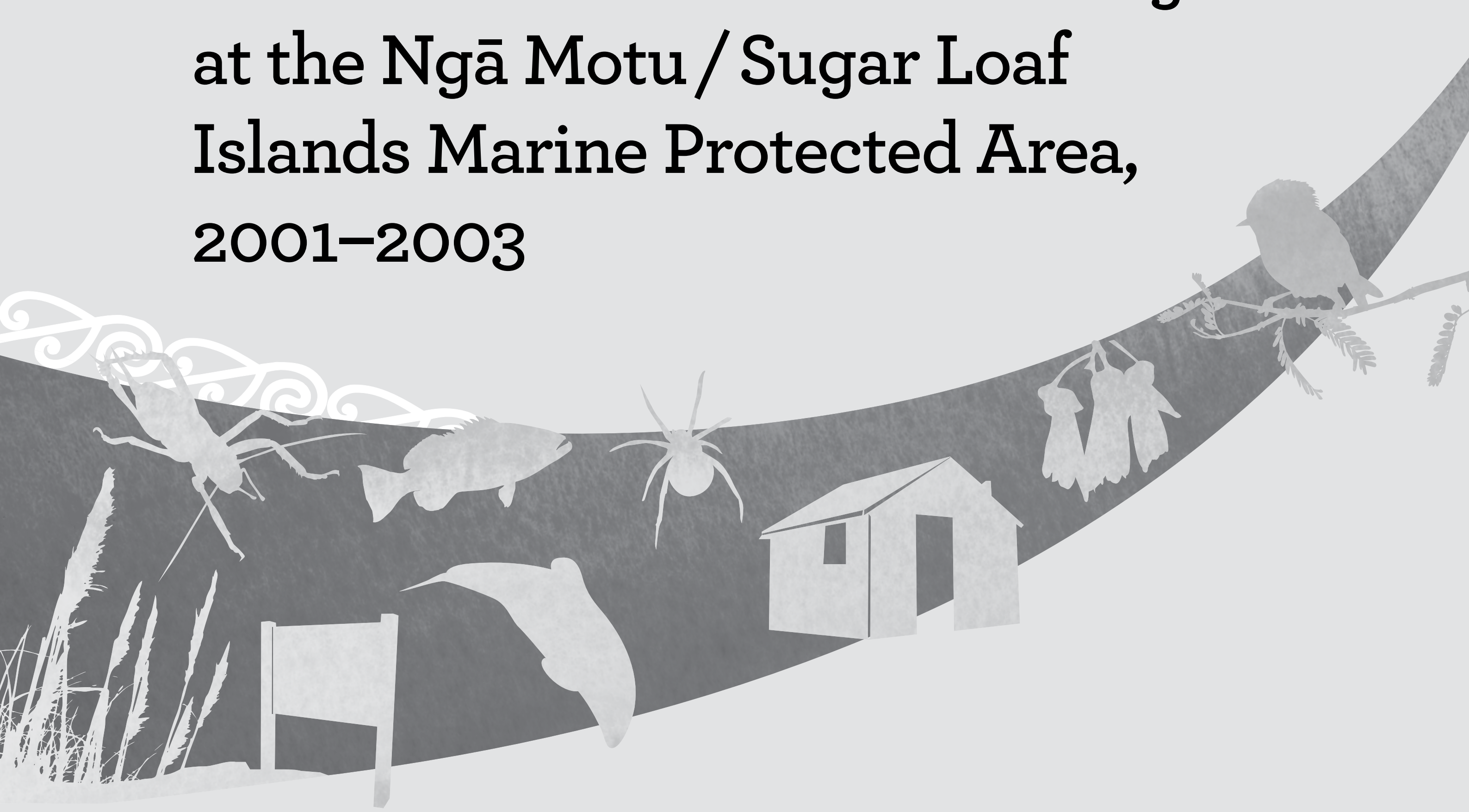
Benthic invertebrate monitoring at the Ngā Motu / Sugar Loaf Islands Marine Protected Area, 2001–2003



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Sonja Miller, Simon McDonald and Bryan Williams

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Abstract

Ngā Motu/Sugar Loaf Islands Marine Protected Area (SLIMPA), which lies off the west coast of the North Island, New Zealand, was established in 1991. However, baseline data to assess its effects on the conservation or rehabilitation of reef communities were not collected until a decade later. In 2001, an invertebrate monitoring programme was initiated to detect long-term trends over time at sites under different management regimes, and to establish a baseline for future monitoring and impact assessments at SLIMPA. At the time of survey, SLIMPA comprised two fisheries management zones. Within the largest zone, all commercial fishing (except trolling for kingfish (*Seriola grandis*) and kahawai (*Arripis trutta*)), recreational set netting and longlining, were prohibited. In the second zone, which was a circular 'Conservation Area', all fishing except trolling and spear fishing for kingfish and kahawai was prohibited. During 2001, 2002 and 2003, the benthic assemblages of subtidal rocky reefs were surveyed at two sites within each of the two zones and at two reference sites outside SLIMPA. The densities of many of the benthic species surveyed significantly differed between survey sites and years, but in many cases a significant site-by-year interaction resulted in observed patterns being inconsistent. There were significant associations between kina (*Evechinus chloroticus*) and species such as coralline algae, suggesting that kina were associated with 'barrens' habitat. The catch-per-unit-effort and size of rock lobsters (*Jasus edwardsii*) were higher inside the Conservation Area than at any other site. However, it was difficult to detect statistically significant trends for species monitored because of the high variability in species metrics and the short monitoring time-frame. Therefore, we recommend that the power of the sampling design be increased and data be obtained over a longer period of time in the future to provide valuable information for the management of SLIMPA. Data from the reference sites used in this survey will also provide useful baseline information for future monitoring of Tapuae Marine Reserve.

Keywords: benthic invertebrate monitoring, species protection, underwater visual census, benthic community, Ngā Motu (Sugar Loaf Islands), marine protected area, New Zealand

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1. Introduction

Ngā Motu / Sugar Loaf Islands Marine Protected Area (SLIMPA) is located between the Port Taranaki breakwater and Herekawe Stream, Back Beach, New Plymouth, New Zealand. At the time of survey, SLIMPA covered 749 ha of seabed, foreshore and water surrounding Ngā Motu/ Sugar Loaf Islands (hereafter 'Ngā Motu'). However, in June 2008, the southern boundary of SLIMPA was altered when Tapuae Marine Reserve was gazetted. The offshore islands provide a unique semi-sheltered environment along a coastline that is generally very exposed. The subtidal marine habitats include caves, rock faces with crevices and overhangs, large pinnacles, boulder fields, and extensive areas of sand. The area is influenced by the northeast flow of the Tasman Current, and seasonally by the southeast flow of the West Auckland Current.

SLIMPA is not a marine reserve; rather, it is a marine protected area. Under the Fisheries Act 1983, regulations to control commercial and recreational fishing in the area were gazetted in 1986 when the area was declared a marine park, with formal establishment of SLIMPA occurring five years later under the Sugar Loaf Islands Marine Protected Area Act 1991. The area's Conservation Management Plan notes the presence of a diverse range of underwater habitats within SLIMPA, and states that the natural character of these habitats needs to be protected and maintained (Fechney 1997). SLIMPA is managed jointly by the Department of Conservation (DOC) and the Ministry for Primary Industries (MPI) under the SLIMPA Act 1991, and by the Taranaki Regional Council under the Resource Management Act 1991. Specifically, the foreshore, islands, seabed and water are managed by DOC as a conservation park, and the fisheries resources within SLIMPA are managed by MPI.

Recreational fishing (including potting for rock lobsters *Jasus edwardsii*) and diving are popular activities within SLIMPA. Consequently, two fisheries management zones were established in 1986 to manage access to fisheries resources within SLIMPA (Fig. 1). In the smallest zone, hereafter referred to as the 'Conservation Area'[1], which was a circle (500 m radius) with Waikaranga (Seal Rocks) at its centre, all fishing except trolling and spear fishing for kingfish (*Seriola grandis*) and kahawai (*Arripis trutta*) was prohibited. In the largest zone, which made up the rest of SLIMPA, all commercial fishing (except trolling for kingfish and kahawai), recreational set netting and long lining were prohibited. Spoil dumping and activities that may disturb the foreshore and seabed, including anchoring by commercial vessels and mining, were also restricted throughout SLIMPA.

SLIMPA is influenced by processes that occur beyond its boundaries, such as long-shore sediment transport. Human activities also have the potential to alter the ecological state of SLIMPA. For example, the close proximity of New Plymouth and Port Taranaki exposes SLIMPA to risks such as toxic chemical or petroleum spills, or the accidental introduction of foreign marine organisms from ballast water or the hulls of ships. Baseline information and ongoing monitoring will enable early assessment of the effects of any spill on SLIMPA and early detection of potential marine invasive species.

To manage effectively, managers need to be able to document changes associated with management practices, and to distinguish variability associated with natural change from that resulting from human impacts and management (Thrush et al. 1988). Although SLIMPA was established in 1991, there was no attempt to describe natural variability in any ecological assemblage occurring within it, or to assess the ecological effects of the fisheries management zones until late February and March 2000. At this time, DOC's New Plymouth Area Office undertook a pilot study of selected rocky reef assemblages within SLIMPA and at two reference sites. Following this pilot study, monitoring surveys of the benthic invertebrate community were

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[1] The Conservation Area is now part of Tapuae Marine Reserve.

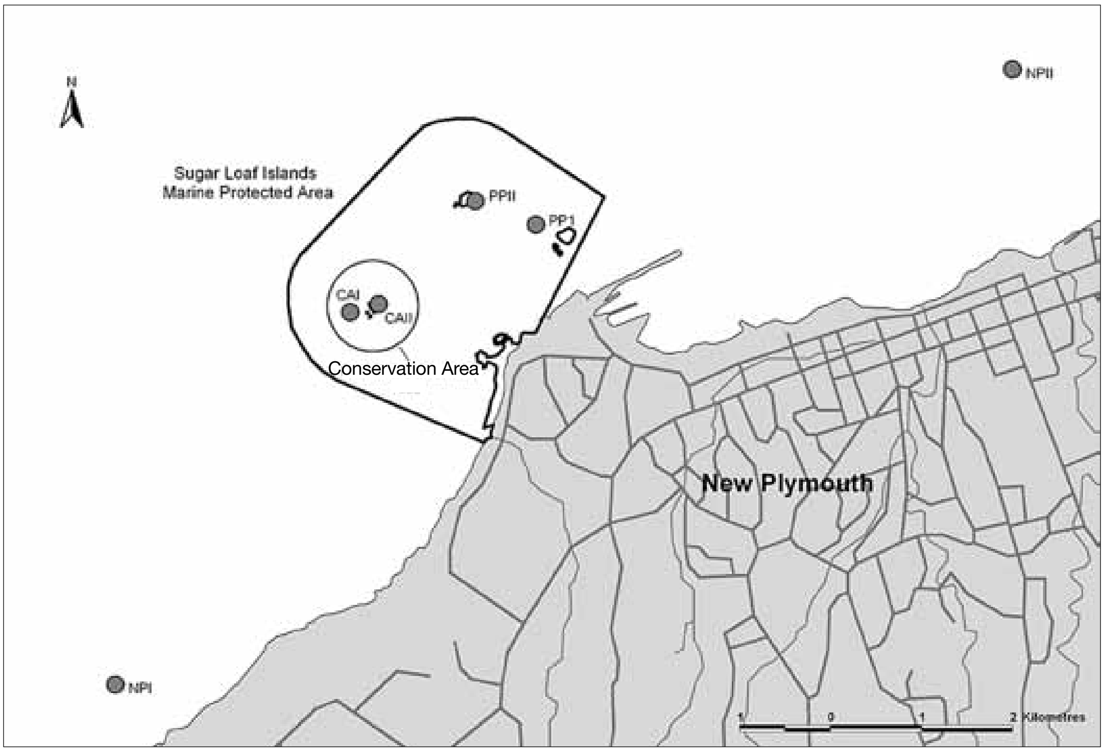

Figure 1. SLIMPA survey sites: Conservation Areas CAI (Post Office) and CAII (Seal Rock); partially protected areas PPI (Bill's Rock) and PPII (Saddleback); and the reference sites from the no-protection areas NPI (Tapuae) and NPII (Waiwhakaiho).

carried out through the summer months of 2001, 2002 and 2003 as part of a larger programme that included the monitoring of reef fish populations.

The primary objective of monitoring at SLIMPA was to detect long-term trends over time at specific sites within different management zones. This report presents and discusses the results of the benthic invertebrate monitoring survey undertaken in 2001, 2002 and 2003. Focal species included rock lobster, sea urchin (or kina, *Evechinus chloroticus*) and three molluscs (*Cookia sulcata, Trochus viridis* and *Calliostoma punctulatum*), all of which are integrally linked with subtidal habitat structure (e.g. the distribution of common kelp *Ecklonia radiata*) within SLIMPA.

2. Methods

2.1 Site selection

Two sites from each management zone and two reference sites outside SLIMPA were selected for sampling (Table 1). Sites CAI and CAII were located inside the Conservation Area, sites PPI and PPII were within SLIMPA but outside the Conservation Area (i.e. under partial protection), and sites NPI and NPII were no-protection reference sites (Fig. 1, Table 1). All of the sites sampled within SLIMPA contained habitats that were considered typical of the subtidal reefs occurring around Ngā Motu. Unfortunately, similar reference sites were not available nearby due to the unique characteristics of Ngā Motu on the Taranaki coast. However, reefs supporting similar communities to those found in SLIMPA are located a short distance away, rendering them useful as reference sites (based on Kelly 1999). Both reference sites were exploited by commercial and recreational fishers and divers. Habitat descriptions for each site are given in Table 1.

A visual record of the habitat types present at each site was made using underwater video and photographs. This information is held at the DOC Taranaki Area Office.

Table 1. Description of the SLIMPA monitoring sites.

CODE	SITE	MANAGEMENT ZONE	HABITAT DESCRIPTION
CAI	Post Office	Conservation Area	At a depth of 6 m, the reef is covered with *Carpophyllum maschalocarpum*. The seabed surrounding the reef is a mixture of lava reef and broken rock in the north, and lava base covered in part by large boulders, cobbles, shell fragments and sand in the south.
CAII	Seal Rock	Conservation Area	The seabed is lava with a cover of large bare rocks and boulders, and has an established area of common kelp (*Ecklonia radiata*) forest. Lava rock walls surround the study area. The intertidal section of the walls is covered in *C. maschalocarpum*.
PPI	Bill's Rock	Partial protection	This is an isolated volcanic reef surrounded by sand/mud. The western face of the reef slopes down to the seabed and has a 70% cover of common kelp, while the eastern face is a sheer drop off of 7.5 m, at the northern end of which is a small cave with a mud bottom.
PPII	Saddleback	Partial protection	This area is exposed to the westerly swell, and its substrate is large boulders (boulder bank). The boulder bank runs north–south with the slope east at 16 m depth, and west at 8 m depth, closest to the island. There are clumps of common kelp at the base of the boulder bank.
NPI	Tapuae	No protection (outside SLIMPA)	This is a low volcanic reef that rises up to 1 m above the surrounding sea floor. It contains overhangs, large boulders up to 1 m in diameter, small boulders, pebbles, sand and shell fragments. There is a high percentage cover of silt over parts of the reef. Small clusters of common kelp are present.
NPII	Waiwhakaiho	No protection (outside SLIMPA)	This is a large, flat, volcanic reef with an overhang approximately 1.5 m high. The overhang generally runs east–west and is horseshoe-shaped. The base of the overhang is mud/pebble sediment.

2.2 Survey methods

2.2.1 Benthic community

SCUBA divers sampled the subtidal algal and benthic invertebrate assemblage at each site using randomly placed 1 m^2 quadrats on selected reefs. Each diver used a sampling method that required a random number of kick cycles at random directions between each quadrat sampled (care was taken with the random method to ensure that quadrat samples were independent from each other). Within each quadrat, the substrate type and depth were recorded. The abundance of grazing invertebrates, percentage cover of algae and encrusting invertebrates, and density of kelp in each quadrat were also recorded on pre-printed data sheets (a hard copy of this information is stored at the DOC Taranaki Area Office).

All survey work was carried out in late summer – early autumn of each survey year (2001, 2002 and 2003). The timing of sampling was determined by sea and weather conditions.

2.2.2 Rock lobsters

Rock lobsters were surveyed at each site using diver counts and visual estimations of sex and carapace length at den sites where they were known to aggregate. A single diver (Bryan Williams) thoroughly searched all known rock lobster shelters at each site. Carapace length (estimated in 10 mm increments) and sex were determined without removing lobsters from their shelters. The sex of all but three individuals was determined over the 3 survey years. Dive conditions determined the sampling effort or search time at each location surveyed. Search time was estimated by subtracting the descent and ascent times from diver bottom time at each site. Bottom time and sampling depth were recorded using an Aladan Air dive computer.

2.3 Data analysis

Data from each year's surveys were entered into a Microsoft Excel workbook and then groomed to ensure consistency and correct identification of species. Since identification and recording of benthic species was highly variable between divers, much of the benthic data were amalgamated into broad taxonomic or functional groups for analysis (e.g. coralline algae, sessile invertebrates (comprising encrusting sponges and ascidians), Chlorophyta and Rhodophyta, and top shells). Subtidal species that were inconsistently recorded (e.g. anemones, brittlestars, bryozoans, tubeworms, whelks, crabs, limpets and chitons) were excluded from the analyses.

2.3.1 Benthic community structure

Canonical Analysis of Principal coordinates (CAP) (Anderson 2004), which is a constrained ordination technique, was used to test the null hypothesis of no significant difference in key species/species groups comprising the benthic invertebrate community between management zones (CA, PP and NP) for each year (Anderson & Willis 2003). The program first carried out Principal Coordinate Analysis (PCA), an unconstrained ordination, to examine patterns in the dataset. A Canonical Discriminant Analysis was then carried out on the resulting PCA axes to produce a constrained ordination that was based on an *a priori* hypothesis to create the plot and maximise group separation (Miller et al. 2005). Data were $\ln(x+1)$ transformed to remove scale differences between invertebrate species included in the analysis (Anderson & Willis 2003) and a Bray-Curtis dissimilarity matrix was calculated. In 2001 and 2003, $m = 4$ was used as the basis for the Canonical Discriminant Analysis, as over 90% of the variation was explained in the first four PCA axes, while in 2002, $m = 3$ was used, as just over 85% of the variation in the original data was explained in the first three PCA axes (Anderson & Willis 2003). Plotting the first two canonical axes for each year allowed differences between management zones and sites to be assessed. Correlations of species/species groups with the canonical axes were also examined to assess which species/species groups may be driving any observed groupings. A 'goodness of fit' test was derived from the classification and compared with the original grouping of the data by management zone to assess the accuracy of the grouping of the benthic invertebrate transect data (Anderson & Willis 2003; Miller et al. 2005).

2.3.2 Benthic community density and percentage cover data

Potential ecological relationships were investigated for the common kelp *Ecklonia radiata*, a laminarian brown alga; species of green and red algae belonging to Chlorophyta and Rhodophyta, respectively; sessile invertebrates; coralline algae; the sea urchin or kina, *Evechinus chloroticus*; Cook's turban shell, *Cookia sulcata*; and the top shells *Calliostoma punctulatum* and *Trochus viridis*. This allowed patterns between monitoring sites to be identified and datasets to be compared between years.

Since many of the data collected (counts, percentage of total cover) were non-normal, over-dispersed and did not meet the assumptions required for Analysis of Variance, data were analysed using generalised linear models (GLMs) (Quinn & Keough 2002) with a negative binomial distribution and a log link function (Gardner et al. 1995). Year and site were included as fixed factors in all GLMs, and the year-by-site interaction was also included in all models. The Wald statistic (Wald χ^2) was used to test the significance of the factors in the model. *Post hoc* Sidak's pairwise comparison tests were also performed to examine possible differences in densities or percentage cover between levels of a factor.

Relationships between habitat-forming species such as common kelp and habitat-determining species such as kina were investigated using simple linear correlation. Where appropriate, regression equations were also fitted to the data to further describe ecological patterns.

The statistical software PASW Statistics 18 (SPSS 2009) was used to conduct all analyses.

2.3.3 Rock lobster abundance and size

The search time for rock lobsters was used to calculate catch-per–unit-effort (CPUE) at each site. CPUE data were also used to determine the relative abundance of male and female rock lobsters.

Rock lobster CPUE data were analysed using GLMs with the Tweedie distribution, which is more appropriate for the analysis of CPUE data where a log link function is used (Candy 2004). Three GLMs were used to analyse the rock lobster CPUE data: the first included year, site and sex as fixed factors, as well as all two-way interaction terms, while the second included only year and site, and their interaction, while the third included only year and zone, and their interaction. Wald χ^2 was used to test the significance of the factors in the model. *Post hoc* Sidak's pairwise comparison tests were also performed to examine possible differences in CPUE between levels of year, site or zone.

Rock lobster carapace length data were analysed using GLMs with the normal distribution and an identity link function. The model included year, zone and sex as factors, as well as all two-way interactions.

2.3.4 Kina size

Kina test diameter data were analysed using a GLM with the normal distribution and an identity link function. The model included year and zone as factors, and their interaction. Wald χ^2 was used to test the significance of the factors in the model. *Post hoc* Sidak's pairwise comparison tests were also performed to assess whether there were any differences in kina test diameter between levels of year or site.

3. Results

Sample sizes (total number of quadrats across all sites) for 2001, 2002 and 2003 were $n = 118$, 144 and 157, respectively. There were small inconsistencies in the number of quadrats sampled between species and between years at the six sites due to difficulties with sampling in rough seas and inconsistent diving conditions. The percentage cover of different substrate types varied considerably between survey sites (Fig. 2). The mean abundance, percentage cover, standard errors and sample sizes for all species surveyed except rock lobsters are summarised in Appendix 1.

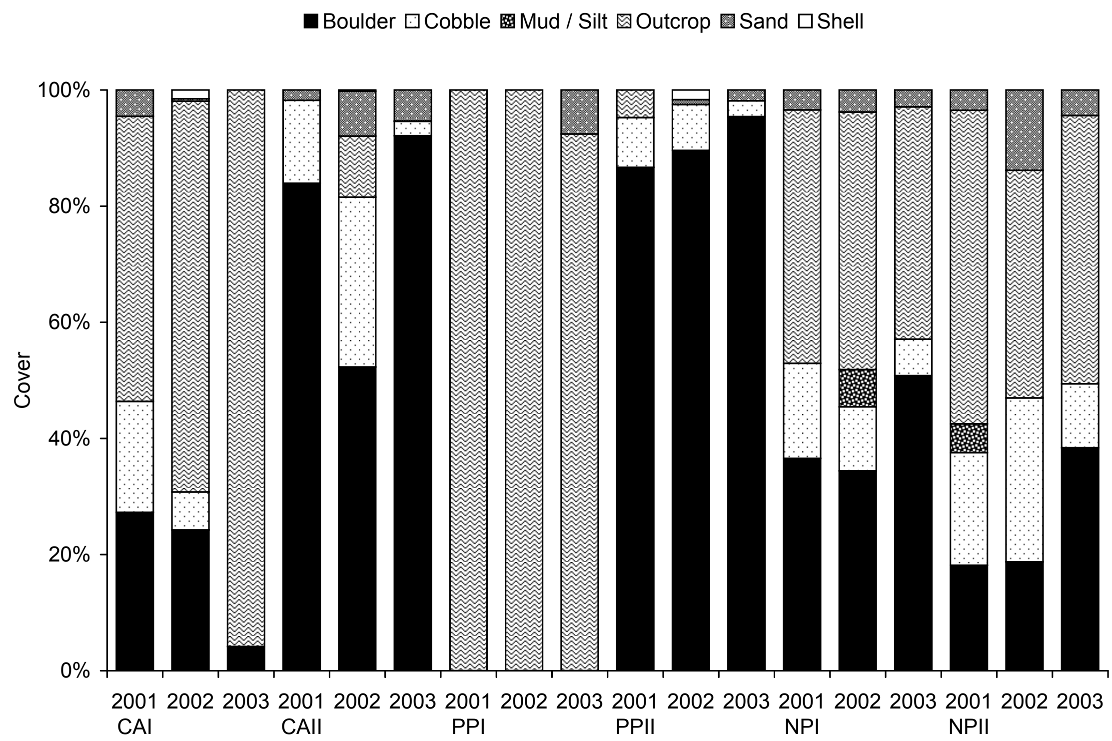

Figure 2. Percentage cover of different substrate types at the six monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

3.1 Benthic community structure

Figure 3 shows the results of the discriminant analysis of principal coordinates for each of the 3 sampling years in two-dimensional space. Each point on the plot represents the assemblage of key benthic species along a single transect. The closer one point is to another, the more similar the assemblages of key benthic species are. In 2001, transects from the Conservation Area of SLIMPA grouped together to the left of the graph. However, transects from the reference sites were also distributed in a similar pattern, while partially protected sites were distributed more to the right of the graph (Fig. 3). In 2002, the spatial groupings of management zones differed, with partially protected sites grouping more to the left, sites in the Conservation Area spread across the top of the graph, and reference sites grouping more to the right of the graph (Fig. 3).
In 2003, the pattern was similar to that of 2002, but with a wider distribution of groups across two-dimensional space (Fig. 3).

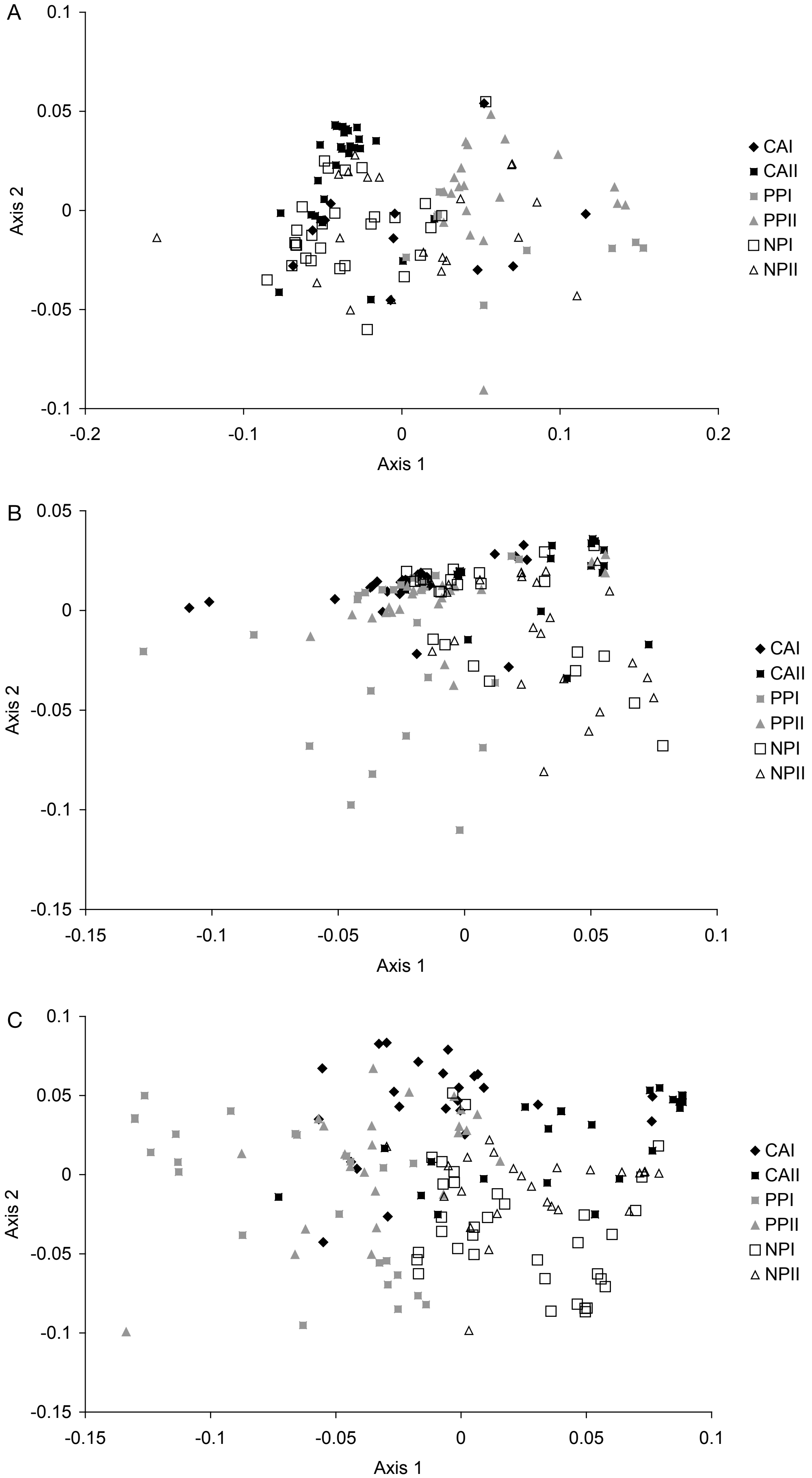

Figure 3. Discriminant analysis of principle component analysis (PCA) axes of key benthic species based on Bray-Curtis dissimilarity in A. 2001 ($m = 4$), B. 2002 ($m = 3$) and C. 2003 ($m = 4$). See Table 1 for an explanation of the monitoring site names.

'Goodness of fit' of the groups resulting from the discriminant analysis is shown in Table 2. Overall, fewer transects were correctly allocated to the appropriate management zone in 2002 than in the other years (Table 2). For example, in 2002, CAP only assigned 37.5% (18 out of a total of 48) of transects correctly to the Conservation Area, with 15 being incorrectly assigned to the partially protected zone and 15 to the no protection zone (Table 2). In contrast, in 2001, CAP assigned over 80% of transects correctly to the partially protected zone (Table 2).

Table 2. Misclassification error derived from the constrained ordination (discriminant analysis of the principal components analysis (PCA)). CA = Conservation Area, PP = partial protection, NP = no protection.

YEAR	CLASSIFICATION	NO. OF TRANSECTS	NO. ASSIGNED TO			% CORRECT	% MISCLASSIFIED OVER YEAR
			CA	PP	NP		
2001	CA	39	25	4	10	64.10	41.53
	PP	30	0	25	5	83.33	
	NP	49	19	11	19	38.78	
2002	CA	48	18	15	15	37.50	47.22
	PP	48	17	25	6	52.08	
	NP	48	19	4	25	52.08	
2003	CA	49	33	10	6	67.35	27.39
	PP	48	9	33	6	68.75	
	NP	60	11	1	48	80.00	

Table 3 shows correlations between the invertebrate and algal species analysed by CAP and axes 1 and 2, where the absolute value of the correlation is > 0.20 (Anderson & Willis 2003). In 2001, common kelp and top shells were negatively correlated with axis 1, indicating a closer association with SLIMPA Conservation Area sites (Table 3). In 2002 and 2003, the location of management zones in two-dimensional space changed, with species that were positively correlated with both axis 1 and axis 2 having a closer association with SLIMPA Conservation Area sites (Fig. 3; Table 3). Kina and coralline algae were positively associated with axes 1 and 2 in 2002, while only kina was positively correlated with both axes in 2003 (Table 3). Chlorophyta/Rhodophyta species were positively correlated with axis 1 in 2002, while top shells and coralline algae were positively correlated with axis 1 in 2003. Sessile invertebrates were positively correlated with axis 2 in 2003 (Table 3).

Table 3. Correlations (r^2) of invertebrate and algal species with axes of canonical analysis of principal coordinates (CAP).

SPECIES/SPECIES GROUP	2001		2002		2003	
	AXIS 1	AXIS 2	AXIS 1	AXIS 2	AXIS 1	AXIS 2
Common kelp (*Ecklonia radiata*)	–0.36	–0.44	–0.35			–0.78
Kina (*Evechinus chloroticus*)		0.66	0.20	0.34	0.37	0.63
Cook's turban shell (*Cookia sulcata*)				0.33		
Chlorophyta and Rhodophyta species		–0.68	0.24	–0.89		–0.26
Sessile invertebrates	0.68	–0.31	–0.83		–0.75	0.30
Coralline algae			0.36	0.58	0.80	
Top shells	–0.61	0.23			0.58	

3.2 Sessile benthic species

The density of common kelp differed significantly between sites (Wald $\chi^2 = 100.26$, d.f. = 5, $P < 0.001$) and years (Wald $\chi^2 = 10.32$, d.f. = 2, $P < 0.001$) (Appendix 2: Table A2.1). The densities at PPII and NPII were significantly lower than at all other sites during the first 2 years of the monitoring programme (Fig. 4), while in 2003, common kelp densities in the Conservation Area (CAI and CAII) and PPI decreased significantly (Fig. 4). Results from the GLM showed that there was also a significant interaction between year and site (Wald $\chi^2 = 38.04$, d.f. = 9, $P < 0.001$) (Table A2.1), making it difficult to identify patterns across sites and years.

The percentage cover of Chlorophyta and Rhodophyta was not significantly different between sites or years, and no clear patterns were apparent, as indicated by a significant interaction between site and year (Wald $\chi^2 = 20.36$, d.f. = 10, $P = 0.026$) (Fig. 5; Appendix 2: Table A2.2).

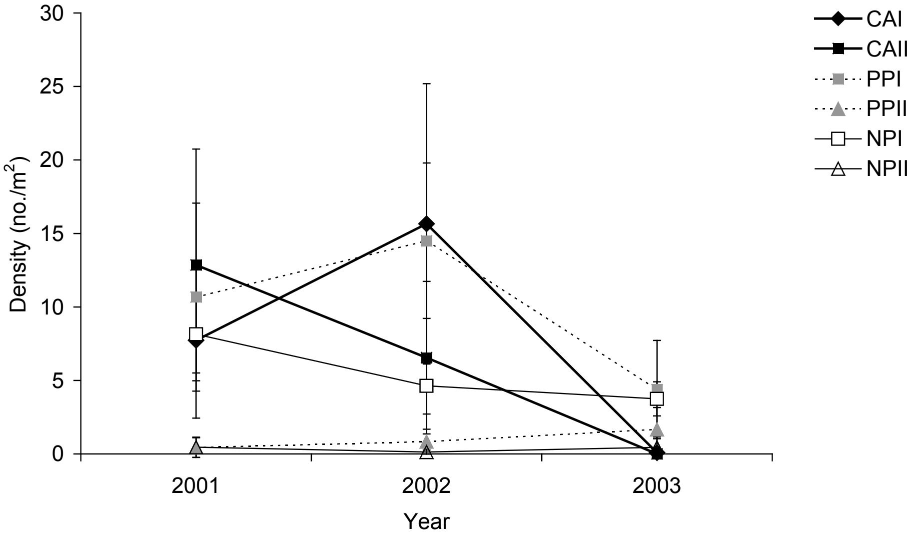

Figure 4. Density (± 95% CI) of common kelp (*Ecklonia radiata*) at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

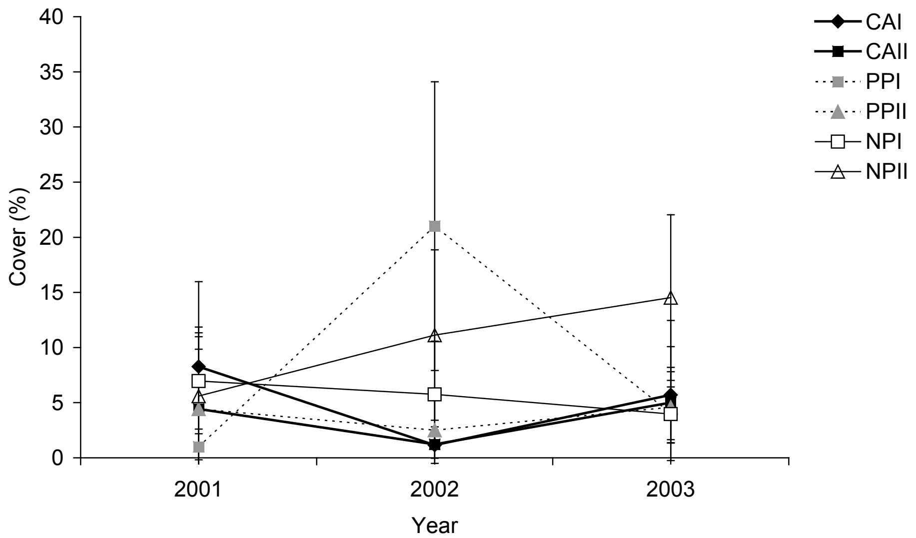

Figure 5. Percentage cover (± 95% CI) of Chlorophyta and Rhodophyta species at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

The percentage cover of sessile invertebrates varied significantly between years (Wald $\chi^2 = 33.361$, d.f. = 2, $P < 0.001$) and sites (Wald $\chi^2 = 188.80$, d.f. = 5, $P < 0.001$), and was higher at CAI, PPI and PPII than at all other sites in 2002 (Fig. 6; Appendix 2: Table A2.3). The percentage cover at CAII and NPI was similar across all 3 years. There was no consistent pattern in percentage cover for sites over time, however, as indicated by a significant site-by-year interaction (Wald $\chi^2 = 61.73$, d.f. = 9, $P < 0.001$) (Table A2.3).

The percentage cover of coralline algae differed significantly between sites (Wald $\chi^2 = 48.51$, d.f. = 5, $P < 0.001$) and years (Wald $\chi^2 = 25.89$, d.f. = 2, $P < 0.001$) (Appendix 2: Table A2.4). Differences between sites were most pronounced in 2003, with CAII, NPI and NPII having a significantly greater percentage cover of coralline algae than CAI, PPI and PPII (Fig. 7). There were no consistent patterns in the percentage cover of coralline algae between sites and years, however, as indicated by a significant site-by-year interaction (Wald $\chi^2 = 95.15$, d.f. = 10, $P < 0.001$) (Fig. 7; Table A2.4).

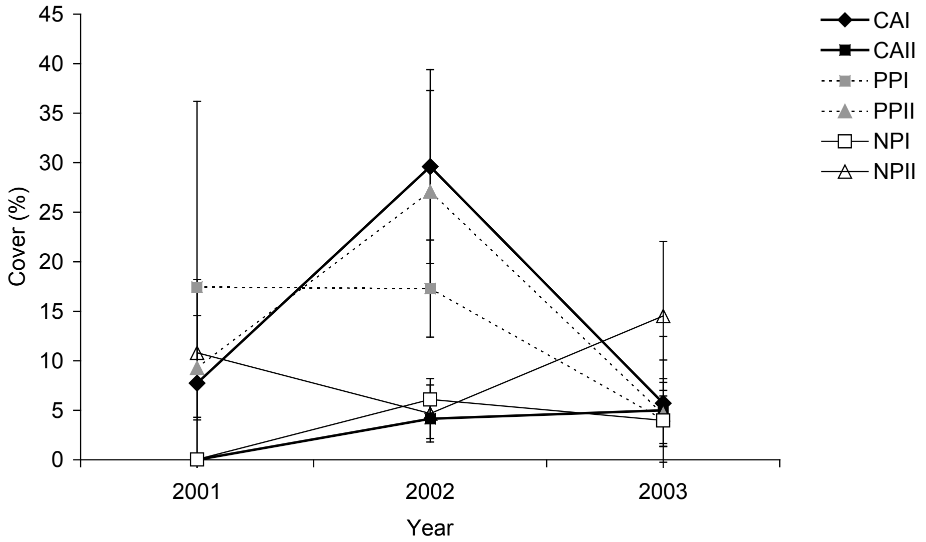

Figure 6. Percentage cover (± 95% CI) of sessile invertebrates (sponges, ascidians and anemones) at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

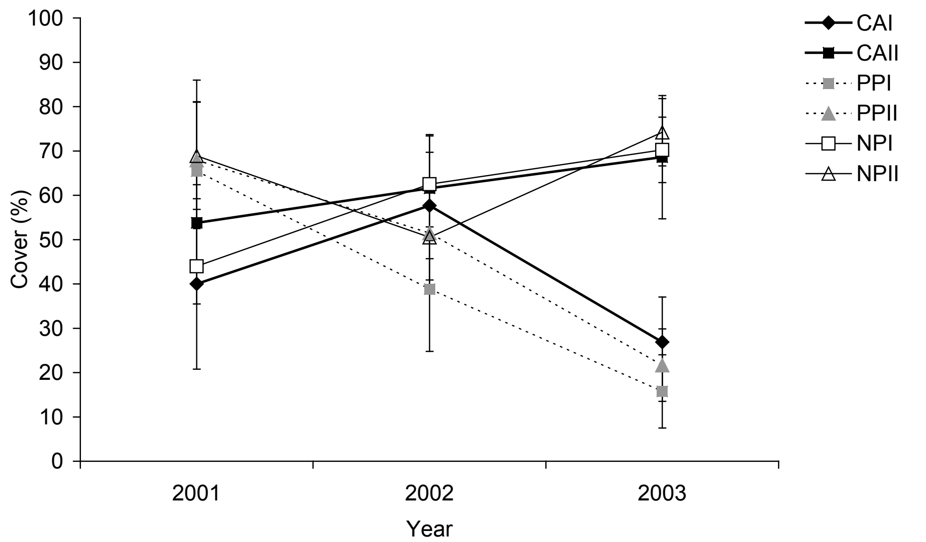

Figure 7. Percentage cover (± 95% CI) of coralline species sampled at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

3.3 Mobile invertebrate grazers

In 2001, densities of kina at CAI, CAII, NPI and PPII were significantly higher than at PPI and NPII (Fig. 8). There was a trend for kina densities at CAI and CAII to be higher than at all other sites across all years, but these differences were only significantly in 2003 (Fig. 8). There were significant differences between sites (Wald $\chi^2 = 55.21$, d.f. = 5, $P < 0.001$) and years (Wald $\chi^2 = 11.68$, d.f. = 2, $P = 0.003$) in kina densities, as well as a significant site-by-year interaction (Wald $\chi^2 = 19.17$, d.f. = 9, $P = 0.024$) (Appendix 2: Table A2.5).

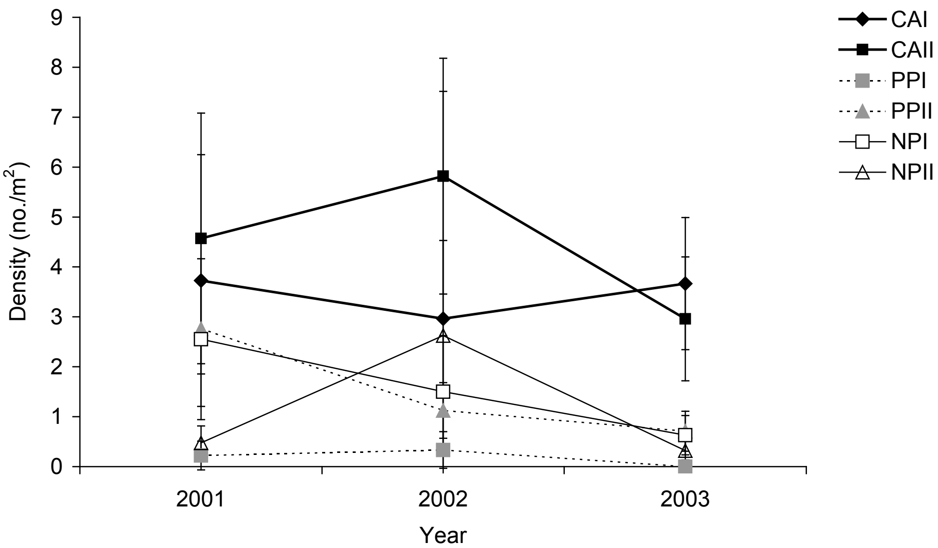

Figure 8. Density (±95% CI) of kina (*Evechinus chloroticus*) at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

The density of Cook's turban shells differed significantly between sites (Wald $\chi^2 = 30.23$, d.f. = 5, $P < 0.001$) and years (Wald $\chi^2 = 100.55$, d.f. = 2, $P < 0.001$), and there was also a significant site-by-year interaction (Wald $\chi^2 = 25.34$, d.f. = 8, $P = 0.001$) (Appendix 2: Table A2.6). There was a trend for the density to be lower at PPI and PPII than at all other sites across all years, but these differences were only significant in 2002 (Fig. 9). There was also a general trend for densities at all sites to increase from 2001 to 2002, but then to decrease again in 2003, almost returning to the 2001 levels (Fig. 9).

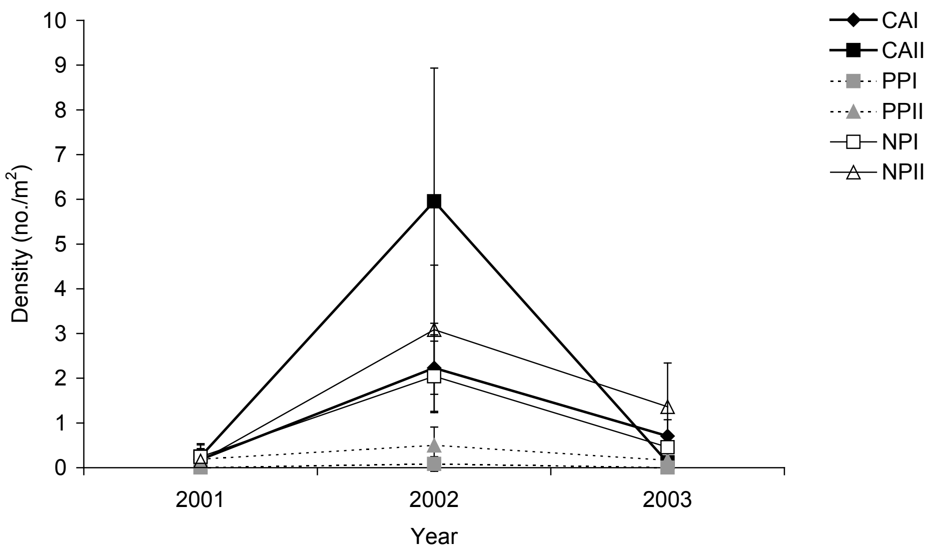

Figure 9. Density (±95% CI) of Cook's turban shells (*Cookia sulcata*) at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

The pattern of top shell density (Fig. 10) across years was the opposite of that seen for Cook's turban shells (Fig. 9). Densities were generally higher in 2001, decreased markedly in 2002, and then increased moderately across all sites (except PPI) in 2003. Densities at PPI remained low across all 3 years (Fig. 10). There were significant differences in top shell densities between sites (Wald $\chi^2 = 30.25$, d.f. = 5, $P < 0.001$) and years (Wald $\chi^2 = 74.87$, d.f. = 2, $P < 0.001$), and there was also a significant site-by-year interaction (Wald $\chi^2 = 17.50$, d.f. = 9, $P = 0.041$) (Appendix 2: Table A2.7).

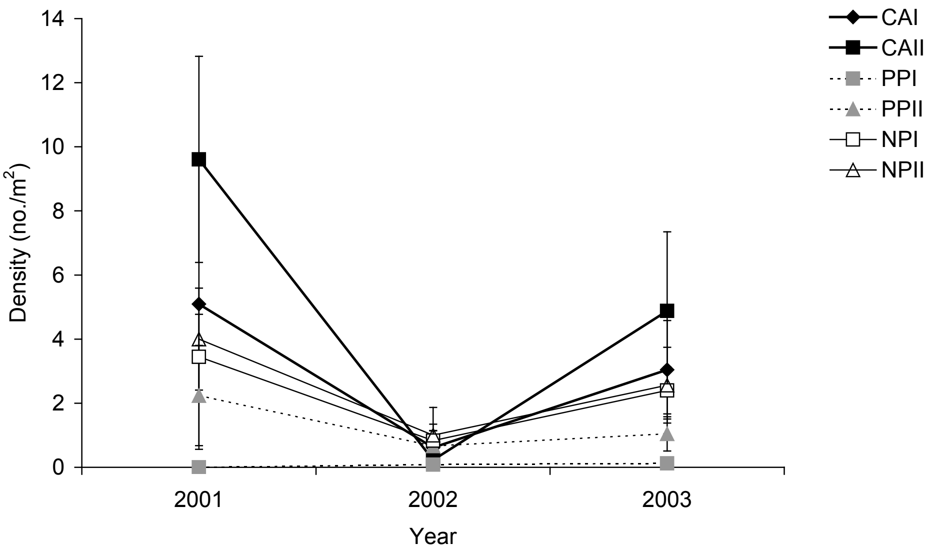

Figure 10. Density (± 95% CI) of top shells (*Calliostoma punctulatum* and *Trochus viridis*) at the monitoring sites from 2001 to 2003. See Table 1 for an explanation of the monitoring site names.

3.4 Species associations

To identify ecological patterns in the data collected from all sites over the three-year monitoring programme, correlation analysis was carried out for all two-way combinations of the following species/species groupings: common kelp; Chlorophyta and Rhodophyta species; sessile invertebrate species; coralline species; kina; Cook's turban shell; and top shells (Table 4). Eleven of these correlations were significant (Table 4).

There were significant negative correlations between kina density and common kelp density, and between kina density and the percentage cover of Chlorophyta and Rhodophyta, and a significant positive correlation between kina density and the percentage cover of coralline species. This indicates that kina were largely associated with coralline habitat devoid of large brown kelp and palatable algae, also known as 'barrens' habitat (Table 4).

There were also significant correlations between large grazers such as kina and the smaller grazing invertebrates (top shells) at the monitoring sites (Table 4). The significant positive correlations between kina density and top shell density, and between the percentage cover of coralline species and top shell density indicate a degree of overlap in habitat distributions between these grazers at the monitoring sites (Table 4). Although Cook's turban shell had a significant negative correlation with top shell density, this large mollusc had a significant positive association with the percentage cover of coralline species (Table 4). There were significant negative correlations between the percentage cover of coralline species and the percentage cover of sessile invertebrates; the percentage cover of coralline species and the percentage cover of Chlorophyta and Rhodophyta species; the percentage cover of sessile invertebrates and top shell density; and the percentage cover of common kelp and the percentage cover of sessile invertebrates. All of these significant associations demonstrate differentiation in the spatial distribution of each of these species across the monitoring sites (Table 4).

Table 4. Correlations between benthic invertebrate species/groups across all survey sites and years. * $P < 0.05$; ** $P < 0.01$; two-tailed tests.

	Ecklonia radiata	*Evechinus chloroticus*	*Cookia sulcata*	Coralline species	Chlorophyta & Rhodophyta	Sessile invertebrates
Evechinus chloroticus	–0.270**					
Cookia sulcata	–0.034	0.086				
Coralline species	0.061	0.110*	0.131**			
Chlorophyta & Rhodophyta	0.047	–0.214**	–0.060	–0.102*		
Sessile invertebrates	–0.124*	–0.088	0.039	–0.340**	–0.065	
Top shells	–0.028	0.185**	–0.195**	0.200**	–0.027	–0.258**

Regression models were fitted to the data for all combinations of species/species groupings for which there were significant correlations (Appendix 3). However, all of these models had low r^2 values, indicating that they did not describe enough of the variation around the fitted models to be useful in describing relationships between species abundance using observed and model-predicted values (Appendix 3).

3.5 Rock lobster den census

In total, 1234 rock lobsters were encountered during 1077 minutes of searching, which included repeat dives at each den site during each year of the census. Sample sizes of rock lobsters from den sites varied due to the differences in population densities at each site.

A summary of the mean catch-per-unit-effort (CPUE) data is presented in Appendix 4. A comparison of mean CPUE data for male and female rock lobsters between sites and years (Fig. 11) showed that differences were only significant in 2001 at NPI and in 2002 at NPII. GLM analysis indicated that there were significant differences in rock lobster CPUE between sites (Wald $\chi^2 = 120.36$, d.f. = 5, $P < 0.001$), but no significant differences between years (Appendix 5). However, there was a significant site-by-year interaction (Wald $\chi^2 = 28.53$, d.f. = 8, $P < 0.001$) (Appendix 5). When the data were pooled by sex (i.e. male and female data were combined), GLM analysis showed a similar pattern, with significant site (Wald $\chi^2 = 126.42$, d.f. = 5, $P < 0.001$) and interaction (Wald $\chi^2 = 23.93$, d.f. = 9, $P = 0.004$) effects (Fig. 12; Appendix 6). When CPUE data were pooled by sex and zone (i.e. CA, PP and NP), CPUE was significantly higher in the Conservation Area than in the partially protected and reference sites in 2002 and 2003 (Fig. 13). GLM analyses showed that there was a significant difference in rock lobster CPUE between zones (Wald $\chi^2 = 31.48$, d.f. = 2, $P < 0.001$) (Appendix 7), being significantly higher in the Conservation Area than at the partially protected or reference sites, which did not significantly differ from each other (pairwise comparisons; Appendix 7).

To assess the variability in size between male and female rock lobsters surveyed, carapace size frequency data were initially explored by sex and year, combining size frequency estimates for all monitoring sites (Fig. 14). These data were then explored by site, year and sex to examine size variability between monitoring sites (Fig. 15). GLM analysis indicated that rock lobster carapace length significantly differed between the sexes (Wald $\chi^2 = 8.09$, d.f. = 1, $P = 0.004$) and between sites (Wald $\chi^2 = 120.27$, d.f. = 5, $P < 0.001$), but that there was no significant difference between years (Appendix 8). However, there was a significant site-by-year interaction (Wald $\chi^2 = 26.65$, d.f. = 8, $P = 0.001$), indicating that differences in carapace lengths between sites were not consistent across all years of the den census (Appendix 8). Pairwise comparisons suggested that, overall, male rock lobsters had larger carapace lengths than female rock lobsters (Appendix 8), and that rock lobsters at CAI and CAII had significantly larger carapace lengths than individuals at sites NPII, PPI and PPII.

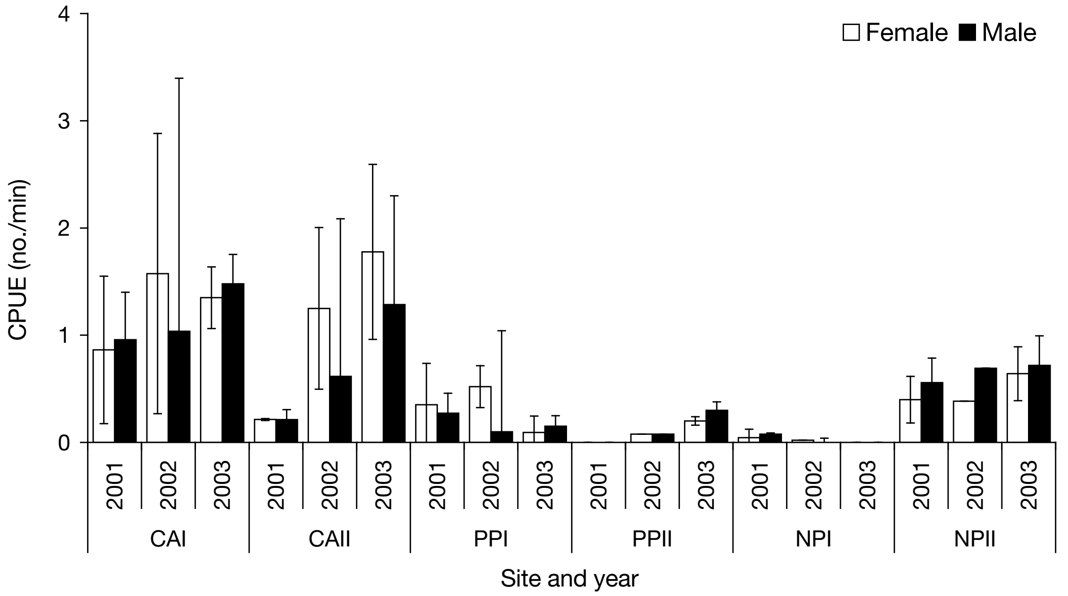

Figure 11. Mean catch-per-unit-effort (CPUE) (±95% CI) for male and female rock lobsters (*Jasus edwardsii*) across sites and years. See Table 1 for an explanation of the monitoring site names.

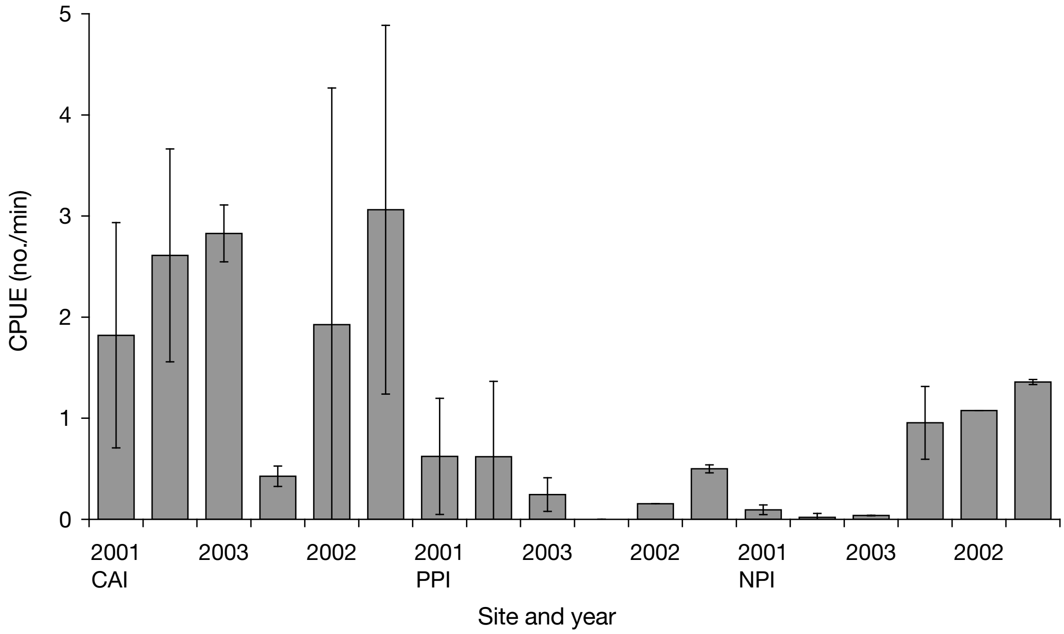

Figure 12. Pooled (male and female) catch-per-unit-effort (CPUE) (±95% CI) for rock lobsters (*Jasus edwardsii*) across sites and years. See Table 1 for an explanation of the monitoring site names.

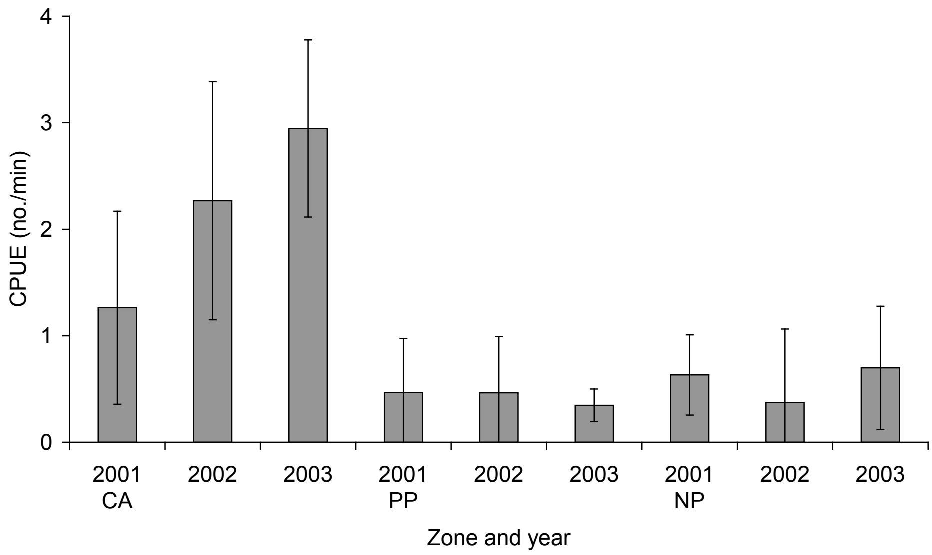

Figure 13. Pooled catch-per-unit-effort (CPUE) (±95% CI) for rock lobsters (*Jasus edwardsii*) across zones (CA = Conservation Area, PP = partial protection, NP = no protection) and years.

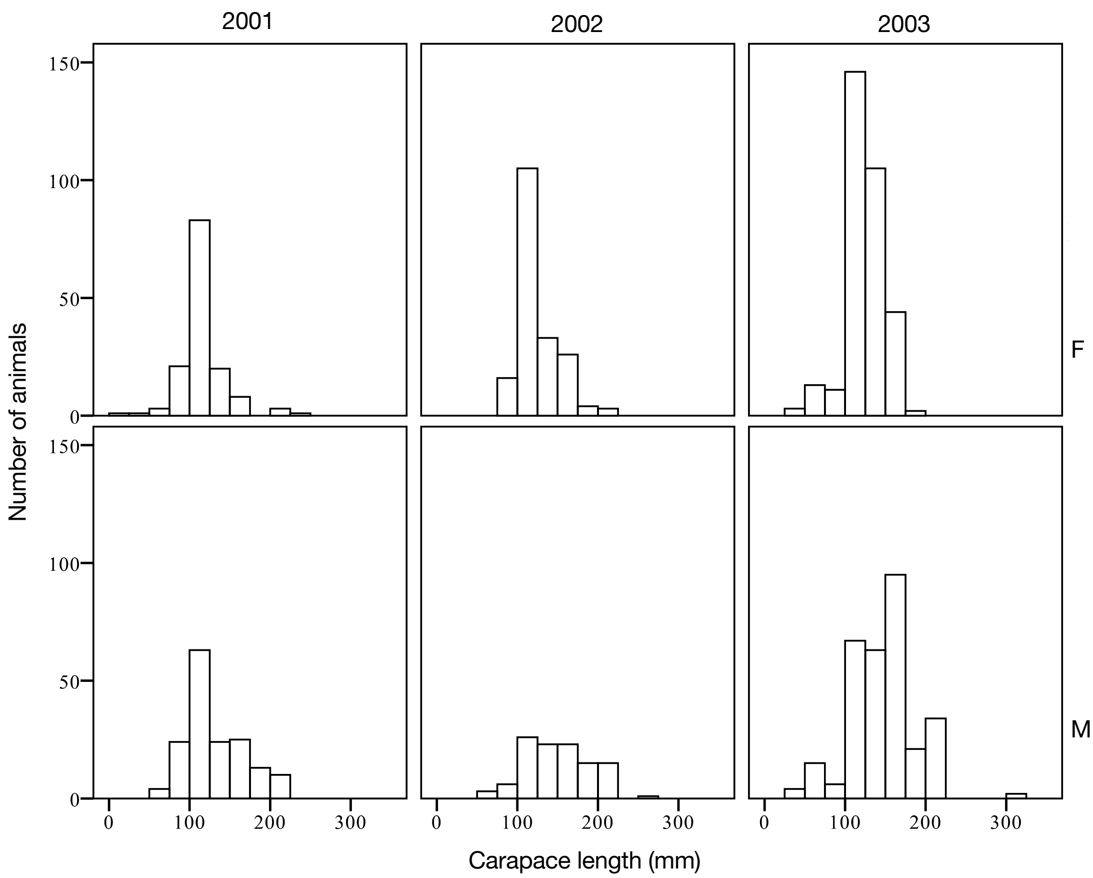

Figure 14. Size frequency distribution of female (F) and male (M) rock lobsters (*Jasus edwardsii*) in 2001, 2002 and 2003.

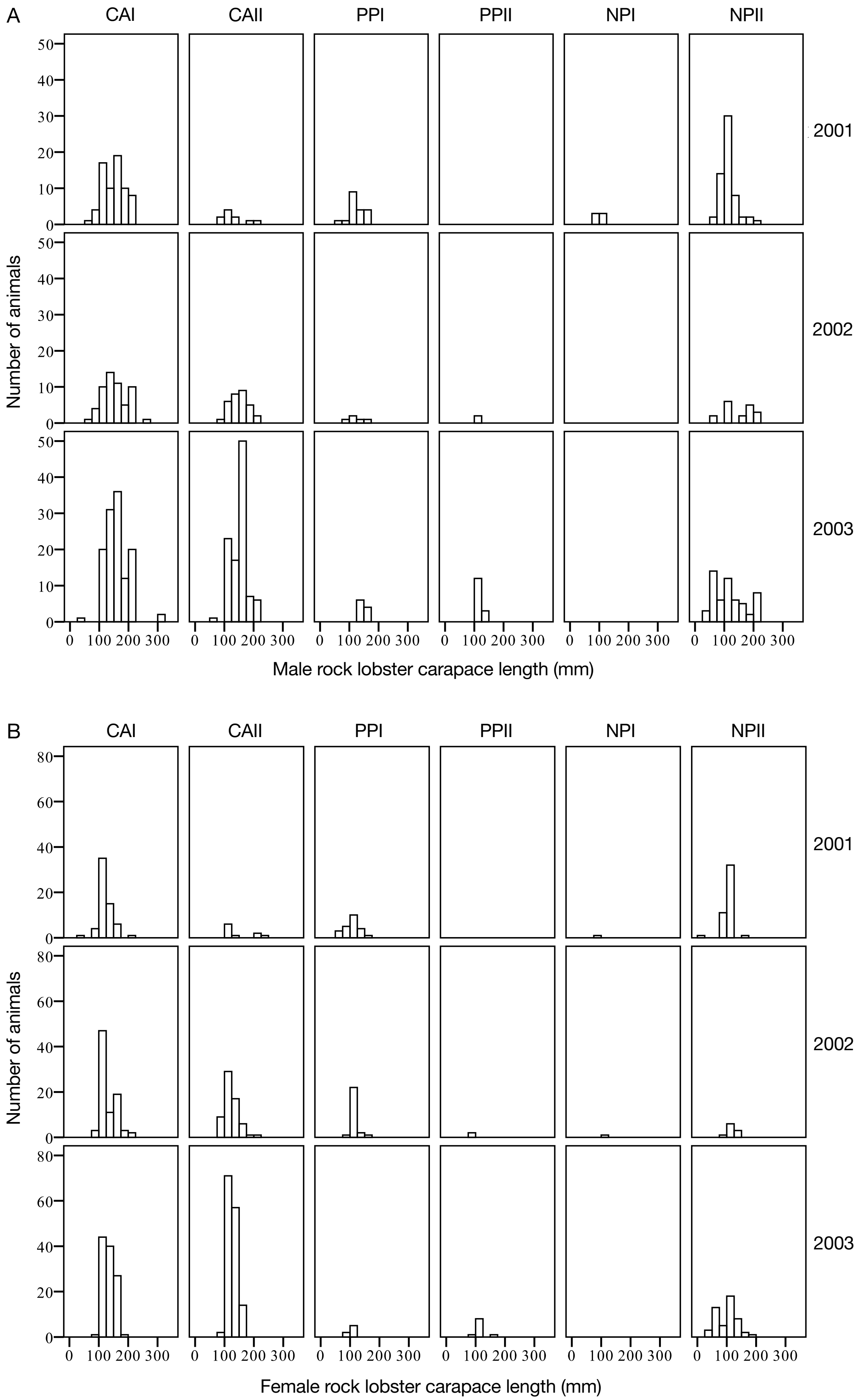

Figure 15. Size frequency distribution of A. male and B. female rock lobsters (*Jasus edwardsii*) at each site during 2001, 2002 and 2003. See Table 1 for an explanation of the monitoring site names.

3.6 Kina size data

When kina size frequency data were pooled by zone across years, there was a clear difference in test diameter between zones (i.e. CA vs. PP vs. NP) (Fig. 16). There were significant differences in kina mean test diameter between zones (Wald $\chi^2 = 222.82$, d.f. = 2, $P < 0.001$) and years (Wald $\chi^2 = 64.36$, d.f. = 2, $P < 0.001$), and a significant year-by-zone interaction (Wald $\chi^2 = 71.88$, d.f. = 4, $P < 0.001$) (Appendix 9).

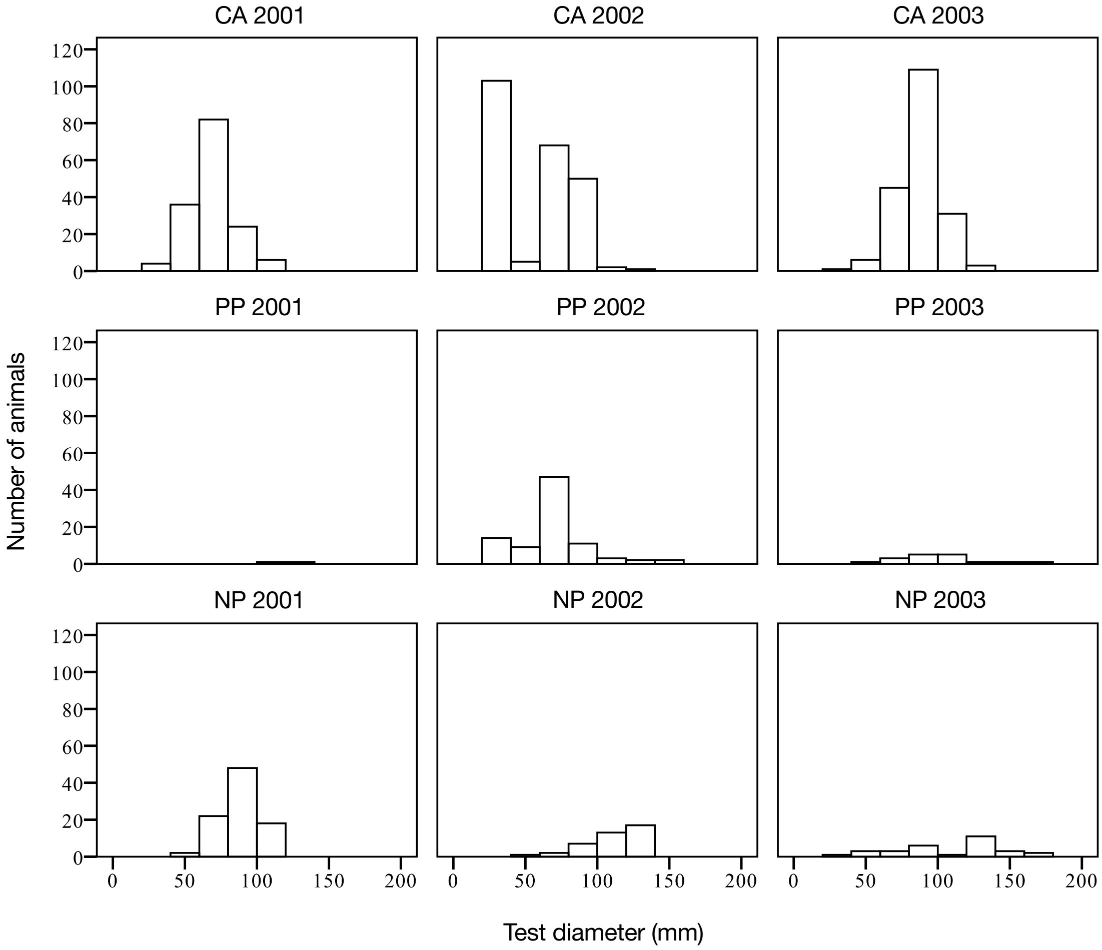

Figure 16. Size frequency distribution of kina (*Evechinus chloroticus*) in each zone (CA = Conservation Area, PP = partial protection, NP = no protection) during 2001, 2002 and 2003.

4. Discussion

The primary objective of this long-term monitoring programme was to establish a framework from which the level of preservation or rehabilitation of reef communities within the Sugar Loaf Islands Marine Protected Area (SLIMPA) could be assessed. The data obtained from this monitoring programme will enable conservation managers to document any changes associated with the special protection status of SLIMPA, to distinguish variability associated with natural changes from that induced through human impacts (e.g. fishing) and to assess the effectiveness of management practices on significant ecological relationships.

The results of the monitoring programme to date show that there is a high level of variability in benthic community structure between the monitoring locations. Of particular note are the differences in the relative abundance and size-frequency estimates of important species (i.e. rock lobsters and kina) between the Conservation Area surrounding Waikaranga and Tokatapu rocks (CA), the monitoring sites outside this management zone within SLIMPA (PP), and sites that lie outside the SLIMPA boundary (NP). However, it should be noted that much of the variation observed in the metrics of the benthic species in this monitoring programme can probably be explained by unavoidable differences in the topographic relief of reference reefs versus SLIMPA reefs (Miller et al. 2005). For example, at reference sites, the maximum vertical relief was 1 m compared with c. 7–20 m at SLIMPA sites (Miller et al. 2005).

The significant positive correlations between kina density and top shell density, and between the percentage cover of coralline species and top shell density may indicate a degree of overlap in the habitat distributions of these grazers at the monitoring sites. The significant negative correlations between kina density and both common kelp density and the percentage cover of Chlorophyta and Rhodophyta species, and the significant positive correlation between kina density and the percentage cover of coralline species are similar to patterns observed in many temperate marine environments throughout New Zealand, where large numbers of kina graze on reefs and remove all but the toughest algae (Shears & Babcock 2003). CAP analysis suggested that the benthic community structure estimated using key species/species groups differs between management zones and years, with kina being the only species consistently associated with the SLIMPA Conservation Area across all years. In 2002 and 2003, there was also an association between coralline algae and the SLIMPA Conservation Area, suggesting the presence of kina barrens habitat in this management zone (Andrew & Choat 1982).

Since comparable monitoring data were not collected prior to the establishment of SLIMPA, a before-after-control-impact survey design could not be used for the SLIMPA monitoring. Furthermore, Miller et al. (2005) also noted that it is not possible to determine the relative contribution of habitat versus management regime on the benthic invertebrate community through the SLIMPA monitoring. Therefore, observed differences in community structure (or in abundance and size) between management zones cannot be directly attributed to management action. However, according to Kelly (1999), if differences in metrics for species being monitored between control and protected sites are consistent through time, then temporal variability can be discounted as a possible driver for the observed patterns—although spatial variability cannot. Added to this, if observed patterns for monitored species are consistent with and/or similar to those observed in other marine protected areas, this can strengthen the suggestion that protection may be contributing to the observed patterns (Kelly 1999).

According to the results of the SLIMPA monitoring, the abundance and carapace length of rock lobsters were generally higher within the Conservation Area (CA) than at other monitoring sites, suggesting that the Conservation Area may be effective in increasing rock lobster abundance and size. The estimates suggest that rock lobsters have responded positively to the no-take management policy within the CA, as is the case in other marine reserves around New Zealand

(Babcock et al. 1999; Davidson et al. 2002). However, the positive response of rock lobsters to the CA may be confounded by non-random site selection of the CA, and the natural spatial variability between the CA and the reference sites (PP and NP) (Osenberg & Schmitt 1996; Osenberg et al. 2006). Furthermore, the small-scale differences in density and size frequency between monitoring sites may be confounded by the sampling method used to census rock lobsters, which failed to account for predictable changes in the depth distribution of adult males and females (in the absence of a fishery) that lead to fluctuations in sex ratios and size frequencies in this species (MacDiarmid 1991). This confounding could be avoided in future survey work in SLIMPA and the neighbouring Tapuae Marine Reserve by following the sampling design used by Kelly et al. (2000) when sampling rock lobsters. In their rock lobster surveys of marine reserves in northeastern New Zealand, Kelly et al. (2000) sampled each site at two depths (< 10 and 10–25 m) using five 10 × 50 m band transects per sampling location, to factor in seasonal differences in rock lobster distribution with depth.

Density estimates may also be adversely affected by differences in behaviours exhibited towards divers in the CA compared with the non-protected areas. However, these behavioural differences are likely to be minor as, even if rock lobsters are 'diver adverse', they can still generally be observed in their dens (C. Lilley, DOC, pers. comm. 2010). Underwater visual censuses by divers are subject to bias, as a proportion of the population will not be seen, and the behaviour and experience of divers will affect estimates (Edgar et al. 2004). However, it should be noted that for this study a single diver collected all of the rock lobster data, thereby avoiding between-diver differences in the rock lobster dataset.

By adopting the sampling strategy used in the pilot study (Duffy et al. 2003), where a stratified random sampling design was used to sample both high- and low-density rock lobster habitat, conservation managers will find it easier to determine factors affecting changes in rock lobster populations and the role of rock lobsters in regulating prey species such as kina. Furthermore, if this survey is replicated, the collection of information to quantify sea state, underwater visibility, depth profile (corrected for the large (> 3 m) tidal variation in the New Plymouth coastal area) and diver effort would improve the utility of the rock lobster dataset.

Trophic cascades have previously been documented following the establishment of marine reserves in which a strict no-take policy is enforced (Shears & Babcock 2004), whereby the densities and size frequency of commercially targeted species (e.g. rock lobsters, snapper (*Pagrus auratus*)) are seen to increase dramatically, and common kelp forests re-establish in place of urchin barrens (Babcock et al. 1999). Such patterns were not apparent within the CA of SLIMPA, despite there being higher densities of rock lobsters and an observed increase in the size of common kelp at these sites. However, the density of kina was higher within the CA than at the other monitoring sites (although this difference was not statistically significant), which suggests that rehabilitation of the relatively small Conservation Area may be occurring, albeit at a slower rate than, for example, at the Cape Rodney–Okakari Point (Goat Island) Marine Reserve. There is likely to have been a more rapid recovery of demersal predatory species such as snapper and blue cod (*Parapercis colias*) (known to be key predators of kina) in the absence of fishing pressure at this latter reserve due to its larger area (Shears & Babcock 2004).

With the incorporation of the SLIMPA Conservation Area into the much larger (1404 ha) Tapuae Marine Reserve in 2008, the protection status of the Conservation Area (including the survey sites CAI and CAII) was upgraded to that of a marine reserve, with all fishing prohibited. Consequently, previously commonly targeted predatory species (such as snapper, blue cod and rock lobsters) are likely to recover in the former Conservation Area, facilitating a trophic cascade, which may lead to changes in benthic community structure such as reduced kina densities, less 'barrens' habitat and increased macroalgal cover (as outlined in Shears & Babcock 2004). Continued monitoring of sites CAI and CAII as part of any future monitoring of Tapuae Marine Reserve may enable changes in community structure to be detected.

A before-after-control-impact-paired-series (BACIPS) study is considered the most rigorous survey protocol for assessing the effectiveness of unreplicated interventions such as establishing marine protected areas (Stewart-Oaten et al. 1986; Lincoln-Smith et al. 2006; Osenberg et al. 2006), yet there are limited opportunities to implement such studies (see Osenberg & Schmitt (1996) for further discussion). However, with one of the reference survey sites from this monitoring programme (NPI) now being part of Tapuae Marine Reserve, future monitoring of the marine reserve will have some components of a BACIPS study, as there is a 3 year time-series of 'before' data for NPI. In addition, there is a 3 year time-series of data collected from the partially protected zones (PPI and PPII). Although this will mean that 'before' data for Tapuae Marine Reserve will come from only one site, these data will still be valuable in separating the effects of marine reserve status from those attributable to natural temporal heterogeneity. It would therefore be prudent to continue monitoring all sites from the SLIMPA benthic invertebrate monitoring programme as part of any future monitoring and assessment of the effects of Tapuae Marine Reserve.

This monitoring programme revealed high levels of variability in the abundance estimates of kelp and sub-canopy algae, and of sessile and mobile benthic invertebrates that occupy the subtidal reef systems within SLIMPA. The variation associated with these reef assemblages could be resolved by developing inexpensive sampling methods that can be carried out frequently to increase the power of the monitoring programme. For example, although repetitive sampling at each monitoring site using diver quadrats is an expensive process, costs can be reduced by incorporating other concurrent means of monitoring, such as using an underwater camera mounted on a quadrapod (Coyer & Witman 1990). Camera images can be used to generate indices, from which abundance estimates of sessile invertebrate species can be obtained, to help improve species resolution. Frequent sampling with a drop camera can also provide qualitative data that can be collected cheaply; for example, Cole (2003) used a drop camera at five random points located within a 20-m radius of a GPS mark to sample the percentage cover of kelp canopy. By increasing sampling effort using relatively inexpensive methods and, at the same time, increasing species resolution, the power to detect patterns in algal and invertebrate communities will be improved, and spatial variability in SLIMPA and non-SLIMPA populations may be analysed more effectively, ultimately reducing management reaction times. Further, stratifying sampling effort by depth would reduce spatial variability in abundance estimates and improve the ability to detect changes in species distributions within sites, also enabling better comparisons of species distribution and abundance across zones (Green 1979; Kingsford & Battershill 1998).

5. Recommendations

Recommendations for future monitoring at SLIMPA and within the neighbouring Tapuae Marine Reserve include:

- Collect ancillary information that will allow sea state, underwater visibility depth, and diver effort to be quantified, to strengthen analyses of rock lobster catch-per-unit-effort data
- Carry out a quantitative assessment of rock lobster data quality in conjunction with rock lobster surveys, should more than one diver be involved in rock lobster data collection
- Use band-transects in conjunction with catch-per-unit-effort data collection to provide quantitative information on rock lobster abundance and distribution (see MacDiarmid 1991)
- Increase species resolution for the invertebrate data to improve the power to detect patterns and trends in the data, and increase sampling effort using relatively inexpensive methods, e.g. drop cameras
- Stratify sampling effort by depth to improve the utility of the data for detecting changes in species distributions within sites, and to allow suitable comparisons across zones

6. Conclusions

The aim of this initial 3-year monitoring programme was to detect long-term trends in benthic invertebrate assemblages over time at sites under different management regimes, and to establish a baseline for future monitoring and impact assessments at SLIMPA. Due to the high variability in species metrics and the short (3-year) time-frame of monitoring, it was not possible to detect many statistically significant trends over time. However, by increasing the power of the sampling design through the use of relatively inexpensive monitoring techniques and collecting data over a longer period of time, valuable information for the management of SLIMPA will be obtained in the future. This monitoring programme has successfully established a baseline for future monitoring of not only SLIMPA, but also Tapuae Marine Reserve.

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Appendix 1

Summary of species abundance estimates at monitoring sites, excluding rock lobsters (*Jasus edwardsii*)

Table A1.1. Mean density of common kelp (*Ecklonia radiata*).

SITE	YEAR	MEAN NUMBER OF PLANTS/m^2	QUADRATS SAMPLED (*n*)	SE
CAI	2001	7.73	11	2.70
	2002	15.65	26	4.87
	2003	0.08	24	0.06
CAII	2001	12.86	28	4.02
	2002	6.55	22	2.65
	2003	0.00	25	0.00
PPI	2001	10.67	9	3.26
	2002	14.50	24	2.70
	2003	4.38	24	1.71
PPII	2001	0.43	21	0.34
	2002	0.83	24	0.43
	2003	1.67	24	0.76
NPI	2001	8.14	29	1.35
	2002	4.63	24	0.98
	2003	3.74	35	0.59
NPII	2001	0.45	20	0.35
	2002	0.13	24	0.07
	2003	0.44	25	0.36

Table A1.2. Mean percentage cover per quadrat of Chlorophyta and Rhodophyta species.

SITE	YEAR	MEAN % COVER PER QUADRAT	QUADRATS SAMPLED (*n*)	SE
CAI	2001	8.27	11	3.93
	2002	1.15	26	0.85
	2003	5.71	24	2.23
CAII	2001	4.43	28	3.35
	2002	1.23	22	0.65
	2003	5.00	25	3.81
PPI	2001	1.00	9	0.60
	2002	21.00	24	6.68
	2003	4.04	24	1.22
PPII	2001	4.43	21	3.79
	2002	2.50	24	1.83
	2003	4.58	24	1.65
NPI	2001	6.97	29	2.23
	2002	5.75	24	2.46
	2003	3.97	35	2.16
NPII	2001	5.60	20	2.16
	2002	11.13	24	3.94
	2003	14.52	25	3.83

Table A1.3. Mean percentage cover per quadrat of sessile invertebrates.

SITE	YEAR	MEAN % COVER PER QUADRAT	QUADRATS SAMPLED (*n*)	SE
CAI	2001	7.73	11	5.35
	2002	29.62	26	4.99
	2003	5.71	24	2.23
CAII	2001	0.00	28	0.00
	2002	4.14	22	1.01
	2003	5.00	25	3.81
PPI	2001	17.44	9	9.57
	2002	17.29	24	2.50
	2003	4.04	24	1.22
PPII	2001	9.29	21	2.69
	2002	27.08	24	5.20
	2003	4.58	24	1.65
NPI	2001	0.03	29	0.03
	2002	6.08	24	1.08
	2003	3.97	35	2.16
NPII	2001	10.80	20	3.32
	2002	4.67	24	1.47
	2003	14.52	25	3.83

Table A1.4. Mean percentage cover per quadrat of coralline species.

SITE	YEAR	MEAN % COVER PER QUADRAT	QUADRATS SAMPLED (*n*)	SE
CAI	2001	40.00	11	9.81
	2002	57.69	26	6.13
	2003	26.88	24	5.19
CAII	2001	53.79	28	4.39
	2002	61.59	22	6.02
	2003	68.60	25	7.10
PPI	2001	65.44	9	10.48
	2002	38.83	24	7.16
	2003	15.75	24	4.21
PPII	2001	67.90	21	6.73
	2002	51.46	24	5.40
	2003	21.67	24	4.17
NPI	2001	43.97	29	4.34
	2002	62.50	24	5.69
	2003	70.23	35	3.76
NPII	2001	68.90	20	6.17
	2002	50.50	24	5.77
	2003	74.20	25	3.87

Table A1.5. Mean density of kina (*Evechinus chloroticus*).

SITE	YEAR	MEAN NUMBER OF KINA/m^2	QUADRATS SAMPLED (*n*)	SE
CAI	2001	3.73	11	1.29
	2002	2.96	26	0.80
	2003	3.67	24	0.67
CAII	2001	4.57	28	1.28
	2002	5.82	22	1.21
	2003	2.96	25	0.63
PPI	2001	0.22	9	0.15
	2002	0.33	24	0.19
	2003	0.00	24	0.00
PPII	2001	2.76	21	0.46
	2002	1.13	24	0.28
	2003	0.71	24	0.20
NPI	2001	2.55	29	0.82
	2002	1.50	24	0.57
	2003	0.63	35	0.20
NPII	2001	0.47	20	0.17
	2002	2.63	24	2.50
	2003	0.32	25	0.10

Table A1.6. Mean density of Cook's turban shells (*Cookia sulcata*).

SITE	YEAR	MEAN NUMBER OF SHELLS/m^2	QUADRATS SAMPLED (*n*)	SE
CAI	2001	0.18	11	0.18
	2003	0.71	24	0.19
	2002	2.23	26	0.51
CAII	2003	0.12	25	0.07
	2001	0.25	28	0.13
	2002	5.95	22	1.52
PPI	2001	0.00	9	0.00
	2003	0.00	24	0.00
	2002	0.08	24	0.08
PPII	2003	0.17	24	0.08
	2001	0.19	21	0.11
	2002	0.50	24	0.21
NPI	2001	0.24	29	0.09
	2003	0.46	35	0.10
	2002	2.04	23	0.40
NPII	2001	0.15	20	0.11
	2003	1.36	25	0.50
	2002	3.08	24	0.74

Table A1.7. Mean density of top shells (*Calliostoma punctulatum* and *Trochus viridus*).

SITE	YEAR	MEAN NUMBER OF TOP SHELLS/m^2	QUADRATS SAMPLED (*n*)	SE
CAI	2001	5.09	11	2.31
	2002	0.62	26	0.27
	2003	3.04	24	0.78
CAII	2001	9.61	28	1.64
	2002	0.23	22	0.13
	2003	4.88	25	1.26
PPI	2001	0.00	9	0.00
	2002	0.08	24	0.08
	2003	0.13	24	0.07
PPII	2001	2.24	21	0.80
	2002	0.67	24	0.25
	2003	1.04	24	0.27
NPI	2001	3.45	29	0.68
	2002	0.83	24	0.26
	2003	2.40	35	0.38
NPII	2001	4.00	20	0.81
	2002	1.00	24	0.44
	2003	2.56	25	0.60

Appendix 2

Output of generalised linear model (GLM) analyses for benthic species monitored in SLIMPA, excluding rock lobsters (*Jasus edwardsii*)

A2.1 Common kelp (*Ecklonia radiata*) density (number of plants/m^2), with pairwise comparisons by year and site

Model information

Dependent variable	*Ecklonia radiata* density
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	46.921	1	<0.001
Year	10.324	2	0.006
Site	100.257	5	<0.001
Year*Site	38.041	9	<0.001

Dependent variable: *Ecklonia radiata* density
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of Ecklonia radiata *density by year*

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I–J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	0.141	0.268	1	0.936	–0.500	0.781
	2003	5.962*	0.318	1	<0.001	5.203	6.721
2002	2001	–0.141	0.268	1	0.936	–0.781	0.500
	2003	5.822*	0.328	1	<0.001	5.039	6.604
2003	2001	–5.962*	0.318	1	<0.001	–6.721	–5.203
	2002	–5.822*	0.328	1	<0.001	–6.604	–5.039

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Ecklonia radiata* density.

* The mean difference is significant at the 0.05 level.

Pairwise comparison of Ecklonia radiata *density by site*

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	8.745*	0.496	1	<0.001	7.293	10.197
	PPI	–1.402*	0.451	1	0.028	–2.723	–0.082
	PPII	0.943	0.475	1	0.516	–0.448	2.335
	NPI	–0.879	0.428	1	0.456	–2.131	0.373
	NPII	2.003*	0.552	1	0.004	0.387	3.620
CAII	CAI	–8.745*	0.496	1	<0.001	–10.197	–7.293
	PPI	–10.147*	0.375	1	<0.001	–11.245	–9.049
	PPII	–7.802*	0.418	1	<0.001	–9.024	–6.579
	NPI	–9.624*	0.346	1	<0.001	–10.638	–8.610
	NPII	–6.742*	0.492	1	<0.001	–8.182	–5.302
PPI	CAI	1.402*	0.451	1	0.028	0.082	2.723
	CAII	10.147*	0.375	1	<0.001	9.049	11.245
	PPII	2.345*	0.347	1	<0.001	1.329	3.361
	NPI	0.523	0.278	1	0.604	–0.291	1.337
	NPII	3.405*	0.446	1	<0.001	2.098	4.712
PPII	CAI	-0.943	0.475	1	0.516	–2.335	0.448
	CAII	7.802*	0.418	1	<0.001	6.579	9.024
	PPI	–2.345*	0.347	1	<0.001	–3.361	–1.329
	NPI	–1.822*	0.316	1	<0.001	–2.747	–0.897
	NPII	1.060	0.471	1	0.310	–0.319	2.439
NPI	CAI	0.879	0.428	1	0.456	–0.373	2.131
	CAII	9.624*	0.346	1	<0.001	8.610	10.638
	PPI	–0.523	0.278	1	0.604	–1.337	0.291
	PPII	1.822*	0.316	1	<0.001	0.897	2.747
	NPII	2.882*	0.423	1	<0.001	1.645	4.120
NPII	CAI	–2.003*	0.552	1	0.004	–3.620	–0.387
	CAII	6.742*	0.492	1	<0.001	5.302	8.182
	PPI	–3.405*	0.446	1	<0.001	–4.712	–2.098
	PPII	–1.060	0.471	1	0.310	–2.439	0.319
	NPI	–2.882*	0.423	1	<0.001	–4.120	–1.645

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Ecklonia radiata* density.

* The mean difference is significant at the 0.05 level.

A2.2 Percentage cover of Chlorophyta and Rhodophyta species, with pairwise comparisons by year and site

Model information

Dependent variable	Percentage cover of Chlorophyta and Rhodophyta
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	119.317	1	< 0.001
Year	1.146	2	0.564
Site	8.794	5	0.118
Year*Site	20.355	10	0.026

Dependent variable: Percentage cover of Chlorophyta and Rhodophyta
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of percentage cover of Chlorophyta and Rhodophyta species by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	0.048	0.366	1	0.999	–0.827	0.922
	2003	–0.262	0.351	1	0.838	–1.099	0.575
2002	2001	–0.048	0.366	1	0.999	–0.922	0.827
	2003	–0.310	0.310	1	0.683	–1.051	0.431
2003	2001	0.262	0.351	1	0.838	–0.575	1.099
	2002	0.310	0.310	1	0.683	–0.431	1.051

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable percentage cover of Chlorophyta and Rhodophyta.

Pairwise comparison of percentage cover of Chlorophyta and Rhodophyta species by site

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	0.232	0.493	1	1.000	–1.212	1.676
	PPI	–0.148	0.575	1	1.000	–1.832	1.537
	PPII	0.024	0.489	1	1.000	–1.408	1.455
	NPI	–0.357	0.461	1	1.000	–1.706	0.992
	NPII	–0.936	0.476	1	0.530	–2.330	0.457
CAII	CAI	–0.232	0.493	1	1.000	–1.676	1.212
	PPI	–0.380	0.549	1	1.000	–1.987	1.228
	PPII	–0.208	0.458	1	1.000	–1.548	1.131
	NPI	–0.589	0.428	1	0.937	–1.841	0.663
	NPII	–1.168	0.444	1	0.120	–2.467	0.131
PPI	CAI	0.148	0.575	1	1.000	–1.537	1.832
	CAII	0.380	0.549	1	1.000	–1.228	1.987
	PPII	0.171	0.545	1	1.000	–1.425	1.768
	NPI	–0.209	0.520	1	1.000	–1.733	1.314
	NPII	–0.789	0.534	1	0.895	–2.351	0.774
PPII	CAI	–0.024	0.489	1	1.000	–1.455	1.408
	CAII	0.208	0.458	1	1.000	–1.131	1.548
	PPI	–0.171	0.545	1	1.000	–1.768	1.425
	NPI	–0.381	0.423	1	0.999	–1.618	0.857
	NPII	–0.960	0.439	1	0.354	–2.245	0.325
NPI	CAI	0.357	0.461	1	1.000	–0.992	1.706
	CAII	0.589	0.428	1	0.937	–0.663	1.841
	PPI	0.209	0.520	1	1.000	–1.314	1.733
	PPII	0.381	0.423	1	0.999	–0.857	1.618
	NPII	–0.579	0.408	1	0.920	–1.773	0.614
NPII	CAI	0.936	0.476	1	0.530	–0.457	2.330
	CAII	1.168	0.444	1	0.120	–0.131	2.467
	PPI	0.789	0.534	1	0.895	–0.774	2.351
	PPII	0.960	0.439	1	0.354	–0.325	2.245
	NPI	0.579	0.408	1	0.920	–0.614	1.773

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable percentage cover of Chlorophyta and Rhodophyta.

A2.3 Percentage cover of sessile invertebrates, with pairwise comparisons by year and site

Model information

Dependent variable	% cover of sessile invertebrates
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	480.922	1	< 0.001
Year	33.361	2	< 0.001
Site	188.801	5	< 0.001
Year*Site	61.727	9	< 0.001

Dependent variable: % cover of sessile invertebrates
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of percentage cover of sessile invertebrates by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–6.701*	0.244	1	< 0.001	–7.282	–6.119
	2003	–6.721*	0.241	1	< 0.001	–7.296	–6.146
2002	2001	6.701*	0.244	1	< 0.001	6.119	7.282
	2003	–0.020	0.131	1	0.998	–0.333	0.292
2003	2001	6.721*	0.241	1	< 0.001	6.146	7.296
	2002	0.020	0.131	1	0.998	–0.292	0.333

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable % cover of sessile invertebrates.

* The mean difference is significant at the 0.05 level.

Pairwise comparison of percentage cover of sessile invertebrates by site

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	13.100*	0.267	1	< 0.001	12.319	13.880
	PPI	0.223	0.220	1	0.996	–0.421	0.868
	PPII	0.157	0.201	1	1.000	–0.430	0.744
	NPI	3.136*	0.403	1	< 0.001	1.957	4.316
	NPII	1.410*	0.205	1	< 0.001	0.809	2.011
CAII	CAI	–13.100*	0.267	1	< 0.001	–13.880	–12.319
	PPI	–12.876*	0.271	1	< 0.001	–13.671	–12.082
	PPII	–12.943*	0.251	1	< 0.001	–13.677	–12.208
	NPI	–9.963*	0.433	1	< 0.001	–11.231	-8.696
	NPII	–11.690*	0.259	1	< 0.001	–12.449	–10.930
PPI	CAI	–0.223	0.220	1	0.996	–0.868	0.421
	CAII	12.876*	0.271	1	< 0.001	12.082	13.671
	PPII	–0.066	0.207	1	1.000	–0.672	0.539
	NPI	2.913*	0.406	1	< 0.001	1.724	4.102
	NPII	1.186*	0.211	1	< 0.001	0.568	1.805
PPII	CAI	–0.157	0.201	1	1.000	–0.744	0.430
	CAII	12.943*	0.251	1	< 0.001	12.208	13.677
	PPI	0.066	0.207	1	1.000	–0.539	0.672
	NPI	2.979*	0.396	1	< 0.001	1.821	4.138
	NPII	1.253*	0.191	1	< 0.001	0.694	1.812
NPI	CAI	–3.136*	0.403	1	< 0.001	–4.316	–1.957
	CAII	9.963*	0.433	1	< 0.001	8.696	11.231
	PPI	–2.913*	0.406	1	< 0.001	–4.102	–1.724
	PPII	–2.979*	0.396	1	< 0.001	–4.138	–1.821
	NPII	–1.727*	0.398	1	< 0.001	–2.892	–0.561
NPII	CAI	–1.410*	0.205	1	< 0.001	–2.011	–0.809
	CAII	11.690*	0.259	1	< 0.001	10.930	12.449
	PPI	–1.186*	0.211	1	< 0.001	–1.805	–0.568
	PPII	–1.253*	0.191	1	< 0.001	–1.812	–0.694
	NPI	1.727*	0.398	1	< 0.001	0.561	2.892

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable % cover of sessile invertebrates.

* The mean difference is significant at the 0.05 level.

A2.4 Percentage cover of coralline species, with pairwise comparisons by year and site

Model information

Dependent variable	% cover of coralline species
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	13721.062	1	< 0.001
Year	25.887	2	< 0.001
Site	48.506	5	< 0.001
Year*Site	95.145	10	< 0.001

Dependent Variable: % cover of coralline species
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of percentage cover of coralline species by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	0.043	0.085	1	0.942	–0.159	0.245
	2003	0.363*	0.084	1	< 0.001	0.164	0.563
2002	2001	–0.043	0.085	1	0.942	–0.245	0.159
	2003	0.320*	0.075	1	< 0.001	0.141	0.499
2003	2001	–0.363*	0.084	1	< 0.001	–0.563	–0.164
	2002	–0.320*	0.075	1	< 0.001	–0.499	–0.141

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable % cover of coralline species.

* The mean difference is significant at the 0.05 level.

Pairwise comparison of percentage cover of coralline species by site

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	–0.433*	0.116	1	0.003	–0.773	–0.093
	PPI	0.146	0.130	1	0.990	–0.236	0.527
	PPII	–0.066	0.118	1	1.000	–0.413	0.280
	NPI	–0.378*	0.113	1	0.012	–0.709	–0.048
	NPII	–0.475*	0.118	1	0.001	–0.822	–0.129
CAII	CAI	0.433*	0.116	1	0.003	0.093	0.773
	PPI	0.579*	0.121	1	< 0.001	0.225	0.933
	PPII	0.366*	0.108	1	0.010	0.050	0.682
	NPI	0.054	0.102	1	1.000	–0.244	0.353
	NPII	–0.043	0.108	1	1.000	–0.358	0.273
PPI	CAI	–0.146	0.130	1	0.990	–0.527	0.236
	CAII	–0.579*	0.121	1	< 0.001	–0.933	–0.225
	PPII	–0.212	0.123	1	0.732	–0.572	0.148
	NPI	–0.524*	0.118	1	< 0.001	–0.869	–0.180
	NPII	–0.621*	0.123	1	< 0.001	–0.981	–0.262
PPII	CAI	0.066	0.118	1	1.000	–0.280	0.413
	CAII	–0.366*	0.108	1	0.010	–0.682	–0.050
	PPI	0.212	0.123	1	0.732	–0.148	0.572
	NPI	–0.312*	0.104	1	0.041	–0.618	–0.006
	NPII	–0.409*	0.110	1	0.003	–0.731	–0.087
NPI	CAI	0.378*	0.113	1	0.012	0.048	0.709
	CAII	–0.054	0.102	1	1.000	–0.353	0.244
	PPI	0.524*	0.118	1	< 0.001	0.180	0.869
	PPII	0.312*	0.104	1	0.041	0.006	0.618
	NPII	–0.097	0.104	1	0.999	–0.402	0.208
NPII	CAI	0.475*	0.118	1	0.001	0.129	0.822
	CAII	0.043	0.108	1	1.000	–0.273	0.358
	PPI	0.621*	0.123	1	< 0.001	0.262	0.981
	PPII	0.409*	0.110	1	0.003	0.087	0.731
	NPI	0.097	0.104	1	0.999	–0.208	0.402

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable % cover of coralline species.

* The mean difference is significant at the 0.05 level.

A2.5 Kina (*Evechinus chloroticus*) density (number of kina/m²), with pairwise comparisons by year and site

Model information

Dependent variable	*Evechinus chloroticus* density
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	4.683	1	0.030
Year	11.683	2	0.003
Site	55.209	5	< 0.001
Year*Site	19.171	9	0.024

Dependent Variable: *Evechinus chloroticus* density
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of Evechinus chloroticus *density by year*

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–0.117	0.289	1	0.969	–0.806	0.573
	2003	5.350*	0.334	1	< 0.001	4.553	6.148
2002	2001	0.117	0.289	1	0.969	–0.573	0.806
	2003	5.467*	0.266	1	< 0.001	4.832	6.102
2003	2001	–5.350*	0.334	1	< 0.001	–6.148	–4.553
	2002	–5.467*	0.266	1	< 0.001	–6.102	–4.832

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Evechinus chloroticus* density.

* The mean difference is significant at the 0.05 level.

Pairwise comparison of Evechinus chloroticus *density by site*

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	–0.222	0.285	1	1.000	–1.055	0.611
	PPI	12.102*	0.606	1	<0.001	10.328	13.875
	PPII	0.971*	0.319	1	0.034	0.038	1.903
	NPI	0.941*	0.300	1	0.025	0.063	1.819
	NPII	1.541*	0.364	1	<0.001	0.474	2.607
CAII	CAI	0.222	0.285	1	1.000	–0.611	1.055
	PPI	12.323*	0.593	1	<0.001	10.587	14.060
	PPII	1.192*	0.294	1	0.001	0.332	2.053
	NPI	1.163*	0.273	1	<0.001	0.362	1.963
	NPII	1.763*	0.343	1	<0.001	0.759	2.766
PPI	CAI	–12.102*	0.606	1	<0.001	–13.875	–10.328
	CAII	–12.323*	0.593	1	<0.001	–14.060	–10.587
	PPII	–11.131*	0.602	1	<0.001	–12.894	–9.368
	NPI	–11.161*	0.601	1	<0.001	–12.919	–9.402
	NPII	–10.561*	0.635	1	<0.001	–12.420	–8.701
PPII	CAI	–0.971*	0.319	1	0.034	–1.903	–0.038
	CAII	–1.192*	0.294	1	0.001	–2.053	–0.332
	PPI	11.131*	0.602	1	<0.001	9.368	12.894
	NPI	–0.030	0.309	1	1.000	–0.934	0.874
	NPII	0.570	0.371	1	0.865	–0.517	1.658
NPI	CAI	–0.941*	0.300	1	0.025	–1.819	–0.063
	CAII	–1.163*	0.273	1	<0.001	–1.963	–0.362
	PPI	11.161*	0.601	1	<0.001	9.402	12.919
	PPII	0.030	0.309	1	1.000	–0.874	0.934
	NPII	0.600	0.356	1	0.763	–0.441	1.641
NPII	CAI	–1.541*	0.364	1	<0.001	–2.607	–0.474
	CAII	–1.763*	0.343	1	<0.001	–2.766	–0.759
	PPI	10.561*	0.635	1	<0.001	8.701	12.420
	PPII	–0.570	0.371	1	0.865	–1.658	0.517
	NPI	–0.600	0.356	1	0.763	–1.641	0.441

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Evechinus chloroticus* density.

* The mean difference is significant at the 0.05 level.

A2.6 Cook's turban shell (*Cookia sulcata*) density (number of shells/m²), with pairwise comparisons by year and site

Model information

Dependent variable	*Cookia sulcata* density
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	46.510	1	< 0.001
Year	100.554	2	< 0.001
Site	30.227	5	< 0.001
Year*Site	25.338	8	0.001

Dependent variable: *Cookia sulcata* density
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of Cookia sulcata *density by year*

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–6.546	101 736.748	1	1.000	–242 927.235	242 914.143
	2003	–0.520	0.352	1	0.362	–1.360	0.319
2002	2001	6.546	101 736.748	1	1.000	–242 914.143	242 927.235
	2003	6.026	101 736.748	1	1.000	–242 914.663	242 926.715
2003	2001	0.520	0.352	1	0.362	–0.319	1.360
	2002	–6.026	101 736.748	1	1.000	–242 926.715	242 914.663

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Cookia sulcata* density.

Pairwise comparison of Cookia sulcata *density by site*

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	0.158	0.393	1	1.000	–0.993	1.310
	PPI	20.457	406946.994	1	1.000	–1191438.306	1191479.220
	PPII	0.965	0.409	1	0.241	–0.232	2.162
	NPI	0.081	0.352	1	1.000	–0.949	1.110
	NPII	–0.261	0.379	1	1.000	–1.371	0.848
CAII	CAI	–0.158	0.393	1	1.000	–1.310	0.993
	PPI	20.298	406946.994	1	1.000	–1191438.465	1191479.062
	PPII	0.807	0.388	1	0.439	–0.331	1.944
	NPI	–0.078	0.328	1	1.000	–1.037	0.882
	NPII	–0.420	0.357	1	0.984	–1.464	0.625
PPI	CAI	–20.457	406946.994	1	1.000	–1191479.220	1191438.306
	CAII	–20.298	406946.994	1	1.000	–1191479.062	1191438.465
	PPII	–19.491	406946.994	1	1.000	–1191478.255	1191439.272
	NPI	–20.376	406946.994	1	1.000	–1191479.139	1191438.387
	NPII	–20.718	406946.994	1	1.000	–1191479.481	1191438.045
PPII	CAI	–0.965	0.409	1	0.241	–2.162	0.232
	CAII	–0.807	0.388	1	0.439	–1.944	0.331
	PPI	19.491	406946.994	1	1.000	–1191439.272	1191478.255
	NPI	–0.885	0.346	1	0.148	–1.898	0.129
	NPII	–1.227*	0.374	1	0.015	–2.321	–0.132
NPI	CAI	–0.081	0.352	1	1.000	–1.110	0.949
	CAII	0.078	0.328	1	1.000	–0.882	1.037
	PPI	20.376	406946.994	1	1.000	–1191438.387	1191479.139
	PPII	0.885	0.346	1	0.148	–0.129	1.898
	NPII	–0.342	0.310	1	0.991	–1.250	0.566
NPII	CAI	0.261	0.379	1	1.000	–0.848	1.371
	CAII	0.420	0.357	1	0.984	–0.625	1.464
	PPI	20.718	406946.994	1	1.000	–1191438.045	1191479.481
	PPII	1.227*	0.374	1	0.015	0.132	2.321
	NPI	0.342	0.310	1	0.991	–0.566	1.250

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Cookia sulcata* density.

* The mean difference is significant at the 0.05 level.

A2.7 Top shell (*Calliostoma punctulatum* and *Trochus viridus*) density (number of top shells/m^2), with pairwise comparisons by year and site

Model information

Dependent variable	Top shell density
Probability distribution	Negative binomial (1)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	5.455	1	0.020
Year	74.872	2	< 0.001
Site	30.253	5	< 0.001
Year*Site	17.503	9	0.041

Dependent variable: Top shell density
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of top shell density by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–3.031*	0.268	1	< 0.001	–3.671	–2.391
	2003	–4.283*	0.188	1	< 0.001	–4.731	–3.835
2002	2001	3.031*	0.268	1	< 0.001	2.391	3.671
	2003	–1.252*	0.247	1	< 0.001	–1.841	–0.664
2003	2001	4.283*	0.188	1	< 0.001	3.835	4.731
	2002	1.252*	0.247	1	< 0.001	0.664	1.841

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable top shell density.
* The mean difference is significant at the 0.05 level.

Pairwise comparison of top shell density by site

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	–0.037	0.282	1	1.000	–0.864	0.790
	PPI	12.454*	0.572	1	<0.001	10.778	14.130
	PPII	0.604	0.263	1	0.280	–0.166	1.375
	NPI	0.108	0.243	1	1.000	–0.603	0.818
	NPII	–0.024	0.249	1	1.000	–0.754	0.706
CAII	CAI	0.037	0.282	1	1.000	–0.790	0.864
	PPI	12.491*	0.580	1	<0.001	10.792	14.190
	PPII	0.642	0.280	1	0.283	–0.178	1.461
	NPI	0.145	0.261	1	1.000	–0.618	0.908
	NPII	0.013	0.267	1	1.000	–0.768	0.795
PPI	CAI	–12.454*	0.572	1	<0.001	–14.130	–10.778
	CAII	–12.491*	0.580	1	<0.001	–14.190	–10.792
	PPII	–11.850*	0.574	1	<0.001	–13.531	–10.168
	NPI	–12.346*	0.562	1	<0.001	–13.992	–10.701
	NPII	–12.478*	0.565	1	<0.001	–14.132	–10.824
PPII	CAI	–0.604	0.263	1	0.280	–1.375	0.166
	CAII	–0.642	0.280	1	0.283	–1.461	0.178
	PPI	11.850*	0.574	1	<0.001	10.168	13.531
	NPI	–0.497	0.240	1	0.444	–1.199	0.206
	NPII	–0.628	0.247	1	0.151	–1.351	0.094
NPI	CAI	–0.108	0.243	1	1.000	–0.818	0.603
	CAII	–0.145	0.261	1	1.000	–0.908	0.618
	PPI	12.346*	0.562	1	<0.001	10.701	13.992
	PPII	0.497	0.240	1	0.444	–0.206	1.199
	NPII	–0.132	0.225	1	1.000	–0.789	0.526
NPII	CAI	0.024	0.249	1	1.000	–0.706	0.754
	CAII	–0.013	0.267	1	1.000	–0.795	0.768
	PPI	12.478*	0.565	1	<0.001	10.824	14.132
	PPII	0.628	0.247	1	0.151	–0.094	1.351
	NPI	0.132	0.225	1	1.000	–0.526	0.789

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable top shell density.

* The mean difference is significant at the 0.05 level.

Appendix 3

Regression analysis of species abundance data with significant correlations, excluding rock lobsters (*Jasus edwardsii*)

A3.1 Density of kina (*Evechinus chloroticus*; number/m^2) and common kelp (*Ecklonia radiata*; number/m^2)

Model summary

MODEL	r	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.141	0.020	0.017	11.121

Predictors: (Constant), *Evechinus chloroticus* density (number/m^2)

ANOVA

MODEL		SS	D.F.	MS	F	P
1	Regression	1 037.159	1	1 037.159	8.385	0.004
	Residual	51 453.224	416	123.686		
	Total	52 490.383	417			

Predictors: (Constant), *Evechinus chloroticus* density (number/m^2)
Dependent variable: *Ecklonia radiata* density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	t	P
		B	SE	ß		
1	(Constant)	5.780	0.598		9.669	< 0.001
	Total *Evechinus chloroticus* density	–0.349	0.120	–0.141	–2.896	0.004

Dependent variable: *Ecklonia radiata* density (number/m^2)

Model

Ecklonia radiata density = 5.780 – 0.349(*Evechinus chloroticus* density)

A3.2 Percentage cover of sessile invertebrates and density of common kelp (*Ecklonia radiata*; number/m^2)

Model summary

MODEL	r	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.101	0.010	0.008	11.164

Predictors: (Constant), % cover of sessile invertebrates

ANOVA

MODEL		SS	D.F.	MS	F	P
1	Regression	531.393	1	531.393	4.263	0.040
	Residual	51 975.452	417	124.641		
	Total	52 506.845	418			

Predictors: (Constant), % cover of sessile invertebrates
Dependent variable: *Ecklonia radiata* density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	t	P
		B	SE	ß		
1	(Constant)	5.757	0.643		8.948	< 0.001
	Total % cover of sessile invertebrates	–0.046	0.022	–0.101	–2.065	0.040

Dependent variable: *Ecklonia radiata* density (number/m^2)

Model

Ecklonia radiata density = 5.757 – 0.046(% cover of sessile invertebrates)

A3.3 Density of top shells (*Calliostoma punctulatum* and *Trochus viridus*; number/m^2) and kina (*Evechinus chloroticus*; number/m^2)

Model summary

MODEL	*r*	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.174	0.030	0.028	4.459

Predictors: (Constant), top shell density (number/m^2)

ANOVA

MODEL		SS	D.F.	MS	*F*	*P*
1	Regression	258.383	1	258.383	12.994	< 0.001
	Residual	8272.239	416	19.885		
	Total	8530.622	417			

Predictors: (Constant), top shell density (number/m^2)
Dependent variable: *Evechinus chloroticus* density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	*t*	*P*
		B	SE	ß		
1	(Constant)	1.625	0.249		6.526	< 0.001
	Total top shell density	0.180	0.050	0.174	3.605	< 0.001

Dependent variable: *Evechinus chloroticus* density (number/m^2)

Model

Evechinus chloroticus density = 1.625 + 0.180(top shell density)

A3.4 Percentage cover of coralline species and density of kina (*Evechinus chloroticus*; number/m²)

Model summary

MODEL	*r*	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.012	0.000	–0.002	4.528

Predictors: (Constant), % cover of sessile invertebrates

ANOVA

MODEL		SS	D.F.	MS	*F*	*P*
1	Regression	1.209	1	1.209	0.059	0.808
	Residual	8529.413	416	20.503		
	Total	8530.622	417			

Predictors: (Constant), % cover of coralline species
Dependent variable: *Evechinus chloroticus* density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	*t*	*P*
		B	SE	ß		
1	(Constant)	2.146	0.428		5.010	< 0.001
	Total % cover of coralline species	–0.002	0.007	–0.012	–0.243	0.808

Dependent variable: *Evechinus chloroticus* density (number/m^2)

Model

Evechinus chloroticus density = 2.146 – 0.002(% cover of coralline species)

A3.5 Percentage cover of species of Chlorophyta and Rhodophyta, and density of kina (*Evechinus chloroticus*; number/m^2)

Model summary

MODEL	r	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.108	0.012	0.009	4.502

Predictors: (Constant), % cover of Chlorophyta and Rhodophyta

ANOVA

MODEL		SS	D.F.	MS	F	P
1	Regression	99.617	1	99.617	4.915	0.027
	Residual	8431.005	416	20.267		
	Total	8530.622	417			

Predictors: (Constant), % cover of Chlorophyta and Rhodophyta
Dependent variable: *Evechinus chloroticus* density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	t	P
		B	SE	ß		
1	(Constant)	2.255	0.238		9.493	< 0.001
	Total % cover of Chlorophyta and Rhodophyta	–0.032	0.014	–0.108	–2.217	0.027

Dependent variable: *Evechinus chloroticus* density (number/m^2)

Model

Evechinus chloroticus density = 2.255 – 0.032(% cover of Chlorophyta and Rhodophyta)

A3.6 Density of top shells (*Calliostoma punctulatum* and *Trochus viridus*; number/m²) and Cook's turban shell (*Cookia sulcata*; number/m²)

Model summary

MODEL	r	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.160	0.026	0.023	11.121

Predictors: (Constant), top shell density (number/m²)

ANOVA

MODEL		SS	D.F.	MS	F	P
1	Regression	70.547	1	70.547	10.932	0.001
	Residual	2684.432	416	6.453		
	Total	2754.978	417			

Predictors: (Constant), top shell density (number/m²)
Dependent variable: *Cookia sulcata* density (number/m²)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	t	P
		B	SE	ß		
1	(Constant)	1.234	0.142		8.695	<0.001
	Total top shell density	–0.094	0.028	–0.160	–3.306	0.001

Dependent variable: *Cookia sulcata* density (number/m²)

Model

Cookia sulcata density = 1.234 – 0.094(top shell density)

A3.7 Percentage cover of coralline species and density of Cook's turban shell (*Cookia sulcata*; number/m^2)

Model summary

MODEL	*r*	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.121	0.015	0.012	2.555

Predictors: (Constant), % cover of coralline species

ANOVA

MODEL		SS	D.F.	MS	*F*	*P*
1	Regression	40.375	1	40.375	6.187	0.013
	Residual	2714.603	416	6.525		
	Total	2754.978	417			

Predictors: (Constant), % cover of coralline species
Dependent variable: *Cookia sulcata* density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	*t*	*P*
		B	SE	ß		
1	(Constant)	0.494	0.241		2.050	0.041
	Total % cover of coralline species	0.010	0.004	0.121	2.487	0.013

Dependent variable: *Cookia sulcata* density (number/m^2)

Model

Cookia sulcata density = 0.494 + 0.010(% cover of coralline species)

A3.8 Percentage cover of sessile invertebrates and density of top shells (*Calliostoma punctulatum* and *Trochus viridus*; number/m^2)

Model summary

MODEL	r	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.180	0.033	0.030	4.298

Predictors: (Constant), % cover of sessile invertebrates

ANOVA

MODEL		SS	D.F.	MS	F	P
1	Regression	259.267	1	259.267	14.035	< 0.001
	Residual	7703.373	417	18.473		
	Total	7962.640	418			

Predictors: (Constant), % cover of sessile invertebrates
Dependent variable: Top shell density (number/m^2)

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	t	P
		B	SE	ß		
1	(Constant)	2.893	0.248		11.680	< 0.001
	Total % cover of sessile invertebrates	–0.032	0.009	–0.180	–3.746	< 0.001

Dependent variable: Top shell density (number/m^2)

Model

Top shell density = 2.893 – 0.032(% cover of sessile invertebrates)

A3.9 Percentage cover of species of Chlorophyta and Rhodophyta and sessile invertebrates

Model summary

MODEL	*r*	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.216	0.047	0.044	30.968

Predictors: (Constant), % cover of Chlorophyta and Rhodophyta

ANOVA

MODEL		SS	D.F.	MS	*F*	*P*
1	Regression	19627.965	1	19627.965	20.466	<0.001
	Residual	399916.078	417	959.031		
	Total	419544.043	418			

Predictors: (Constant), % cover of Chlorophyta and Rhodophyta
Dependent variable: % cover of coralline species

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	*t*	*P*
		B	SE	ß		
1	(Constant)	55.104	1.634		33.726	<0.001
	Total % cover of Chlorophyta and Rhodophyta	–0.445	0.098	–0.216	–4.524	<0.001

Dependent variable: % cover of coralline species

Model

% cover of coralline species = 55.104 – 0.445(% cover of Chlorophyta and Rhodophyta)

A3.10 Percentage cover of sessile invertebrates and coralline species

Model summary

MODEL	r	r^2	ADJUSTED r^2	SE OF ESTIMATE
1	0.319	0.102	0.100	30.058

Predictors: (Constant), % cover of sessile invertebrates

ANOVA

MODEL		SS	D.F.	MS	F	P
1	Regression	42 802.704	1	42 802.704	47.377	< 0.001
	Residual	376 741.339	417	903.456		
	Total	419 544.043	418			

Predictors: (Constant), % cover of sessile invertebrates
Dependent variable: % cover of coralline species

Coefficients

MODEL		UNSTANDARDISED COEFFICIENTS		STANDARDISED COEFFICIENTS	t	P
		B	SE	ß		
1	(Constant)	58.638	1.732		33.850	< 0.001
	Total % cover of sessile invertebrates	–0.416	0.060	–0.319	–6.883	< 0.001

Dependent variable: % cover of coralline species

Model

% cover of coralline species = 58.638 – 0.416(% cover of sessile invertebrates)

Appendix 4

Summary of rock lobster (*Jasus edwardsii*) catch-per-unit-effort (CPUE) data at the monitoring sites from 2001 to 2003

Sampling depth data are also included; SE = standard error. See Table 1 for an explanation of the monitoring site names.

	CAI	CAII	PPI	PPII	NPI	NPII
2001						
Male count	69	10	19	0	6	59
Female count	62	10	23	0	1	45
Sex ratio (male:female)	1.113	1.000	0.826	0.000	6.000	1.311
Total count	131	20	42	0	7	104
Total search time (minutes)	69	47	63	28	70	97
CPUE (pooled)	1.821	0.427	0.623	0.000	0.094	0.955
SE (pooled)	0.568	0.052	0.293	0.000	0.024	0.184
CPUE (male)	0.958	0.213	0.272	–	0.086	0.557
SE (male)	0.351	0.005	0.197	–	0.040	0.111
CPUE (female)	0.863	0.214	0.351	–	0.044	0.398
SE (female)	0.226	0.047	0.095	–	0.006	0.117
Mean depth (m)	19.2	18	19	18.5	15.3	17.5
2002						
Male count	56	31	5	2	0	18
Female count	85	63	26	2	1	10
Sex ratio (male:female)	0.659	0.492	0.192	1.000	0.000	1.800
Total count	141	94	31	4	1	28
Total search time (minutes)	54	51	50	26	51	26
CPUE (pooled)	2.611	1.925	0.620	0.154	0.020	1.077
SE (pooled)	0.537	1.195	0.380	–	0.020	-
CPUE (male)	1.037	0.615	0.100	0.077	0.000	0.692
SE (male)	0.667	0.385	0.100	–	0.000	-
CPUE (female)	1.574	1.250	0.520	0.077	0.020	0.385
SE (female)	1.204	0.750	0.480	–	0.020	-
Mean depth (m)	19	14.8	19.8	19	13.5	18
2003						
Male count	122	104	10	15	0	56
Female count	113	144	7	10	0	50
Sex ratio (male:female)	1.080	0.722	1.429	1.500	0.000	1.120
Total count	235	248	17	25	0	106
Total search time (minutes)	83	83	72	50	79	78
CPUE (pooled)	2.828	3.063	0.245	0.500	0.038	1.359
SE (pooled)	0.144	0.930	0.085	0.020	0.001	0.013
CPUE (male)	1.479	1.285	0.151	0.300	0.000	0.718
SE (male)	0.147	0.416	0.078	0.020	0.000	0.128
CPUE (female)	1.350	1.778	0.094	0.200	0.000	0.641
SE (female)	0.140	0.518	0.049	0.040	0.000	0.141
Mean depth (m)	19	13.7	18	18	11.7	18.7

Appendix 5

Generalised linear model (GLM) analysis output for rock lobster (*Jasus edwardsii*) catch-per-unit-effort (CPUE) data, with pairwise comparisons by year, site and sex

Model information

Dependent variable	CPUE (number of rock lobsters/min)
Probability distribution	Tweedie (1.5)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	143.993	1	< 0.001
Year	4.405	2	0.111
Site	120.355	5	< 0.001
Sex	0.290	1	0.590
Year*Site	28.529	8	0.000
Year*Sex	3.382	2	0.184
Site*Sex	2.856	5	0.722

Dependent variable: CPUE (number of rock lobsters/min)
Model: (Intercept), Year, Site, Sex, Year*Site, Year*Sex, Site*Sex

Pairwise comparison of rock lobster CPUE by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–8.618*	0.273	1	< 0.001	–9.269	–7.966
	2003	–0.331	55600.749	1	1.000	–132760.346	132759.683
2002	2001	8.618*	0.273	1	< 0.001	7.966	9.269
	2003	8.286	55600.749	1	1.000	–132751.728	132768.301
2003	2001	0.331	55600.749	1	1.000	–132759.683	132760.346
	2002	–8.286	55600.749	1	1.000	–132768.301	132751.728

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

* The mean difference is significant at the 0.05 level.

Pairwise comparison of rock lobster CPUE by site

(I) SITE	(J) SITE	MEAN DIFFERENCE	SE	D.F.	SIDAK P	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	0.586	0.208	1	0.069	–0.022	1.195
	PPI	1.691*	0.229	1	< 0.001	1.020	2.362
	PPII	19.647*	0.388	1	< 0.001	18.512	20.781
	NPI	21.262	111201.498	1	1.000	–325554.306	325596.830
	NPII	0.745*	0.214	1	0.007	0.119	1.371
CAII	CAI	–0.586	0.208	1	0.069	–1.195	0.022
	PPI	1.105*	0.254	1	< 0.001	0.361	1.848
	PPII	19.060*	0.403	1	< 0.001	17.882	20.239
	NPI	20.676	111201.498	1	1.000	–325554.893	325596.244
	NPII	0.159	0.240	1	1.000	–0.544	0.862
PPI	CAI	–1.691*	0.229	1	< 0.001	–2.362	–1.020
	CAII	–1.105*	0.254	1	< 0.001	–1.848	–0.361
	PPII	17.956*	0.426	1	< 0.001	16.710	19.202
	NPI	19.571	111201.498	1	1.000	–325555.997	325595.139
	NPII	–0.946*	0.259	1	0.004	–1.705	–0.186
PPII	CAI	–19.647*	0.388	1	< 0.001	–20.781	–18.512
	CAII	–19.060*	0.403	1	< 0.001	–20.239	–17.882
	PPI	–17.956*	0.426	1	< 0.001	–19.202	–16.710
	NPI	1.615	111201.498	1	1.000	–325573.953	325577.184
	NPII	–18.902*	0.406	1	< 0.001	–20.089	–17.714
NPI	CAI	–21.262	111201.498	1	1.000	–325596.830	325554.306
	CAII	–20.676	111201.498	1	1.000	–325596.244	325554.893
	PPI	–19.571	111201.498	1	1.000	–325595.139	325555.997
	PPII	–1.615	111201.498	1	1.000	–325577.184	325573.953
	NPII	–20.517	111201.498	1	1.000	–325596.085	325555.052
NPII	CAI	–0.745*	0.214	1	0.007	–1.371	–0.119
	CAII	–0.159	0.240	1	1.000	–0.862	0.544
	PPI	0.946*	0.259	1	0.004	0.186	1.705
	PPII	18.902*	0.406	1	< 0.001	17.714	20.089
	NPI	20.517	111201.498	1	1.000	–325555.052	325596.085

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

* The mean difference is significant at the 0.05 level.

Pairwise comparison of rock lobster CPUE by sex (M = male; F = female)

(I) SEX	(J) SEX	MEAN DIFFERENCE	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
	(I – J)					LOWER	UPPER
F	M	0.109	0.201	1	0.590	–0.286	0.503
M	F	–0.109	0.201	1	0.590	–0.503	0.286

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

Appendix 6

Generalised linear model (GLM) analysis output for rock lobster (*Jasus edwardsii*) catch-per-unit-effort (CPUE) data, with pairwise comparisons by year and site

Model information

Dependent variable	CPUE (number of rock lobsters/min)
Probability distribution	Tweedie (1.5)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	33.405	1	< 0.001
Year	1.638	2	0.441
Site	126.422	5	< 0.001
Year*Site	23.930	9	0.004

Dependent variable: CPUE (number of rock lobsters/min)
Model: (Intercept), Year, Site, Year*Site

Pairwise comparison of rock lobster CPUE by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–8.722*	0.300	1	< 0.001	–9.438	–8.006
	2003	–9.000*	0.244	1	< 0.001	–9.582	–8.418
2002	2001	8.722*	0.300	1	< 0.001	8.006	9.438
	2003	–0.278	0.282	1	0.690	–0.951	0.395
2003	2001	9.000*	0.244	1	< 0.001	8.418	9.582
	2002	0.278	0.282	1	0.690	–0.395	0.951

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

* The mean difference is significant at the 0.05 level.

Pairwise comparison of rock lobster CPUE by site

(I) SITE	(J) SITE	MEAN DIFFERENCE (I − J)	SE	D.F.	SIDAK P	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	0.559	0.233	1	0.221	–0.124	1.241
	PPI	1.652*	0.255	1	< 0.001	0.905	2.400
	PPII	19.646*	0.435	1	< 0.001	18.371	20.920
	NPI	4.046*	0.431	1	< 0.001	2.785	5.308
	NPII	0.755*	0.241	1	0.025	0.050	1.459
CAII	CAI	–0.559	0.233	1	0.221	–1.241	0.124
	PPI	1.094*	0.283	1	0.002	0.266	1.921
	PPII	19.087*	0.452	1	< 0.001	17.764	20.410
	NPI	3.488*	0.448	1	< 0.001	2.177	4.798
	NPII	0.196	0.270	1	1.000	–0.593	0.985
PPI	CAI	–1.652*	0.255	1	< 0.001	–2.400	–0.905
	CAII	–1.094*	0.283	1	0.002	–1.921	–0.266
	PPII	17.993*	0.478	1	< 0.001	16.594	19.392
	NPI	2.394*	0.460	1	< 0.001	1.048	3.740
	NPII	–0.898*	0.289	1	0.028	–1.744	–0.052
PPII	CAI	–19.646*	0.435	1	< 0.001	–20.920	–18.371
	CAII	–19.087*	0.452	1	< 0.001	–20.410	–17.764
	PPI	–17.993*	0.478	1	< 0.001	–19.392	–16.594
	NPI	–15.599*	0.579	1	< 0.001	–17.296	–13.903
	NPII	–18.891*	0.456	1	< 0.001	–20.226	–17.556
NPI	CAI	–4.046*	0.431	1	< 0.001	–5.308	–2.785
	CAII	–3.488*	0.448	1	< 0.001	–4.798	–2.177
	PPI	–2.394*	0.460	1	< 0.001	–3.740	–1.048
	PPII	15.599*	0.579	1	< 0.001	13.903	17.296
	NPII	–3.292*	0.452	1	< 0.001	–4.614	–1.969
NPII	CAI	–0.755*	0.241	1	0.025	–1.459	–0.050
	CAII	–0.196	0.270	1	1.000	–0.985	0.593
	PPI	0.898*	0.289	1	0.028	0.052	1.744
	PPII	18.891*	0.456	1	< 0.001	17.556	20.226
	NPI	3.292*	0.452	1	< 0.001	1.969	4.614

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

* The mean difference is significant at the 0.05 level.

Appendix 7

Generalised linear model (GLM) analysis output for rock lobster (*Jasus edwardsii*) catch-per-unit-effort (CPUE) data, with pairwise comparisons by year and zone

Model information

Dependent variable	CPUE (number of rock lobsters/min)
Probability distribution	Tweedie (1.5)
Link function	Log

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	3.258	1	0.071
Year	0.599	2	0.741
Zone	31.475	2	< 0.001
Year*Zone	3.698	4	0.448

Dependent variable: CPUE (number of rock lobsters/min)
Model: (Intercept), Year, Zone, Year*Zone

Pairwise comparison of rock lobster CPUE by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–0.017	0.361	1	1.000	–0.879	0.845
	2003	–0.216	0.303	1	0.855	–0.939	0.507
2002	2001	0.017	0.361	1	1.000	–0.845	0.879
	2003	–0.199	0.355	1	0.923	–1.047	0.648
2003	2001	0.216	0.303	1	0.855	–0.507	0.939
	2002	0.199	0.355	1	0.923	–0.648	1.047

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

* The mean difference is significant at the 0.05 level.

Pairwise comparison of rock lobster CPUE by zone (CA = Conservation Area; PP = partially protected; NP = not protected)

(I) ZONE	(J) ZONE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CA	PP	1.573*	0.335	1	< 0.001	0.774	2.372
	NP	1.313*	0.304	1	< 0.001	0.588	2.037
PP	CA	–1.573*	0.335	1	< 0.001	–2.372	–0.774
	NP	–0.260	0.379	1	0.869	–1.166	0.645
NP	CA	–1.313*	0.304	1	< 0.001	–2.037	–0.588
	PP	0.260	0.379	1	0.869	–0.645	1.166

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable CPUE (number of rock lobsters/min).

* The mean difference is significant at the 0.05 level.

Appendix 8

Generalised linear model (GLM) analysis output for rock lobster (*Jasus edwardsii*) mean carapace length (mm), with pairwise comparisons by year, site and sex

Model information

Dependent variable	Carapace length (mm)
Probability distribution	Normal
Link function	Identity

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	1945.516	1	< 0.001
Year	2.741	2	0.254
Site	120.272	5	< 0.001
Sex	8.087	1	0.004
Year*Site	26.647	8	0.001
Year*Sex	3.630	2	0.163
Site*Sex	4.052	5	0.542

Dependent variable: Carapace length (mm)
Model: (Intercept), Year, Site, Sex, Year*Site, Year*Sex, Site*Sex

Pairwise comparison of rock lobster carapace length by year

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	–8.952	7.744	1	0.574	–27.443	9.540
	2003	–12.368	8.048	1	0.329	–31.584	6.849
2002	2001	8.952	7.744	1	0.574	–9.540	27.443
	2003	–3.416	6.079	1	0.923	–17.932	11.100
2003	2001	12.368	8.048	1	0.329	–6.849	31.584
	2002	3.416	6.079	1	0.923	–11.100	17.932

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable carapace length (mm).

Pairwise comparison of rock lobster carapace length by site

(I) SITE	(J) SITE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK P	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CAI	CAII	3.891	2.837	1	0.939	–4.416	12.197
	PPI	18.414*	3.644	1	< 0.001	7.745	29.084
	PPII	35.299*	6.476	1	< 0.001	16.340	54.259
	NPI	22.979	21.946	1	0.995	–41.275	87.232
	NPII	24.863*	2.684	1	< 0.001	17.005	32.721
CAII	CAI	–3.891	2.837	1	0.939	–12.197	4.416
	PPI	14.524*	4.206	1	0.008	2.208	26.839
	PPII	31.409*	6.856	1	< 0.001	11.335	51.482
	NPI	19.088	22.062	1	0.999	–45.504	83.680
	NPII	20.972*	3.412	1	< 0.001	10.981	30.963
PPI	CAI	–18.414*	3.644	1	< 0.001	–29.084	–7.745
	CAII	–14.524*	4.206	1	0.008	–26.839	–2.208
	PPII	16.885	7.230	1	0.256	–4.283	38.053
	NPI	4.564	22.021	1	1.000	–59.909	69.038
	NPII	6.449	4.124	1	0.848	–5.625	18.522
PPII	CAI	–35.299*	6.476	1	< 0.001	–54.259	–16.340
	CAII	–31.409*	6.856	1	< 0.001	–51.482	–11.335
	PPI	–16.885	7.230	1	0.256	–38.053	4.283
	NPI	–12.321	23.474	1	1.000	–81.048	56.407
	NPII	–10.437	6.791	1	0.863	–30.318	9.445
NPI	CAI	–22.979	21.946	1	0.995	–87.232	41.275
	CAII	–19.088	22.062	1	0.999	–83.680	45.504
	PPI	–4.564	22.021	1	1.000	–69.038	59.909
	PPII	12.321	23.474	1	1.000	–56.407	81.048
	NPII	1.884	22.060	1	1.000	–62.703	66.472
NPII	CAI	–24.863*	2.684	1	< 0.001	–32.721	–17.005
	CAII	–20.972*	3.412	1	< 0.001	–30.963	–10.981
	PPI	–6.449	4.124	1	0.848	–18.522	5.625
	PPII	10.437	6.791	1	0.863	–9.445	30.318
	NPI	–1.884	22.060	1	1.000	–66.472	62.703

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable carapace length (mm).

* The mean difference is significant at the 0.05 level.

Pairwise comparison of rock lobster carapace length by sex (M = male; F = female)

(I) SEX	(J) SEX	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
F	M	–16.543*	5.817	1	0.004	–27.945	–5.142
M	F	16.543*	5.817	1	0.004	5.142	27.94

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable carapace length (mm).

* The mean difference is significant at the 0.05 level.

Appendix 9

Generalised linear model (GLM) analysis output for kina (*Evechinus chloroticus*) mean test diameter (mm), with pairwise comparisons by year and management zone

Model information

Dependent variable	*Evechinus chloroticus* test diameter (mm)
Probability distribution	Normal
Link function	Identity

Tests of model effects

SOURCE	TYPE III		
	WALD CHI-SQUARE	D.F.	*P*
(Intercept)	1773.636	1	< 0.001
Year	64.357	2	< 0.001
Zone	222.819	2	< 0.001
Year*Zone	71.880	4	< 0.001

Dependent variable: *Evechinus chloroticus* test diameter (mm)
Model: (Intercept), Year, Zone, Year*Zone

Pairwise comparison of Evechinus chloroticus *test diameter and year*

(I) YEAR	(J) YEAR	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
2001	2002	13.270*	5.455	1	0.044	0.246	26.295
	2003	–8.204	5.724	1	0.390	–21.872	5.464
2002	2001	–13.270*	5.455	1	0.044	–26.295	–0.246
	2003	–21.474*	2.712	1	< 0.001	–27.949	–14.999
2003	2001	8.204	5.724	1	0.390	–5.464	21.872
	2002	21.474*	2.712	1	< 0.001	14.999	27.949

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Evechinus chloroticus* test diameter (mm).

* The mean difference is significant at the 0.05 level.

Pairwise comparison of rock lobster CPUE by zone (CA = Conservation Area; PP = partially protected; NP = not protected)

(I) ZONE	(J) ZONE	MEAN DIFFERENCE (I – J)	SE	D.F.	SIDAK *P*	95% WALD CI FOR DIFFERENCE	
						LOWER	UPPER
CA	NP	–31.138*	2.135	1	< 0.001	–36.235	–26.041
	PP	–23.512*	5.589	1	< 0.001	–36.857	–10.167
NP	CA	31.138*	2.135	1	< 0.001	26.041	36.235
	PP	7.626	5.838	1	0.471	–6.313	21.565
PP	CA	23.512*	5.589	1	< 0.001	10.167	36.857
	NP	–7.626	5.838	1	0.471	–21.565	6.313

Pairwise comparisons of estimated marginal means based on the linear predictor of the dependent variable *Evechinus chloroticus* test diameter (mm).

* The mean difference is significant at the 0.05 level.