathedral Rock) to east (Von Luckner's Cove). See methods for site abbreviations. Bars represent standard errors of the mean. B) Size frequency distribution of red rock lobster at the Mercury Islands (all sites). Red dotted line indicates the size bin including minimum legal size limit (95 mm).

The long-spined sea urchin, *Centrostephanus rodgersii*, was present in very low densities at the Mercury Islands. Only two individuals were recorded in the benthic community quadrats (Roger's Spot at a depth of 6 m and Coralie Bay at 8 m), and only one was recorded in the targeted urchin transects (Green Island at 7 m), all within kelp forest habitat. The occasional individual was noted during the fish surveys, during other dives, and the drop camera surveys, albeit infrequently. The highest densities were observed in drop camera surveys in kina barrens on the steep sloping reefs to the east of the Von Luckner's Cove (see Fig. 11b, Appendix 1i).

3.4 Reef Fish Surveys

3.4.1 Reef Fish Assemblages

In total, 27 benthic-pelagic fish species were recorded during the underwater visual censuses (UVCs). Depth had a significant impact on the benthic-pelagic reef fish community, but this effect varied among sites (Table 3). Most sites were similar in their benthic-pelagic fish assemblage and there was a general deviation by depth (Fig. 21). In general, spotty *Notolabrus celidotus* and red moki *Cheilodactylus spectabilis* were most associated with the shallow depth, leatherjackets *Meuschenia scaber* and snapper *Chrysophrys auratus* with the deep stratum, and collectively these species had a large contribution to the variation between the depth strata (40%, SIMPER). The deep depth at Sisters Rocks West and Roger's Spot clustered together separately from the other sites, and shallow depth at Kawhiti was distinct in its benthic-pelagic fish assemblage (Fig. 21). The separation of shallow depth at Kawhiti from the most sites was largely due to the presence of black angelfish *Palma alboscapularis*, the relatively high density of sweep *Scorpius lineolata*, and the absence of leatherjackets *M. scaber* and snapper *C. auratus* (51%, SIMPER). The clustering of the deep stratum at Roger's Spot and Sister Rocks West was associated with red moki *C. spectabilis*, two-spot demoiselle *C. dispila* and spotty *N. celidotus* densities (59.3%, SIMPER), and the separation from the other cluster was mostly driven by goatfish *Upeneichthys lineatus*, leatherjacket *M. scaber*, red moki *C. spectabilis*, and two-spot demoiselle *C. dispila* (45.5%, SIMPER).

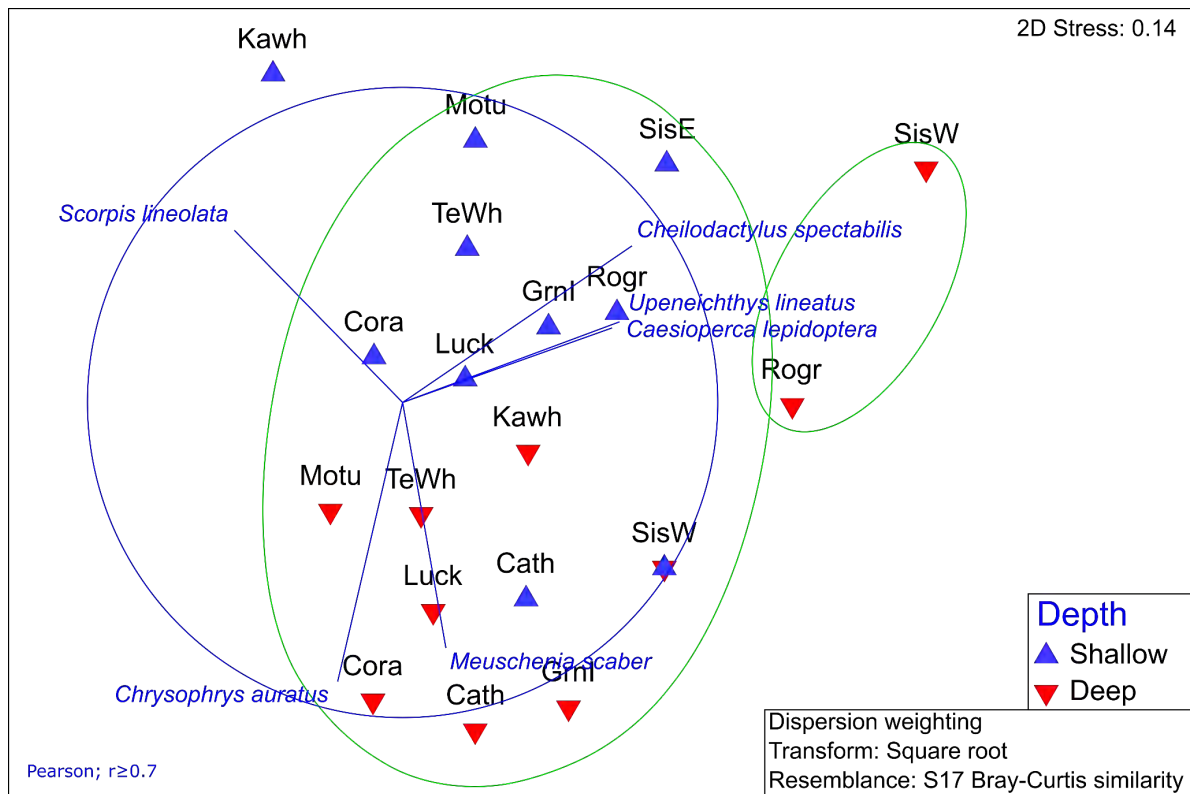


Figure 21. Non-Metric MDS ordination showing variation in the benthic-pelagic fish community between two depth strata across sites. Based on Bray-Curtis similarities of square root transformed weight dispersed density data (9999 perms) for 27 fish species. The green line depicts the clustering of the samples according to similarity profile by permutation (Type I SIMPROF, 9999 perms). The overlaid vectors show the Pearson correlation ($r \geq 0.7$) of taxa abundance with the nMDS coordinates. Note that the depth strata vary from the depth strata used for the benthic community (Shallow, 5-10 m, and Deep, 12-18 m).

3.4.2 Abundance of Key Reef Fish Species

Overall, the three most abundant species were schooling planktivores, with the two most abundant, two-spot demoiselle *C. dispila* and koheru *Decapterus koheru*, accounting for 84% of all fishes recorded (Fig. 22a, Appendix 2). Five species (two-spot demoiselle *C. dispila*, goatfish *U. lineatus*, spotty *N. celidotus*, leatherjacket *M. scaber* and red moki *C. spectabilis*) were present at all sites surveyed, whereas kahawai *Arripis trutta*, short-tail stingray *Bathytoshia brevicaudatus*, scarlet wrasse *Pseudolabrus miles*, marblefish *Aplodactylus arctidens*, painted moki *Morwong ehippium*, orange wrasse *Pseudolabrus luculentus* and kingfish *Seriola lalandi* were only recorded at single sites (Fig. 22b, Appendix 2). An additional 31 fish species were recorded during the dives outside of the transects, bringing the total recorded fishes recorded to 56 species (Appendix 3).

Spatial representation of abundance across the islands displayed higher abundances in the west, decreasing eastward (Fig. 22b). This is heavily skewed however by two-spot

demoiselle *C. dispila* and koheru *D. koheru*. In terms of species diversity by location, this showed a similar west to east pattern, with the exception of Moturehu, being the most diverse (Fig. 22b). More detailed plots of fish density by site are shown for 12 of the more abundant species (Figs. 23, 24).

Several of the reef fish species (e.g., red moki, parore, spotties, banded wrasse and goatfish) were most abundant at the two most sheltered sites, Sister Rocks and Roger's Spot, indicating their coastal affinities. Conversely, the red pigfish *Bodianus unimaculatus* was most abundant at Von Luckner's Cove, a sign of this species predominantly offshore distribution. Of note was a large school of tarakihi *Nemadactylus macropterus* at Sister Rock (west islet), outside of the transects down deep on the sand.

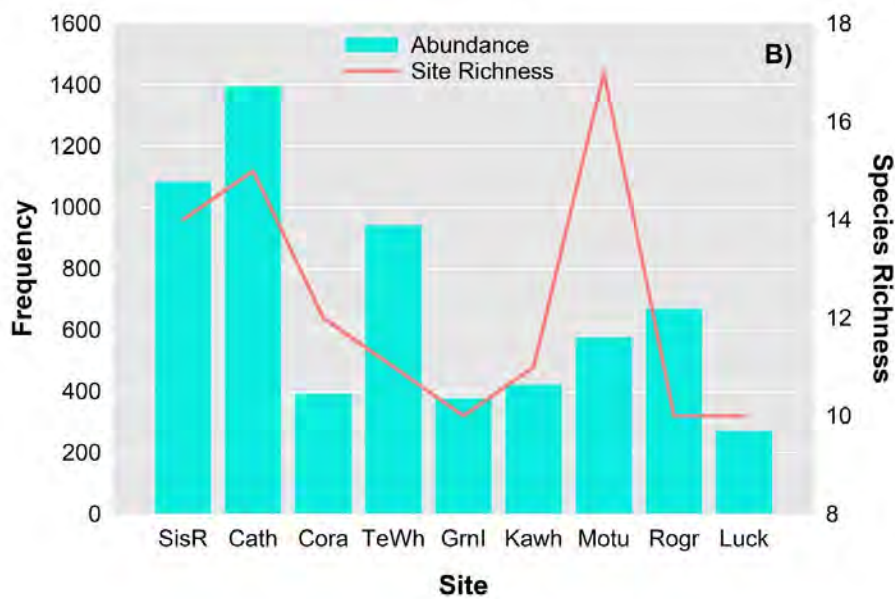
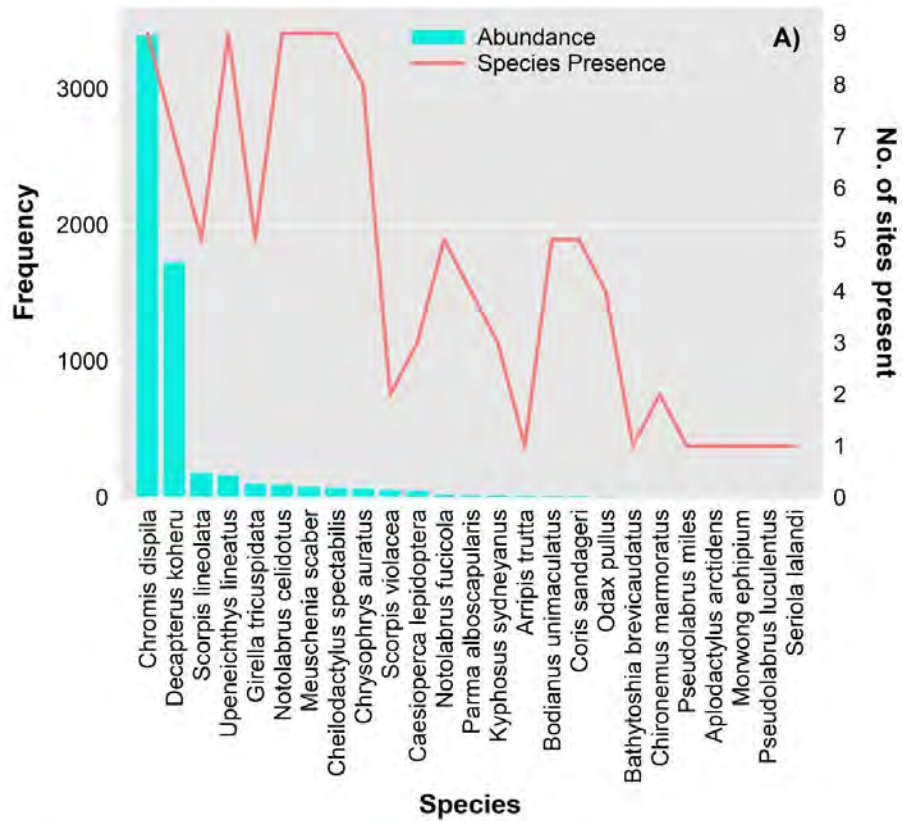


Figure 22. A) Individual fish species abundance (all sites combined), in order of abundance, descending from left to right along the x-axis (green bars), and species presence across the nine study sites (red line). B) Overall fish abundance per site (all species combined - green bars), and fish species richness by site (red line). Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove). See methods for site abbreviations.

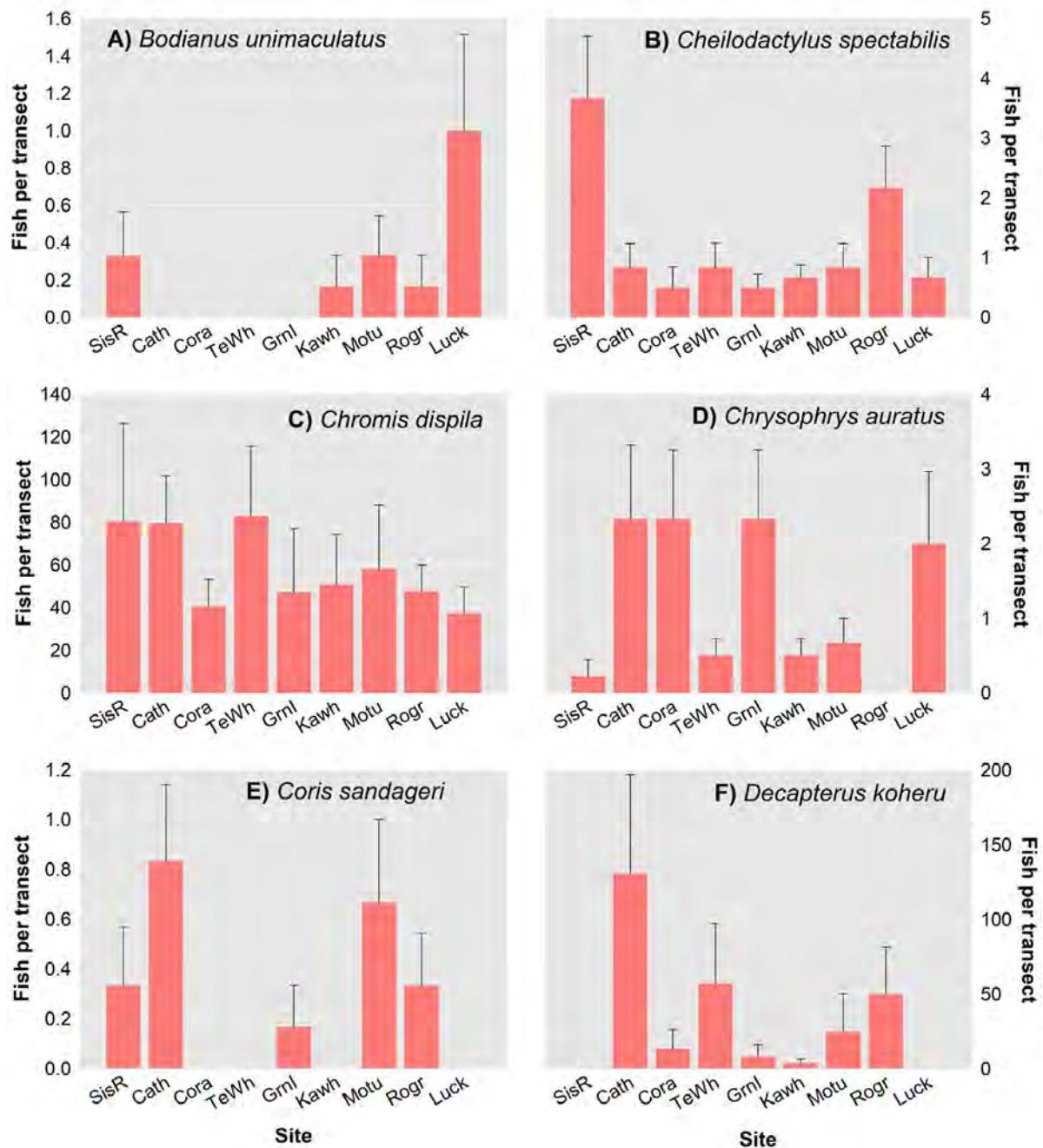


Figure 23. Mean density of fish per transect (625m³) at each site for: A) pigfish *Bodianus unimaculatus*, B) red moki *Cheilodactylus spectabilis*, C) two-spot demoiselle *Chromis dispila*, D) snapper *Chrysophrys auratus*, E) sandagers wrasse *Coris sandageri*, and F) koheru *Decapterus koheru*. Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove), see methods for site abbreviations. Bars represent the standard error of the means. Note the different scales on the y-axes for each plot.

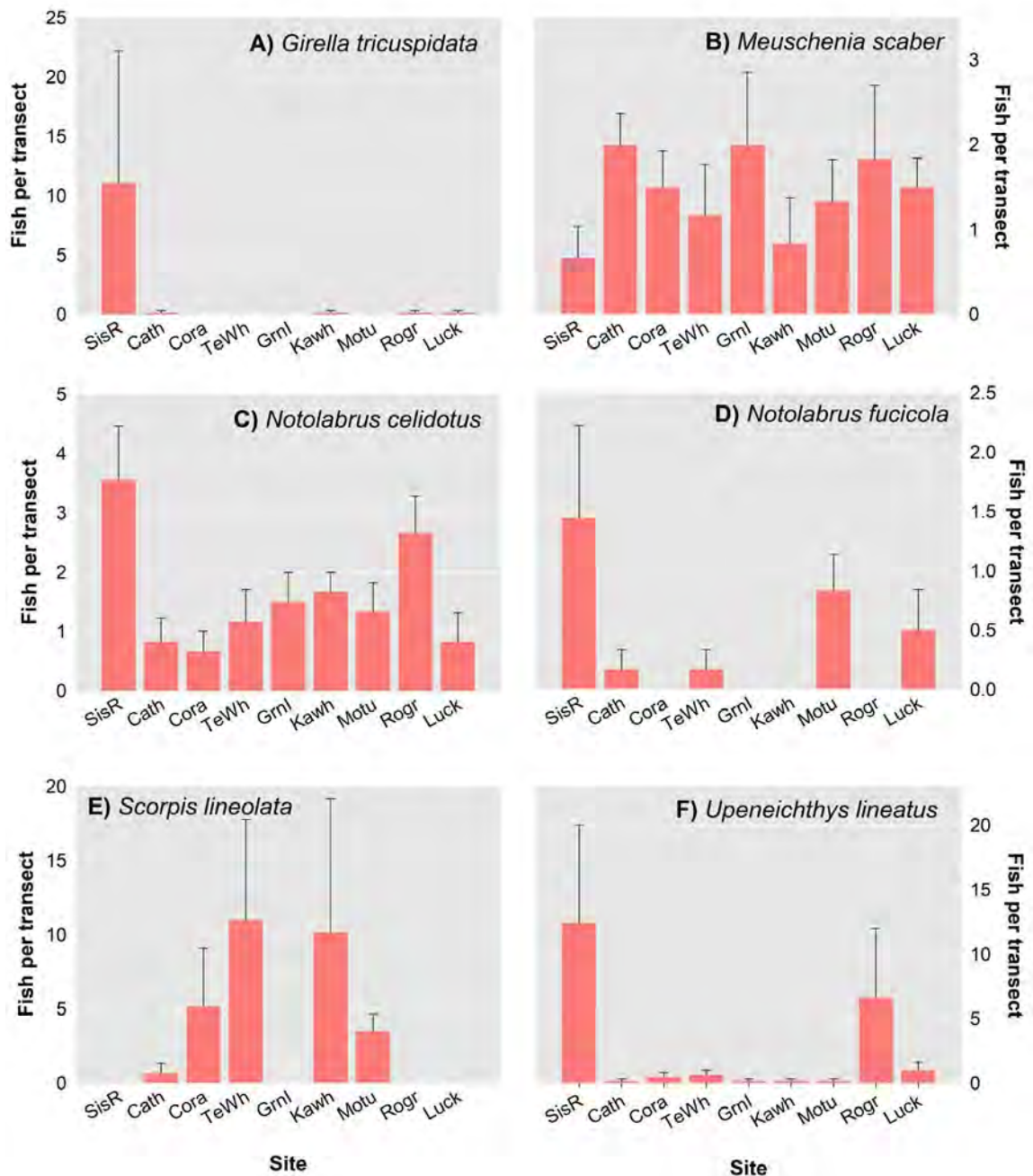


Figure 24. Mean density of fish per transect (625m³) at each site for: A) parore *Girella tricuspidata*, B) leatherjacket *Meuschenia scaber*, C) spotty *Notolabrus celidotus*, D) banded wrasse *Notolabrus fucicola*, E) sweep *Scorpius lineolata*, and F) goatfish *Upeneichthys lineatus*. Sites are arranged from west (Sister Rocks) to east (Von Luckner's Cove), see methods for site abbreviations. Bars represent the standard error of the means. Note the different scales on the y-axes for each plot.

3.4.3 Size-Structure of Key Reef Fish Species

Size was documented for ecologically and commercially important reef fishes during the fish surveys. Only two species were recorded in sufficient numbers to gain any meaningful size frequency distributions: snapper *C. auratus* and red moki *C. spectabilis*.

Snapper were approximately normally distributed, with a median size of 200 mm TL (Fig. 25a). Only 8% were above legal recreational catch limit. Red moki represented a left-skewed distribution, with a median size of 350 mm TL (Fig. 25b). Similarly, only 12 % of red moki recorded were larger than the minimum legal size.

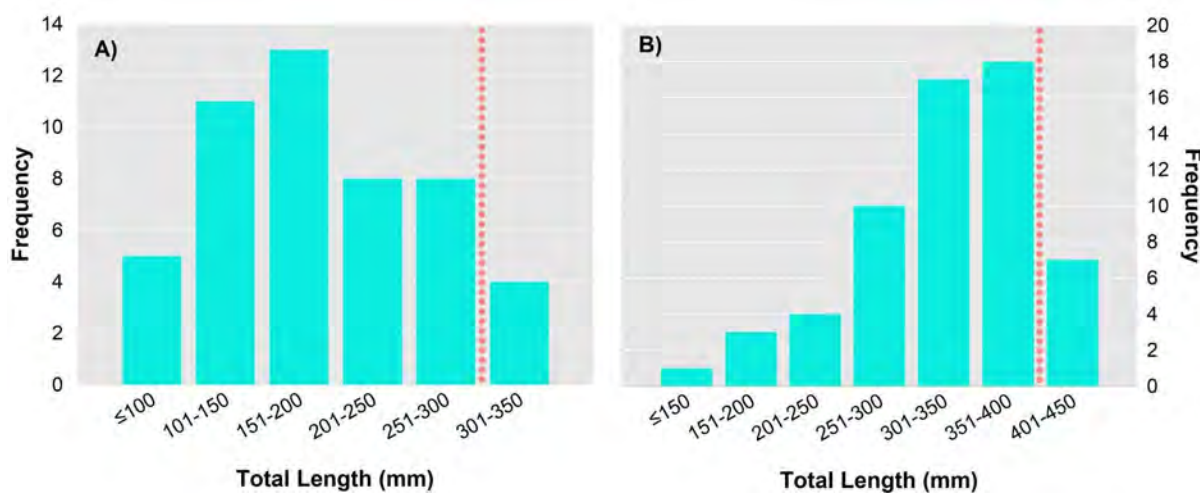


Figure 25. Size frequency distribution of A) snapper (*Chrysophrys auratus*) and B) red moki (*Cheilodactylus spectabilis*) across the Mercury Islands (all sites). Red dotted line indicates recreational minimum legal size.

3.5 Inventory of Species

Overall, 166 species were documented during the surveys. Animals accounted for 129 species across 11 phyla. The most speciose group were fishes, in particular teleosts; the most diverse invertebrate group recorded were sponges (Appendix 3). Thirty-eight species of algae were recorded from the surveys, including 7 chlorophytes, 15 rhodophytes and 16 phaeophytes and (Appendix 4).

4 Discussion

4.1 Rocky Reef Habitats of the Mercury Islands

The overall biogenic reef habitats were typical of both open coast and offshore island environments in northeastern New Zealand, however, were more so coastally influenced habitats than oceanic. As such, the rocky reef habitat is more similar to locations such as Te Whanganui-a-hei/Hahei or Hauturu-o-toi/Little Barrier Island, and less so like the islands further offshore, such as the Poor Knights Islands, Mokohinau Islands or Alderman Islands. Overall, there was a natural environmental gradient from west-east, reflecting a change from more coastal to offshore reef habitats. This is likely due to a combination of multiple factors: distance from the mainland (west to east), wave exposure, and coastal versus offshore currents. Whilst these factors are inherently linked, they are separate, depending for instance on the aspect or direction of the reefs, or the pathway of the southward-flowing East Auckland Current. This is illustrated in the data, as wave exposure only predicted a relatively small amount of the variation in the benthic reef communities and in species composition. This suggests that there are site-specific differences and highlights the general patchy and mosaic nature of subtidal reefs at the Mercury Islands.

The sea urchin or kina *Evechinus chloroticus* is a habitat defining species, and the occurrence of extensive kina barrens in northeastern New Zealand is largely regarded as a result of trophic cascades driven by overfishing of kina predators (Shears & Babcock 2002). The extent of kina barrens was highly variable among the survey sites and covered between 0 and 20% of the reef in the line transects (Fig. 2). This contrasts other offshore island locations in northeastern New Zealand, such as the Mokohinau Islands, where kina barrens form a distinctive band below the shallow mixed algal zone (Shears & Babcock 2004, Shears et al. 2008a). However, drop camera surveys over a wider area at the benthic survey sites recorded some larger areas of kina barrens. For example, at Cathedral Rock, Te Whanga Bay and Green Island kina barrens dominated the reef in a more typical depth band from ~3-10 m, whereas in the inner part of Coralie Bay, kina barrens and turfing algae dominated ~2-7 m. In contrast, at Von Luckner's Cove, one of the most exposed sites, an area of barrens was present in 2-8 m of water in the most sheltered part of the bay and barrens were also dominant on the exposed and steep sloping reef to the east from ~7-18 m depth. This variability in the extent and depth distribution of barrens among sites, and in relation to wave exposure, highlights the importance of environmental factors in determining the abundance of urchins and where they can overgraze macroalgae and form barrens (Shears et al. 2008a). It also highlights the utility of multiple modes of

survey (i.e., quadrats, transects, reef profiles, drop camera), as one technique alone might mis-represent the broader understanding of the habitat compositions. Moreover, while there were low counts of kina in the benthic quadrats, there were very dense but isolated clusters, in some cases limited to single boulders surrounded by kelp stands, e.g., Rogers Spot, Kawhitu and Moturehu. This was the pattern of habitat in general at the Mercury Islands - a heterogeneous subtidal environment formed by a mosaic of habitat types.

During the March 2022 surveys there was a high cover of red filamentous algae and the dinoflagellate *Ostreopsis siamensis* in the kina barrens habitat, which was likely associated with the warm summer water temperatures (temperatures ranged from 21.6-22.7°C during the survey). These blooms were most evident in the areas of barrens around Green Island, Te Whanga Bay and Cathedral Rock, and not as evident in deeper barren areas such as at Von Luckner's Cove. Blooms of *Ostreopsis* are known to have a negative impact on kina populations and can cause mortality (Shears and Ross 2009). During these seasonal blooms kina display a highly cryptic behaviour, which combined with the high cover of filamentous algae make distinguishing between kina barrens and turfing algal habitat difficult. It is also likely that these blooms directly impact urchin numbers and inhibit sea urchin grazing, which facilitates turfing algae and may promote the growth of other seaweeds such as *C. flexuosum*. These blooms may therefore play a role in contributing to the patchy nature of kina barrens, turfing algae and algal forests at some sites.

The observed patterns of habitat and habitat-defining species are broadly consistent with historical observations from the Mercury Islands (Grace 1972b, Grace & Grace 1976). These historical observations also included evidence for *Ecklonia* die-back, similar to what we documented at Sister Rocks and Cathedral Rock. However, the surveys led by Grace were both largely qualitative, so it is difficult to directly compare if the sites and the overall reef health has changed or not over the ensuing five decades. Furthermore, Grace's papers were only at two sites, so do not provide habitat descriptions across the wider island group, which given the heterogenous nature of the present surveys is important. One comparison of note was at Roger's Spot. Here the biota was generally similar then to our data; however, two species recorded there by Grace, *Haliotis iris* and *Lessonia variegata*, were not recorded in the present study. Both species predominantly occur in shallow water so may have not been captured in our shallowest quadrat surveys at 4-6 m. Further investigations would be needed to determine if there has been a long-term disappearance of these species at this site, and if so, the likely cause.

Kina size structure was consistent with that of other offshore fished locations in northeastern New Zealand (Shears et al. 2008a). The unimodal size distribution and large size suggests that predation does not play a significant role in structuring kina size, and that kina are unlikely resource limited. Where predators are large and abundant, such as in marine reserves, kina typically have a bimodal size distribution, most individuals are cryptic and only the largest size classes exhibit an exposed behaviour (Spyksma et al. 2017). Kina behaviour was mostly exposed during the benthic surveys (winter 2021), which is consistent with a lack of predation on conspecifics (Spyksma et al. 2017). It is also important to note that there has been a commercial kina harvesting operation around the Mercury Islands and the surrounding region since 1992. While this could have played a role in reducing kina populations and the extent of kina barrens in parts of the island, the level of harvest and impact on kina barrens is unknown.

Centrostephanus rodgersii was found in very low densities during the present surveys, with only two individuals recorded in quadrat surveys. This contrasts to other offshore locations to the north of the Mercury Islands such as the Mokohinau Islands and Poor Knights Islands, where this species has increased from ~ 0.1 to $\sim 1 \text{ m}^{-2}$ (at 5-12 m deep) between 1999 and 2022 and has begun to form barrens habitats (Balemi & Shears 2023). However, preliminary evidence from the drop camera surveys indicated *C. rodgersii* were common in some locations such as on the steep reefs southeast of Von Luckner's Cove. *Centrostephanus rodgersii* is generally most abundant in offshore compared to coastal areas in northeastern New Zealand, so it would be expected to be more common on parts of the Mercury Islands protruding more into the East Auckland Current, such as the northern-most point of Ahuahu and eastern parts of Whakau. At present *C. rodgersii* may not be exerting high pressure on the macroalgal forests and sessile invertebrate communities (as they also consume animal material - Byrne & Andrew 2020) at Mercury Islands. However, based on the evidence of limited but dense clusters, it is important to monitor as this species is expected to increase with warming temperatures. Furthermore, future monitoring efforts might benefit from additional surveys of rocky points and outcrops that are exposed to southward flowing current and likely more prone to *C. rodgersii* establishment.

4.2 Faunal Abundance and Diversity

A wide diversity of sessile invertebrates shared the understory substrate with the encrusting and low-profile algal species. Sponges and ascidians, in particular the

encrusting, colonial species, dominated the sessile assemblages. This indicates good water flow laden with planktonic food supply, typical of temperate environs. However, the diversity and abundance of some sessile invertebrate fauna was lower than reefs at northern offshore islands, with limited species of gorgonians, and groups such as wool bryozoans not widely spread. For instance, 68 species of cnidarians have been recorded from the Poor Knights Islands across several studies (Sim-Smith & Kelly 2009), and over 300 species of bryozoans have been recorded from the Spirit's Bay region (Cryer et al. 2000). Firstly, this is due in large part to a lack of targeted taxonomic expertise in these areas during our broad sampling efforts. But also, this belies both the shallow, low gradient and often bouldery nature of the reefs, and the mid-way between coastal and offshore location (i.e., islands surrounded by water <50 m deep and not in the direct path of the East Auckland Current).

Macro-invertebrate records were generally low in both abundance and species richness in the various surveys. The mobile invertebrates were dominated by a couple of species, *Cookia sulcata* and kina. These two species are algal grazers, and thus interact with a range of algal coverage across the sites. *Cookia sulcata* browse on a wide range of turfing and small foliose algae, and their juveniles will graze occasionally on the stipes and blades of kelp (Cook 2010). However, as aforementioned, kina are well documented as grazing macroalgae such as *Ecklonia radiata* extensively; however, apart from dense clusters, they occurred in low densities. All other mobile invertebrates were both small and relatively low in abundance. Species that lived interstitially (e.g., brittle stars, polychaetes) or were minute (e.g., micro-gastropods, <5 mm) were not recorded in our survey techniques. However, these species, whilst undoubtedly important and largely underappreciated, probably play a smaller role in the broader ecology of the subtidal rocky reef ecosystem. An interesting and uncommon find was the large and conspicuous gastropod, *Hydatina physis*, recorded at ~6 m at Sister Rocks. This is at the southern extent of its range and has only been found once before this far south (at Opito Bay, www.mollusca.co.nz).

Rock lobsters were previously reported as common at the Mercury Islands (Grace 1972a, Grace & Grace 1976), but were recorded in low densities during our surveys and the population was dominated by sublegal sized lobster. Nineteen individuals (out of 47 total) were estimated to be at or above the legal-size limit on the 20 transects sampled (a total reef area of 10,000 m²). Densities of legal-sized lobster of <1 per 500m² transect are typical for fished areas in the Hauraki Gulf (LaScala-Gruenewald et al. 2021) where rock lobster populations are considered to be functionally extinct (State-of-our-Gulf 2020). In

contrast, within no-take marine reserves lobster populations are dominated by adult individuals greater than the minimum legal-size limit. The low numbers recorded and the truncated size structure at the legal-size limit, indicate a high level of harvesting pressure on rock lobster at the Mercury Islands.

In general, the reef fish community at the Mercury Islands was more similar to northeastern coastal assemblages (e.g., Leigh and Tawharanui) than offshore assemblages (e.g., Poor Knights & Mokohinau) (Brook 2002, Allard 2020). For instance, the strong presence of spotties, sweep, jack mackerel and parore are indicative of more sheltered, coastal sites, and the lack of more subtropical species common on the offshore islands, such as combfish, Lord Howe coralfish, rainbowfish and crimson cleanerfish. This is probably largely due to the island's proximity to the mainland and not being situated in the direct path of the East Auckland Current flowing southward from warmer source locations (Zeldis et al. 2004). There were, however, some species recorded that are not common on coastal reefs, such as Sandager's wrasse, black angelfish and pigfish, albeit in low numbers. Furthermore, these were recorded at the more exposed and/or easternmost sites, which highlights both the presence of an exposure gradient at the Mercury Islands, and the closer proximity of sites such as Von Luckner's Cove at Whakau to offshore currents. The presence of these species is actually more akin to Hahei than the other coastal locations described above (Allard 2020), which could be explained by both current patterns delivering some northern more tropical larvae and also Hahei and Mercury Islands sharing a higher degree of exposure gradient than other coastal locations.

The only previous documentation of reef fishes at the Mercury Islands was by Grace (1972, 1973), at Whakau. The present study has added 23 further species not recorded in Grace (1972) or (1973) to the reef fish documented at this group of islands. Collectively, this brings the total to 68 species of reef fish on record at the Mercury Islands, which is higher than the maximum number of species reported (57 species) for other locations including offshore island groups in northern New Zealand (Brooks 2002). Note that our observations did not include any targeted surveys for crypto-benthic fishes (although these fishes were recorded where observed), and also excluded true pelagic species such as tunas and pelagic sharks (as recorded by Grace 1973).

Some species of particular interest (for the most, species commonly harvested) were also recorded for size, to gain an understanding of size structure. Due to the low numbers of certain species that were highlighted *a priori* (e.g., kingfish, kahawai, butterfish), only red moki and snapper were recorded for size information. Red moki favoured the two most sheltered sites, which is unsurprising, given their predominance on coastal reefs

(Brook 2002). These fish are particularly important turf fossickers, which is confirmed by the higher percentages of turfs at the sheltered sites. They are also a potential target for harvesting, and the small percentage of counts above the minimum legal catch limit indicates some fishing pressure.

Snapper numbers were low in the surveys, and their size structure indicated a small and unimodal population. Again, this suggests that there is a level of harvesting pressure, and also a small but steady stream of larval supply (i.e., not punctuated larval pulses). However, caution is needed with these results, as snapper are well documented as being averse to divers outside of marine protected areas, and even size-skewed as the larger individuals tend to be more averse than smaller ones (Willis et al. 2000). Thus, their density is likely somewhat higher. Due to their purported low numbers and smaller sizes though, snapper are unlikely to play a large role in maintaining kina numbers at the Mercury Islands.

Collectively, the species inventory serves to record which species were present at the Mercury Islands. However, this list should not be seen as an exhaustive list of the species richness or biodiversity of the Mercury Islands, as many of the highly cryptic species (e.g., burrowing and interstitial invertebrates, and fishes such as belonging to the families Gobiesocidae, Plesiopidae and Brotulidae) are seldom seen without destructive sampling techniques. Additionally, some taxa require specialised taxonomic expertise to correctly identify the species (e.g., cross-sectional microscope views of sponge spicula); however, that level of taxonomic thoroughness was outside the remit of the project. Lastly, any species from soft sediment or pelagic habitats were recorded if encountered, but these habitats were also not surveyed specifically. Regardless, this study has documented 166 species of flora and fauna and will serve as a record for future monitoring and surveys.

4.3 Overall status and impacts on reef assemblages at Mercury Islands

The reef assemblages and associated species of the Mercury Islands were generally typical of other fished islands in northeastern New Zealand that are located near to the mainland with little influence of East Auckland Current, e.g., reef fish and macroalgal assemblages are more similar to coastal locations than offshore island groups such as the Poor Knights, Mokohinau's, Alderman's and White Island that have more subtropical species and clearer water. In general, the reef assemblages appear relatively healthy, except for the clear influence of fishing on target species and the indirect effects of fishing on reef ecosystems, as evident by the presence of kina barrens at some locations. The abundance of key target species such as snapper and crayfish was low and their sizes generally small (primarily at or below minimum legal size) which is typical of fished locations in northeastern New Zealand (LaScala-Gruenewald et al. 2021, Allard 2020). The extent of kina barrens varied around the islands considerably, which is also consistent for fished locations where the extent and depth distribution of barrens varies in relation to a number of factors such as wave exposure (Shears et al 2008). At highly exposed sites on the northern side of the island group, such as Coralie Bay, Von Luckner's Cove, Kawhitu and Moturehu the reefs were dominated by lush macroalgal forests and barrens were restricted to sheltered areas or deep water. In contrast, in more sheltered parts of the island group such as Cathedral Rocks and Green Island barrens were more extensive, dominating the reef between 2 and 10 m depth.

Located between ~5 and 15 km offshore from the Coromandel Peninsular there is a low but variable influence of sediment runoff from the mainland. This is apparent following rain events, with areas in the southern parts of the island group most influenced by plumes of sediment largely originating from the mainland (Figure 26). In general, there was little evidence of sediment impacts on the reef with healthy kelp forests extending to depths of 20m or more around the island group, which is consistent with generally high water clarity (Blain et al. 2021). Similarly, no invasive species were recorded in the surveys or observed on the reefs², which is typical for reefs at offshore islands in northeastern New Zealand.

The March 2022 surveys coincided with a large marine heatwave (Bell et al 2023), and this provides some insight into what future impacts might occur at the Mercury Islands if temperatures continue to rise. Widespread sponge necrosis was observed at a number of locations across New Zealand where the 2022 marine heatwave was most intense (Bell et

² *Caulerpa brachypus* has since been found in sandy habitats at Great Mercury Island www.mpi.govt.nz/biosecurity/major-pest-and-disease-threats/

al. 2023). Data from the drop camera surveys at the Mercury Islands were included in this national study and indicated minimal sponge necrosis in March 2022, despite the warmer than average sea conditions. During the March 2022 surveys blooms of *Ostreopsis siamensis* and filamentous algae were observed on shallow reefs (<12 m) at the Mercury Islands as well as at other coastal and offshore locations such as Leigh and the Mokohinau Islands during the marine heatwave. These appear to be associated with the warm sea conditions, and while *O. siamensis* can impact kina populations, the impact on reef ecosystem and foodweb dynamics is poorly understood. Some areas of kelp (*E. radiata*) die-back were also observed during the March 2022 surveys, but a link between die-back and warm water temperatures has not been established and similar events were also reported by Grace in the 1970's (1972b).



Figure 26. Sediment plumes from runoff from the Coromandel Peninsula extending out to the Mercury Islands. Image date: 17/7/2021 Source: <https://discover.maxar.com/>

4.4 Future monitoring and research

The unprecedented warm water temperatures experienced in northeastern New Zealand in 2022 and the novel impacts of the marine heatwave observed on rocky reefs (Bell et al

2023) raise a number of concerns for the future of rocky reefs in the region and the need for both increased biological and physical monitoring. Repeating the current monitoring on a 1-2 yearly basis would provide a starting point in beginning to understand changes occurring in the subtidal reef communities. Of particular note, would be better understanding whether subtropical species such as *Centrostephanus rodgersii*, which can have large impacts on the reef, are increasing and whether sponges are being impacted by marine heatwaves.

A key recommendation would be to add more monitoring sites across the island group, in order to gain a more thorough understanding of the spatial variability in flora and fauna, and variety of reef habitats, across the Mercury Islands. More detailed biological surveys of reefs but also other habitats would also provide a greater understanding of the wider biodiversity. For instance, crypto-benthic fish surveys would be beneficial to document the small and secretive fish species not targeted by our surveys. Furthermore, dedicated invertebrate taxonomic surveys would result in a much higher number of species identified, in particular for taxa such as porifera, which display high levels of regional endemism (Gordon 2009).

In situ monitoring of water temperatures at the Mercury Islands is also key to understand how the oceanography is changing and subsequently interpreting observations and changes in the reef communities. Water temperature can be monitored cheaply through diver-deployment of temperature loggers on small moorings (serviced every 3 to 12 months) or through deployment and maintenance of a more advanced buoy system that stores and transmits SST and other water quality information real time, e.g., the Aqualink buoy at the Poor Knights Islands³.

Collecting information on the level of commercial, recreational and customary harvest occurring around the Mercury Islands for key species such as crayfish, reef fish (including snapper), kina and paua would also aid in terms of understanding the drivers of variation in these species and key habitats, such as kina barrens, as well as interpreting long-term changes. This will also aid in developing management strategies aimed at protecting, restoring and increasing the resilience of reef ecosystems at the Mercury Islands to future changes.

³ <https://aqualink.org/sites/3293>

4.4 Concluding Remarks

The results of this study document the reef community composition and the species presence and abundance across the Mercury Islands. As such, these data serve as a first point in data collection of these communities and form a “baseline” from which to conduct future surveys and compare changes over time. A true baseline, pre-human impact is not possible, thus we cannot know what the original health and composition of the reef communities should look like. This highlights why documenting this now is imperative. Subsequently, future monitoring would be hugely beneficial, given the changing state of the marine environment in northern New Zealand.

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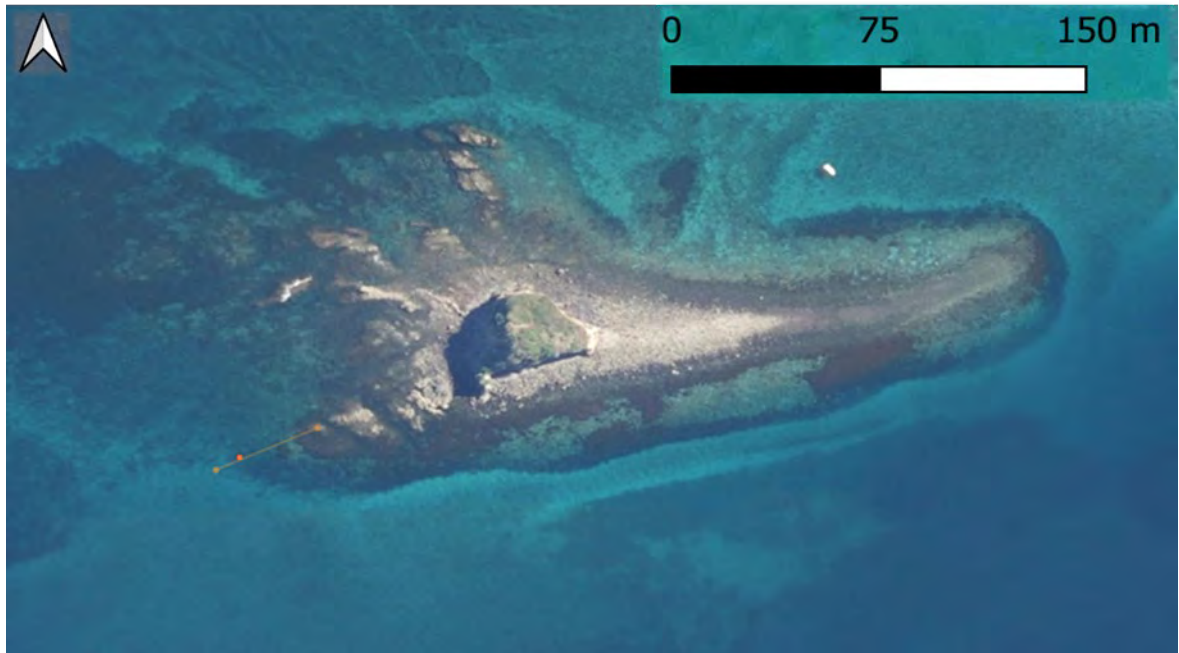
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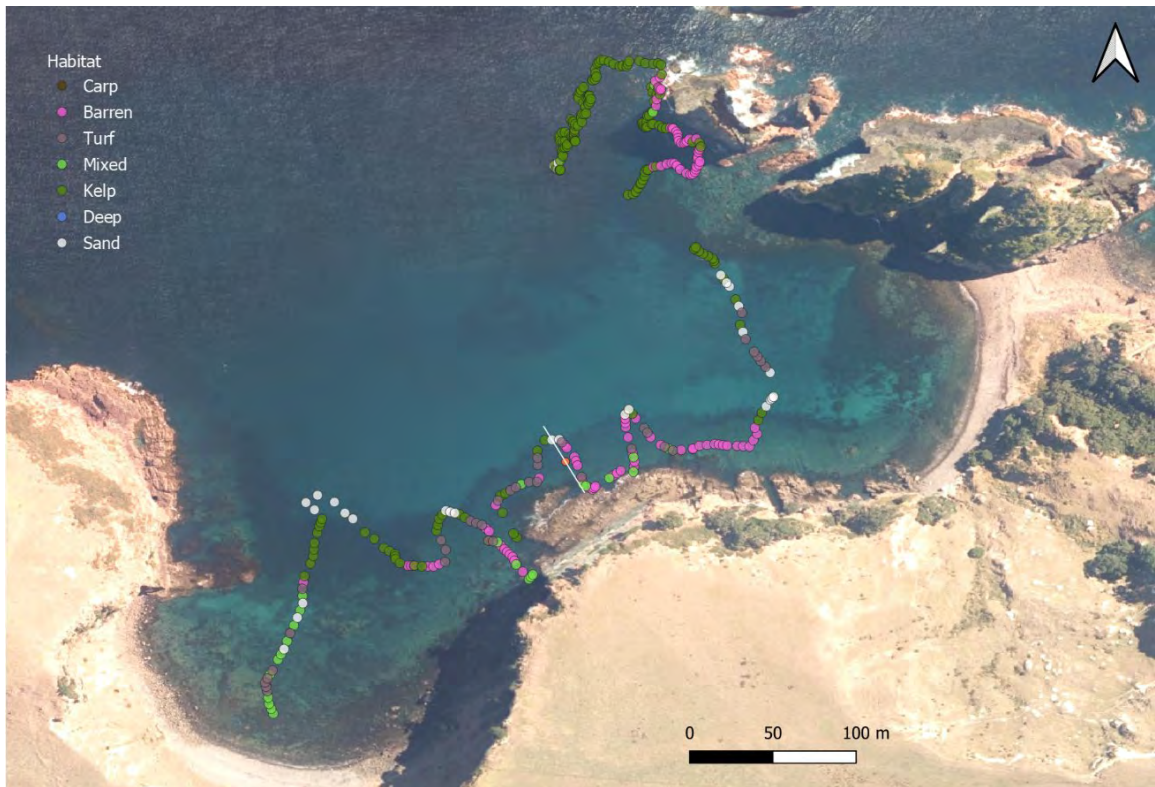
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5. Appendix

Appendix 1. Aerial images of monitoring sites showing approximate position of transect (straight line) and where available positions of georeferenced photos from drop camera and diver surveys, colour coded for broad habitat type (Table 1). Habitat abbreviations: Carp = Shallow *Carpophyllum* forest, Barren = Urchin barren, Turf = Turfing algae, Mixed = Mixed macroalgae forest, Kelp = *Ecklonia radiata* forest, Deep = Deep reef.



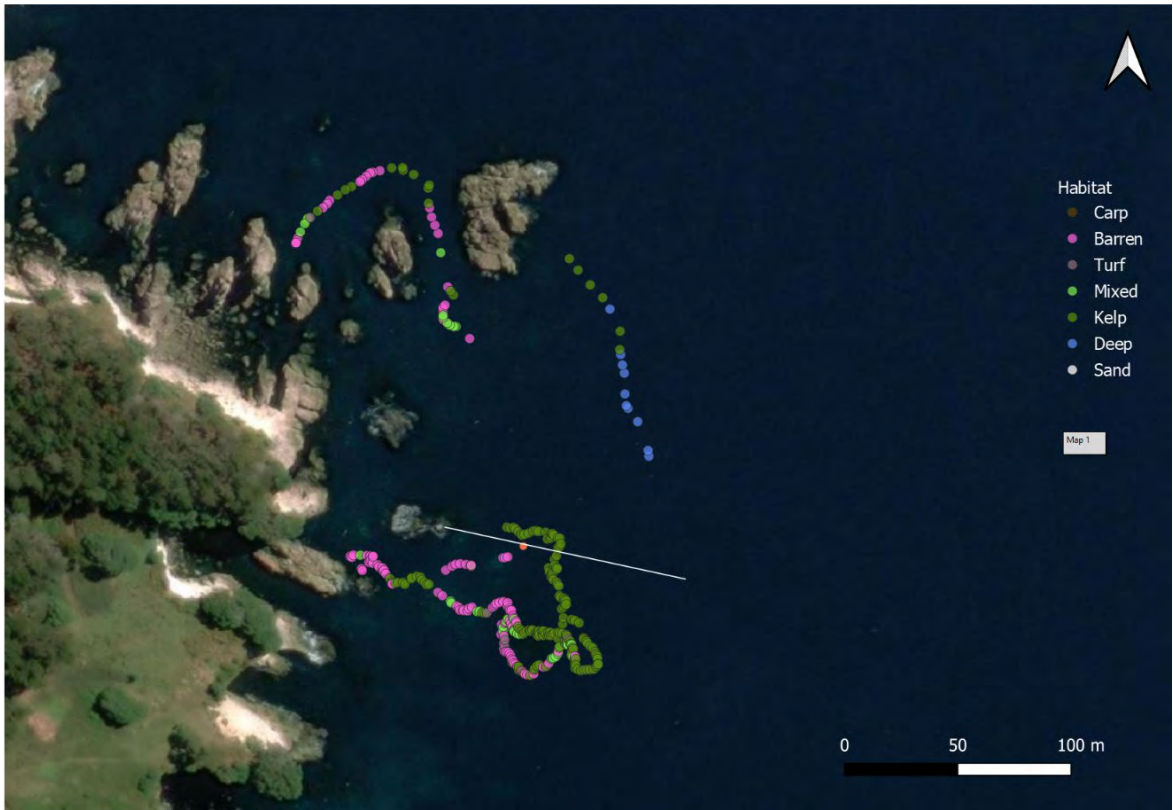
A) Sister Rocks (east), on the western side of Ahuahu (Great Mercury Island), outside the entrance to Huruhi Harbour. Note that drop camera imagery was not collected at this site.



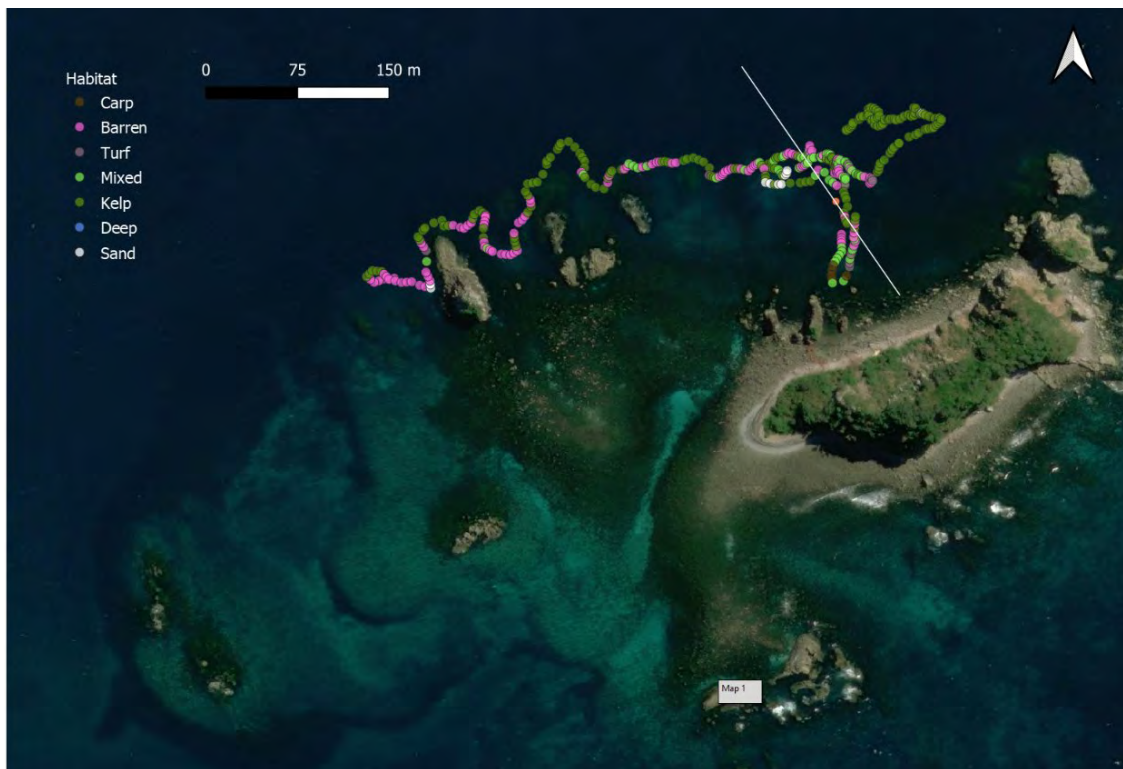
B) Cathedral Rocks, north side of Ahuahu (Great Mercury Island).



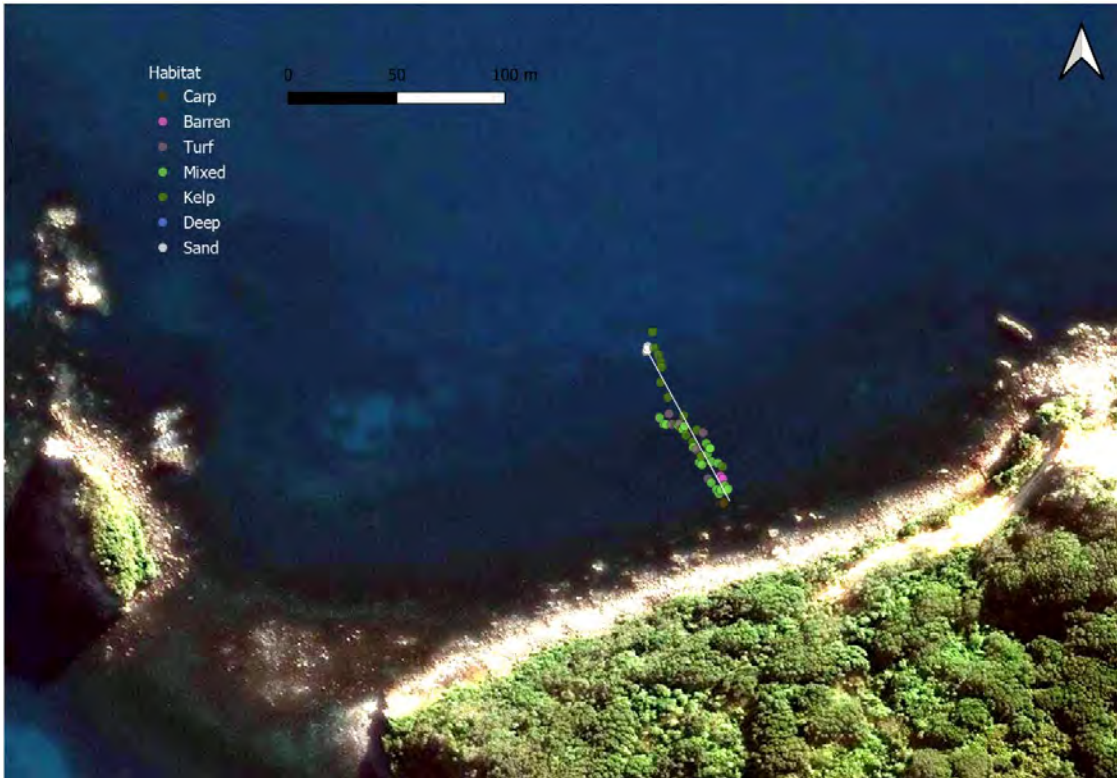
C) Coralie Bay, northeastern side of Ahuahu (Great Mercury Island).



D) Te Whanga Bay, eastern side of Ahuahu (Great Mercury Island).



E) Green Island, and small island SE of Ahuahu with extensive shallow reef areas.



F) Kawhiti, north side of Motu Kawhiti (Stanley Island).



G) Moturehu (Double Island), north-west point.



H) Rogers Spot, western side of Whakau (Red Mercury Island). Note that drop camera imagery was not collected at this site.



I) Von Luckner's Cove, eastern side of Whakau (Red Mercury Island). Note the pink barren circles (furthest right) are where the highest *Centrostephanus rodgersii* densities were found, amongst kina-dominated barrens habitat.

Appendix 2. Summary matrix of fish species by site across the Mercury Islands. *Aarc*=*Aplodactylus arctidens*; *Atru*=*Arripis trutta*; *Bbre*=*Bathytoshia brevicaudata*; *Buni*=*Bodianus unimaculatus*; *Clep*=*Caesioperca lepidoptera*; *Cspe*=*Cheilodactylus spectabilis*; *Cmar*=*Chironemus marmoratus*; *Cdis*=*Chromis dispila*; *Caur*=*Chrysophrys auratus*; *Csan*=*Coris sandageri*; *Dkoh*=*Decapterus koheru*; *Gtri*=*Girella tricuspidata*; *Ksyd*=*Kyphosus sydneyanus*; *Msc*=*Meuschenia scaber*; *Meph*=*Morwong ephippium*; *Ncel*=*Notolabrus celidotus*; *Nfuc*=*Notolabrus fucicola*; *Opul*=*Odax pullus*; *Palb*=*Parma alboscapularis*; *Pluc*=*Pseudolabrus luculentus*; *Pmil*=*Pseudolabrus miles*; *Slin*=*Scorpius luteolineata*; *Svio*=*Scorpius violacea*; *Slal*=*Seriola lalandi*; *Ulin*=*Upeneichthys lineatus*.

	SisR	Cath	Cora	TeWh	Grnl	Kawh	Motu	Rogr	Luck	SUM
Aarc	0	0	0	0	0	0	1	0	0	1
Atru	0	14	0	0	0	0	0	0	0	14
Bbre	0	0	0	0	2	0	0	0	0	2
Buni	3	0	0	0	0	1	2	1	6	13
Clep	50	0	0	0	0	0	1	1	0	52
Cspe	33	5	3	5	3	4	5	13	4	75
Cmar	0	1	0	0	1	0	0	0	0	2
Cdis	725	478	243	499	285	306	350	287	223	3396
Caur	2	15	14	3	14	3	5	0	12	68
Csan	3	5	0	0	1	0	3	1	0	13
Dkoh	0	785	80	344	49	24	150	300	0	1732
Gtri	100	1	0	0	0	1	0	1	1	104
Ksyd	0	13	2	0	0	0	3	0	0	18
Msc	6	12	9	7	12	5	8	10	9	78
Meph	1	0	0	0	0	0	0	0	0	1
Ncel	32	5	4	7	9	10	8	16	5	96
Nfuc	13	1	0	1	0	0	5	0	3	23
Opul	4	0	1	1	0	0	2	0	0	8
Palb	3	0	0	0	0	5	10	0	2	20
Pluc	0	0	0	0	0	0	1	0	0	1
Pmil	0	0	0	2	0	0	0	0	0	2
Slin	0	4	31	68	0	61	21	0	0	185
Svio	0	55	2	0	0	0	0	0	0	57
Slal	0	0	1	0	0	0	0	0	0	1
Ulin	110	1	3	4	1	1	1	40	6	167
SUM	1085	1395	393	941	377	421	576	670	271	6129

Appendix 3. Species inventory for animals observed at the Mercury Islands during the trips.

Family	Species Name	Common Name	Māori Name
Marine Mammals			
Balaenopteridae	<i>Balaenoptera brydei</i>	Bryde's whale	
Delphinidae	<i>Delphinus delphis</i>	Common dolphin	Aihe/terehu/kākahi
Otariidae	<i>Arctocephalus forsteri</i>	New Zealand fur seal	Kekeno
Fishes			
Aplodactylidae	<i>Aplodactylus arctidens</i>	Marblefish	Kehe
Arripidae	<i>Arripis trutta</i>	Kahawai	Kahawai
Blennidae	<i>Parablennius laticlavius</i>	Crested blenny	
Carangidae	<i>Decapterus koheru</i>	Koheru	Kōheru
Carangidae	<i>Pseudocaranx georgianus</i>	Trevally	Arāra
Carangidae	<i>Seriola lalandi</i>	Kingfish	Haku
Carangidae	<i>Trachurus novaezelandiae</i>	Jack mackerel	Hauture
Chironemidae	<i>Chironemus marmoratus</i>	Hiwihwi	Hiwihwi
Clinidae	<i>Cristiceps aurantiacus</i>	Crested weedfish	
Congridae	<i>Conger monganius</i>	Northern conger eel	Ngōiro
Dasyatidae	<i>Bathytoshia brevicaudatus</i>	Short-tail stingray	Whai
Diodontidae	<i>Allomycterus pilatus</i>	Porcupinefish	Kōpūtōtara
Girellidae	<i>Girella tricuspidata</i>	Parore	Parora
Gobiesocidae	<i>Dellichthys morelandi</i>	Urchin clingfish	
Gobiidae	<i>Gobiopsis atrata</i>	Black goby	
Kyphosidae	<i>Kyphosus sydneyanus</i>	Silver drummer	
Labridae	<i>Bodianus unimaculatus</i>	Pigfish	Pākurakura
Labridae	<i>Coris sandageri</i>	Sandager's wrasse	
Labridae	<i>Notolabrus celidotus</i>	Spotty	Paketi/Pākirikiri
Labridae	<i>Notolabrus fucicola</i>	Banded wrasse	Tāngahangaha
Labridae	<i>Notolabrus inscriptus</i>	Green wrasse	
Labridae	<i>Odax pullus</i>	Butterfish	Mararī/Kōeaea
Labridae	<i>Pseudolabrus luculentus</i>	Orange wrasse	
Labridae	<i>Pseudolabrus miles</i>	Scarlet wrasse	
Latridae	<i>Cheilodactylus spectabilis</i>	Red Moki	Moki/Nanua
Latridae	<i>Morwong ehipium</i>	Painted moki	
Latridae	<i>Nemadactylus douglasii</i>	Porae	Porae

Latridae	<i>Nemadactylus macropterus</i>	Tarakihi	Tarakihi
Monacanthidae	<i>Meuschenia scaber</i>	Leatherjacket	Kōkiri
Mullidae	<i>Upeneichthys lineatus</i>	Goatfish	Āhuruhuru
Muraenidae	<i>Gymnothorax prasinus</i>	Yellow moray	Pūharakeke
Myliobatidae	<i>Myliobatis tenuicaudatus</i>	Eagle ray	Whai keo
Pempheridae	<i>Pempheris adspersa</i>	Bigeye	
Pinguipedidae	<i>Parapercis colias</i>	Blue cod	Pākirikiri, Rāwaru
Pomacentridae	<i>Chromis dispila</i>	Two-spot demoiselle	
Pomacentridae	<i>Parma alboscapularis</i>	Black angelfish	
Scorpaenidae	<i>Scorpaena papillosa</i>	Dwarf scorpionfish	
Scorpidae	<i>Scorpis lineolata</i>	Sweep	Hui
Scorpidae	<i>Scorpis violacea</i>	Blue maomao	Mao mao
Serranidae	<i>Caesioperca lepidoptera</i>	Butterfly perch	
Sparidae	<i>Chrysophrys auratus</i>	Snapper	Tāmure
Trachichthyidae	<i>Optivus elongatus</i>	Slender roughy	Puramorehu
Tripterygiidae	<i>Bellapiscis lesleyae</i>	Mottled twister	
Tripterygiidae	<i>Bellapiscis medius</i>	Twister	
Tripterygiidae	<i>Cryptichthys joettae</i>	Cryptic triplefin	
Tripterygiidae	<i>Forsterygion flavonigrum</i>	Yellow-black triplefin	
Tripterygiidae	<i>Forsterygion lapillum</i>	Common triplefin	
Tripterygiidae	<i>Forsterygion malcolmi</i>	Banded triplefin	
Tripterygiidae	<i>Forsterygion maryannae</i>	Oblique-swimming triplefin	
Tripterygiidae	<i>Forsterygion varium</i>	Variable triplefin	
Tripterygiidae	<i>Karalepis stewarti</i>	Scaly-headed triplefin	
Tripterygiidae	<i>Notoclinops caerulepunctus</i>	Blue-dot triplefin	
Tripterygiidae	<i>Notoclinops segmentatus</i>	Blue-eyed triplefin	
Tripterygiidae	<i>Notoclinops yaldwyni</i>	Yaldwyn's triplefin	
Tripterygiidae	<i>Ruanoho decemdigitatus</i>	Long-finned triplefin	
Tripterygiidae	<i>Ruanoho whero</i>	Spectacled triplefin	

Tunicates

Didemnidae	<i>Didemnum densum</i>	
Holozoidae	<i>Hypsistezoa fasmeriana</i>	Strawberry ascidian
Polyclinidae	<i>Aplidium</i> sp. (brain)	
Pseudodistomidae	<i>Pseudodistoma novaezelandiae</i>	
Styelidae	<i>Botrylloides leachii</i>	
Styellidae	<i>Cnemidocarpa nisiotis</i>	Saddle sea squirt

Echinoderms			
Asteriidae	<i>Coscinasterias muricata</i>	Eleven-armed starfish	
Diadematoidea	<i>Centrostephanus rodgersii</i>	Long-spined urchin	
Echinometridae	<i>Evechinus chloroticus</i>	Kina	Kina
Ophiidermatidae	<i>Ophiopsammus maculata</i>	Snake brittle star	
Stichopodidae	<i>Australostichopus mollis</i>	Sea cucumber	
Brachiopods			
Terebratellidae	<i>Calloria inconspicua</i>	Red lampshell	Papa kura iti
Bryozoans			
Lepraliellidae	<i>Celleporaria agglutinans</i>		
Steginoperellidae	<i>Steginoporella neozelanica</i>	Stick bryozoan	
Crustaceans			
Paguridae	<i>Pagurus novaezealandiae</i>	Hermit crabs	
Palinuridae	<i>Jasus edwardsii</i>	Red rock lobster	Koura
Palinuridae	<i>Sagmariasus verreauxi</i>	Packhorse lobster	Koura
Plagusidae	<i>Gainusia chabrus</i>	Red rock crab	Pāpaka ura
Annelids			
Serpulidae	<i>Spirobranchus cariniferus</i>	Blue tube worm	
Molluscs			
Acanthochitonidae	<i>Cryptoconchus porosus</i>	Butterfly chiton	
Aplustridae	<i>Hydatina physis</i>	Rose-petal bubble shell	
Aplysiidae	<i>Aplysia argus</i>	Ringed sea hare	
Aplysiidae	<i>Aplysia cf. parvula</i>	Sea hare	
Buccinidae	<i>Buccinum lineata</i>	Lined whelk	Kawari
Buccinidae	<i>Cominella quoyana</i>	Whelk	Kawari
Chromodorididae	<i>Ceratosoma amoenum</i>	Clown nudibranch	
Dendrodorididae	<i>Dendrodoris krusensternii</i>	Gem nudibranch	
Glycymerididae	<i>Tucetona laticostata</i>	Dog cockle	Kua kua/Kuhakuha
Haliotidae	<i>Haliotis iris</i>	Black-footed pāua	Pāua
Ischnochitonidae	<i>Eudoxochiton nobilis</i>	Noble chiton	
Muricidae	<i>Dicathais orbita</i>	White rock shell	
Octopodidae	<i>Octopus tetricus</i>	Common octopus	Wheke
Pectinidae	<i>Pecten novaezealandiae</i>	Common scallop	Kuakua/Tipa
Ranellidae	<i>Charonia lampas</i>	Trumpet shell	Awanui/Pūtatarā
Trochidae	<i>Coelotrochus viridis</i>	Green topshell	
Turbinidae	<i>Astraea heliotropium</i>	Circular saw shell	

Turbinidae	<i>Cookia sulcata</i>	Cook's turban shell	Toitoi/Ngāruru
Vermetidae	<i>Dendropoma</i> sp.	Vermetid snail	
Vermetidae	<i>Thylacodes aotearoicus</i>	Vermetid snail	
Vermetidae	<i>Thylacodes zelandicus</i>	Vermetid snail	
Cnidarians			
Alcyoniidae	<i>Alcyonium aurantiacum</i>	Deadman's fingers	
Corallimorphidea	<i>Corynactis australis</i>	Jewel anemone	
Flabellidae	<i>Monomyces rubrum</i>	Solitary cup coral	
Rhizangiidae	<i>Culicia rubeola</i>	Colonial cup coral	
Sagartiidae	<i>Anthothoe albocincta</i>	Common anemone	
Sertulariidae	<i>Sertularia subarticulatus</i>	Feather hydroid	
Solanderiidae	<i>Solanderia ericopsis</i>	Fan hydroid	
Tubulariidae	<i>Ectopleura crocea</i>	Tubular hydroid	
Sponges			
Ancorinidae	<i>Ecionemia alata</i>	Black pillow sponge	
Ancorinidae	<i>Penares tylotaster</i>		
Ancorinidae	<i>Stelletta sandalinum</i>		
Clionidae	<i>Cliona celata</i>		
Darwinellidae	<i>Darwinella</i> cf. <i>gardineri</i>		
Darwinellidae	<i>Darwinella oxedata</i>		
Darwinellidae	<i>Dendrilla rosea</i>		
Dysideidae	<i>Dysidea</i> sp.		
Guitarridae	<i>Tetrapocillon novaezealandiae</i>		
Halichondriidae	<i>Ciocalypta polymastia</i>		
Hymedesmiidae	<i>Stylopus australis</i>		
Latrunculiidae	<i>Latrunculia procumbens</i>		
Leucaltidae	<i>Leucettusa tubulosa</i>		
Leucosoleniidae	<i>Leucosolenia asconoides</i>		
Myxillidae	<i>Iophon minor</i>		
Polymastiidae	<i>Polymastia</i> cf. <i>massilis</i>		
Polymastiidae	<i>Polymastia hirusta</i>		
Raspailiidae	<i>Raspailia topsenti</i>		
Suberitidae	<i>Aptos tenta</i>		
Tethyidae	<i>Tethya bergquistae</i>	Pink golf-ball sponge	
Tethyidae	<i>Tethya burtoni</i>	Orange golf-ball sponge	
Tethyidae	<i>Tethya complexa</i>	Armoured golf-ball sponge	

Appendix 4. Species inventory for all marine algae recorded during the surveys

Family	Species Name	Common Name
Chlorophyta		
Caulerpaceae	<i>Caulerpa flexilis</i>	Sea rimu
Caulerpaceae	<i>Caulerpa geminata</i>	Sea grapes
Codiaceae	<i>Codium convolutum</i>	
Codiaceae	<i>Codium cranwellae</i>	
Derbesiaceae	<i>Pedobesia claviformis</i>	
Ulvaceae	<i>Ulva</i> sp.	Sea lettuce
Rhodophyta		
Bonnemaisoniaceae	<i>Aparagopsis armata</i>	
Caulacanthaceae	<i>Taylorophycus filiformis</i>	
Champiaceae	<i>Champia langii</i>	
Corallinaceae	<i>Corallina officianalis</i>	Coralline turf
Corallinaceae	<i>Jania</i> spp.	
Corallinaceae	<i>Lithophyllum</i> sp.	
Delesseriaceae	<i>Hymenena</i> sp.	
Gracilariaceae	<i>Curdiea codioides</i>	
Gracilariaceae	<i>Curdea coriacea</i>	
Kallymeniaceae	<i>Kallymenia</i> sp.	
Peyssonneliaceae	<i>Peyssonnelia</i> spp.	
Plocamiaceae	<i>Plocamium</i> spp.	
Pterocladaceae	<i>Pterocladia lucida</i>	Agar weed
Rhodomelaceae	<i>Laurencia distichophylla</i>	
Rhodomelaceae	<i>Vidalia colensoi</i>	
Phaeophyta		
Dictyotaceae	<i>Dictyota kunthii</i>	
Dictyotaceae	<i>Dictyota ocellata</i>	
Dictyotaceae	<i>Distromium skottsbergii</i>	
Dictyotaceae	<i>Zonaria aureomarginata</i>	
Lessoniaceae	<i>Ecklonia radiata</i>	Common kelp
Lessoniaceae	<i>Lessonia variegata</i>	Strap kelp
Sargassaceae	<i>Carphophyllum angustifolium</i>	
Sargassaceae	<i>Carphophyllum maschalocarpum</i>	Flapjack

Sargassaceae	<i>Carphophyllum plumosum</i>	Plumose algae
Sargassaceae	<i>Cystophora retroflexa</i>	
Sargassaceae	<i>Sargassum sinclarii</i>	
Scytosiphonaceae	<i>Colpomenia</i> sp.	
Sporochnaceae	<i>Carpomitra costata</i>	
Stypocaulaceae	<i>Halopteris virgata</i>	
Syringodermataceae	<i>Microzonia velutina</i>	
Xiphophoraceae	<i>Xiphophora chondrophylla</i>	
