Pacific Eco-Logic Ltd

Kelp cover and urchin barrens in the Bay of Islands: A 2016 Baseline

A report prepared for the Bay of Islands Maritime Park Inc.

Fish Forever Working Group

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Abstract

A common cause of tall brown algae (kelp) loss in north-eastern New Zealand has been grazing by the sea urchin kina (*Evechinus chloroticus).* This has resulted in "urchin barrens" dominated by algal turfs and felts, and coralline paints. This has mainly occurred in the 3-10m depth range although these barrens can extend deeper on exposed open coasts, and can be shallower in more sheltered sites, especially where suitable substrate is limited. A second large urchin species *Centrostephanus rodgersii* arrived from east Australia via the East Auckland current in the 1960's. Its role in the creation and maintenance of urchin barrens in New Zealand is unclear.

Kelp has recovered over time in northern marine reserves once populations of the predators of kina have recovered sufficiently to significantly reduce kina numbers. While community groups have sought to establish marine protected areas in the outer Bay of Islands, there is currently no protection for the main predators of kina, except for the last 6 years of rahui in Maunganui Bay. The purpose of this project was to assess the current extent and condition of the kelp habitats and urchin barrens in the outer Bay of Islands, especially the eastern Bay of Islands.

We collected a broad range of biological cover and physical data for 561 quadrats located in the shallows and spread over 13 sectors in the outer Bay of Islands. Eleven of these analysis units were in the eastern Bay of Islands, one was at Tapeka and one was at Black Rocks in the western Bay of Islands. The benthic cover at Tapeka, and especially the Black Rocks units was found to be distinctively different to that found in the eastern Bay of Islands. The highest percent cover for urchin barrens was found in these two areas although the characteristics of each area were very different. Different elements (compared to eastern Bay of Islands' sites) included more red algae, more encrusting fauna, and more algal turfs. Maunganui Bay was also different to the other areas assessed with more *Centrostephanus*, more *Ecklonia* (versus other kelp species), and more algal felts.

There were significant differences in the percent cover for all kelps (excluding juveniles). Tapeka and Black Rocks were significantly different to each other and to the eastern Bay of Islands units. Outer Motuarohia was significantly different to the Southern Brett Peninsula and Outer Urupukapuka Island). The third highest proportion of urchin barrens was found in the Oke Bay- Opourua Bay- unit. Outer Motukiekie-Moturua Islands had the fourth highest urchin barren cover. A Spearman rank test found a significant positive relationship between the amount of space occupied by kina during the day (as represented by % kina cover) and the percent urchin barren. This is unsurprising but does show that the barrens are likely being maintained by kina (which move around and feed at night). There was no relationship between the relatively uncommon *Centrostephanus* % cover and the extent of urchin barrens in shallow waters.

Tapeka had the highest proportion of urchin barren in the quadrats. At 80%, with 72% being typical urchin barrens, this area was shown in various statistical tests to have a benthic cover that was significantly different biologically to that found in the main eastern analysis units . The next highest recorded proportion of urchin barrens was for Black Rocks in the western Bay of Islands. In contrast to Tapeka, and all the main eastern units, most of these barrens were non-typical. Other factors could have affected the observations for Black Rocks including columnar basalt geology, an average quadrat slope of 74 degrees and intensive mussel harvest.

The third highest proportion of urchin barrens was found in the Oke Bay- Opourua Bay 54% of the quadrats with more than two thirds being typical urchin barrens.   Outer Motukiekie-Moturua Islands had the fourth highest urchin barren cover.

The highest percent cover for tall brown algae was found for the Motuwheteke Island-Whapukapirau Bay (Brett Peninsula) (48.4% +/- 4.7). Three other units were very similar: Cape Brett –Ohututea Bay, Maunganui Bay; and Outer Urupukapuka Island. The “sheltered water reefs” inside Waewaetorea and Ohaku Islands had a similar mean, but with a very high level of variability reflecting the patchiness of the remaining kelpp. The lowest kelp percent cover was 12% for Tapeka, followed by 21.2% for Black Rocks. In the eastern Bay of Islands the lowest percent cover for tall brown algae was 38.7% for Oke Bay-Opourua Bay although this unit was also highly variable.

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Contents

Introduction

The Fish Forever working group of Bay of Islands Maritime Park Incorporated has been assembling information about the marine environments of the Bay of Islands for the last few years. Purposes for this include:

- Improving the state of knowledge about the marine environments of the Bay of Islands, including their values, threats to those values and actions that could improve the state of those marine environments;
- Collecting information that could be used in a marine protected areas application and/or a marine protected areas forum process
- Gathering information that could be used to assist and encourage management agencies to undertake appropriate actions and develop appropriate policies to better protect the marine environments of the marine environment
- Informing the community about the values, threats and remedial actions that could be undertaken to improve the state of marine environments in the Bay of Islands

This report provides information about algal cover and urchin barrens in the marine environments of the eastern Bay of Islands plus the Black Rocks area. It began with a 2015 request by Dr John Booth for a review of his draft manuscript about long-term changes in the marine environments of the Bay of Islands. As part of that review we observed that his time-sequenced aerial photo interpretation of areas missing shallow kelp forest did not always correspond with our extensive snorkelling and diving experience in the Bay. There were also a number of locations where slope or shadows on current day aerial imagery precluded any remote assessment of current day condition. We offered to provide a more detailed in-water assessment of the current state of urchin barrens and shallow algae cover focusing on the outer Bay of Islands.

The loss of kelp forest has been observed in many locations e.g. Araujo et al. (2016), Connell et al. (2008); Roberts (2007). There can be a number of stressors leading to this outcome. Causes can include increased water temperatures, reduced water clarity, storms, sea urchin grazing, and commercial kelp harvest. A common cause is sea urchin grazing. The correlation between (often extensive) shallow rocky reef without kelp cover, and high densities of sea urchins, has been established in various temperate locations (e.g. Reisewitz et al. (2005) McLean (1962)).

The primary purpose of this project was to assess the extent and condition of the kelp cover and sea urchin barrens in the 3-10m depth range for the outer Bay of Islands; especially those steep reefs of the outer coasts that had not been assessed remotely by John Booth. A secondary purpose was to establish a quantitative baseline that can be used to monitor future change, including those resulting from marine reserves or other management changes.

As previously discussed, a variety of drivers can lead to the loss of macro-algae beds (Araujo et al., 2016). A common reason is sea urchin grazing. Sea urchin barrens have been found to have significantly fewer taxa than the macro-algal beds they replaced (Ling, 2008). It has also been shown that if the numbers and size of the natural predators of sea urchins are able to increase sufficiently then the kelp forest is eventually able to return (Shears and Babcock, 2003). In New Zealand the expansion of kelp beds and the loss of sea urchin barrens have been observed in long-term no-take marine reserves at Leigh (Shears and Babcock, 2003) and Tawharanui (Roger Grace, pers. comm.).

These phenomena are often referred to as trophic cascades where one change leads to a series of consequential environmental changes.

The species primarily responsible for New Zealand sea urchin barrens is the common native sea urchin or kina (*Evechinus chloroticus*). The underlying driver for the loss of shallow kelp beds and the associated expansion of sea urchin barrens is typically considered to have resulted from reductions in the number and size of sea urchin predators. Without the predation pressure the numbers and sizes of sea urchins increase. In northern New Zealand the predators of kina are primarily larger snapper (*Pagrus auratus*) and red rock lobster (*Jasus edwardsii*) (Babcock et al., 1999; Shears & Babcock 2002).

A second prominent urchin species, *Centrostephanus rodgersii,* arrived from eastern Australia relatively recently via the East Auckland current. The first published New Zealand record is in Morton and Miller (1968) who refer to increasing numbers being found by divers in shallow waters in northern New Zealand. Pecorino et al (2012) refer to a 1967 pers. comm. record for *Centrostephanus* being found in the waters around the Poor Knights Island in 1967. The spread of *Centrostephanus* from the New South Wales and Victorian coast in Australia, both to and around Tasmania and north-east New Zealand, has been attributed to deeper penetration southwards and eastwards of the East Australian Current (Ling et al 2009). *Centrostephanus* is a strong grazer that is known to overgraze macroalgal beds and maintain alternative and stable barrens habitats (e.g. Ling et al 2009). Its role in the creation and maintenance of urchin barrens in New Zealand is currently unclear. This is addressed further in the discussion section of this report.

Methodology

Field methods

A review of existing field methods found that none would be entirely suitable for this project because we needed to cover a long length of coastline in a short time, and collect sufficient replicates to allow us to undertake meaningful analyses. We also wanted to avoid using scuba with its logistical complications (including being unable to accurately determine position underwater), limitations on bottom (i.e. assessment) time and requirements for additional people to be involved in the field work. Instead we modified existing methodologies based on visual assessments of percent cover for different types of cover.

The core of the methodology was a 5m x 5m quadrat in which the percentage of different cover classes was assessed. The cover class assessment was made by a snorkeler supported by a skilled boat operator who recorded the data called out by the snorkeler as well as a variety of other data such as the GPS position. Typically this required up to four or five free dives to check detail such as species present in different sectors of the quadrat. Table 1 contains a description of each of the 19 cover classes assessed. This included various species of tall brown algae, red algae, juvenile tall brown algae, algal turfs, algal felts, encrusting sponges and anemones, coralline paints and substrate without biotic cover. No quadrat included all cover classes and some cover classes were only used occasionally. Also collected was the percent cover and median size of each of the sea urchins- kina and *Centrostephanus*. This is not the standard method for collecting data on these species but was consistent with the percent cover methodology used in this project. It was not practical to collect relative abundance data by the standard approaches based on counting individuals given that all assessments were done by snorkelling. In addition the focus of this study was seabed cover not the numbers of urchins in quadrats.

Also assessed were the extent (as percent cover) of typical and atypical urchin barrens. Table 2 explains the difference between the two types of kina barrens which were distinguished in the field based on cover types and patterns.

Table 3 describes the other data recorded for each quadrat. This included: location and site condition data, median slope and the slope range (in degrees), the representativeness class, exposure class and analysis unit (the 13 units are listed in Table 4). The purpose of the analysis units was to group nearby areas with generally similar exposure and geomorphology, so as to facilitate comparisons between different parts of the Bay of Islands. Map 1 shows the boundaries of the analysis units.

Quadrats were assessed at approximately 50metre intervals along the shore. The purpose of the assessment was to quantitatively determine cover types in the shallow water depth zone where kina barrens are most commonly found (3-10metres). Quadrats were only assessed where there was appropriate substrate and conditions. In terms of the latter, more turbid areas associated with active erosion or areas associated with unusual features affecting cover were not included. The boat operator determined the general location of each quadrat with the snorkeler fine-tuning the specific location to include appropriate substrate. The snorkeler swam along the shallows between quadrats to assess the representativeness of each quadrat and to identify other trends such as extensive kina barrens.

The precise position and depth at each GPS point was as close to the quadrat position as was practical given that onshore swells on steep rocky coasts could be unpredictable. Caution was needed to prevent damaging the inflatable boat, the outboard motor mounted on the transom with the chart plotter-depth sounder, and the boat’s oars.

Table 1: Cover classes assessed for each quadrat

Cover class category	Cover class	Description and notes
Tall brown algae cover	*Ecklonia radiata*	
	Carpophyllum spp	
	Lessonia	Found in more exposed sites
	Cystophora spp	
	Other tall browns	e.g. *Landsburgia*
	Juvenile tall brown algae species	These juveniles are typically dominated by the genus *Carpophyllum* but can include other genera
Low brown algae	Low brown algae species	This is primarily Microzonia once it is taller than a turf (5cm)

Cover class category	**Cover class**	**Description and notes**
Red algae	*Pterocladia lucida* and *Pterocladiella capillacea*	*Pterocladia lucida* and *Pterocladiella capillacea* are two of the most common non-coralline red algae found in the shallows of the Bay of Islands
	Other red algae species	Examples include *Methanthalia*
Turfs	Turfs including corallines and brown algae	This primarily consists of non-encrusting coralline algae or the low brown algae species *Microzonia* less than 5cm in height. In some sites on the Brett Peninsula the turf was taller than 5cm and was recorded as “tall turf”.
Algal felts		Filamentous brown algae often found in more sheltered sites. Typically a microscope is needed to confirm species identity. To the casual observer algal felts look like slime
Encrusting	Encrusting sponges and anemones	Encrusting sponges and anemones are typically found on walls and in darker locations such as caves and arches. Sponges are also found in deeper lower-light sites below the kelp forest. Sponges and anemones are present in lesser amounts in more open rocky reefs often in microsites where there is less light or maybe they initially developed under kelp forest.
Coralline paints		These include pink and purple encrusting coralline algae species, and red crusting algae
Mussel communities		This cover class is very limited in its extent and typically includes other attached encrusting fauna
Bare rock		This is abraded subtidal rock without biological cover. In practice very little shallow subtidal rock is bare
Cobbles		Where rocky reefs are patchy a small area of cobbles may be included in a corner of the quadrat.
Sand		In most cases this is sand washed up onto rock. Occasionally where reefs are patchy a small area of sand may be included in a corner of the quadrat
Kina		% cover and median size class (S, M,L)
Centrostephanus		% cover and median size class (S, M,L)

Table 2: Types of urchin barrens in the study area

Type of urchin barrens	Description
Typical urchin barrens	This is based on cover categories and the pattern of those categories. Included are turfs (especially low turfs), algal felts, coralline paints and space occupied by urchins. Excluded are all tall brown algae including juveniles. Also excluded are red, other brown and green algae except where they form low turfs or algal felts. Patches of sand and small cobbles are excluded as they are generally unsuitable substrates for macro-algae. Mussel-communities and extensive areas of encrusting sponge and anemone growth on walls are excluded as are areas of abraded bare rock. The latter is rare in subtidal environments.
Non-typical or atypical urchin barrens/ urchin modified habitat	This is based on cover categories and the pattern of those categories. Non-typical urchin barrens/ modified habitats are relatively common on more exposed open coast rocky reefs. They can be distinguished from classical urchin barrens in that their appearance resembles thinning hair. Patchy tall brown algae are scattered through the low stature cover classes typically found in urchin barrens. Tall turfs (taller than 5cm) can also be present and complicate assessments of what is an urchin barren. These ecological communities can still have a moderate level of cover and so it may be more appropriate to call them urchin modified habitats This category was determined part way through the survey work and so it has not been fully applied to the early assessments.

Typical urchin barren

Typical urchin barren

Non-typical urchin barren (thinning) 1

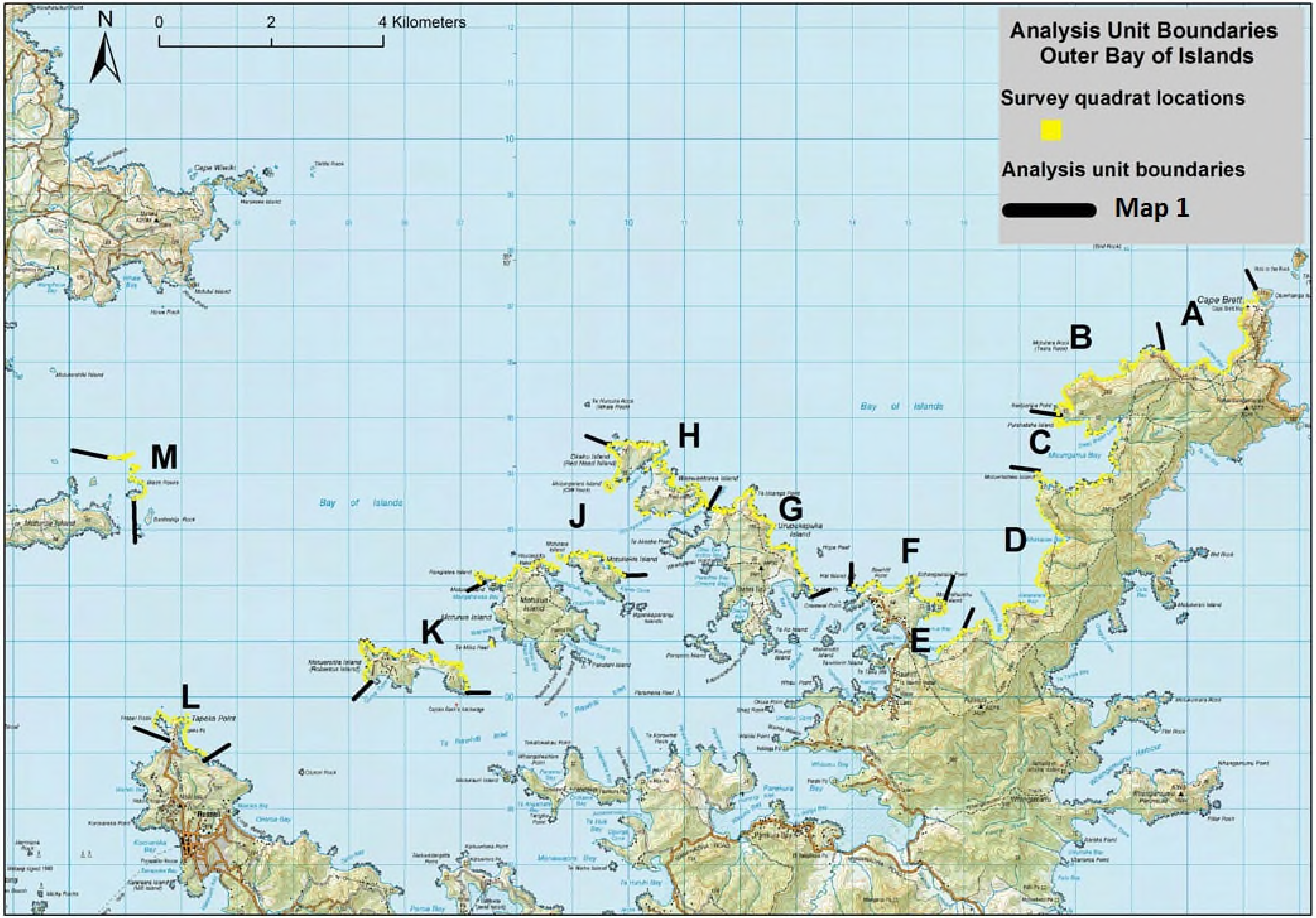
Non-typical urchin barren (thinning) 2

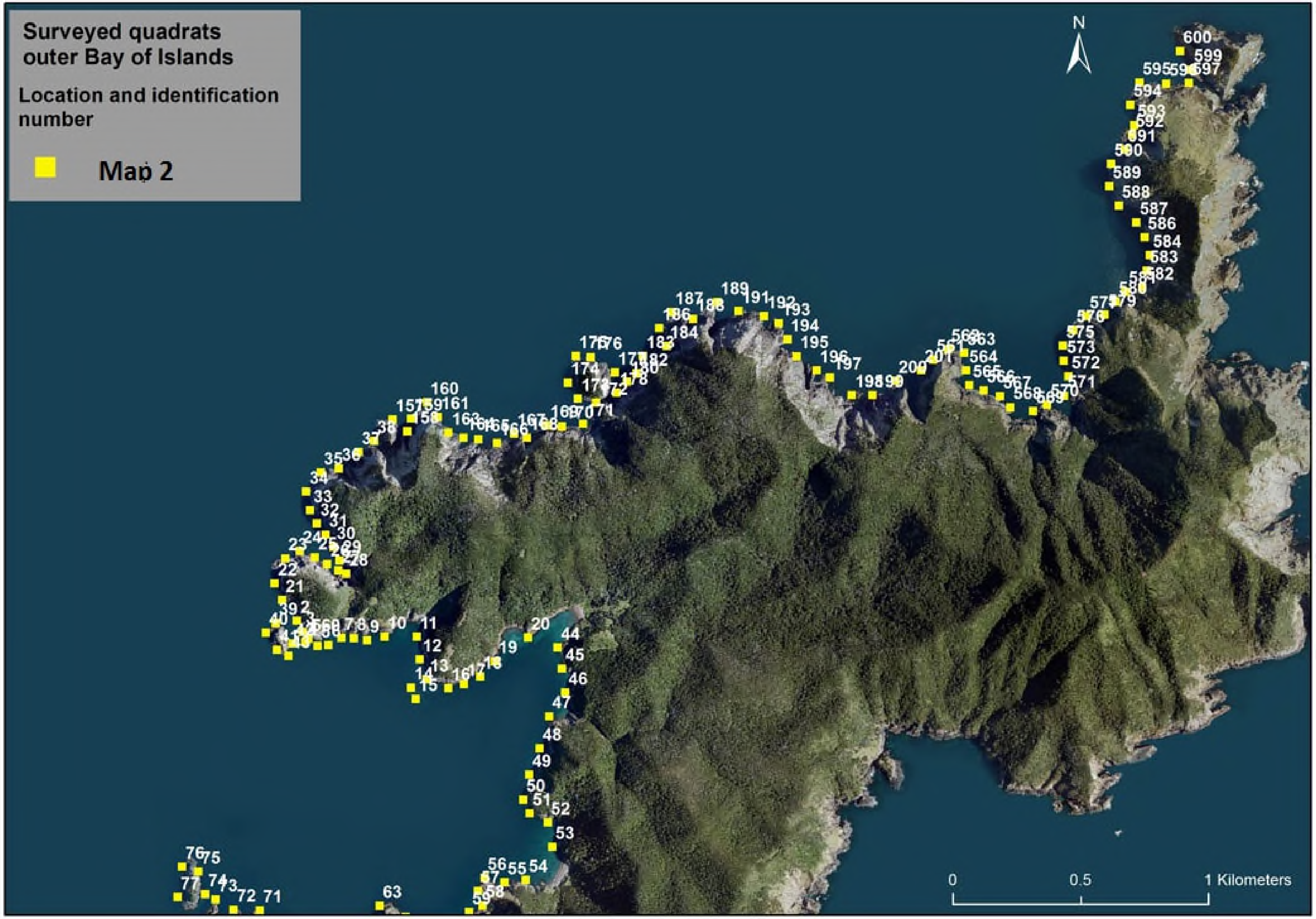
Table 3: Other data collected at each quadrat point

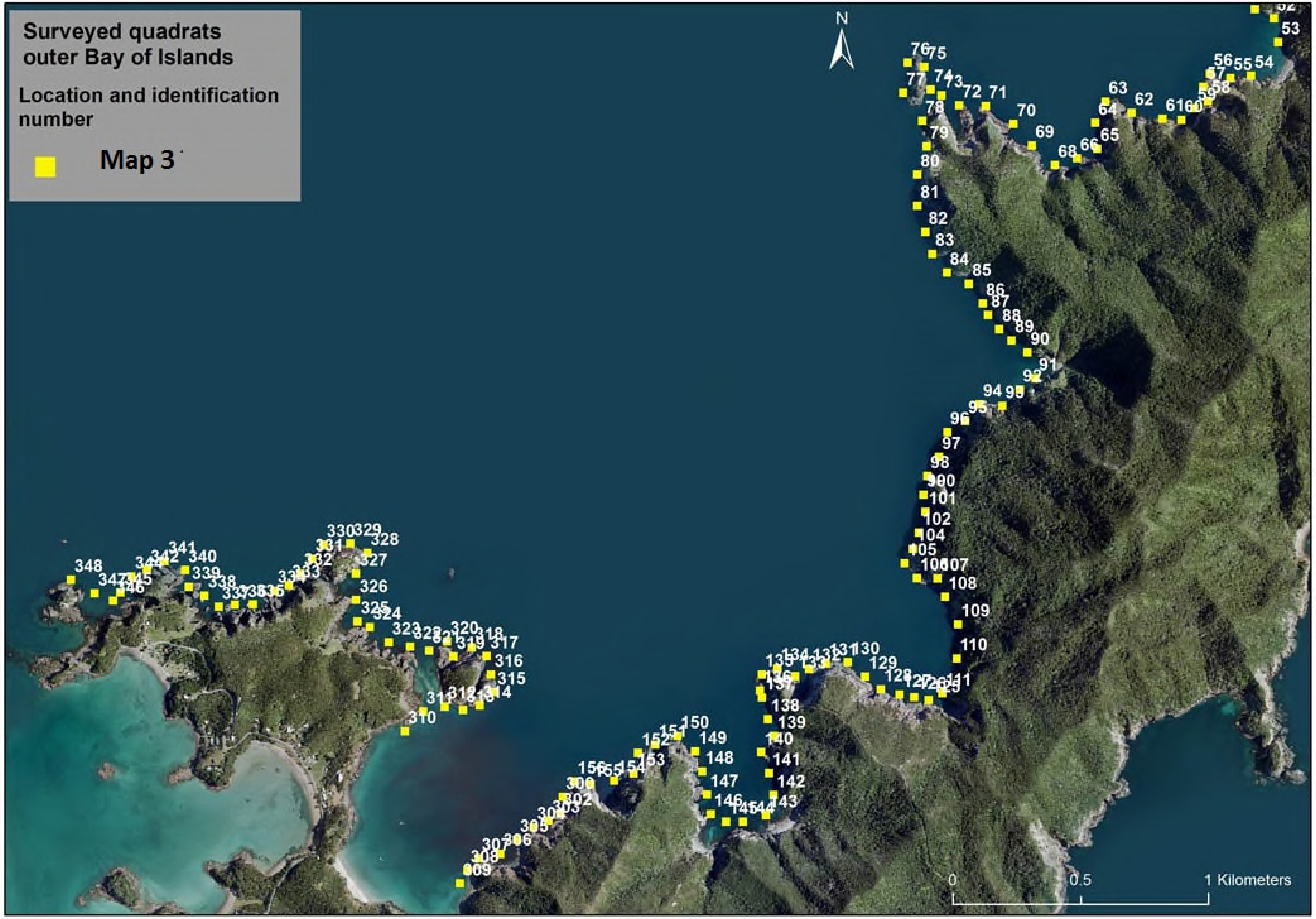
Data item	Notes
Quadrat number	As assigned sequentially by the GPS chartplotter
Locality	Broad locality name
GPS	Eastings & northings using WG84 datum (with decimal minutes rather than seconds)
Depth at GPS point	Depth at the GPS position was recording
Date	Date of assessment
Time	Start time for quadrat assessment
Depth range	For the assessed quadrat at the time of assessment
High tide time	Nearest high tide
Exposure class	This is for the quadrat overall (3 classes: sheltered, partly exposed and exposed)
Analysis unit	Sites from a similar locality and average exposure class are grouped into analysis units or sectors. Thirteen analysis units were used for this project. Table 4 lists the analysis units and Map 1 shows the boundaries of these units
Substrate (and basic geomorphology)	This is the primary substrate and geomorphology and primarily includes: rock wall (if >55 degrees slope), rock slope(s), rock flat, rock platform and boulders.
Other geomorphology	This is an optional column that can be used to record additional geomorphology information if required. It can include substrate that is present in low levels (e.g. boulders, broken rock, sand or cobbles). This is most likely where the rock reefs are patchy in a matrix of sand or cobbles. Sometimes the orientation of a wall is included where it is not obvious.
Visibility	Underwater visibility rounded to the nearest metre
Wind	Direction and speed in knots at the quadrat site at time of assessment
Swell	Swell size at the quadrat site at the time of assessment
Median slope	Of the quadrat overall (in degrees)
Slope range	Of the quadrat overall (in degrees)
Representativeness	This indicates how representative the quadrat cover is compared to that found in nearby areas with a similar substrate and at a similar depth (3 classes-typical (T), moderately representative (M) and not-typical (N). In practice the "N" class was rarely used as we tried to avoid non-typical sites.
Notes	Observations included unusual or notable fish seen, characteristics of the encrusting cover, and observations about the cover seen between quadrats. The latter focused on the extent of kina barrens.

Table 4: Analysis units used in this project

Group	Geographical area or sector
A	Cape Brett- Pig Gully/Ohututea Bay
B	Pig Gully-Maunganui Bay/Kariparipa Point
C	Maunganui Bay
D	Motuwheteke Island-Whapukapirau Bay
E	Oke Bay-Opourua Bay-Moturahurahu
F	Moturahurahu Island- Albert Channel
G	Urupukapuka Outer-Waewaetorea Passage
H	Outer Waewaetorea & Okahu Islands
I	Sheltered Waewaetorea & Okahu
J	Outer Motukiekie-Moturua Islands
K	Outer Motuarohia
L	Outer Tapeka
M	Black Rocks


Analysis Unit Boundaries
Outer Bay of Islands
Survey quadrat locations
Analysis unit boundaries
Map 1
N
0
2
4 Kilometers
A
B
C
D
E
F
G
H
J
K
L
M
Bay of Islands
Cape Brett


Surveyed quadrats
outer Bay of Islands
Location and identification number
Map 2
N
0
0.5
1 Kilometers


Surveyed quadrats
outer Bay of Islands
Location and identification number
Map 3
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0.5
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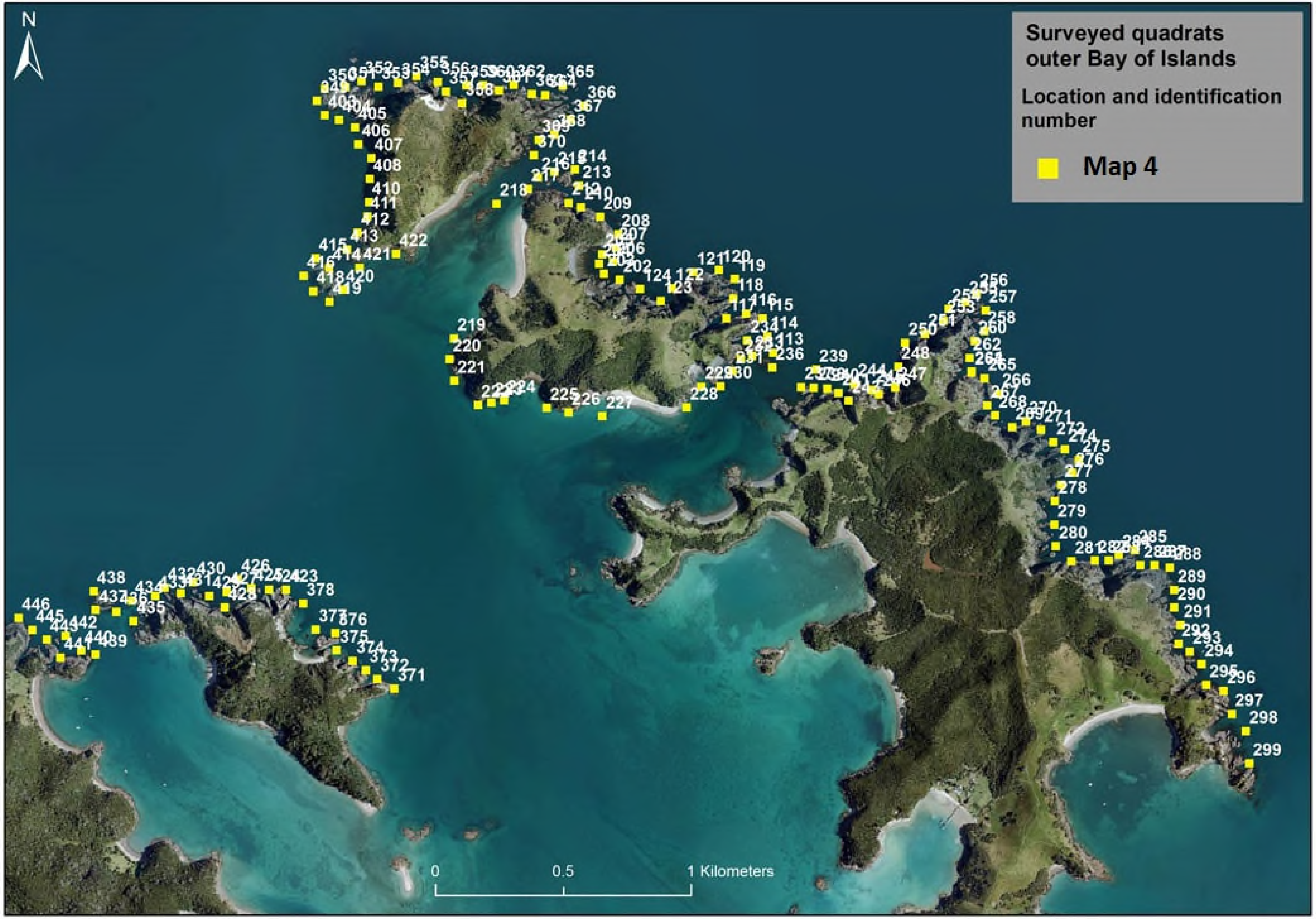
N
Surveyed quadrats
outer Bay of Islands
Location and identification number
Map 4
0
0.5
1 Kilometers

Surveyed quadrats
outer Bay of Islands
Location and identification number
Map 5
N
382
381
383
384
386
390
380
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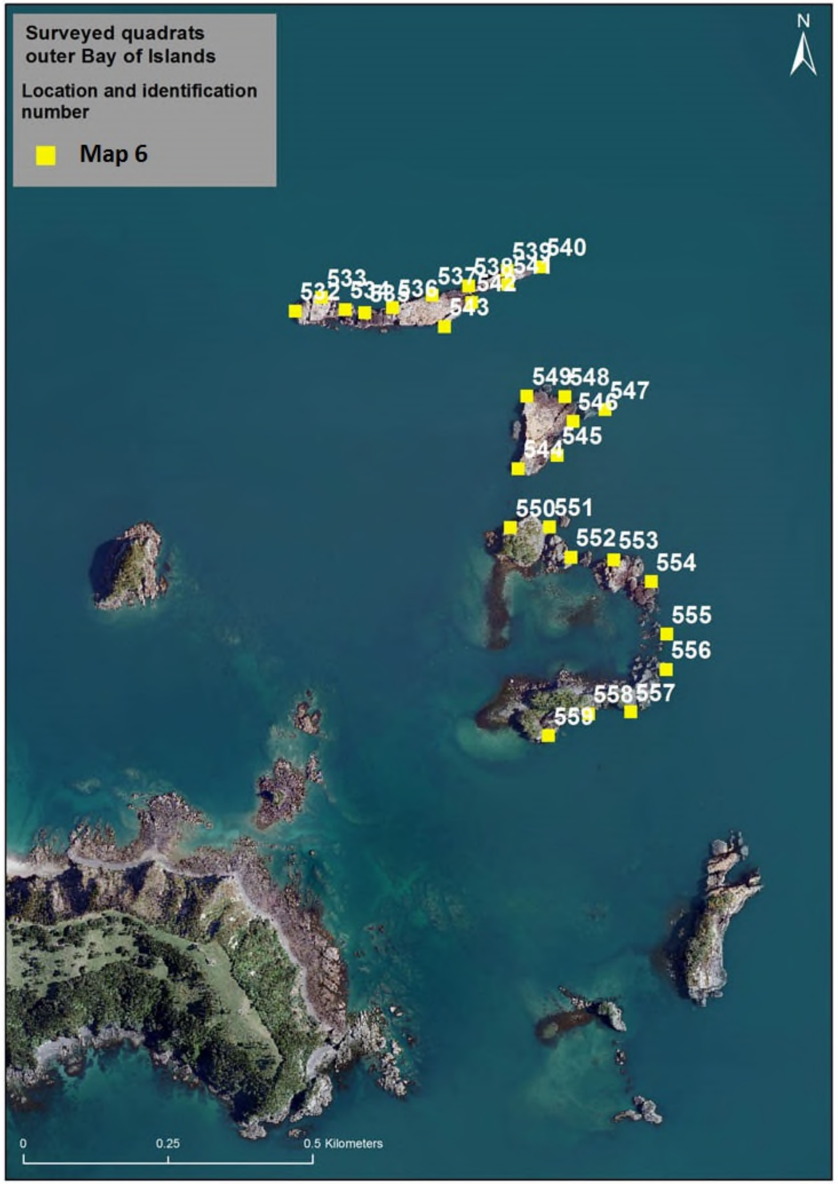
401
402
0
0.5
1 Kilometers


Surveyed quadrats
outer Bay of Islands
Location and identification number
Map 6
N
533
536
537
540
543
549
548
547
545
550
551
552
553
554
555
556
558
557
0
0.25
0.5 Kilometers

Field work was delayed until well into autumn because persistent easterly swells and winds made the exposed shores we were assessing too difficult to survey safely, effectively and accurately. We completed as much fieldwork as possible by early June. By this time we had data for561 quadrats along mostly exposed Bay of Islands' shorelines. The vast majority of quadrats were in the eastern Bay of Islands. This included all the shoreline from Cape Brett to the Albert Channel; the exposed shore of Urupukapuka Island, the entire shoreline of Waewaetorea and Okahu Islands, the relatively exposed shorelines for Motukiekie and Moturua Islands, all except the southern shore of Motuarohia (Roberton), and the Tapeka area. In the western Bay of Islands we were only able to complete quadrats for part of the Black Rocks-Battleship Rock marine area. Other locations in the western Bay of Islands were assessed in the context of special marine areas and features.

It was not possible to measure cover for as many quadrats as we would have liked around the Black and Battleship Rocks because an increasing northerly wind made conditions too rough to accurately assess subtidal percent cover. In addition, the assessment work from western Tapeka Beach to Long Beach had to be halted before we reached Long Beach for safety reasons, because the fuel line to the motor was leaking.

Analysis methodology

The data from the field survey was entered into a large Excel spreadsheet. Percent cover was entered by cover category along with environmental context data and any general observations. Checks were built into the spreadsheet to ensure that cover totalled (and did not exceed) 100% for each quadrat. Urchin barrens were not part of this 100% as they were separately determined in the field using cover class type and pattern.

Cover-type means and the associated 95% confidence intervals were calculated for each of the analysis units listed in Table 4 (boundaries are shown in Map 1). Means and 95% confidence intervals were also calculated for typical and atypical urchin barrens (definitions are in Table 2 in Field Methods) and the combined tall brown algae species for each analysis unit.

Additional statistical analyses of the benthic cover data were undertaken by Olivier Ball of NorthTec in Whangarei. The methods and results from these analyses are in Appendix 1. The results from these and other analyses are discussed in later sections of this report.

Results and analysis

Maps 2-5 show the location of each of the 561 surveyed quadrats. Table 1 in Appendix 2 contains a descriptive summary of the attributes of each of the surveyed areas. This is arranged by locality and survey date/time. Where appropriate, these descriptions include comments about the shallow areas between the quadrats.

In the following Analysis section Tables 5-17 contain the means and 95% confidence intervals for each cover class for each of the 13 analysis units shown in Map 1 and listed in Table 4. To reduce table complexity, those cover classes that do not apply or are present in low amounts in only one or two quadrats in an analysis unit, have not been included in the relevant table(s).

Figures 1-13 show the average percent covers for each of the 13 analysis units: mature tall brown algae (all species); juvenile tall brown algae; typical and non-typical urchin barrens; others (either other biotic cover such as encrusting organisms or bare substrate). This graph also shows the combined percent cover for all urchin barrens. Tables 18-30 accompany figures 1-13. They contain the numerical data – specifically the means and 95% confidence intervals.

The extent of urchin barrens was estimated in the field based on the extent of certain cover classes particularly algal turfs, algal felts, coralline paints, kina and *Centrostephanus.* Brown algae and non-coralline red algal cover were excluded from the estimates of urchin barren percent cover. Encrusting fauna (primarily sponges and anemones) were generally excluded from kina barren calculations, especially in steeper and/or darker locations. Subtidal substrate without biotic cover was uncommon except in more sheltered sites where the extent of rock reef was limited. In these cases a number of the quadrats included a small area of sand or cobbles. Subtidal bare rock was rare and usually the result of abrasion. These bare surfaces were not included in the estimations of urchin barrens as neither bare sand nor cobbles form kelp habitat. The percent covers for the algae, urchin barrens and others do not always add to exactly 100% cover. This is because the field quadrat estimates of urchin barren extent were rounded up or down, while the cover estimates for particular cover types were assessed/ calculated to give a total of exactly 100%.

Analysis unit cover pattern tables: Tables 5-17

Table 5: Percent cover by category for Analysis Unit A: Cape Brett-Pig Gully/Ohututea Bay (34 Quadrats)

Cover type	Tall browns total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anemones	Coralline paints	kina	Centrostephenus
Mean	45.86	18.89	24.03	2.57	0.37	9.78	1.77	22.71	0.49	4.00	16.23	3.51	0.11
95% confidence interval	8.25	7.73	6.82	3.01	0.42	2.31	1.06	4.02	0.67	1.16	3.70	0.96	0.11

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 6: Percent cover by category for Analysis Unit B: Pig Gully/Ohututea Bay-Maunganui Bay (58 quadrats)

Cover type	Tall browns total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Other low browns except turfs	Pterocladia lucida & capsularis	Other reds & greens	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Mean	42.90	19.93	22.80	0.00	0.17	5.91	0.17	2.41	0.08	19.81	0.34	2.93	19.42	2.66	3.22	0.10
95% confidence intervals	5.94	5.36	4.57		0.23	2.19	0.23	1.04	0.17	3.72	0.47	1.06	5.31	2.85	0.68	0.08

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 7: Percent cover by category for Analysis Unit C: Maunganui Bay (54 quadrats)

Cover type	Tall brown algae* total	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Other low browns except turfs	Other reds & greens	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	46.25	35.49	10.60		0.18	1.04	0.84	0.36	16.47	12.75	0.36	12.33	6.84	1.84	0.93
95% CI	6.17	6.70	3.54		0.20	0.87	0.98	0.72	3.49	5.47	0.34	2.75	2.85	0.68	0.51

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 8: Percent cover by category for Analysis Unit D: Motuwheteke Island- Whapukapuka Bay (64 quadrats)

Cover type	Tall brown algae*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Mussels	Bare substrate	kina %	Centrostephenus %
Average	48.42	29.85	18.59		0.55	3.72	1.12	22.45	6.09	1.20	12.79	0.26	1.62	2.22	0.29
95% confidence intervals	4.65	5.16	3.48		0.45	1.23	0.63	4.09	2.55	0.55	1.73	0.34	0.83	0.53	0.24

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 9: Percent cover by category for Analysis Unit E: Oke Bay – Opourua Bay- Moturahurahu (16 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	38.71	24.88	12.06	0.00	1.76	1.53	0.31	29.65	1.29	1.06	18.82	5.29	2.94	0.12
95% CI	8.97	9.88	6.59		1.72	1.27	0.61	8.55	2.62	1.47	5.09	3.06	0.84	0.16

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 10: Percent cover by category for Analysis Unit F: Moturahurahu- Albert Channel (29 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Other low browns except turfs	Pterocladia lucida & capsularis	Other reds & greens	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	42.03	14.47	27.25	0.00	2.21	4.43	2.30	2.20	0.67	25.80	2.17	0.83	15.77	0.43	3.20	0.13
95% CI	9.20	4.98	6.97		1.32	1.38	1.87	1.08	0.79	7.11	2.27	0.68	2.89	0.49	0.95	0.13

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 11: Percent cover by category for Analysis Unit G: Urupukapuka Island outer- Waewaetorea Passage (55 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Other low browns except turfs	Pterocladia lucida & capsularis	Other reds & greens	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	47.79	19.43	26.82	1.07	0.46	2.30	0.09	4.68	16.85	1.43	5.11	19.06	1.32	3.29	0.04	47.79
95% CI	5.10	4.25	3.94	1.51	0.36	1.09	0.18	1.78	3.34	0.94	1.29	3.16	0.95	0.98	0.05	5.10

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 12: Percent cover by category for Analysis Unit H: Outer Waewaetorea and Okahu Islands (48 quadrats)

Cover type*	Tall brown algae total	Ecklonia	Carpophyllum	Lessonia	Cystophora	Other	Juvenile tall browns	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	44.86	16.51	20.67	6.35	1.10	0.26	4.06	6.02	22.96	1.43	3.04	13.55	1.14	2.84	0.10
95% CI	4.96	4.27	4.81	2.97	0.76	0.50	1.55	2.11	3.87	1.19	0.94	2.40	0.94	0.73	0.13

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 13: Percent cover by category for Analysis Unit I: Sheltered Waewaetorea Island and Okahu Island (35 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	46.08	29.28	15.92	0.00	0.89	1.89	0.50	22.00	6.14	1.69	13.53	5.06	3.03	0.14
95% CI	15.27	8.96	5.29		0.84	0.90	0.41	5.01	3.67	1.00	2.70	1.83	0.88	0.18

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 14: Percent cover by category for Analysis Unit J: Outer Motukiekie-outer Moturua (39 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Other low browns except turfs	Pterocladia lucida & capsularis	Other reds & greens	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	40.30	23.67	14.13	0.00	2.50	6.94	0.19	1.26	0.20	27.13	1.20	4.72	13.72	1.48	2.98	0.00
95% CI	6.21	5.79	3.59		1.53	2.00	0.43	0.72	0.30	5.27	1.52	1.64	1.85	0.94	0.62	0.00

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 15: Percent cover by category for Analysis Unit K: Outer Motuarohia (53 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Other	Juvenile tall browns	Other low browns except turfs	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	41.57	24.17	11.38	2.64	3.28	0.09	6.06	1.51	5.74	22.19	0.34	4.49	13.34	2.02	2.75	0.00
95% CI	5.82	5.06	3.16	2.19	1.45	0.19	1.68	0.91	3.10	4.29	0.66	1.01	2.11	1.18	0.64	

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Table 16: Percent cover by category for Analysis Unit L: Tapeka (23 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Pterocladia lucida & capsularis	Other reds & greens	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Bare substrate	kina %	Centrostephenus %
Average	11.96	8.83	2.17	0.00	0.96	1.67	4.13	0.17	43.96	5.83	3.25	19.88	3.83	5.33	0.00
95% CI	4.31	3.40	0.92		0.90	1.04	2.38	0.34	5.23	4.12	1.67	4.08	1.85	1.21	

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

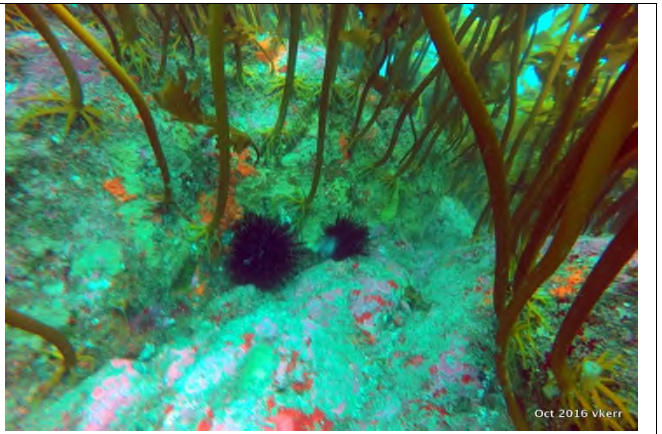
Table 17: Percent cover by category for Analysis Unit M: Black Rocks and Battleship Rocks (27 quadrats)

Cover type	Tall brown algae total*	Ecklonia	Carpophyllum	Lessonia	Cystophora	Juvenile tall browns	Other low browns except turfs	Pterocladia lucida & capsularis	Turfs incl corallines and browns	Algal felts	Encrusting sponges & anenomies	Coralline paints	Mussels	Bare substrate	kina %	Centrostephenus %
Average	21.21	18.57	2.43	0.30	0.18	2.54	0.21	10.70	37.43	3.04	19.79	1.25	3.89	0.00	0.07	0.00
95% CI	3.71	4.10	1.41	0.41	0.18	1.26	0.30	4.71	4.99	2.32	5.59	1.59	2.53		0.10	

*Tall browns include: Ecklonia, Carpophyllum, Lessonia and Cystophora which are also analysed separately

Dense Carpophyllum kelp

Dense Ecklonia kelp 1



Centrostephanus urchins under Ecklonia 1

Tall brown algae and urchin barrens cover: Tables 18-30, figures 1-13 and commentary

Figure 1: Percent cover by category for Analysis Unit A: Cape Brett-Pig Gully/Ohututea Bay

(34 Quadrats)

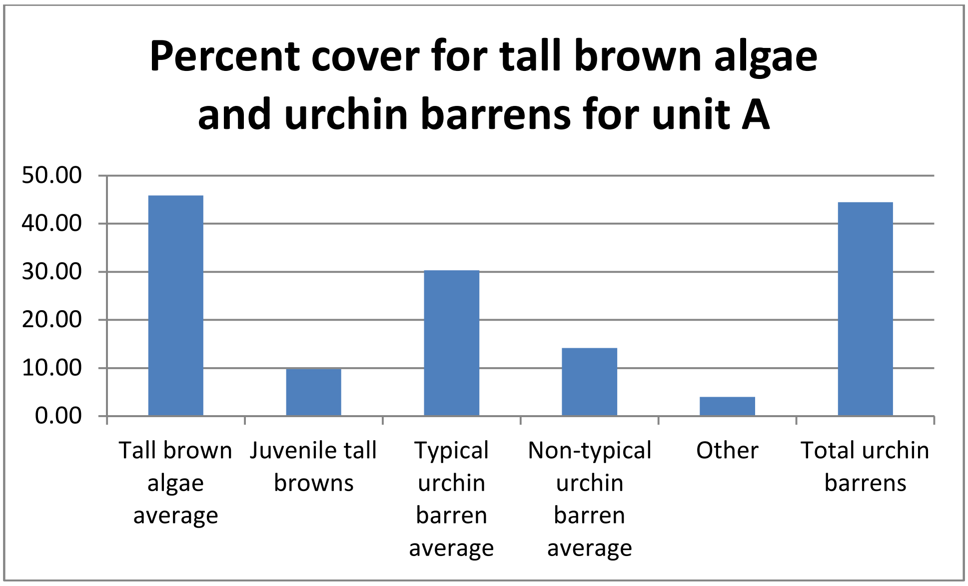


Table 18: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit A

Cover type	Tall brown algae	Juvenile tall browns	Typical urchin barren	Non-typical urchin barren	Other	Total urchin barrens
average	45.86	9.78	30.29	14.17	4	44.46
95% CI	8.25	2.31	10.45	4.36		

This section of coast contained relatively extensive urchin barrens, totalling 44.5% of the quadrat area. Some areas of urchin barrens were continuous between two quadrats. Typically the urchin barrens were deeper than other surveyed locations in the Bay of Islands. They extended from 4-5m to more than 10m in depth. There were patches of heavily thinning kelp, especially *Carpophyllum*. These areas were assigned to the non-typical kina barren (14% cover) category. Cover averaged 10% for juvenile tall brown algae, signifying some recovery was occurring in some urchin barrens. Kina cover was relatively high compared to surveyed areas further south on the Brett Peninsula. Only the occasional *Centrostephanus* was seen in this area.

The average slope for the quadrats in analysis unit A was 44.3 degrees (with 95% confidence intervals of +/- 5.7%). There were some steep walls. Even the steeper sites had urchin barrens, typically below 4-5m. Kina were typically large except near the Cape (Brett).

The tall brown alga *Lessonia* was common in several areas near Cape Brett and in the channel between Cape Brett and Otuwhanga Island.

Figure 2: Percent cover by category for Analysis Unit B: Pig Gully/Ohututea Bay- Maunganui Bay (58 quadrats)

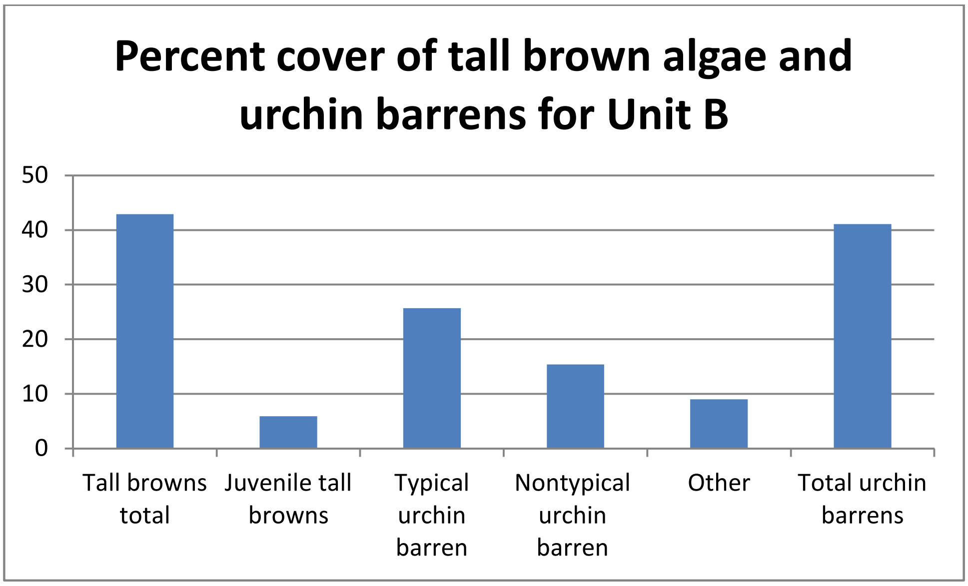


Table 19: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit B

Cover type	**Tall browns total**	**Juvenile tall browns**	**Typical urchin barren**	**Non-typical urchin barren**	**Other**	**Total urchin barrens**
average	42.9	5.91	25.71	15.37	9	41.08
95% CI	5.94	2.19	8.29	4.91		

Quadrat cover in this section of coast contained on average 41% urchin barrens. This consisted of an average of 25.7% typical (95% confidence intervals of 8.29%) and 15.8% non-typical (95% confidence intervals of 4.9%). There were some extensive areas of urchin barrens. To the south these were mainly typical urchin barrrens. In the north non-typical kina barrens with thinning kelps, turfs and coralline paints were more common. Kina cover varied between quadrats. Few *Centrostephanus* were seen.

Visibility on this section of coast was generally relatively high except in the vicinity of an eroding papa cave where visibility was less than 1m and still much reduced for about 500m on either side. This section of coast included other caves and a small island separated from the mainland by a narrow gut. Average slope was 42.12% (95% confidence intervals of 4.32%) with some very steep walls in places.

Mature tall brown algae cover totalled about 43% with a juvenile tall brown cover of 5.9%. This cover of mature tall brown algae was similar to that in Analysis Unit A. However, the cover of juvenile tall browns was less, possibly signalling a lower rate of recovery from urchin barrens. Unlike

Analysis Unit A, no *Lessonia* was found in the quadrats, probably because this section of coast is protected from strong easterly swells.

Figure 3: Percent cover by category for Analysis Unit C: Maunganui Bay (54 quadrats)

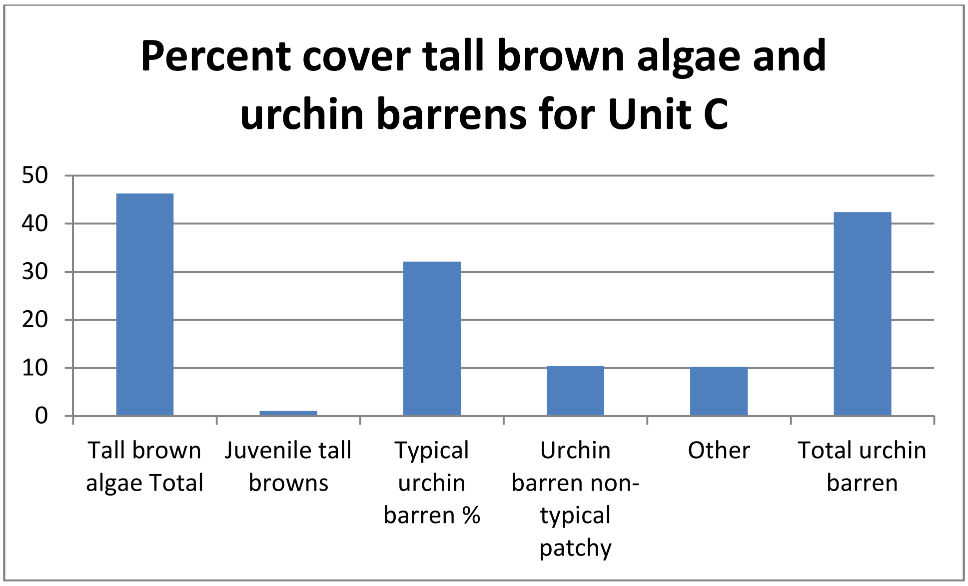


Table 20: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit C

Cover type	Tall brown algae total	Juvenile tall browns	Typical urchin barren	Non-typical urchin barren	Other	Total urchin barren
Average	46.25	1.04	32.09	10.35	10.27	42.44
95% CI	6.17	0.87	8.97	3.99		

Maunganui Bay as a whole had a relatively high proportion of tall brown algae and a moderate amount of urchin barrens. This may not be the impression of many visitors who see large areas of urchin barrens on the inside of Putahataha Island, along the adjoining mainland on the northern side of the bay and at White Reef. These areas were where most *Centrostephanus* were seen, especially inside of Putahataha Is and on the barrens component of White Reef. Some of the urchin barrens, especially in the west and at White Reef, were dominated by *Centrostephanus* – a feature not seen elsewhere.

A number of quadrat locations had a relatively high proportion of *Ecklonia* without obvious urchin barrens. . Along the eastern part of the northern shore and in Deep Water Cove, the reefs extend onto sand at relatively shallow depths.

Along the long eastern shore urchin barrens were found in shallows from <3m to 3.5m, then *Ecklonia* forest was on rock reef that terminated to sand at 7-8m. In the southern part of the Bay there was a variety of cover combinations. Relatively few quadrats were all urchin barrens. There were blocks of the tall brown algae *Ecklonia & Carpophyllum* with turfs, juvenile tall brown algae, encrusting sponges and anemones and coralline paints. *Centrostephanus* and kina were present, with the latter being most abundant.

Figure 4: Percent cover by category for Analysis Unit D: Motuwheteke Island- Whapukapirau Bay (64 quadrats)

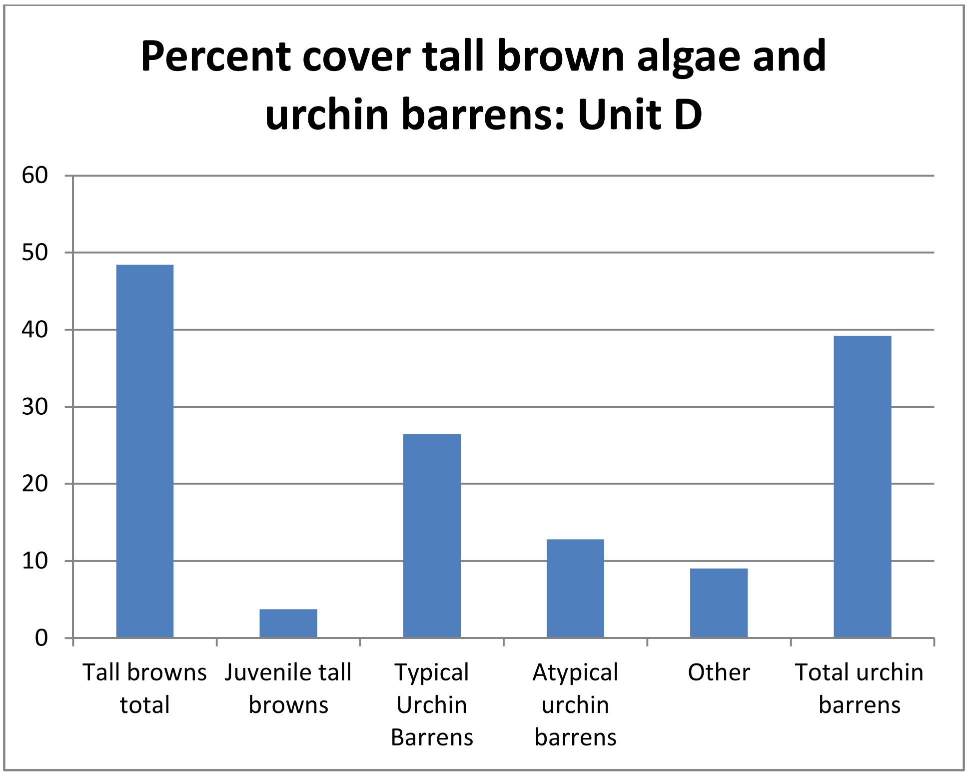


Table 21: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit D

Cover Type	Tall brown algae total*	Juvenile tall browns	Typical Urchin Barrens	Atypical urchin barrens	Other	Total urchin barrens
Average	48.42	3.72	26.46	12.77	9	39.23
95% CI	4.65	1.23	7.08	4.46		

This unit was characterised by a rocky shore with some boulder and cobble fields, especially in bay heads. There were blocks of *Ecklonia & Carpophyllum* kelps with Ecklonia being relatively abundant.

Other cover classes included turfs, juvenile tall browns, encrusting sponges and anemones and coralline paints. *Centrostephanus* and kina were present, with the latter being most abundant. Compared to Maunganui Bay (Unit C) there were far fewer juvenile snapper on the open coast south of Deep Water Cove. Schooling plankton-feeding fish (e.g. parore, demoiselles, blue maomao) were present in places. The caves along this coast were biologically less complex than Deep Water Cove arch. Kina barrens were often small and/or occupied a narrow depth band.

In the middle part of this unit kelps *Ecklonia* & *Carophyllum* dominated the shallows with patches of turfs, including areas of tall diverse turfs. There were urchin barrens with kina and only the very occasional *Centrostephanus*. The few remaining small patches of subtidal and intertidal mussel communities were scattered. Overall kina numbers were low. The usual reef fish species were present together with kingfish and kahawai. Blue maomao schools were near headlands.

Whapukapirau Bay is relatively shallow with low rock walls around the margins. Visibility was reduced in the west because of wind re-suspending sediment. Patchy bottom kelp was intermingled with turfs etc.

Figure 5: Percent cover by category for Analysis Unit E: Oke Bay – Opourua Bay- Moturahurahu

(16 quadrats)

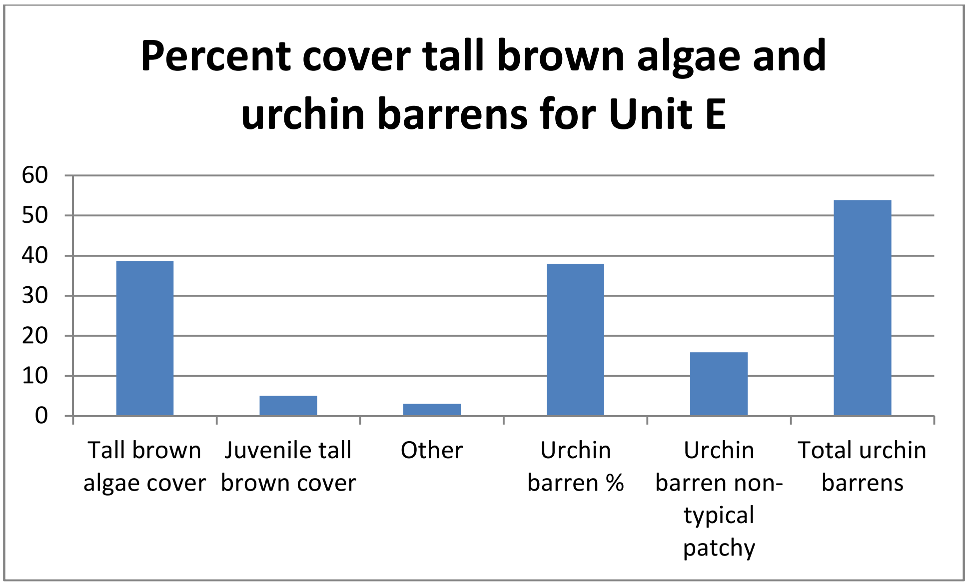


Table 22: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit E

Cover type	Tall brown algae cover*	Juvenile tall brown cover	Other	Urchin barren %	Urchin barren non-typical patchy	Total urchin barrens
Average	38.71	5	3	37.94	15.88	53.82
95% CI	8.97	1.53		17.15	10.22	

There were relatively few quadrats in this relatively sheltered unit (16 compared to 30-60 for most units). This reflects the shorter length of coastline in this unit. As a consequence the 95% confidence intervals are not as tight as those for other units.

Unit E has more extensive urchin barrens compared to units on the more open exposed coast. This included a high proportion of typical urchin barrens such as extensive areas in the northwest of Oke Bay. Urchin barrens dominated more than 50% of the assessed area.

There were some patches of *Carpophyllum* and *Ecklonia*. Overall the proportion of the area dominated by tall brown algae species was lower in this unit compared to the other analysis units. Reef fish numbers were low. The relatively sheltered southern and western shores of Moturahurahu Island were in this unit. The urchin barrens around Moturahurahu Island were mostly on the south and western sides of the Island. On the south side there was dense *Ecklonia* below the urchin barrens found in the shallows.

Figure 6: Percent cover by category for Analysis Unit F:Moturahurahu Is-Albert Channel

(29 quadrats)

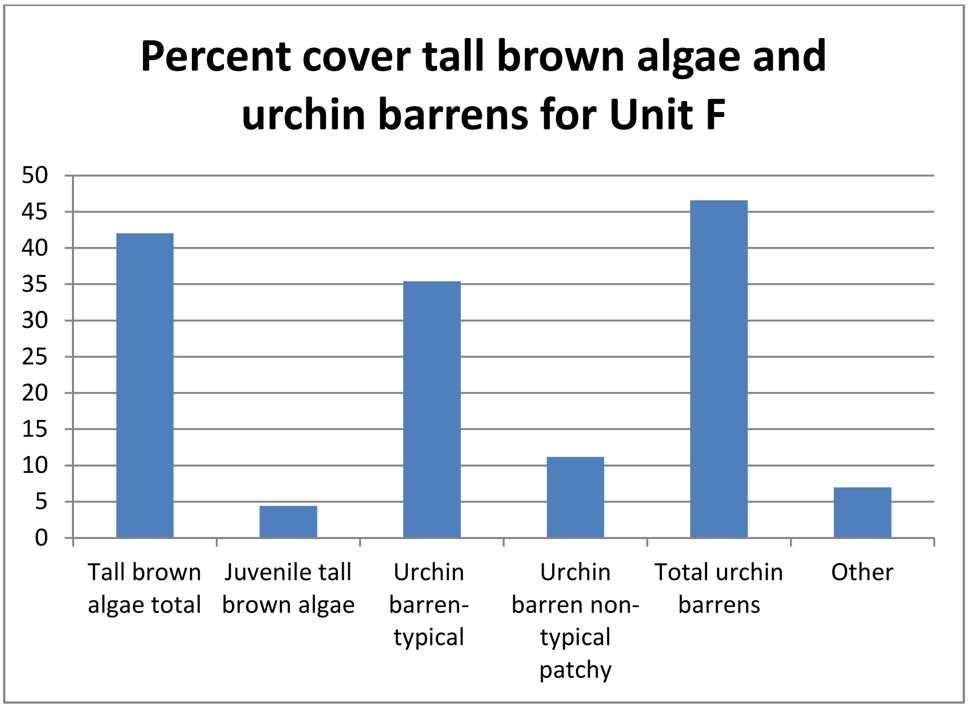


Table 23: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit E

Cover type	**Tall brown algae total***	**Juvenile tall brown algae**	**Urchin barren-typical**	**Urchin barren non-typical patchy**	**Total urchin barrens**	**Other**
Average	42.03	4.43	35.43	11.17	46.6	7
95% CI	9.2	1.38	14.08	5.79		

Urchin barrens made up 46.6% of the 29 quadrats surveyed in Unit F. This unit includes only the exposed northern and eastern shores of Moturahurahu Island. In this area there were extensive areas that were, until several years ago, mussel-dominated communities. The mussels have been stripped and now these areas contain a variety of red and brown algae. On the north side of the island the algal cover is very diverse including lower stature brown algae species such as *Microzonaria, Zonaria* and *Glossostigma;* and a variety of red algae species. The tall brown algae present were mostly juveniles.

The coast to Kohangatara Point contained a mosaic of diverse kelp communities and urchin barrens. Around Kohangatara Point there were steep walls, also with a mosaic of diverse kelp communities and urchin barrens. Fish around Kohangatara Point included blue knifefish and kingfish. Heading east there were walls with kelp and patchy kelp cover in places. The shallow bay to the west of the large arch contained very extensive urchin barrens. There were also urchin barrens to the east of the large arch. There were a few *Centrostephanus* but kina were definitely dominant in the shallows. Overall there were extensive urchin barrens immediately to the west of Kohangatara Point; and in large bay to the west of the arch (near Hat Island).

Figure 7: Percent cover by category for Analysis Unit F: Outer Urupukapuka- Waewaetorea Passage (55 quadrats)

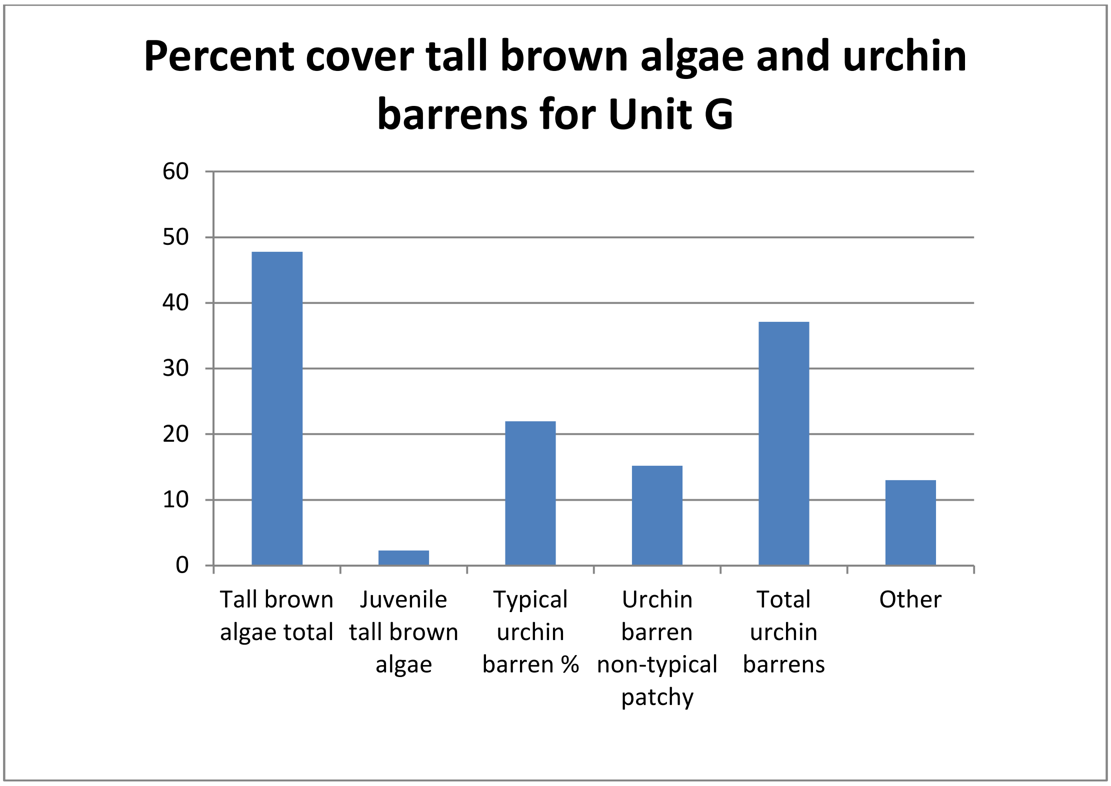


Table 24: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit G

Cover type	Tall brown algae total*	Juvenile tall brown algae	Typical urchin barren	Urchin barren non-typical patchy	Total urchin barrens	Other
Average	47.8	2.3	21.96	15.18	37.14	13
95% CI	5.1	1.9	7.7	4.74		

Urchin barrens made up 37% of the area of the 55 quadrats assessed. This is less than that observed for most of the other units. In the north and northeast of Urupukapuka Island we found that where kina were present they were often in dense congregations. Otherwise they were very sparse or absent. We found *Centrostephanus* in only 2 of 17 quadrats in this part of the unit. There were some typical kina barrens, but most were patchy non-typical kina-modified habitats.

The mid-section of the eastern outer shore of Urupukapuka Island was dominated by rock walls in the shallows with some more gradual sloping rock platforms. Typically *Carpophyllum , Cystophora* and *Pterocladia* were found in the most shallow parts of reefs. Below this it was predominantly the tall brown alga *Carphophyllum* with increasing amounts of *Ecklonia* as depth increases. There were some relatively dense patches of tall brown algae in the shallows. Initially kina were patchy and often in cracks. As we went further south kina abundance increased. Presumably this was because the amount of more suitable less steep habitat increased. Only one *Centrostephenus* was seen in this part of Unit G.

In the southern part of the waters around the eastern outer shore of Urupukapuka Island the slope of the shallow rock reef eased. Urchin barren extent increased significantly, presumably because the shallow rock reef was less steep and in general there was less exposure to heavy swells. Many hundreds of kina were seen compared to only two *Centrostephanus*.

Overall there was an occasional plant of the tall brown alga *Lessonia.* None were observed in the quadrats.

Figure 8: Percent cover by category for Analysis Unit H: Outer Waewaetorea and Okahu

(48 quadrats)

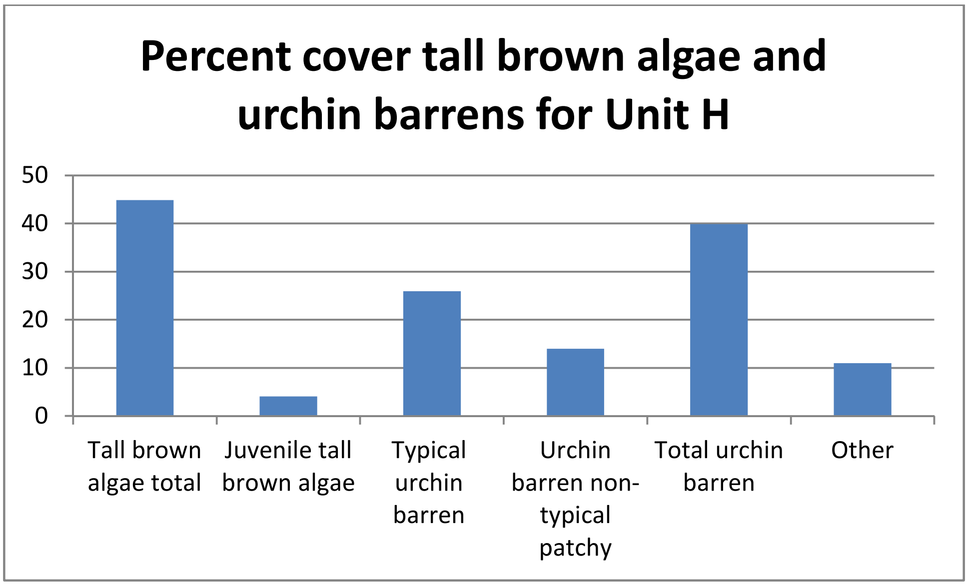


Table 25: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit H

Cover type	Tall brown algae total	Juvenile tall brown algae	Typical urchin barren	Urchin barren non-typical patchy	Total urchin barren	Other
Average	44.86	4.06	25.92	13.98	39.9	11
95% CI	4.96	1.55	8.07	5.43		

This unit contains the more exposed sections of the waters around Waewaetorea (eastern shore) and Okahu (north and eastern shores) Islands. Urchin barren cover in the 48 quadrats was 40% which is lower than that found in a number of units. Around the outer coast of Waewaetorea there were patches of urchin barrens (some with high kina densities) and patches of tall brown algae in good condition.

The benthic habitats in the waters surrounding the outer northern and north-eastern shores of Okahu Island are diverse with variable topography including guts and canyons parallel to the shore. Urchin barrens were often found in a narrow band and were usually non-typical. There were a few areas of typical kina barrens. No *Centrostephanu*s were seen. The steeper walls had more algae cover and diversity. A rock shelf in the northeast contained a patch of the tall brown alga *Landsburgia* which is not common in the Bay of Islands. On exposed outer shore coralline turfs were often tall. The red algae *Pterocladiella capillacea* was common in the shallows.

Figure 9: Percent cover by category for Analysis Unit I: Sheltered Waewaetorea and Okahu

(35 quadrats)

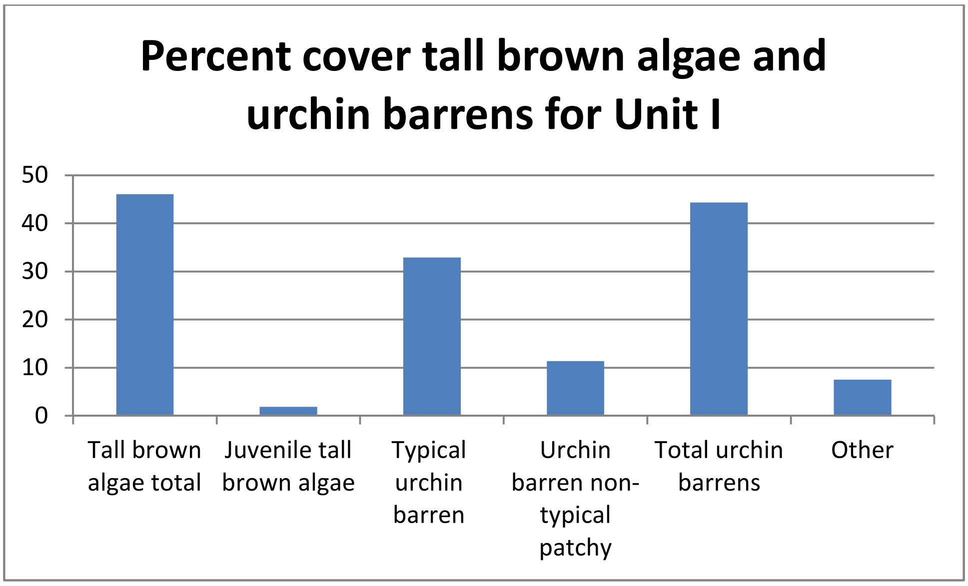


Table 26: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit I

Cover type	Tall brown algae total	Juvenile tall brown algae	Typical urchin barren	Urchin barren non-typical patchy	Total urchin barrens	Other
Average	46.05	1.89	32.92	11.39	44.31	7.5
95% CI	15.27	0.9	10.98	5.67		

The relatively large confidence intervals for this unit reflect the high level of variability between quadrats and the moderate number of replicates (35 quadrats). The maximum depth of rock reef in these sheltered sites was often quite shallow and so the generalised pattern of shallow mixed brown algae above urchin barrens above *Ecklonia* forest was typically compressed into a small depth range. The urchin barrens were mostly on the shallowest part of the reef 0.5m to 2.5m (at low tide) with *Ecklonia* kelp in good condition below this.

Where the overall slope was gentle it was possible to have a relatively homogenous 5m x5m quadrat. Where the overall reef slope was relatively steep in sheltered waters it was sometimes difficult ensure that only rocky reef was included in the 5m x5m quadrat. In such cases the quadrat might include the urchin barren (which is typically shallower than what is found in more exposed locations) as well as much of the *Ecklonia* forest below. In these sites the Ecklonia forest may only occupy 1-2m of depth range before the reef terminates onto sand seabed.

Figure 10: Percent cover by category for Analysis Unit J: Outer Motukiekie-outer Moturua

(39 quadrats)

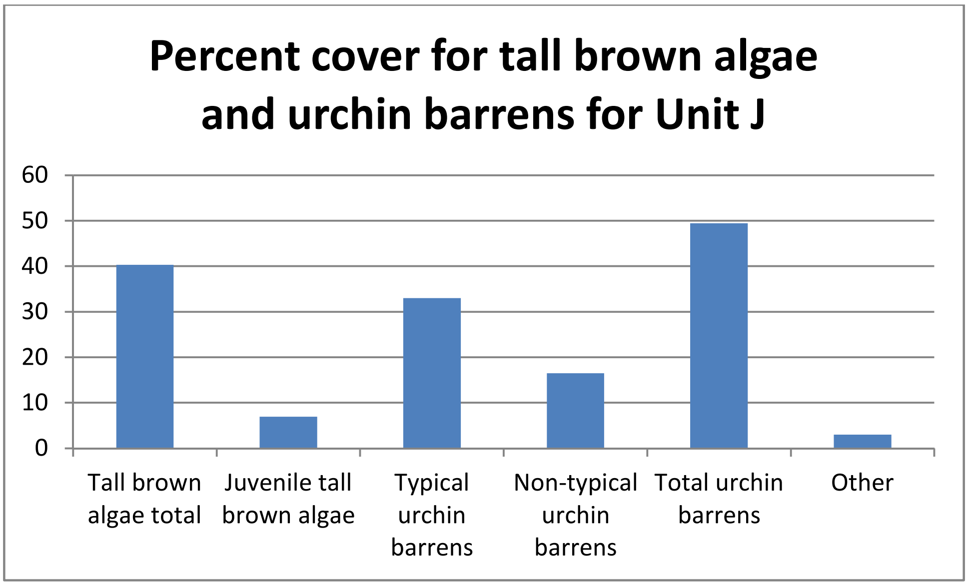


Table 27: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit J

Cover type	**Tall brown algae total**	**Juvenile tall brown algae**	**Typical urchin barrens**	**Non-typical urchin barrens**	**Total urchin barrens**	**Other**
Average	40.3	6.94	32.98	16.48	49.46	3
95% CI	6.21	2	10.45	6.04		

Unit J had a higher proportion of urchin barrens (49.46%) than most of the eastern Bay of Islands analysis units. Conversely it also had a lower proportion of mature tall brown algae although juvenile tall brown algae coverage was more.

Along the eastern shore of Motukiekie the profile typically began in 1-2m of water with the tall brown alga *Cystophora* with the red alga *Pterocladia lucida*, scattered smaller tall brown algae *Carpophyllum* and *Ecklonia* (deeper). Below this were urchin barrens dominated by low turfs to 4.5m. Below this was typically *Ecklonia* forest which was absent on the moderately frequent sand areas. There were also areas of boulders with low turfs. Areas previously dominated by intertidal and subtidal mussel beds until 2011 still had none. These areas were now dominated by *Cystophora, Pterocladia lucida*, occasional tall coralline turf, and occasional other brown algae.

Along the northern shore of Motukiekie Island there were relatively little typical urchin barrens on the mainly low slope boulders and rock. Non -typical urchin barrens were usually in 4-7m of water depth with thinning kelps and varying densities of lower stature cover. Some areas had a relatively high proportion of kelps, especially on the steep rock faces.

There were more kina on the sheltered, less steep side of Motutara Island at the entrance to the passage between Motukiekie and Moturua Islands. The outer exposed northern slopes of Motutara Island are steeper with more extensive algae cover and very few urchins. The shallow reef on the west was dominated by the tall brown algae *Carpophyllum* and *Lessonia.*

The survey work along the northern shore of Moturua Island was in rougher conditions with reduced visibility. This led to the quadrats being moved several times so as to find suitable conditions for assessing percent cover. In general algae dominated cover on steeper rock slopes. Here there were very few urchins. There were relatively few typical urchin barrens. For the north-west shores there were non-typical urchin barrens with thinning kelp and low stature cover, and areas with abundant kelp cover. For low slope areas on the western side of Moturua Island and by the small western islands there were typical urchin barrens in the expected depth range.

Figure 11: Percent cover by category for Analysis Unit K: Outer Motuarohia (Roberton Island)

(53 quadrats)

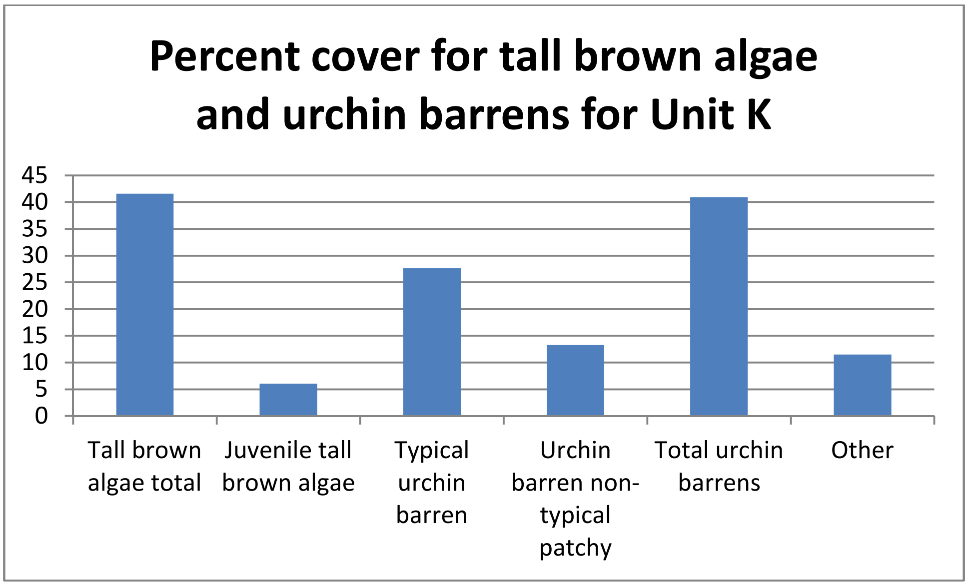


Table 28: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit K

Cover type	Tall brown algae total	Juvenile tall brown algae	Typical urchin barren	Urchin barren non-typical patchy	Total urchin barrens	Other
Average	41.57	6.06	27.62	13.30	40.92	11.5
95% CI	5.82	1.68	7.89	3.69		

On the western side of Motuarohia Island the rock reef descends to 5m depth in the south-west corner and to 8-9m in the mid part of the western shore. By the north-west corner there were steep rock walls to greater depths. Kelps were primarily *Ecklonia* with some *Carpophyllum & Cystophor*a. Urchin barrens in the south-west corner were mainly found at 2-6m depth with *Ecklonia* below. The shallow water communities in the northern section of the western shore varied. There were some walls with minimal urchin barrens in the shallows. In comparison lower slope areas contained relatively large amounts of typical urchin barrens. Kina were often small, especially in the south.

On the north shore there were steep walls with the tall brown algae *Ecklonia, Lessonia* and limited amounts of *Carpophyllum*. Often the red alga *Pterocladiella capillacea* was present as well as encrusting anemones and small amounts of encrusting sponges. Typically there was a zone of thinning kelp at 4-5m with turfs, juvenile tall brown algae, turfs and encrusting fauna. Kina were often absent unless there were deep slots. No *Centrostephanus* were seen. In bays, where there were low gradient rock slopes, urchin barrens typically dominated with some *Ecklonia* and *Carpophyllum* (especially on the margins). The mid-sections of shallow gradient bays containing rock flats were dominated by urchin barrens.

On the north-eastern shores there were still steep rock slopes, some without any urchin barrens, and some with the non-typical urchin "barrens". Many platforms and rock bases in bays were urchin barrens. The really bare barrens had far fewer kina than those barrens with more cover.

The eastern shore of Motuarohia was variable, but it was generally shallow with sand, cobbles, boulders and areas of rock. Boulders and rock mainly had a turf and coralline paint cover. Occasional wall areas were similar to the walls on the northern shore. No *Centrostephanus* were seen.

The last reef in this unit was the isolated Te Miko Reef. There was a relatively small amount of urchin barrens on top of this reef which is now bare (having been cleared of its former mussel cover). There was a zone between 2-4m with thinning kelp (usually *Carpophyllum* with *Cystophora*), encrusting fauna, turfs and juvenile tall brown algae. No kina were seen.

Figure 12: Percent cover by category for Analysis Unit L: Tapeka (23 quadrats)

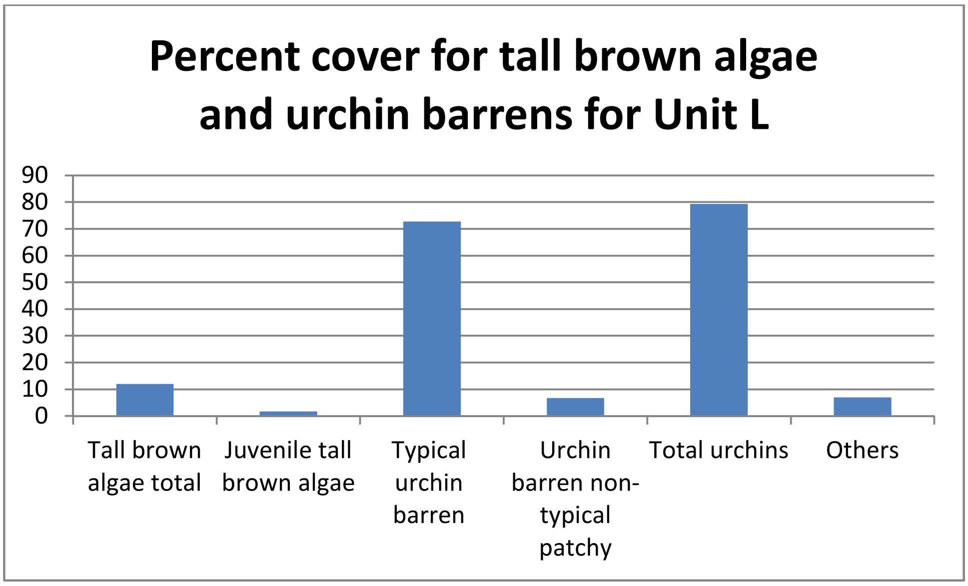


Table 29: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit L

Cover type	Tall brown algae total	Juvenile tall brown algae	Typical urchin barren	Urchin barren non-typical patchy	Total urchins	Others
Average	11.96	1.67	72.71	6.67	79.38	7
95% CI	4.3	1.04	12.15	7.37		

Unit L (Tapeka) had the highest percent cover for urchin barrens of any surveyed unit at nearly 80%. This was dominated by typical urchin barrens at 73% (with 95% confidence limits of +/-12%). Conversely tall brown algae coverage was very low. Algal turfs were high at 44% cover (with 95% confidence intervals of 5%) as were coralline paints at 20% cover (with 95% confidence intervals of 4%). The confidence intervals are relatively large because of the lower sample size of only 23. It had been intended to measure more quadrats in this unit but a fuel line leak ended surveying earlier than intended. Even though conditions were calm and visibility was generally good in the Bay of Islands on that day visibility did reduce significantly at the western-most point – probably because of the effect of an outgoing tide. The south and west of the surveyed area contained a very high proportion of urchin barrens on rock & boulders. Most algae were found on the steep outer faces on very exposed rock walls and slopes.

Figure 13: Percent cover by category for Analysis Unit M: Black Rocks and Battleship Rocks

(Western Bay of Islands) (27 quadrats)

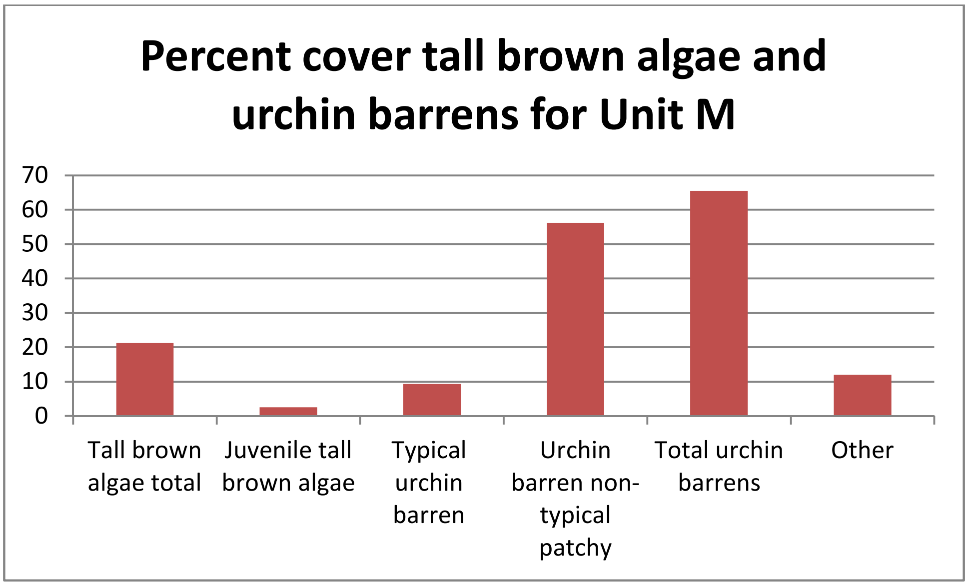


Table 30: Percent cover and 95% confidence intervals for tall brown algae and urchin barrens for Analysis Unit M

Cover type	**Tall brown algae total**	**Juvenile tall brown algae**	**Typical urchin barren**	**Urchin barren non-typical patchy**	**Total urchin barrens**	**Other**
Average	21.21	2.54	9.29	56.18	65.47	12
95% CI	3.7	1.4	10.3	9.03		

The differently coloured graph represents the western Bay of Islands location of this unit. Unit M had a high proportion of recorded urchin barrens although not as much as for Unit L (Tapeka). The barrens here were primarily non-typical barrens (whereas at Tapeka typical urchin barrens predominated). As with Tapeka some of the 95% confidence intervals were high, reflecting the relatively small number of quadrats (27) and the high degree of variability for urchin barrens between different quadrats. Again we had intended to measure more quadrats but increasing northerly winds and swells meant that we had to stop our assessment in this area earlier than planned.

Unit M was dominated by steep walls, often with 70-90 degree slopes. The average slope for this unit was higher at 74 degrees (with 95% confidence intervals of 10.7 degrees) than that found in the other units. The bottom depth varied depending on the location.

In the north the intertidal contained scattered mussels, limpets and abundant barnacles. The first 2m of subtidal wall had a cover of the tall brown algae *Carpophyllum* (mostly *C mashalocarpum*) with *Cystophora*, occasional *Ecklonia;* abundant red alga *Pterocladia;* some mussels, and some tall coralline turfs. Where mussels had been removed there were more low turfs and algal felts. For the subtidal walls from 2-7m deep *Ecklonia* formed 10-30% of the cover with *Pterocladia*, tall coralline turfs, and encrusting fauna (sponges, anemones, bryozoans). Occasional mussels were present. Very few kina were seen. The kina that were seen were usually associated with areas of mussel removal.

The southern Black Rocks group was similar to the northern Rock but with less diverse encrusting fauna. The intertidal area was similar to the northern Rock plus the occasional *Lessonia.* There were fewer tall brown algae in the 2.5m-7.5m depth range. There was also a higher cover of encrusting fauna (especially in some locations), as well as more low turfs and algal felts.

It is possible that some of the extent of urchin barrens (primarily non-typical) should be attributed to damage done by humans harvesting large quantities of mussels, rather than to kina browsing. This is particularly so given the relatively low percent cover for kina in the quadrats. The geology and slope may also have been significant. More detailed assessment would be required to establish what might be an appropriate level of urchin barrens for this unit.

Discussion

Typical and non-typical urchin barrens

During the field work it became apparent that there were several types of urchin barrens. The first was the obvious classical urchin barrens. In such barrens taller algae have been removed and the biological cover is dominated by low algal turfs and felts, coralline paints and urchins. Such barrens are typically seen on rock reef of low slope in more sheltered waters. They can also occur on exposed rock reef. Non-typical urchin barrens are more often found on rock reef in exposed locations. In such non-typical barrens there are either or both thinning tall brown algae and larger areas of juvenile tall brown algae regenerating.

Typical urchin barrens

These are based on cover categories and the pattern of those categories. Excluded are all tall brown algae including juveniles. Also excluded are red, other brown and green algae except where they form low turfs or algal felts. Patches of sand and cobbles are excluded as they are unsuitable substrate for much algal growth. Mussel-communities, and extensive areas of encrusting sponge and anemone growth on walls, are also excluded as they are often present because there is a steep wall and/or past mussel communities rather than urchins have modified the algal cover.

Included are turfs, algal felts, coralline paints and the space occupied by urchins.

Non-typical urchin barrens

Non-typical urchin barrens (or urchin modified habitats) are relatively common on more exposed open coast rocky reefs. They can be distinguished from classical urchin barrens in that their appearance resembles thinning hair. Patchy tall brown algae are scattered through low covers usually found in urchin barrens. Tall turfs (taller than 5cm) can also be present and complicate assessments of what is an urchin “barren”. These ecological communities can still have a moderate level of cover and so it may be more appropriate to call them urchin modified habitats rather than "barrens". It is possible that the thinning tall brown algae represent a state of declining condition while the presence of more juvenile tall brown algae might represent the start of a renewal. There would need to be repeat monitoring of the same areas over at least several years to determine whether this is the case.

The "non-typical" urchin barrens category was determined about 20% of the way through the survey work. Some effort was made to apply this category retrospectively but that was difficult and so all of Unit C and parts of Units B and D may under-represent the extent of non-typical versus typical urchin barrens in those areas. The overall extent of urchin barrens in those units would not have been affected, however.

Extent of urchin barrens

The extent of urchin barrens, including the relative proportions of typical and non-typical urchin barrens varied between the 13 analysis units. There was also considerable variation within some units. Table 31 shows the extent of this variation.

Table 31: Proportion of kina barrens in quadrats for each analysis unit

Location	Analysis unit	Total urchin barrens % cover	Typical urchin barrens % cover	Non-typical urchin barrens % cover
Cape Brett –Ohututea Bay	A	44	30	14
Ohututea Bay-Maunganui Bay	B	41	26	15
Maunganui Bay	C	42	32	10
Motuwheteke Island- Whapukapirau Bay	D	39	26	13
Oke Bay-Opourua Bay- Moturahurahu	E	54	38	16
Moturahurahu-Albert Channel	F	47	35	11
Outer Urupukapuka Island	G	37	22	15
Outer Waewaetorea and Okahu Islands	H	40	26	14
Sheltered Waewaetorea-Okahu	I	44	33	11
Outer Motukiekie-Moturua Islands	J	50	33	17
Outer Motuarohia	K	41	28	13
Tapeka Point	L	80	72	7
Black Rocks	M	65	9	56

Tapeka (unit L) had the highest total urchin barren in the quadrats. At 80%, with 72% being typical urchin barrens, this area was shown in various statistical tests (see Appendix 1) to have a benthic cover that was significantly different biologically to that found in the main eastern Bay of Islands units (A-K). The next highest recorded proportion of urchin barrens was for Black Rocks (unit M) which is in the western Bay of Islands. In contrast to Tapeka, and all the main eastern units, most of these barrens were non-typical. The average slope in this unit was 73 degrees (with 95% confidence intervals of 4 degrees) and some of the attributed non-typical urchin barren may be the outcome of steep slopes and intensive human harvesting of mussels. This unit was also recorded as having significantly different benthic cover to the other assessed units. Part of the explanation for the differences could also be the columnar basalt geology in this area.

The third highest proportion of urchin barrens was found in the Oke Bay- Opourua Bay- sheltered side of Moturahurahu Island. Here urchin barrens covered 54% of the quadrats with more than two thirds being typical urchin barrens. This area is relatively sheltered with more gradual slopes (an average of 26 degrees with 95% confidence intervals of 6.5 degrees). Outer Motukiekie-Moturua Islands had the fourth highest urchin barren cover. Part of the reason for this could be the extensive removal of mussels. Also part of this area tends to be more sheltered from easterly swells than the outside of Urupukapuka, Waewaetorea and Okahu Islands which may make conditions for kina more favourable and there may be more harvesting of kina predators.

A Spearman rank test found a significant positive relationship between the amount of space occupied by kina during the day (as represented by % kina cover) and the percent urchin barren (Appendix 1). This is unsurprising but does show that the barrens are probably being maintained by kina (which move around and feed at night). There was no relationship between the relatively rare *Centrostephanus* % cover and the extent of urchin barrens in the shallows.

Centrostephanus urchins

The observed *Centrostephanus rodgersii* distribution was patchy. Where it occurred it was generally present in low numbers. It was locally abundant in only a few places. It was notable that there were several relatively dense populations in Deep Water Cove-Maunganui Bay (e.g. White Reef and Putatuhataha Island eastern shore). Deep Water Cove-Maunganui Bay has been a no-fishing area for the last six years. Because it contains the sunken wreck *The Canterbury*, it is popular with local dive operators. In addition to (or instead of) diving the wreck, divers will often spent time around White Reef and Putatuhataha Island. These locations are popular with swim-with-dolphins boats which also stop for their customers to snorkel, especially on White Reef.

As the fishing closure exempts the harvest of the common sea urchin (kina) it is possible that the urchins are being cut open by some divers to attract fish such as snapper. It is noticeable that the shallow-water densities of *Centrostephanus* are considerably higher in the locations most used by divers. It is possible that the fish feeding by some is encouraging large predators of sea urchin to also feed on the local populations of kina without diver assistance. At this stage it is unclear which, if any, New Zealand fish species are predators of adult *Centrostephanus.*

Centrostephanus arrived in northern New Zealand from eastern Australia during the 1960's (Morton & Miller 1968). I first observed it considerably further south in the waters around White Island (Bay of Plenty) in 1992. There is no evidence that humans assisted its transport to New Zealand. Because of that *Centrostephanus* is treated as a native species by the Department of Conservation (Debbie Freeman, pers. comm.). It is viewed as a species that has expanded its range in response to warmer sea temperatures arising from climate change. It is notable that *Centrostephanus* has increased significantly in the waters around the Poor Knights Islands in recent years and this increase is particularly noticeable in the waters between the two main islands (Kathy Walls and Victoria Froude, pers. observations). It is possible that the significant increase in large snapper resulting from the establishment of the fully protected marine reserve (De Buisson, 2010) has resulted in reductions in kina thereby freeing up habitat for *Centrostephanus* in some areas. Similarly the localised increase in *Centrostephanus* in parts of Deep Water Cove-Maunganui Bay may be a response to possible localised depletions of kina as described above. It is likely that future warmer ocean temperatures will favour *Centrostephanus* which has an ability to adapt to warmer conditions (Pecorino, 2012).

In Australia *Centrostephanus* has expanded its range from New South Wales to Tasmania. It was first reported in the waters off Tasmania in 1978 (Ling, 2008). This expansion has been driven by poleward expansion of the East Auckland Current (EAC) (Ridgeway, 2007). While *Centrostephanus i*s not the only species to spread in this way it is considered to be especially important given its ability to eliminate macroalgae communities and lead to an alternative sea urchin "barrens" state (Ling, 2008). The impoverished benthic communities associated with the *Centrostephanus* barrens had approximately 150 fewer taxa compared to adjacent macroalgal beds (Ling, 2008). In addition to consuming algae (almost all of the 373 species in Tasmanian waters), *Centrostephanus* also consumes encrusting and structure forming invertebrates. He (Ling, 2008) considered that widespread *Centrostephanus* barrens within Tasmanian waters would reduce primary and secondary productivity, with flow-on effects to many species. Such is the importance of *Centrostephanus* that within its historic NSW range approximately 50% of all near-shore rocky reefs is urchin barrens as a result of grazing by this single urchin species. Given the positive effects of climate change on *Centrostephanus* dispersal and development (Ling, 2008) considered that the barrens habitat in Tasmania could expand to reflect the patterns in NSW. In Tasmania *Centrostephanus* been treated as a serious ecological problem.

The study reported here focused on shallow reefs in 3-10m of water (as this is where kina dominated sea urchin barrens are most likely in northern New Zealand (Shears and Babcock, 2004). Shears and Babcock (2004) report that urchin barrens can extend to 20m in exposed offshore locations. Some deeper areas of urchin barrens were observed in more exposed locations where there was good visibility at the time of assessment. Johnson et al. (2005) refer to a shallow limit for incipient *Centrostephanus* barrens of about 8 metres in Tasmania. This shallow limit was thought to be determined by a combination of wave action and mechanical abrasion. If this pattern occurs in New Zealand this may mean that there are areas of *Centrostephanus* barrens in deeper waters than what was assessed in this project. As part of a baited underwater monitoring programme for the western Brett Peninsula an extensive aggregation of *Centrostephanus* was observed at the Twins in 30 metres of water (Vince Kerr, pers. comm.). The more sheltered waters in Maunganui Bay/ Deep Water Cove may have allowed *Centrostephanus* barrens to develop and persist in waters shallower than 8 metres.

Benthic cover excluding urchin barrens

Principal component analyses detailed in Appendix 1 show that the benthic cover of units L and especially M were distinctively different to that found in the other units. Different elements include more red algae, more encrusting fauna, and more algal turfs. Unit C was also different in possessing more *Centrostephanus*, more *Ecklonia* (versus other tall brown algae species), and more algal felts.

A Kruskal-Wallis test looking at the total percent cover for tall brown algae species (excluding juveniles) for the 13 analysis units found significant differences (Appendix 1). Units L (Tapeka) and M (Black Rocks) were significantly different to each other and to the other units. Unit K (outer

Motuarohia) was also significantly different to units D (Motuwheteke Island-Whapukapirau Bay, Southern Brett Peninsula) and G (Outer Urupukapuka Island)

Tall brown algae

The percent cover for all tall brown algae (Table 32) varied between the 13 analysis units, particularly between that found in the eastern Bay of Islands versus the Tapeka and Black Rocks units. There was also considerable variation within some units. The most extreme within unit variation was that observed for the quadrats from" Unit I (Sheltered Waewaetorea and Okahu Islands) where the average cover was 46%+/-15.3%.

Table 32: Proportion of tall brown algae in quadrats for each analysis unit

Location	Analysis unit	Tall brown algae percent cover	Tall brown algae 95% confidence intervals	Juvenile tall brown algae percent cover
Cape Brett –Ohututea Bay	A	45.7	8.3	9.8
Ohututea Bay-Maunganui B**ay**	B	43	6	5.9
Maunganui Bay	C	46.3	6	1
Motuwheteke Island- Whapukapirau Bay	D	48.4	4.7	3.7
Oke Bay-Opourua Bay- Moturahurahu	E	38.7	9	5
Moturahurahu-Albert Channel	F	42	9.2	4.4
Outer Urupukapuka Island	G	47.8	5	2.3
Outer Waewaetorea and Okahu Islands	H	44.9	5	4
Sheltered Waewaetorea-Okahu Islands	I	46	15.3	1.9
Outer Motukiekie-Moturua Islands	J	40.3	6.2	6.9
Outer Motuarohia	K	41.6	5.8	6
Tapeka Point	L	12	4.3	1.7
Black Rocks	M	21.2	3.7	2.5

The highest percent cover for tall brown algae was found for Unit D (Motuweteke Bay-Whapukapirau Bay (48.4% +/- 4.7). Three other units were very similar: A (Cape Brett –Ohututea Bay); C (Maunganui Bay); G (Outer Urupukapuka Island). Unit I (sheltered water reefs inside Okahu and Waewaetoria Islands) also had a similar mean, but as previously discussed there was large variability reflecting the patchiness of the remaining kelp beds. The lowest percent cover was 12% for Unit L (Tapeka), followed by (21.2%) for Unit M (Black Rocks). In the eastern Bay of Islands the lowest percent cover for tall brown algae was 38.7% for Unit E (Oke Bay-Opourua Bay. Again this unit was quite variable with 95%confidence intervals of +/- 9%.

Future work

We collected a broad range of data which could, with more time, be further analysed to look for more correlations between biological patterns and potential factors affecting those patterns. It would also be desirable to increase the number of quadrats for the distinctively different units L and M. With more time it would also be useful to measure quadrats elsewhere in the western sector of the Bay to see how similar and dissimilar the benthic cover is for the eastern and western Bay of Islands.

In future years it would be possible to repeat these assessments. This could help show changes resulting from management actions such as long-term legal protection from the harvesting of fish and shellfish. It could also show variations that might occur with no management changes. To facilitate data comparison in future years we collected data that would allow the future recalculation of each quadrat's mid-point depth at mean sea level. This could be done by firstly determining the mid depth for each quadrat. The difference between the actual assessment time and the nearest high tide time could then be calculated. A standardised curve for the tide depths in the Bay of Islands relative to the stage in the tidal cycle could be used to determine the amount and direction of adjustment that would be need to be made to the observed depth.

Conclusions

We collected a broad range of biological cover and physical data for 561 shallow-water quadrats spread over 13 units in the outer Bay of Islands. Eleven of these units were in the eastern Bay of Islands, one was at Tapeka and one was at Black Rocks in the western Bay of Islands.

Various analyses have shown that the Tapeka, and especially the Black Rocks units are distinctively different to those found in the eastern Bay of Islands. The highest percent cover for urchin barrens was found in these two areas although the characteristics of each area were very different. It is possible that reasons other than urchin browsing may explain some of what was recorded at Black Rocks. It would be useful to measure more quadrats in these two units to increase the sample sizes and new units in the west would provide more information about differences between the eastern and western Bay of Islands benthic communities.

The data collected in this project can be used to monitor change in benthic cover resulting from management actions such as long-term fish and shellfish harvesting closures.

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Appendix 1: Report on statistical analyses undertaken by Olivier Ball [1]

Methods: Data analysis

This report addresses the statistical analyses requiring more sophisticated statistical analysis software than Excel is able to provide

Multivariate analyses

Differences in the mean cover compositions across 13 analysis units and three exposure classes were investigated in two separate principal coordinates analyses (PCoA).
The response matrix for the analysis units comprised 19 cover categories in 13 analysis units. Raw data were used, as transformations and relativisations were not deemed useful or necessary. The response matrix for the exposure classes comprised the same 19 cover categories in three exposure categories. With only three exposure classes, it was difficult to generate a stable 2 D solution so data were relativised by column (variable) maximum.

The Sorensen (Bray Curtis) distance measure was used to quantify differences in coverage by the measured variables between analysis units or exposure categories. A joint plot was used to display which responses (i.e. variables) contributed most strongly (Pearson's r^2 cut-off = 0.1 for the analysis units and 0.9 for the exposure classes) to the gradients reflected by each ordination axis.

Differences in coverage between the 13 analysis units were analysed using the multi-response permutation procedure (MRPP) with the Sorensen distance measure. Pairwise comparisons between groups were also be made. Differences in coverage between the three exposure classes were analysed in the same way.

All multivariate analyses were conducted using the statistical package PC-ORD v. 6.0 (McCune and Mefford 2011).

Other analyses

As the data were non-normal and not transformable, Kruskal-Wallis tests were used to compare kina percent cover (dependent variable) between different analysis units and different exposure scales (independent variables). The total percent cover for all tall brown algae (excluding juvenile tall brown algae) (dependent variable) across the 13 analysis units and across the three exposure categories (independent variables) were also analysed by a Kruskal- Wallis test. Percent kina barrens (dependent variable) across the 13 analysis units and across the three exposure categories (independent variables) were also analysed by Kruskal- Wallis tests. Uncorrected Mann-Whitney pairwise comparisons following each significant Kruskal-Wallis test were conducted to determine where exactly the significant differences lay.

The relationship between kina percent cover and total kina barren coverage was investigated using the Spearman rank correlation coefficient.

[1] Statistical analyses were undertaken by Olivier Ball of NorthTec Whangarei. The draft report was prepared by Olivier Ball and revised by Victoria Froude of Pacific Eco-Logic

The statistical software PAST (Hammer et al 2001) was used for the Kruskal-Wallis and Spearman rank analyses.

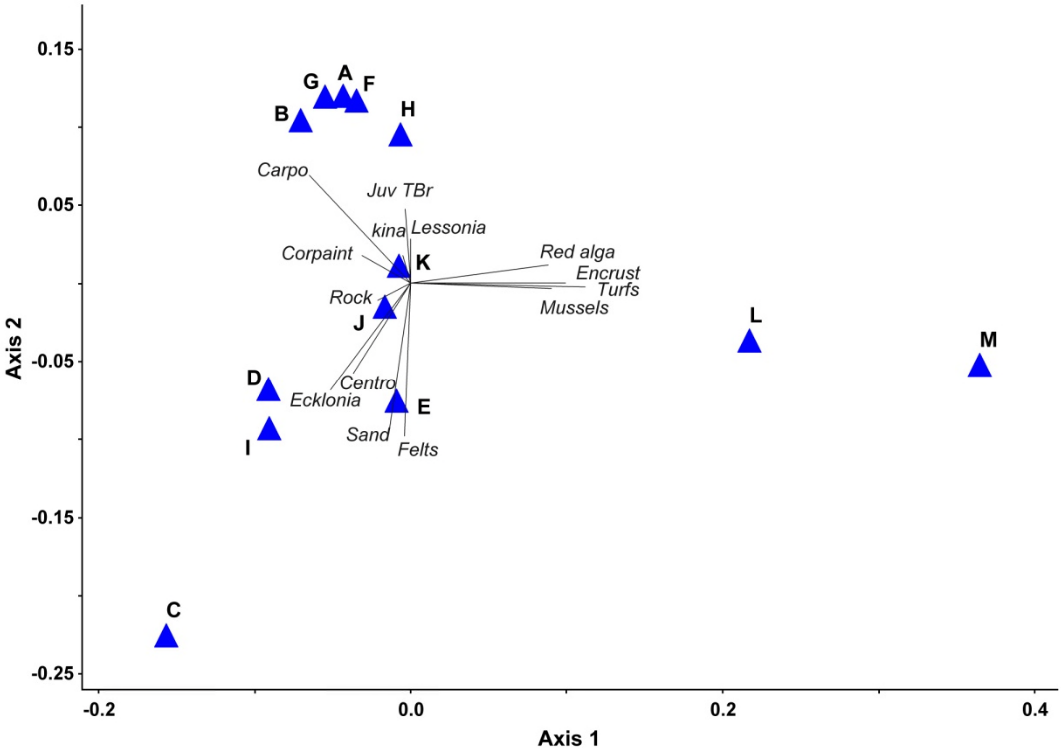
Results

Multivariate analyses: Principal coordinates analyses

The principal coordinates analyses (PCoA) using the 13 analysis units generated two axes that captured 69% of the variation in the input data (Figure 1). Analysis units with similar benthic cover patterns lie closer to one another in the ordination plot, whereas sites with dissimilar benthic cover patterns lie further away from each other. A combination of dichotomies and gradients were obtained with both groupings and a spread of points. Analysis units A, B, F, G and H were tightly clustered and therefore similar. Also, J and K were similar as well as D and I. Analysis units C, L and M were quite distant (and therefore different) from the other points.

A number of variables contributed strongly to the construction of each axis in the ordination. Turfs and encrusting organisms (primarily sponges and anemones) showed the strongest positive correlations with axis 1 (towards analysis units L and M) with mussels and red algae also contributing, whereas the strongest negative associations were shown by *Carpophyllum* and *Ecklonia*. The most influential variables shaping the ordination space for axis 2 were algal felts, sand, *Ecklonia* and *Centrostephenus*, all showing strong negative correlations with that axis. Only *Carpophyllum* showed a strong positive association with axis 2.

Figure 1: PCoA for the benthic cover categories for the 13 analysis units (as represented by the letters A-M)

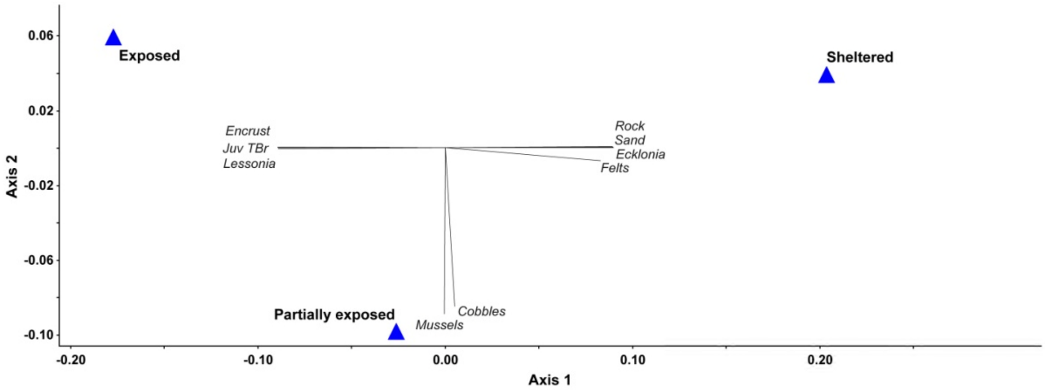


Differences in the cover composition between analysis units were supported by the overall result of the MRPP comparing the 13 groups (A = 0.169, $P \leq 0.001$). Pairwise comparisons between the many analysis units showed that units C, L and M are significantly different to the other units.

The first axis of the PCoA using the three exposure classes (exposed, partly exposed and sheltered) captured 83.4% of the variation in the input data and the second axis the remainder to 100%. There were no dichotomies, only a gradient. The two most distant classes were exposed and sheltered, with partially exposed in between (Figure 2).

Rock, sand, *Ecklonia* and felts showed the strongest positive correlations with axis 1 (towards sheltered), whereas the strongest negative associations towards exposed sites were shown by encrusting organisms, juvenile tall brown algae and *Lessonia*. The most influential variable shaping the ordination space for axis 2 were mussels and cobbles, both showing strong negative correlations with that axis.

igure 2: PCoA for the benthic cover categories for the exposure classes



Comparing kina percent cover between the 13 analysis units and exposure classes

The analysis comparing kina percent cover between the 13 analysis units using a Kruskal-Wallis test had an overall Chi square calculation = 79.9, at 12degrees of freedom where P =1.46 X10^{-12}. This is very significant and means that there are significant differences in kina percent cover between some of the analysis units. Analysis units L and M are the most different from the other units. Unit C is also different to most of the other units (see Figure 3). These results were borne out by the pairwise Mann-Whitney comparisons between analysis units.

The analysis comparing kina percent cover between the three exposure classes using a Kruskal-Wallis test had an overall Chi square calculation = 3.55, at 2 degrees of freedom where P = 0.160. This is not significant and meant that exposure class had no effect on kina percent cover (see Figure 4).

Comparing percent cover for all tall brown algae species between the 13 analysis units and exposure classes

The analysis comparing percent cover for all tall brown algae species (excluding juveniles) across the 13 analysis units using a Kruskal- Wallis test had a Chi square calculation = 84.77, at 12degrees of freedom where P = 4.665 X10^{-13}. This is very significant and means that there are significant differences in the percent cover for all tall brown algae between some of the analysis units. The Mann-Whitney pairwise comparisons showed that analysis units L and M are different when compared to the other analysis units and from each other. Unit K is also significantly different from units D and G. Figure 5 contains the box plots comparing percent cover by analysis unit for all tall brown algae species.

The analysis comparing percent cover for all tall brown algae species (excluding juveniles) across the three exposure classes using a Kruskal- Wallis test had a Chi square calculation = 6.01, at 2degrees of freedom where P = 0.049. This is only just significant. It means that the percent cover for tall brown algae differs significantly between at least two of the three exposure categories. With the Mann-Whitney pairwise comparisons, Exposed and Partly exposed sites were significantly different in terms of the percent cover for all tall brown algae species where P = 0.014. Exposed and Sheltered sites were not different in terms of their tall brown algae percent cover. Figure 6 contains the box plots comparing percent cover by exposure class for all tall brown algae species.

Comparing percent cover for urchin barrens between the 13 analysis units and exposure classes

The percent cover for the urchin barrens across the 13 analysis units was analysed by a Kruskal-Wallis test to give a Chi square calculation = 79.76, at 12degrees of freedom where P = 4.02 $X10^{-12}$. This means that there are significant differences in % urchin barrens between some of the analysis units. Pairwise Mann-Whitney comparisons show that units L and M are very different. Also units E and G and J are different to some extent. Figure 7 contains the box plots comparing percent cover by analysis unit for urchin barrens.

The percent cover for urchin barrens across the three exposure categories was analysed by a Kruskal- Wallis test to give a Chi squared calculation = 6.972, at 2degrees of freedom where P = 0.030. This is a modestly significant result and means that at least 2 of the 3 exposure categories have significantly different urchin barrens coverage. Mann-Whitney pairwise comparisons show that Exposed and Partly exposed sites are significantly different at P = 0.0076. Figure 8 contains the box plots comparing percent cover by exposure class for urchin barrens.

Figure 3: Box plots of kina percent cover (y axis) across the 13 analysis units (A-M)(x axis).
(Line in the box = median, box = 25-75 percent quartiles, whiskers are minimum and maximum values).

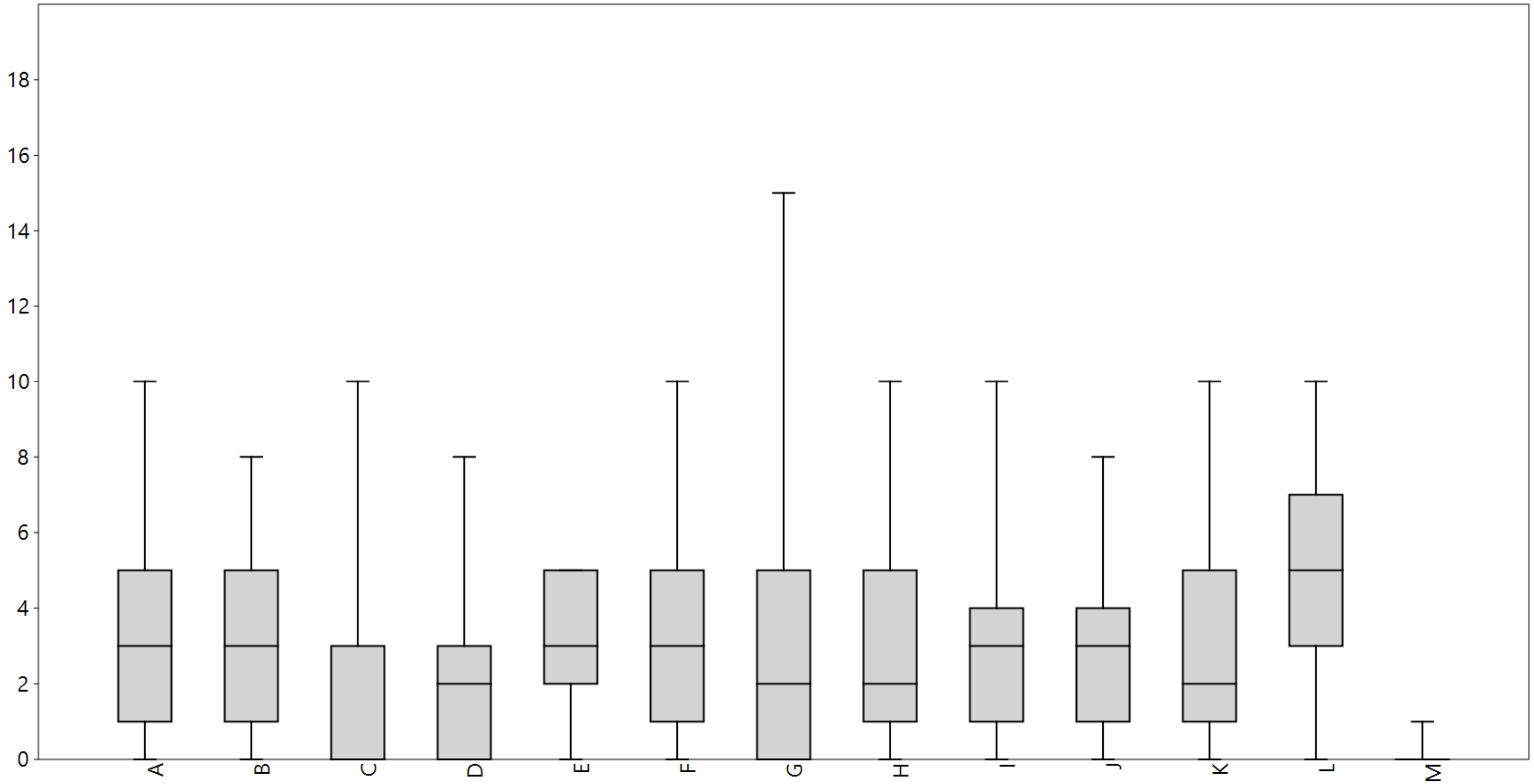


Figure 4: Box plots of kina percent cover (y axis) across the three exposure classes (x axis)
(Line in box = median, box = 25-75 percent quartiles, whiskers are minimum and maximum values.)

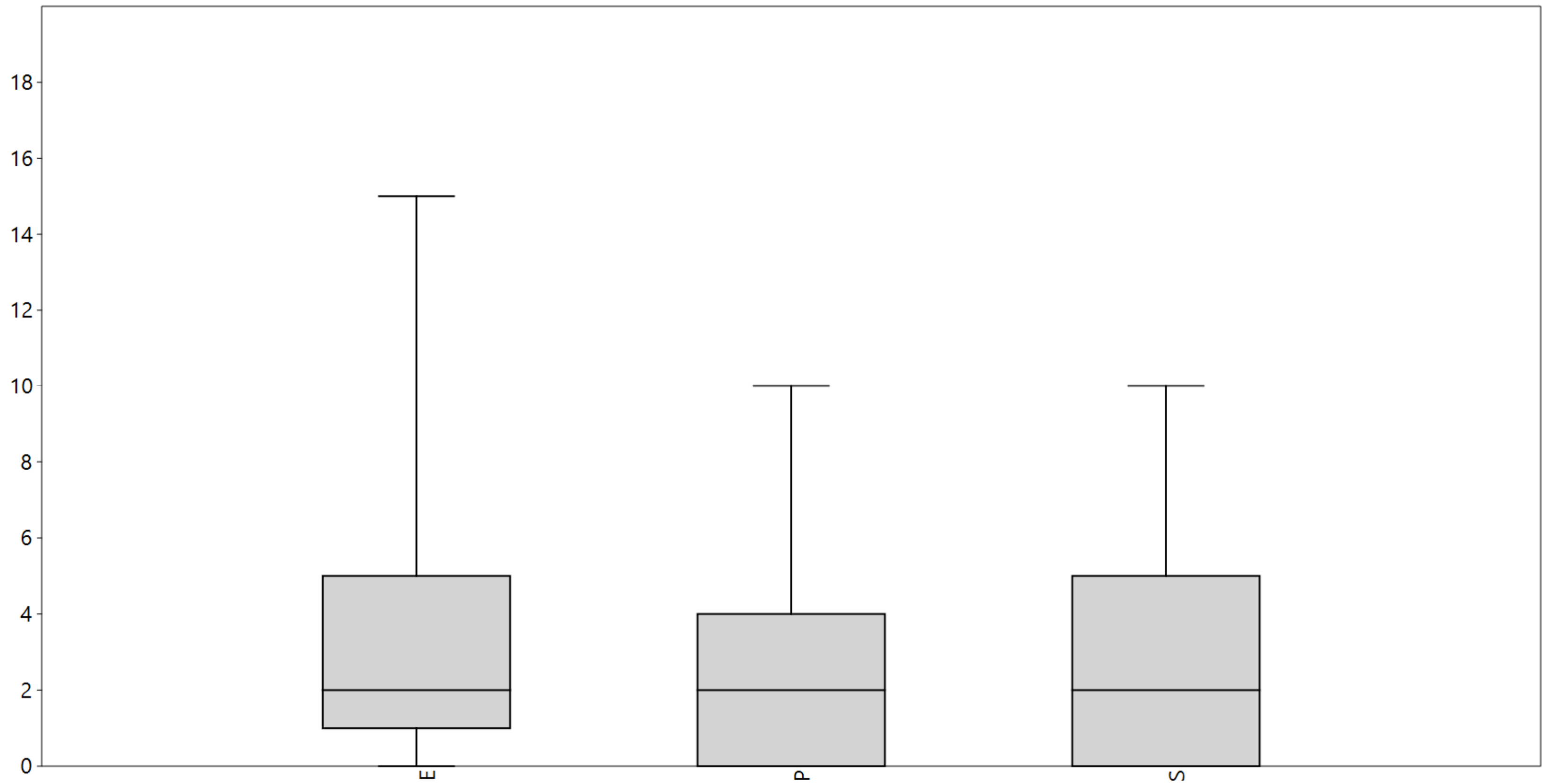


Figure 5: Box plots of tall brown algae cover (y axis) across the 13 analysis units (A-M) (x axis)
(Line in the box = median, box = 25-75 percent quartiles, whiskers are minimum and maximum values)

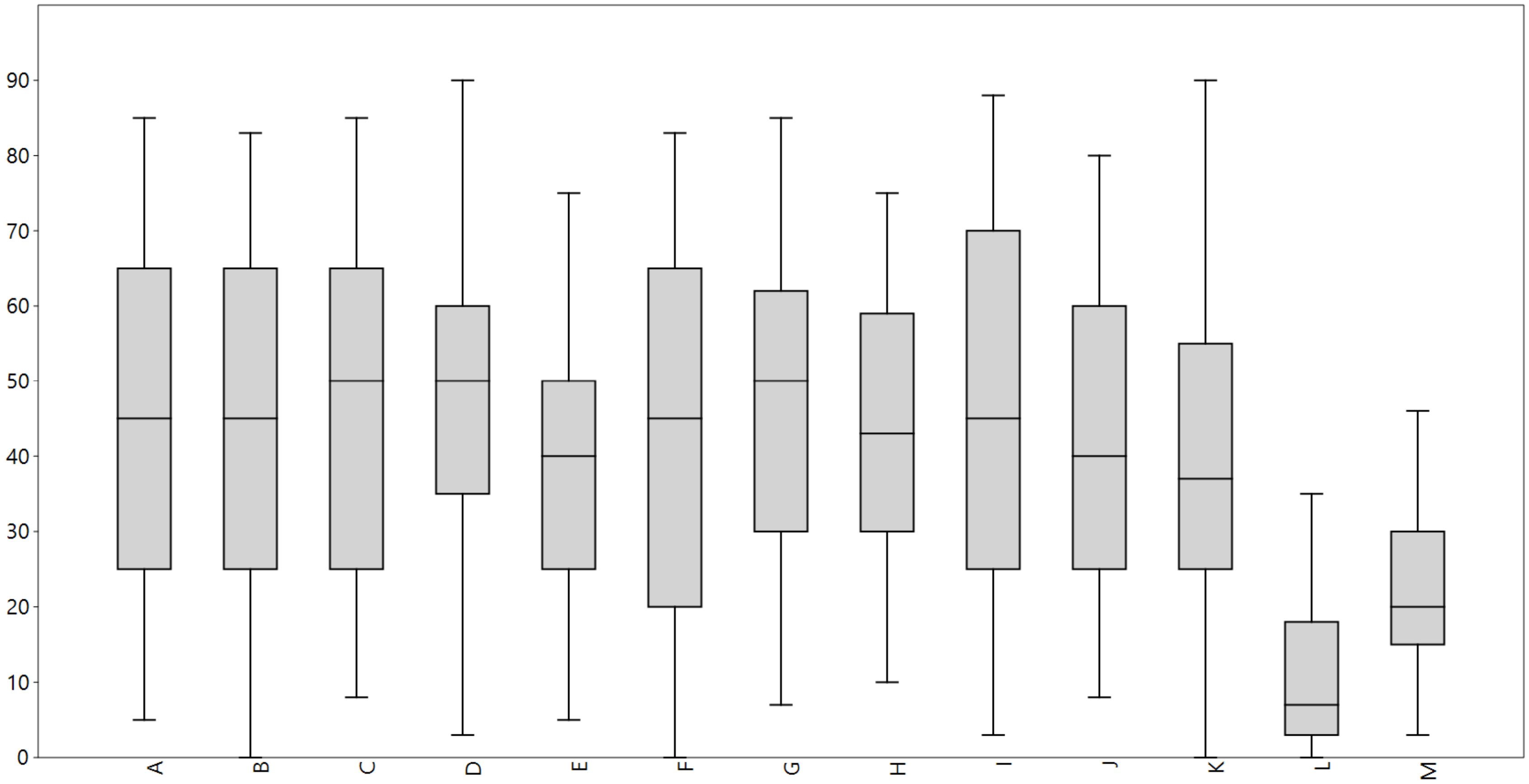


Figure 6: Box plots of tall brown algae percent cover (y axis) across the three exposure classes (x axis)
(Line in box = median, box = 25-75 percent quartiles, whiskers are minimum and maximum values.)

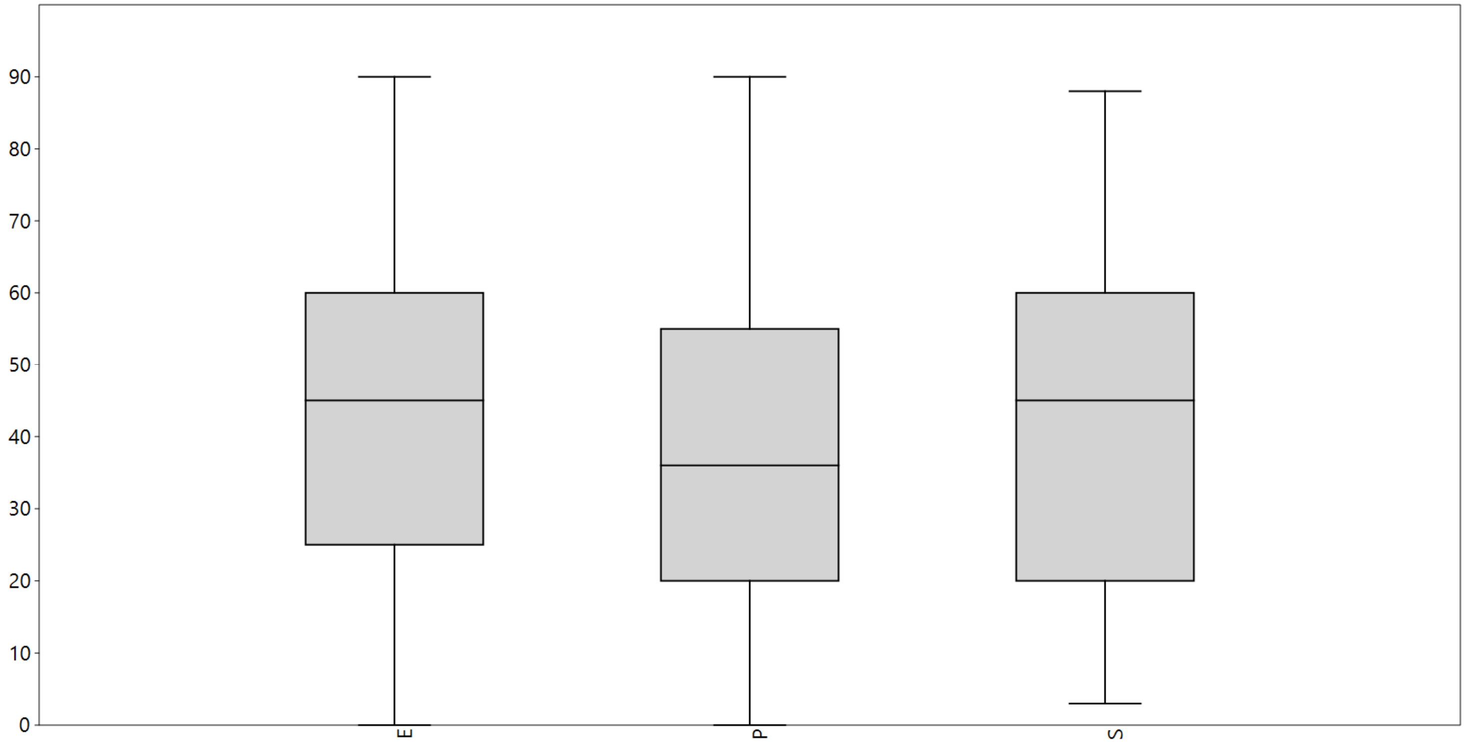


Figure 7: Box plots of percent kina barrens (y axis) across the 13 different analysis units (x axis)
(Line in box = median, box = 25-75 percent quartiles, whiskers are minimum and maximum values)

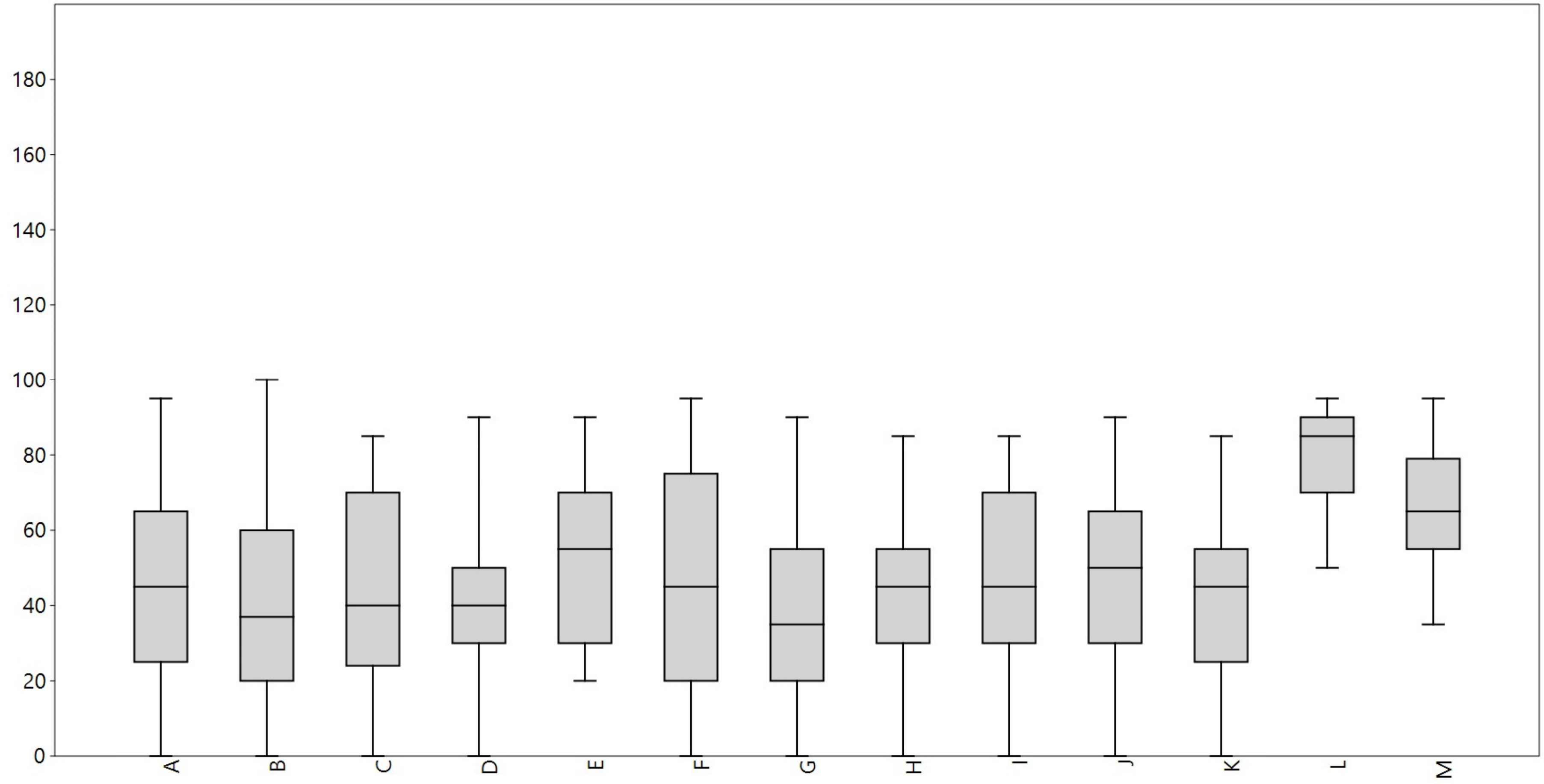
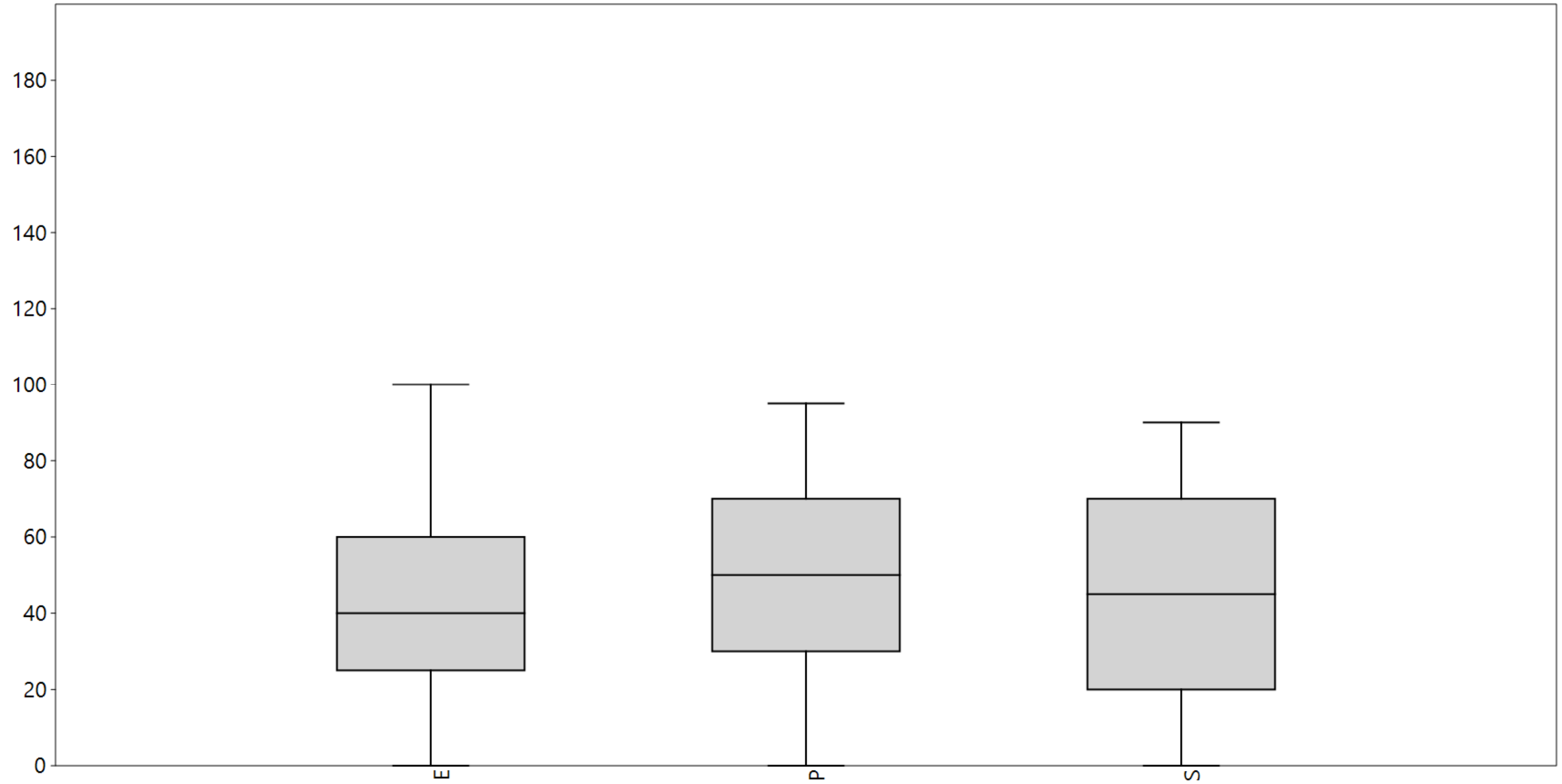


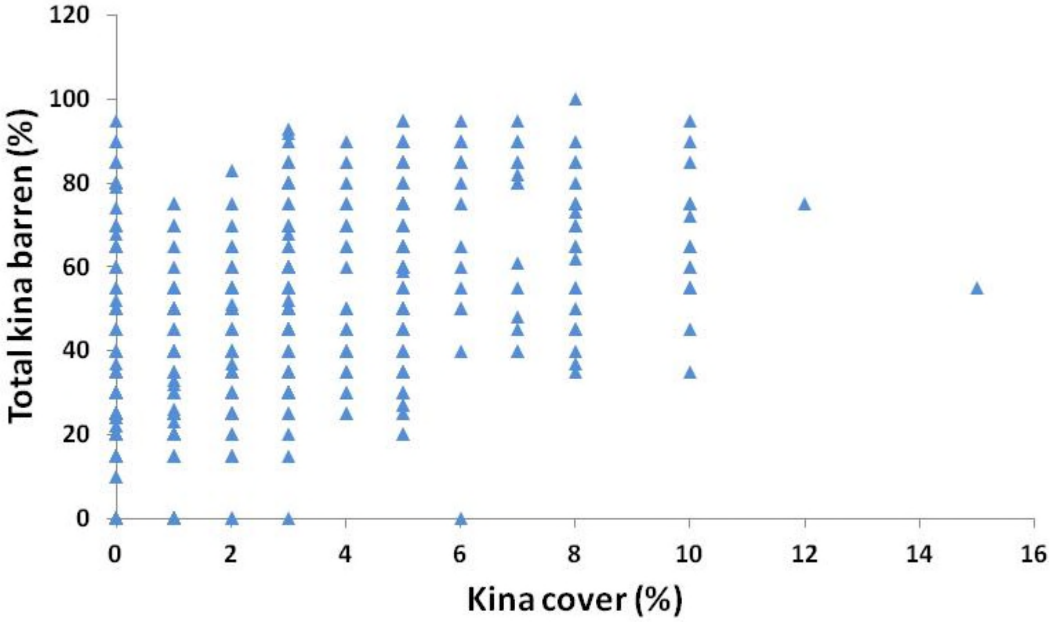
Figure 8: Box plots of urchin barrens percent cover (y axis) across the three exposure classes (x axis)
(Line in box = median, box = 25-75 percent quartiles, whiskers are minimum and maximum values.)



Comparing percent cover for kina with percent cover for urchin barrens

A comparison of percent cover for kina cover with the percent cover or extent of urchin barrens gave a Spearman rank rs = 0.517 where P = $1.21x10^{39}$. This means that there is a very significant positive association between percent cover for kina and the percent cover of urchin barrens.

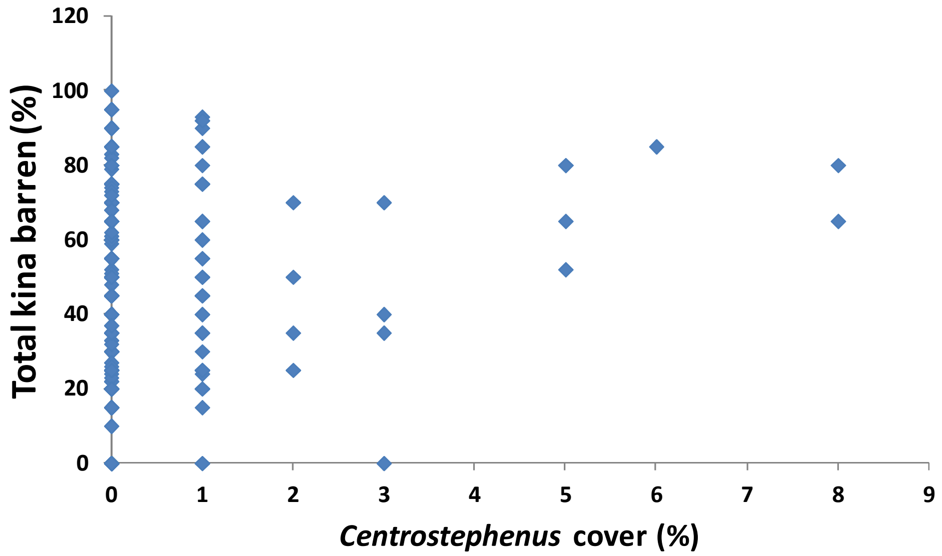
Figure 9: Percent cover of kinas compared to the percent cover of urchin (kina) barrens



Comparing percent cover for Centrostephanus with percent cover for urchin barrens

A comparison of percent cover for *Centrostephanus* compared to the percent cover or extent of urchin barrens gave a Spearman rank rs = 0.075 where P = 0.075. This shows that there is no positive association between the percent cover for *Centrostephanus* versus the percent cover of urchin barrens.

Figure 10: Percent cover of *Centrostephanus* compared to the percent cover of urchin (kina) barrens



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Hammer, Ø., Harper, D.A.T., Ryan, P.D. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4(1): 9pp. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

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Appendix 2: Field observation descriptive summaries

Table 1 contains a qualitative summary of the attributes of the surveyed areas. This is arranged by locality and survey date/ time. Where appropriate this includes some commentary about the shallow areas between the quadrats.

Table 1: Summary of general observations for each snorkel assessment

Locality	**Date and time of assessment**	**General observations**
1-20 Maunganui Bay North and Deep Water Cove	Saturday 26 March, Reassessed 3 June 2016	This is the locality where most *Centrostephanus* were seen, especially inside of Putahataha Is and on the barrens component of White Reef. A number of quadrat locations had a relatively high proportion of *Ecklonia* without obvious urchin barrens. There were also areas of traditional urchin barrens. Some of these urchin barrens, especially in the west and at White Reef, were dominated by *Centrostephanus*. Urchin barrens were primarily inside of Putahataha Is and along the adjoining mainland; and on the southern part of White Reef. Along the eastern part of the northern shore and in Deep Water Cove, the reefs extend onto sand at relatively shallow depths. Schools of koheru, mackerel and some kingfish seen. Usual reef fish present but edible species were present in higher numbers and larger sizes that elsewhere in the Bay. (e.g. butterfish, snapper, pigfish),
Brett Peninsula –heading north from Deep Water Cove	Sunday 27 March 2016 1000-1145	Variable cover between 3-10m but some extensive areas of kina barrens. Visibility up to 10m Parore is the dominant fish species. There were groups demoiselles and kahawai, and relatively low numbers of reef fish (mostly red moki)
Brett Peninsula heading north from morning session	Sunday 27 March, 1400-1530;	As above but stopped survey once NE swells rose to near 2m. Then completed 4 quadrats around Putahataha Island –relatively extensive kina barrens present on inshore/sheltered shore.
Deep Water Cove west continuing from quadrat 26	Sunday 27 March 1600-1715	Kina barrens in shallows from <3m to 3.5m, then *Ecklonia* forest to sand at 7-8m. There is a variety of reef fish including frequent pigfish and juvenile snapper, plus a school of juvenile trevally
Deep Water Cove west continuing south and then west from quadrat X	Monday 28 March 1000-1230	Variety of cover combinations. Relatively few quadrats are all kina barrens. Abundant juvenile snapper and pigfish notable. School 30 mid- sized kingfish Archway is a "special site"
Deep Water Cove rest of southern shore, Motuwheteke Is, plus Brett Peninsula 1500m heading south towards Oke Bay	Monday 28 March 1330-1530	Blocks of *Ecklonia & Carpophyllum* kelps with turfs, juvenile tall browns, encrusting sponges and anemones and coralline paints. *Centrostephanus* and kina present, with the latter being most abundant. Schools of demoiselles, blue maomao, kahawai and

Locality	Date and time of assessment	General observations
		kingfish. Many fewer juvenile snapper on the open coast south of Deep Water Cove
Brett Peninsula heading south to Karerarewa Bay	Tuesday 29 March 0930-1300	Series of caves along this coast -biologically less interesting than Deep Water Cove arch. Rocky shore with some boulder and cobble fields. Kina barrens were often small and/or narrow depth band. *Ecklonia* was relatively abundant. Numerous parore, usual reef fish with juvenile snapper. School of 50 kingfish
Waewaetorea part eastern shore	Wednesday 30 March 0915-1100	
Karerarewa Bay bay to Whapukapiro Bay	Wednesday 6 April1030-1300	Overall kelps *Ecklonia* & *Carophyllum* dominate shallows with patches of turfs, including areas of tall diverse turfs. Some kina barrens with kina and only the very occasional *Centrostephanus*. Some small patches subtidal and intertidal mussels. Low kina numbers overall. Usual reef fish with schools of kingfish and kahawai. Blue maomao schools near headlands.
Whapukupiro Bay-Oke Bay east	Wednesday 6 April 1430-1700	Whapukapirau Bay is relatively shallow with low walls. Visibility reduced in the west because of wind re-suspending sand. Patchy bottom kelp intermingled with turfs etc. Some large schools of kahawai & kingfish. Some blue maomao by the headlands. Large schools silver drummer by Oke Bay. Low numbers of juvenile snapper. Usual reef fish.
Brett Peninsula coast from south of near the Twins half way to Ohututea Bay	Thursday 7 April 920-1210	In southern sector there was very good visibility - 15m+. Includes some caves and a small island separated from the mainland by a small gut. School kingfish with some kahawai. Diversity of reef fish. Schools of blue maomao by headlands
Brett Peninsula- rest of way to Ohututea Bay	Thursday 7 April 1300-1630	One cave had sea- eroding papa-type rock leading to significantly reduced visibility (<1m at site and still much reduced either side). Reef fish and blue maomao as before. Some very steep walls = 90 degrees with some overhangs. Some typical kina barrens but more commonly non-typical kina barrens with thinning kelps, turfs and coralline paints. Kina numbers not large. Very few *Centrostephanus*.
East side Waewaetorea continuing on from previous session & including north side	Friday 8 April 0930-1210	Reduced visibility compared to Brett Peninsula. Patches of dense kina and patches of kelp in good condition. Some caves – not special. In north central reef, mostly dominated by kina but with *Centrostephanus* in shallows.
Waewaetorea NW, W and S shore to complete circuit	Friday 8 April 2016 1400-1700	Shallow reef. Kina barrens mostly on the shallowest part of the reef 0.5m to 2.3m with kelp in good condition below this. 2 beaches on south have sparse seagrass. Cave in SE was very shallow and surgy. Turfs low and sparse

Locality	Date and time of assessment	General observations
Urupukapuka NE and northern part of east shore	Saturday 9 April 0930-1300	Kina tend to occur in dense congregations when present. Otherwise they are very sparse or absent. *Centrostephanus* only at 2 sites. Some typical kina barrens, most were patchy non-typical kina-modified habitats. Caves- with cover mostly various corallines, encrusting sponges of different colours in low-light areas. Two caves had sparse jewel anemones and one had a few white branching bryozoans.
Urupukapuka east side mid- section	Monday 25 April 1410-1655	Shore is primarily rock walls, some with more gradual sloping rock platforms. Typically *Carpophyllum ,* *Cystophora* and *Pterocladia* in most shallow parts of reefs. Then *Carphophyllum* with increasing *Ecklonia* with depth. Relatively dense patches of kelp in the shallows with more open areas with the red *Pterocladia* and common anemones. Kina patchy-often in cracks. Many more kina in south where there is more suitable less steep habitat. Only one *Centrostephenus* seen (on rock wall). Schools of blue maomao, sweep and parore on some headlands. Small group of kingfish. Usual reef fish &, unusually, 2 pigfish.
Urupukapuka eastern shore –southern- most sector	Tuesday 26 April 0945-1230	Walls initially then lesser slope reefs. Kina barren extent much greater in the south where less slope and less exposure to heavy swells. Very few *Lessonia* but not in plots. Many hundreds of kina seen compared to only 2x *Centrostephanus*. Greater extent of typical kina barrens in this sector. Caves shallow and too rough to enter with cloudy water. Usual reef fish, with some schools of blue maomao, sweep and parore near headlands in the north. Notably large number of silver drummer.
Oke Bay E & S	Tuesday 26 April 1545-1715	More extensive kina barrens compared to more open exposed coast. Some patches of *Carpophyllum* and *Ecklonia*. Low numbers of reef fish. Caves in east included encrusting sponges of various colours, small patches of jewel anemones and white branching bryozoans
NW Oke Bay- anticlockwise circuit Moturahurahu Is-coast around Kohangatara Point	Wednesday 27 April 0930-1230	Extensive typical kina barrens in NW corner of Oke Bay. Around the island most kina barrens are on the south side in the shallows with dense *Ecklonia* below. On the east and north side of the island there are extensive areas that were until recently mussel beds. Now these areas contain a variety of red and brown algae. On the north side algal cover is very diverse including *Zonaria* and *Glossostigma*, various red algae species and mostly juvenile tall brown algae. The coast to Kohangatara Point contained a mixture of diverse kelp and kina barrens. Around Kohangatara Point there are steep walls with diverse

Locality	Date and time of assessment	General observations
		kelp and kina barrens. Fish around Kohangatara Point included blue knifefish and kingfish. Good visibility 10m+
Kohangatara Point to Albert Channel	Wednesday 27 April 1425-1640	Walls with kelp and patchy kelp cover in places. The shallow bay to the west of the large arch contained very extensive kina barrens. There were also some kina barrens to the east of the arch. Arch northern wall is interesting with jewel anemones of a variety of colours, various encrusting and golf ball sponges, white branching and bushy bryozoans, and an unidentified "tusk bryozoan". A few *Centrostephanus* but kina very much dominant in the shallows. Overall extensive kina barrens are in: Oke Bay, especially the NW and passage to Moturahurahu Is; Bay immediately to the west of Kohangatara Point; and large bay to the west of the arch (near Hat Island).
Okahu NW rocks-NE corner and half way into Okahu Channel	Tuesday 28 April 0915-1240	Highly diverse habitat in the north with undulating topography and complex water flows. Kina barrens were often found in a narrow band and were usually non-typical. There were a few areas of typical kina barrens. Water clarity was about half of the Brett Peninsula on the previous day. No *Centrostephanu*s seen. Cave not entered as conditions were too rough. Steeper walls had more algae cover and diversity. Rock shelf in NE contained a patch of *Landsburgia*. On exposed outer shore coralline turfs were often tall. *Pterocladia* was common in shallows. Usual reef fish plus blue maomao, sweep and demoiselles.
Motukiekie SE headland to NE headland	Thursday 28 April 1410-1530	Visibility < 7m with stinging purple threads/tentacles in the north. Typically in 0-2m there was *Cystophora* with *Pterocladia lucida*, scattered smaller *Carpophyllum* and *Ecklonia* (deeper). Below this kina barrens were dominated by low turfs to 4.5m. Below this was typically *Ecklonia* forest which was absent on the moderately frequent sand areas. There were also areas of boulders with low turfs. Areas previously dominated by intertidal and subtidal mussels until 2011 now have none. These areas are now dominated by *Cystophora, Pterocladia lucida*, occasional tall coralline turf, and occasional other brown algae.
Tapeka W beach- east of Tapeka N beach	1 May 1100-1230; 1300-1530	Variable visibility but mostly 6-8m, reducing to 3m at the western-most point. Shallow arch was not deep enough to traverse. South & west contained a high proportion of kina barrens on rock & boulders. Most kelps and other algae were on steep faces on outer very exposed rock walls & slopes.
Okahu NW and part of S	6 May 1410-	Visibility mostly 6-7m, reducing in NE corner to 4m

Locality	Date and time of assessment	General observations
shoreline	1730	due to a large amount of particulates in the water. Rock reef extended to variable relatively shallow depths terminating in boulders & cobbles below in some locations. In places there were urchin barrens. Some were typical kina barrens with others being non-typical. Conditions were too rough to enter the caves. *Lessonia* was by some of cave entrances. Blue knifefish were seen in the NW corner. Otherwise typical reef fish.
Motungarara Island (SW of Okahu)	As above	Strong swells on north & western shores. Urchin barrens were mainly in the sheltered SE corner where it is less steep and there is less rock reef. Urchin density was not directly correlated extent of urchin barren. Many urchins in this area were small.
Motukiekie IsN shore	7 May 0920-1150	Visibility 6-8m. 1+NE swell with caves too rough to enter. Relatively little typical urchin barrens mainly low slope boulders and rock. Non -typical urchin barrens were usually in 4-7m depth with thinning kelps and varying densities of lower stature cover. Some areas had a relatively high proportion of kelps, especially on steep rock faces. There were schools of blue maomao & sweep, 1 kingfish & the usual reef fish.
Motutara Is (entrance to channel between Moturua and Motukiekie)	As above	More kina on sheltered, lee-steep south side. Outer exposed north slopes are steeper with more extensive algae cover and very few urchins. Shallow reef on west is dominated by *Carpophyllum* and *Lessonia.*
Moturua N shore from E corner to 2/3 way to W corner	7 May 1410-1640	NE1m swells stirred up water in shallows requiring quadrats to be moved several times. Visibility mostly 6-8m, but reduced in places. Algae dominated cover on steeper rock slopes. Here there were very few urchins. There were relatively few typical urchin barrens. Schools of blue maomao and sweep & usual reef fish.
Moturua N shore W corner-western shore to two western islands and Rangiatea & Motuoi Is	8 May 1030-1250	On steeper walls there were non-typical urchin barrens with thinning kelp and low stature cover, and areas with abundant kelp cover. For low slope areas on the western side of Moturua by the western islands there were typical urchin barrens in the appropriate depth range.
Motuarohia W shore and western section of N shore	14 May 1410-1700	Calm conditions without swell. Water visibility averaged 7-8m. Western side rock reef to 5m depth in SW corner and 8-9m in mid part of western shore. By the NW corner there were steep rock walls to greater depths. Caves were too shallow to be of much interest. Kelps were primarily *Ecklonia* with some *Carpophyllum & Cystophor*a. Urchin barrens in the SW corner were mainly found at 2-6m depth with

Locality	Date and time of assessment	General observations
		Ecklonia below. Northern section of western shore varied. There were some walls with minimal urchin barrens in the shallows. In comparison lower slope areas contained relatively large amounts of typical urchin barrens. Kina were often small, especially in the south. On the north coast there were steep walls with *Ecklonia, Lessonia* and limited *Carpophyllum*. Often *Pterocladiaella capillacea* was present as well as encrusting anemones and small amounts of encrusting sponges. In bays where there were low slope rock slopes, urchin barrens typically dominated with some *Ecklonia* and *Carpophyllum* (especially on the margins) Small numbers of blue knifefish & juvenile snapper. Typical reef fish in low numbers. No *Centrostephanus* seen.
Motuarohia N side mid-section	15 May 0930-1230	Visibility 8-10m. On steeper rock walls tall brown kelps predominated, with a zone of thinning kelp at 4-5m with turfs, juvenile tall brown algae, turfs and encrusting fauna. Often there was a high proportion of red algae, especially *Pterocladia and Pterocladiaella capillacea*. Kina were often absent unless there were deep slots. No *Centrostephanus* were seen. Flat bay mid-sections containing rock flats were dominated by urchin barrens. Lagoon had a rock bottom with sand and cobbles in the north. *Ecklonia, Carpophyllum* & *Cystophora* were present on rock. The cave was north facing with cover including encrusting sponges and coralline algae. Fish included kingfish, koheru, blue maomao, blue knifefish as well as the usual reef fish.
Motuarohia N shore –NE end plus E shore	15 May 1420-1720	As we travelled eastwards there were still steep rock slopes some without any urchin barrens and some with the non-typical urchin “barrens”. Many platforms and rock bases in bays were urchin barrens. The really bare barrens had far fewer kina than those barrens with more cover. The second lagoon was similar to the first (plus Neptune’s necklace). The eastern shore of Motuarohia was variable, but generally shallow with sand, cobbles, boulders and areas of rock. Boulders and rock mainly had a turf and coralline paint cover. Occasional wall areas were similar to the walls on the northern shore. No *Centrostephanus* were seen.
Te Miko Reef (west of	As above	There was a relatively small amount of urchin barrens

Locality	Date and time of assessment	General observations
Moturua Island)		even though the top is now bare (having been cleared of its former mussel cover). There was a zone between 2-4m with thinning kelp (usually *Carpophyllum* with *Cystophora*), encrusting fauna, turfs and juvenile tall brown algae. No kina were seen.
Black Rocks s	16 May 1000-1320	Mostly walls on all sides, often 70-90 degree slopes. Visibility 7m. Variable bottom depth depending on location. In the north the intertidal contained scattered mussels, limpets and abundant barnacles. The first 2m of subtidal wall had a cover of *Carpophyllum* (mostly *C mashalocarpum*) with *Cystophora*, , occasional *Ecklonia*, abundant *Pterocladia*, some mussels, and some tall coralline turfs. Where mussels had been removed there were more low turfs and algal felts. For the subtidal walls from 2-7m deep *Ecklonia* formed 10-30% of the cover with *Pterocladia*, tall coralline turfs, and encrusting fauna (sponges, anemones, bryozoans). Occasional mussels were present. Very few kina were seen. The kina that were seen were usually associated with areas of mussel removal. The northern most rock is a special site. Abundant blue maomao and sweep. The southern Black Rocks group is similar to the northern Rock but with slightly reduced visibility and less diverse encrusting fauna. The intertidal area was similar to the northern rocks plus the occasional *Lessonia.* There were fewer tall brown in the 2.5m-7.5m depth range. There was also a higher cover of encrusting fauna (especially in some locations), as well as more low turfs and algal felts.
SW corner Ohututea Bay to Otuwhanga Is NW corner (tip of Cape Brett)	4 June 1000-1215; 1310-1600	Water clarity varied from 12m to 8m (for bay heads with salps). Water temperatures decreased by 1 degree from south to north (Cape Brett). Special areas included: Cave with diverse encrusting sponges & anemones "Lagoon" with cave & sheltered rock faces with compression zonation Dolphins Slot between Cape Brett & Otuwhanga Island which included seals and clear water with high current (and more *Lessonia*). This section of coast contained relatively extensive urchin barrens (some non-typical). Some areas of urchin barrens were continuous between two quadrats. Typically the urchin barrens were deeper

Locality	Date and time of assessment	General observations
		than elsewhere, extending from 4-5m to more than 10m in depth. There were patches of heavily thinning kelp, especially *Carpophyllum*. These areas were assigned to the non-typical kina barren category. Kina cover was higher here than further south. Only the occasional *Centrostephanus* was seen. Most sites had slopes and walls with slopes 45-70 degrees. There were a few rock areas with slopes of about 20 degrees. Even the steeper sites had kina barrens but these were typically below 4-5m. Kina were typically large except by Cape Brett. *Lessonia* was common in several areas near Cape Brett and in the channel between Cape Brett and Otuwhanga Island. There were a few areas with tall turfs. There were large schools of blue mackerel towards Cape Brett. Schools of blue maomao were present in the slot north of Cape Brett. Usual reef fish were present.