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BASELINE BIODIVERSITY SURVEY

OF THE

COD GROUNDS COMMONWEALTH MARINE RESERVE

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Survey: Reef Life Survey

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SUMMARY

This report outlines results of subtidal ecological surveys undertaken in the Cod Grounds Commonwealth Marine Reserve (CGCMR) and nearby reference sites off the central coast of New South Wales in May 2009. The CGCMR was established in May 2007 with the primary aim of protecting critical habitat of the endangered grey nurse shark (*Carcharias taurus*). It encompasses an area of 3.1 square kilometres, within a 1000 metre radius of the Cod Grounds pinnacles, which lie approximately 7 km offshore from Laurieton.

Twenty-four transects were surveyed at 11 sites between the 12th and 17th May 2009 by a team of skilled volunteer divers as part of the Reef Life Survey (RLS) program (www.reeflifesurvey.com), using standard RLS underwater visual census protocols. Surveys were based around 50 m transects, with species-level abundance and size data recorded for all fishes, abundance data for large mobile macroinvertebrates, and percentage cover data for sessile biota within a standard area.

The fish fauna of the reserve and nearby reference sites was generally similar in composition to inshore reefs of the area, but with a very high overall biomass. Few rare species were sighted. An average of 15.7 fish species was recorded per 50 m transect, with mado (*Atypichthys strigatus*), silver sweep (*Scorpis lineolata*) and one-spot pullers (*Chromis hypsilepis*) the most abundant. Average fish biomass (over all sites) was 272.4 kg per 500 m^2, and higher carnivores and planktivores were the dominant trophic groups. Four grey nurse sharks were recorded on transects, and a further 18 counted at the base of the main pinnacles (site 8CG).

The mobile macroinvertebrate fauna was dominated by echinoderms and molluscs, with the spiny sea urchin (*Centrostephanus rodgersii*), orange feather star (*Cenolia trichoptera*), eastern slate-pencil urchin (*Phyllacanthus parvispinus*) and the mollusc *Astralium tentoriformis* most important by abundance and frequency of occurrence. Very clear depth-related patterns were evident in the macroinvertebrate fauna, largely related to which urchin species was dominant. *Centrostephanus rodgersii* dominated transects between 25 and 28 m, *P. parvispinus* dominated transects between 29 and 32 m and *Prionocidaris callista* were most abundant on transects deeper than 32 m.

The sessile community was characterised by either a high cover of crustose coralline algae or a diverse sessile invertebrate assemblage and a general lack of large macroalgae. Distinct differences were also noticed in the sessile community between transects at different depths.

Transects less than 29 m had very low sessile invertebrate cover and low taxonomic richness, whilst transects deeper than 29 m had relatively lower cover of crustose coralline algae and higher richness and cover of sponges, ascidians and corals.

The CGCMR encompasses an area of high conservation value, not only due to the presence of a significant grey nurse shark aggregation site, but also because it is a productive area that supports a large biomass of fishes, including many exploited species. Illegal fishing is considered to be the greatest threat to these communities at present. It is recommended that continued monitoring of the area be undertaken, with the addition of more external reference sites so that changes in the communities within the reserve can be compared with similar unprotected reefs nearby.

CONTENTS

1. INTRODUCTION

The Cod Grounds is located in Commonwealth waters approximately four nautical miles off the coast of Laurieton, New South Wales, Australia (Schirmer *et al*., 2004). It consists of three underwater pinnacles rising to ~18 m depth from a seabed approximately 40 m deep (Schirmer *et al*., 2004). The Cod Grounds was identified as a prime habitat for a number of important species; including grey nurse sharks (*Carcharias taurus*), which are listed as endangered under the Threatened Species provisions of the NSW *Fisheries Management Act 1994* (Otway *et al*., 2003) and critically endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*; and black cod (*Epinephelus daemelii*), which are listed as a vulnerable species under the *NSW Fisheries Management Act 1994* and are protected in NSW and Commonwealth waters.

The Cod Grounds Commonwealth Marine Reserve (CGCMR) was declared in May 2007, covering an area within a 1000 metre radius of the three pinnacles of the Cod Grounds, and with a total area of 3.1 square kilometres (Figure 1). This Marine Protected Area (MPA) is managed as an International Union for Conservation of Nature (IUCN) Category 1a (no take) Sanctuary Zone, where all commercial and recreational fishing is prohibited in the Reserve. Its primary aim is to protect important habitat of the critically endangered grey nurse shark. The Commonwealth Recovery Plan for Grey Nurse Sharks in Australia lists nineteen known aggregation sites for grey nurse sharks along Australia's east coast, one of which is the Cod Grounds (Schirmer *et al*., 2004).

This report describes patterns of reef biodiversity in the CGCMR as well as at external sites chosen as 'reference sites'. This report was commissioned by the Department of the Environment, Water, Heritage and the Arts to contribute to the development of suitable monitoring and management strategies of this area. The results of the survey will be used as a baseline on the current condition and biodiversity values of the Reserve to form a basis for future research and monitoring of the Reserve. The survey is part of the performance assessment program for the Reserve, which will determine its effectiveness in protecting the grey nurse shark habitat that the Reserve was set up to safeguard. The broad aim of this study is therefore to enhance knowledge of the biodiversity of the CGCMR and provide baseline data to be used in ongoing monitoring of this area. The methods employed are based on those applied widely in marine park assessments along the temperate Australian coast and tropical island systems, involving quantitative surveys of fishes, mobile macroinvertebrates, and photo quadrats of sessile invertebrates and macroalgae.

1.1 Geology/Geomorphology

The NSW Department of Environment and Climate Change (DECC) completed a swathe sonar and underwater video survey of the CGCMR and surrounding area using a Geoswath 125 kHz interferometric system (Davies *et al*., 2008). These data showed a central rocky reef outcrop rising 24 m from a relatively flat seabed. The reef is surrounded by boulders and cobbles which gently slope and are progressively covered by sand. A combination of underwater video analysis and interpretation of bathymetric features in the reserve show that a combination of at least two distinct rock types or geological facies explain the complexity of the terrain (Davies *et al*., 2008).

The underwater video survey revealed four substrate types, ranging from solid consolidated bedrock outcrop, unconsolidated boulder and cobble, cobbles partially covered by sand, and rippled fine sand with variable amounts of shell grit (troughs). The geomorphology of the CGCMR forms a variety of habitats; including steep outcrops, shallow gutters, boulder/cobble slopes, and sand expanses (Davies *et al*., 2008).

The central peak of the CGCMR consists of a series of sharp, blocky outcrops, with side slopes of around 25 degrees (Davies *et al*., 2008). The peak formations within this area are massive and lack obvious bedding features, rising up to 8 m above the surrounding reef (Davies *et al*., 2008). The peaks appear to consist of Tertiary volcanics of the Comboyne Beds, with the deeper parts of reef apparently composed of a different rock type to the central pinnacle—possibly sedimentary facies of the Tertiary Camden Haven Beds (Davies *et al*., 2008). The solid reef outcrops are surrounded by a seabed comprised of a mixture of cobble and larger boulders, with an area of the western and the south-east corner dominated by sand (Davies *et al*., 2008).

1.2 Oceanography

The East Australian Current (EAC) is the primary oceanographic feature impacting on waters off NSW, and is the largest ocean current close to the coast of Australia. The EAC is formed by the westerly flowing Southern Equatorial Current, which moves into this region from the Pacific Ocean. The EAC hits the continental shelf between 13°S and 22°S latitude where it bifurcates into the northward flowing Hiri Current and the much larger EAC (The East Marine Bioregional Plan Bioregional Profile, Chapter 3; Godfrey *et al*., 1980). The EAC causes upwelling where it moves away from the coast at places like Cape Byron, Smoky Cape and Sugarloaf Point in NSW, and draws nutrient rich water from a depth of 200 m or more

(The East Marine Bioregional Plan Bioregional Profile, 2009; Chapter 3). The coastal circulation near the Cod Grounds is dominated by this southward flowing EAC, which is highly energetic in this region due to topographic variations (Oke and Middleton, 2001). The EAC is also responsible for transporting subtropical species to temperate regions along this coast.

1.3 Previous biological studies

Much of the previous biological work on or around the Cod Grounds has focussed on the grey nurse shark (*Carcharias taurus*). Studies by Otway and Parker (2000) and Otway *et al*. (2003) provide comprehensive data on distribution and abundance of *Carcharias taurus* along the NSW and southern Queensland coasts, with quantitative information patterns of movement and site occupation, population size structure, and sex ratios for this species.

1.4 History of fishing effort

The Cod Grounds Commonwealth Marine Reserve (CGCMR) has been a strictly no-take marine reserve since May 2007. Prior to the MPA being established, commercial fishers operating in the region on and around the Cod Grounds used multi-species, multi-method fishing for several decades (Schirmer *et al*., 2004). Just for the 20 main target species, the average annual commercial fish harvest was estimated on average to be ~27,000 tonnes between 1996/97 and 2002/03; with an additional estimated ~4,000 tonnes of ‘minor’ species (Schirmer *et al*., 2004). The highest reported catches were of snapper (*Chrysophrys auratus*), bonito (*Sarda australis*), sweep (*Scorpis lineolata*) and silver trevally (*Pseudocaranx georgianus*) (Schirmer *et al*., 2004). Data on past recreational fishing pressure in the area are limited, but given the commercial pressure and anecdotal accounts of recreational fishers regularly observed near the Cod Grounds pinnacles (see Schirmer *et al*., 2004; Peter Huettner pers comm.), it would be expected that recreational take would also have been high, and likely would have focussed on many of the same species targeted by the commercial fishers.

2. METHODS

Field surveys at the Cod Grounds were conducted from 12-17 May 2009 by a team of skilled divers from the Reef Life Survey program (www.reeflifesurvey.com) and the University of Tasmania. Geographical coordinates of sites (in WGS84) were recorded using handheld Garmin GPS units (Table 1). Ecological surveys were conducted at varying depths along 18 transects at seven sites in the CGCMR, where no fishing is allowed, and along six transects at four sites outside the CGCMR (Figure 1). Data collected from each site consisted of abundance and size of fishes, abundance of mobile macroinvertebrates and cryptic fishes, and percentage cover of sessile biota. These are described separately below.

Sites were selected to encompass the range of reef types and depth both inside and outside the CGCMR, but with the depth range limited by dive safety considerations and bottom time restrictions. One pair of closed-circuit (re-breather) divers was able to survey reef in depths > 32 m, while depths between 26 and 32 m were surveyed using standard open circuit SCUBA. Depth (as displayed on SCUBA gauges) and underwater visibility (measured along the transect line) were also recorded at each site.

2.1 FISH SURVEYS

Fish census protocols involved a diver laying out a 50 m transect line along a depth contour on reef. The number and estimated size-category of all fishes sighted within 5 m blocks either side of the transect line were recorded on waterproof paper as the diver swam slowly along up and down each side. Size-classes of total fish length (from snout to tip of tail) used are 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 400, 500, 625 mm, and above. Lengths of fish larger than 500 mm were estimated to the nearest 12.5 cm and individually recorded.

2.2 MACROINVERTEBRATE AND CRYPTIC FISH SURVEYS

Large macro-invertebrates (molluscs, echinoderms and crustaceans > 2.5 cm) and cryptic fishes (i.e. inconspicuous fish species closely associated with the seabed that were likely to be overlooked during general fish surveys) are censused along the same transect lines set for fish surveys. Divers swim along the bottom, up then down each side of the transect line, recording all mobile macroinvertebrates and cryptic fishes on exposed surfaces of the reef within 1 m of the line.

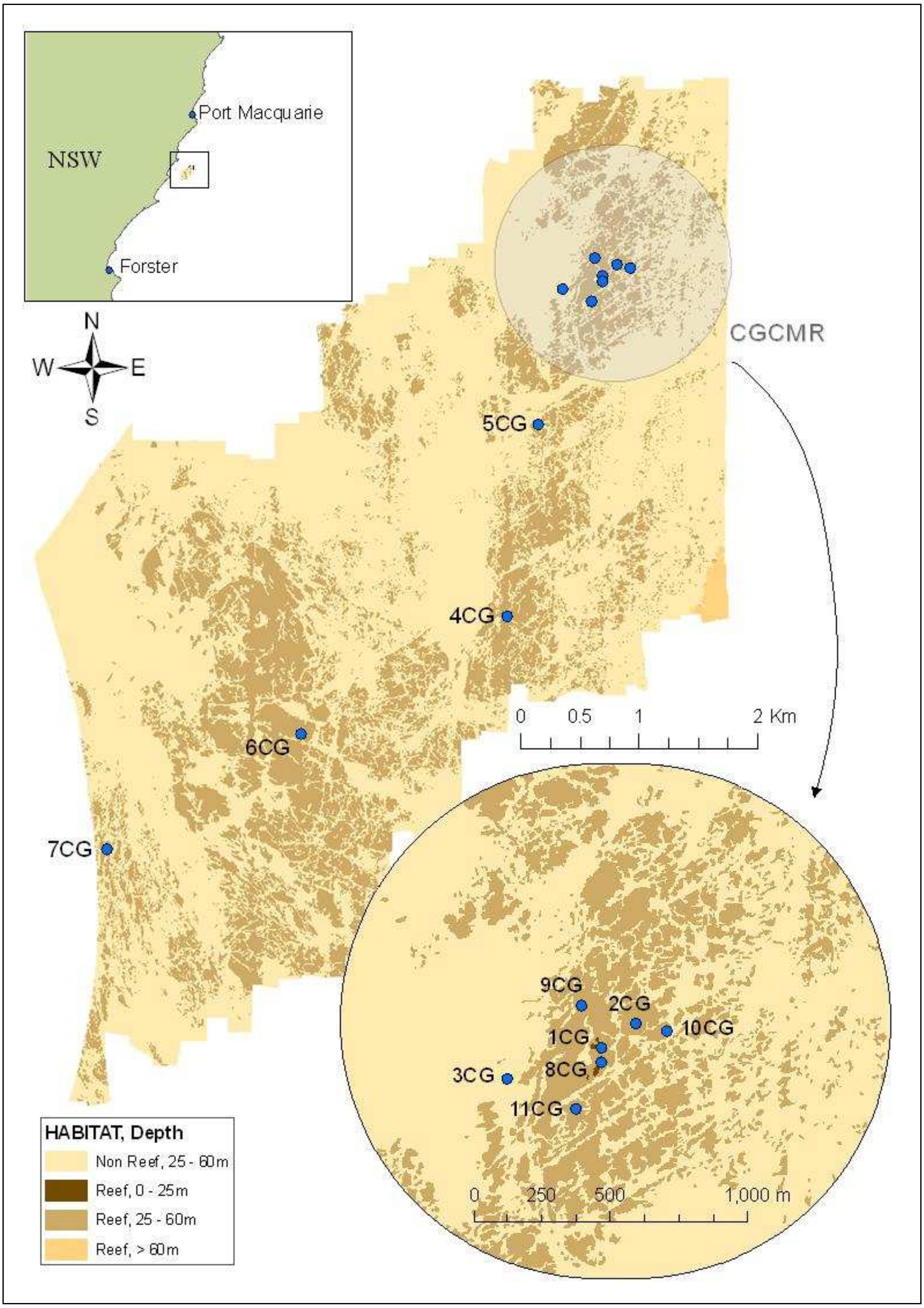


Figure 1. Location of the Cod Grounds Commonwealth Marine Reserve and reef sites surveyed in May 2009. Refer to Table 1 for further site information. Habitat mapping data from Davies *et al*. (2008) and A. Jordan, unpublished data.

Table 1. Site details including marine park zone (CGCMR: Cod Grounds Commonwealth Marine Reserve; Ref: Reference site outside reserve), geographical coordinates (datum = WGS84), depth of transect line, direction from waypoint and underwater visibility for each site surveyed.

Site No.	Reserve status	Site name	Latitude	Longitude	Depth (m)	Date surveyed	Direction of transect from GPS location	Visibility (m)
1CG	CGCMR	Nth of Pinnacles (662)	31.68207	152.90948	27	14/05/2009	NNE	9
	CGCMR				31	14/05/2009	S	
2CG	CGCMR	Cod Gardens (CODGAR)	31.68128	152.91078	28	14/05/2009	NW	10
	CGCMR				29	12/05/2009	NW	
	CGCMR				36	14/05/2009	Swam 50m S then transect to E	
3CG	CGCMR	SW flats (66B)	31.68309	152.90585	27	14/05/2009	NNW	13
	CGCMR				26	14/05/2009	NW	
4CG	Ref	Z - 3 (666)	31.70804	152.90093	29.5	15/05/2009	S	9
	Ref				29	15/05/2009	S	
5CG	Ref	Deep Wall (665)	31.69339	152.90375	42	15/05/2009	SW	8
6CG	Ref	Z - 1 - 28 (M2-28)	31.71699	152.88254	29.5	15/05/2009	E	12
	Ref				29	15/05/2009	NE	
7CG	Ref	Leah's Lumps (L-BUMP)	31.72582	152.86517	35	15/05/2009	E	10
8CG	CGCMR	Cod Grounds Pinnacles (CODGRD)	31.68254	152.90945	25	16/05/2009	S (along W side of pinnacles)	7
	CGCMR				32	16/05/2009	SW (anemone gardens)	
	CGCMR				36	16/05/2009	swam 100m SSE then transect S	
	CGCMR				26	17/05/2009	S (along E side of pinnacles)	7
9CG	CGCMR	Geek Flats (667)	31.6807	152.90872	26	16/05/2009	E	9
	CGCMR				27	16/05/2009	W	
10CG	CGCMR	Steve's Bommie (668)	31.68152	152.91196	31	17/05/2009	S (wrap around top of Sth lump)	8
	CGCMR				30	17/05/2009	N (wrap around top of Nth lump)	
	CGCMR				36.5	17/05/2009	Swam 20m then S	
11CG	CGCMR	SE lumps (66A)	31.68406	152.90851	29	17/05/2009	SW around lump	8
	CGCMR				33	17/05/2009	S	

2.3 MACROALGAL AND SESSILE INVERTEBRATE SURVEYS

Information on the percentage cover of sessile animals and seaweeds along the transect lines set for fish and invertebrate censuses were recorded using photo-quadrats taken sequentially each 2.5 m (or 5 m, see below) along the 50 m transect. Digital photo-quadrats were taken vertically-downward from a height sufficient to encompass an area of at least 0.3 m x 0.3 m. When a wide-angle lens was used and the photo-quadrats encompassed at least 0.5 m x 0.5 m, only 10 images were taken (one every 5 m). The percentage cover of different macroalgal, coral, sponge and other attached invertebrate species in photo-quadrats were digitally quantified in the laboratory using the Coral Point Count with Excel extensions (CPCe) software (Kohler and Gill, 2006). A grid of 56 points was overlaid on each image and the taxon lying directly below each point recorded. Identification was to the lowest possible taxonomic resolution, with taxa for which identification was uncertain grouped with congeners or other members of the family or order.

2.4 STATISTICAL ANALYSES

At most sites, multiple transects were surveyed at different depths (see Table 1). Because community types encountered along individual transects within a site generally matched more closely with transects at similar depths at other sites, rather than transects at other depths within the same site, each transect was regarded as an independent sample in analyses. Thus, the unit of replication was mean value(s) per transect block (i.e. per 250 m^2 for fishes and per 50 m^2 for mobile macroinvertebrates). Exceptions to this rule were species richness data and sessile biota percent cover data, which were expressed as totals or average % per transect (i.e. 2 blocks) respectively. Whilst mean values per transect block were used in most analyses, totals per transect (i.e. 2 blocks) are generally presented in tables, figures and summary data.

Separate univariate analyses and data exploration techniques were used for fish, mobile macroinvertebrate communities, and sessile communities, and then these major taxonomic groups were combined to examine multivariate patterns in overall community structure in the reef communities surveyed.

Univariate metrics that described important community characteristics were calculated for each transect and compared between transects surveyed inside and outside the CGCMR and with transect depth. Metrics examined for fishes were: relative abundance, estimated total biomass (see below for biomass estimation), biomass of fishes > 40 cm TL, biomass of exploited (recreational or commercial) species, and number of species. Mobile invertebrate metrics were: total relative abundance of mobile invertebrates, relative abundance of *Centrostephanus rodgersii*, relative abundance of all sea urchins, and number of species. Sessile community/benthic cover metrics were: % crustose coralline algae, % bare rock, total sessile invertebrate cover and number of biotic taxa/groups (i.e. not including bare substrate categories). Urchin numbers, % crustose coralline algae, and % bare rock were included because they are closely associated with “urchin barren” reef state – habitats where all canopy, understory, and often much of the sessile invertebrate cover, have been overgrazed by dense aggregations of sea urchins, usually *Centrostephanus rodgersii*.

Univariate metrics were used in separate ANCOVAs, with reserve status (inside CGCMR vs. external reference sites) as a fixed factor and transect depth as a continuous covariate. Depth was included as a covariate as it was evident during surveys and from preliminary data exploration that fish, invertebrate and sessile communities differed according to the depth at which transects were surveyed. All dependent variables were log(x+1) transformed, except for species richness (number of taxa recorded per transect block).

To explore patterns in fish community trophic structure, the abundance and biomass of fishes in different trophic groups (herbivores, planktivores, benthic carnivores and higher carnivores) were estimated. Biomass estimates were made for each species on each transect block using fish abundance counts, size estimates, and the length-weight relationships presented for each species (in some cases genus and family) in Fishbase (Froese and Pauly, 2009). In cases where length-weight relationships were described in Fishbase in terms of standard length or fork length rather than total length (TL), length-length relationships provided in Fishbase allowed conversion to total length, as estimated by divers. For improved accuracy in biomass assessments, the bias in divers’ perception of fish size underwater was additionally corrected using relationships presented in Edgar *et al*. (2004). Note that estimates of fish abundance and size made by divers can be greatly affected by fish behaviour for many species (Edgar *et al*., 2004); consequently biomass determinations, like abundance estimates, can reliably be compared only in a relative sense (i.e. for comparisons with data collected using the same methods) rather than providing an accurate absolute estimate of fish biomass for a patch of reef.

The size structure of the fish community was also examined, with the size spectra approach (Dulvy *et al*., 2004; Daan *et al*., 2005) used to quantify the size structure in a way that represents the whole community, including unharvested species, and that can be repeated in future surveys. The methods of the above authors for calculating the size spectra metrics of slope and mid-point height were modified slightly to suit the temperate reef fish community present at the Cod Grounds, which has less fishes in the lower and upper size classes compared to the tropical fish communities for which the approach has been developed and mostly used for (Jennings and Polunin, 1996; Jennings *et al*., 1999).

Firstly, size estimates were corrected as for the biomass calculations above, and then all fishes less than or equal to 12 cm were pooled, as were those greater than 80 cm. Fish abundance in each of the new size classes (i.e. corrected versions of those originally estimated by divers as ≤ 10 cm, 12.5, 15, 20, 25, 30, 35, 40, 50, 62.5, 75 and > 80 cm TL) on each transect was log10(x+1) transformed. Whilst multiple transects at each site were considered separately in the other analyses presented in this report, mean values per site (i.e. across 1-4 transects) were used for this analysis as the size spectrum of some individual transects were non-linear or had an unreliably large r^2. This problem was largely avoided by averaging transects at each site. Size classes (after correction) were also log10(x+1) transformed and re-scaled so that the midpoint was zero; i.e. the mid-point was calculated by subtracting the value of the lowest size class from the greatest and dividing this by two, then adding to the value of the lowest. This value was then subtracted from all the size class values to make the middle of the size class range zero. Least-squares regressions of transformed abundance against size class for each transect was then used to provide the slope and Y-intercept (which now represents the mid-point height) of the size spectra.

Community characteristics and relationships between transects were explored using Principal Coordinates analysis (PCO) and associated plots of principal axes based on Bray-Curtis similarity matrices. Firstly, data for fish, mobile macroinvertebrate and sessile communities were considered separately, with a log(x+1) transformation applied to all data. Then, in order to consider the entire reef assemblage, data from fish, mobile macro-invertebrate and sessile community surveys were combined into one species by transect matrix, and standardised by dividing values by the total of all species abundances/cover values on each transect, and then log(x+1) transforming standardised values. This ensured that the high values for some fish species didn’t dominate the analysis and that cover of sessile taxa (which were expressed as percentages) were not insignificant in comparison. Vector diagrams were added to all MDS plots to show the most important species/taxa in driving overall differences in the community type present.

3. RESULTS

3.1 FISH SURVEYS

Overall, 69 species of fishes were recorded along transects, with 66 of these recorded within the CGCMR. The most abundant species were mado (*Atypichthys strigatus*), silver sweep (*Scorpis lineolata*), and one-spot pullers (*Chromis hypsilepis*), and the most frequently recorded were Maori wrasse (*Ophthalmolepis lineolata*), girdled parma (*Parma unifasciata*) and half-banded sea perch (*Hypoplectrodes maccullochi*) (Table 2). All of these species are commonly found in shallower reefs (<15 m) along the NSW coast, as were the majority of fish species encountered on reefs in the CGCMR and nearby reference sites. The exceptions to this pattern were the pipehorse *Solegnathus dunckeri* (see rare species section below), and schools of teraglin (*Atractoscion aequidens*), both of which are rarely encountered in diveable depths, as well as abundant pelagic species such as highfin amberjack (*Seriola rivoliana*), yellowtail kingfish (*Seriola lalandi*) and rainbow runner (*Elagatis bipinnulata*), which tended to aggregate around the highest pinnacles in the CGCMR.

For sites inside the CGCMR, the average fish abundance per transect (500 m^2) was 388, and the average biomass 179.1 kg. The large mean biomass in the CGCMR was partly due to the high abundance of large wobbegong sharks (*Orectolobus halei* and *O. maculatus*). However, the average abundance and biomass on transects at external reference sites was substantially greater at 5,543 individuals and 552.5 kg, respectively, largely due to the presence of massive schools of mado and silver sweep. These two species averaged more than an order of magnitude greater biomass on reference site transects than those in the CGCMR. While inside/outside MPA differences are potentially influenced by unbalanced survey effort, with only six transects surveyed at four sites outside the CGCMR, the estimated biomass of mado and silver sweep was extraordinarily high on five of these six transects (see Appendices).

The fish community inside the CGCMR was dominated by higher carnivores (20% numbers, 77% biomass) and planktivores (61% of total numbers, 11% of total biomass), with herbivores and benthic carnivores making up very small percentages of numbers and biomass, respectively (4% and 15%, and 2% and 11%). The trophic structure of the fish community at individual sites can be seen in Table 3 and summarised for the CGCMR and reference sites in Table 4.

Table 2. Frequency of occurrence, total abundance and biomass (total kg) of fish species recorded on 24 transects (18 inside the CGCMR and 6 at external reference sites) at 11 sites (7 inside the CGCMR and 4 at external reference sites), representing 12,000 m^2 of reef surveyed. Trophic category (p: planktivore, c: higher carnivore, b: benthic carnivore, h: herbivore).

Species	Transects	Abundance	Biomass	Trophic	Species	Transects	Abundance	Biomass	Trophic
Acanthopagrus australis	6	42	13.2	b	*Mecaenichthys immaculatus*	6	18	0.7	h
Acanthistius ocellatus	2	2	0.5	c	*Meuschenia freycineti*	4	6	6.1	b
Achoerodus viridis	7	14	27.2	c	*Meuschenia scaber*	7	22	3.0	b
Anoplocapros inermis	2	2	0.1	b	*Meuschenia trachylepis*	1	1	0.5	b
Argyrosomus japonicus	1	40	586.3	c	*Nelusetta ayraudi*	1	1	1.4	b
Atractoscion aequidens	1	570	276.5	c	*Nemadactylus douglasi*	9	83	28.2	c
Atypichthys strigatus	8	24884	2048.9	p	*Notolabrus gymnogenis*	17	52	12.1	b
Aulopus purpurissatus	3	3	2.2	c	*Ophthalmolepis lineolata*	22	108	39.1	b
Bodianus frenchii	2	2	2.0	c	*Orectolobus halei*	6	8	1005.0	c
Caesioperca lepidoptera	1	1	0.6	p	*Orectolobus maculatus*	3	3	241.4	c
Carcharias taurus	2	4	282.7	c	*Paracaesio xanthura*	1	100	25.4	p
Centroberyx affinis	1	12	1.7	c	*Parma microlepis*	10	57	12.0	h
Chaetodon guentheri	1	1	0.1	b	*Parma unifasciata*	20	264	32.4	h
Cheilodactylus fuscus	17	572	221.6	b	*Parupeneus spilurus*	16	78	22.3	b
Cheilodactylus vestitus	1	1	0.2	b	*Pempheris affinis*	5	16	0.8	p
Chelmonops truncatus	1	1	0.3	b	*Pempheris compressa*	5	489	65.1	p
Chromis hypsilepis	19	2056	141.5	p	*Plagiotremus tapeinosoma*	2	2	0.1	b
Chrysophrys auratus	14	77	33.4	c	*Prionurus maculatus*	1	2	3.3	h
Coris dorsomacula	2	5	0.3	b	*Prionurus microlepidotus*	4	10	12.3	h
Coris picta	20	104	18.8	b	*Pseudocaranx georgianus*	3	9	3.6	c
Dicotylichthys punctulatus	1	1	0.9	b	*Pseudocoris yamashiroi*	1	1	0.1	b
Dinolestes lewini	3	395	201.6	c	*Rhabdosargus sarba*	6	41	10.3	b
Elagatis bipinnulata	1	5	3.25	c	*Scorpaena cardinalis*	5	9	1.7	c
Enoplosus armatus	15	65	7.2	b	*Scorpis lineolata*	18	8538	978.2	p
Epinephelus daemelii	1	2	3.1	c	*Seriola hippos*	2	18	34.0	c
Epinephelus undulatostriatus	1	3	0.7	c	*Seriola lalandi*	3	35	79.2	c
Eubalichthys bucephalus	1	1	0.4	b	*Seriola rivoliana*	1	4	2.8	c
Eubalichthys mosaicus	1	1	0.1	b	*Suezichthys arquatus*	1	2	0.1	b
Fistularia commersonii	2	2	0.1	c	*Trachichthys australis*	1	1	0.1	c
Fistularia petimba	1	1	0.1	c	*Trachinops taeniatus*	17	1181	6.7	p
Glaucosoma scapulare	2	29	16.2	c	*Trachurus novaezelandiae*	2	24	2.6	c
Heterodontus portusjacksoni	1	1	10.1	c	*Carangoides chrysophrys*	1	2	1.7	c
Hypoplectrodes annulatus	1	1	0.2	c	Unidentified labrid spp.	1	1	0.1	b
Hypoplectrodes maccullochi	20	148	3.8	c	*Upeneichthys lineatus*	4	4	1.0	b
Lotella rhacina	9	13	2.8	c					

Table 3. Number of species, abundance and biomass (kg) of all fishes, and proportions of fishes in different trophic categories recorded on transects inside the CGCMR and at external reference sites (indicated by an asterisk in the site column). Contributions of trophic groups are percentage of total fish biomass.

Site	Depth (m)	fish species	No. of individuals	Total biomass (kg)	% Herbivore	% Planktivore	% Benthic carnivore	% Higher carnivore
1CG	27	9	49	304.9	1.40	0.00	1.83	96.77
1CG	31	21	215	51.8	2.26	10.38	6.41	80.94
2CG	28	12	611	53.4	2.36	87.44	8.86	1.34
2CG	29	6	291	33.9	2.94	83.32	13.74	0.00
2CG	36	23	460	114.8	0.63	16.78	16.63	65.97
3CG	26	21	722	223.9	3.04	17.67	63.67	15.62
3CG	27	26	1043	582.0	1.78	11.52	4.56	82.14
4CG*	29	10	10733	1088.3	0.15	95.67	0.31	3.86
4CG*	29.5	16	3977	562.7	0.09	55.03	0.23	44.65
5CG*	42	14	60	4.4	6.77	3.30	34.08	55.86
6CG*	29	12	5884	596.4	0.58	91.96	0.35	7.11
6CG*	29.5	16	12063	1024.1	0.12	99.18	0.28	0.43
7CG*	35	18	541	39.0	1.14	15.95	24.19	58.72
8CG	25	13	269	29.5	36.08	31.32	18.36	14.24
8CG	26	16	352	257.9	0.73	6.07	1.11	92.09
8CG	32	13	53	7.6	6.31	2.91	71.48	19.30
8CG	36	10	148	13.4	8.92	21.33	62.95	6.80
9CG	26	13	297	19.9	14.54	38.31	33.60	13.55
9CG	27	19	88	50.5	5.48	0.12	9.44	84.97
10CG	30	18	616	487.5	0.18	9.36	12.26	78.20
10CG	31	15	659	55.7	0.85	65.03	8.60	25.53
10CG	36.5	20	814	890.2	0.11	0.83	1.30	97.76
11CG	29	16	138	16.6	19.07	41.16	31.21	8.55
11CG	33	20	168	30.6	7.05	26.51	56.39	10.05
$\bar{x}$ 500 m2		**15.7**	**1677.1**	**272.4**	**5.1**	**34.6**	**20.1**	**40.2**

Table 4. Mean number of species, abundance and biomass (kg) of fish per transect recorded at sites inside the CGCMR (CG) and at external reference sites (Ref), with fishes categorised by major trophic groups (b: benthic carnivore, c: higher carnivore, h: herbivore, p: planktivore).

Fish trophic group	Species		Abundance		Biomass	
	CG	Ref	CG	Ref	CG	Ref
b	6.7	5.2	58 (14.9%)	11.8 (0.2%)	18.8 (10.5%)	3.4 (0.6%)
c	4.7	4.3	78.6 (20.2%)	17.5 (0.3%)	138.1 (77.2%)	60.9 (11.0%)
h	1.8	1.5	15.8 (4.1%)	11 (0.2%)	2.9 (1.6%)	1.2 (0.2%)
p	3	3.3	236 (60.8%)	5502 (99.3%)	19.2 (10.7%)	486.9 (88.2%)

Univariate analyses revealed very few significant differences in important fish community metrics between transects (Table 5). Only total fish abundance was different between the CGCMR transects and those surveyed outside the reserve, with the external transects averaging more than 40 times the fish abundance than CGCMR transects. As mentioned above, this result should be interpreted with caution due to the uneven sample sizes, but without losing sight of the extraordinarily high numbers of fish at the reference sites surveyed. Significant differences in fish abundance and biomass were also detected with depth, with transects at the intermediate depths of 29 to 31 m having greater abundance and biomass than the deeper and shallower transects surveyed. This pattern was also largely driven by the high fish abundances on the reference site transects in this depth range (Fig 2).

Table 5. Results of ANCOVAs of important fish community metrics with location (sites inside the CGCMR or external reference sites) as an independent factor and depth as a continuous covariate. Degrees of freedom for these factors and error are 1, 1 and 21, respectively.

Variable	Location			Depth			Error
	MS	F	P	MS	F	P	MS
Number of species	22.3	0.929	0.346	12.8	0.534	0.473	24.0
Abundance (total)	24.08	17.961	<0.001	7.37	5.495	0.029	1.34
Biomass (total)	8.60	3.758	0.066	10.79	4.71	0.042	2.29
Biomass (> 40 cm TL)	13.5	0.603	0.446	4.27	0.191	0.667	22.4
Biomass (exploited)	0.57	0.061	0.808	1.67	0.176	0.679	9.48

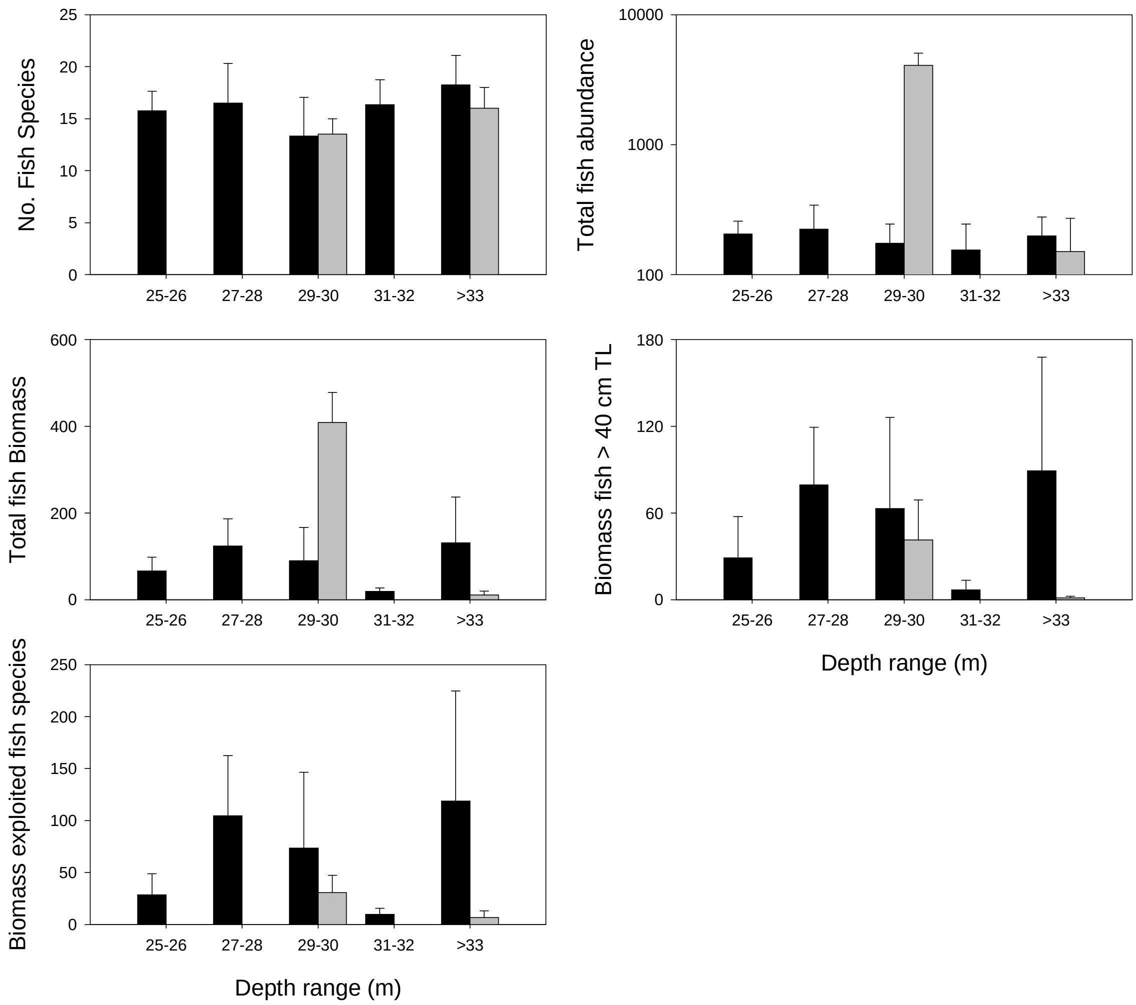


Figure 2. Variation in the species richness, abundance and biomass of the fish community censused on transects at different depths, inside the CGCMR (black fill) and at external reference sites (grey fill). Data have been binned into five depth categories, with sample sizes of 4,4,3,3 and 4 transects for CGCMR, respectively, and 4 and 2 for external reference sites, which only had transects in the 29-30 m and > 33 m categories. Y-axes represent mean values (+SE) per transect (500 m^2). Note that the Y-axis for total fish abundance is on a log-scale.

Fish community size structure

The size spectra analysis provided average slopes of -6.49 (±0.66 SE) and -9.43 (±2.02 SE) for sites inside the CGCMR and external reference sites, respectively (Fig. 3). Corresponding mid-point heights were 2.11 (±0.30 SE) and 2.44 (±0.56 SE). These results are in agreement with the univariate and trophic structure results, suggesting an overall greater abundance/biomass at reference sites, but that this is made up by smaller individuals, largely the planktivores.

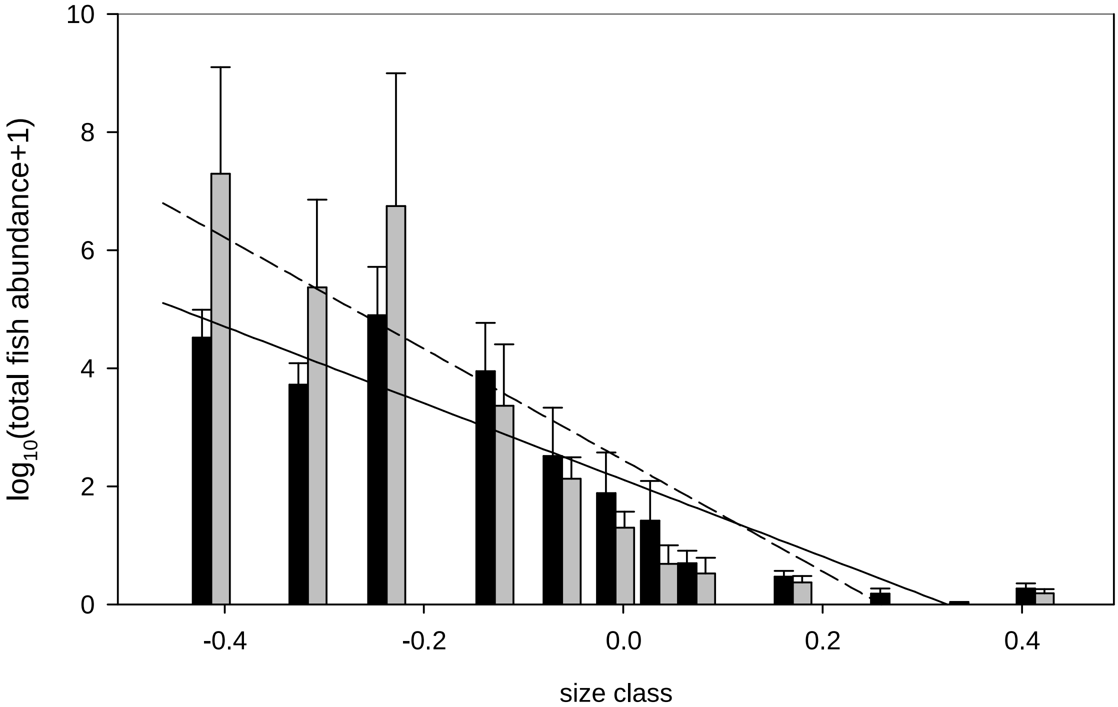
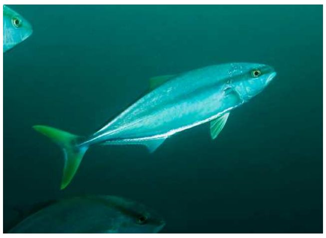


Figure 3. Size spectra for sites inside the CGCMR (black fill, solid line) and for external reference sites (grey fill, dashed line), based on site means. Size classes are re-scaled, transformed sizes; see text for calculations of these and fish abundances. Note that sample sizes are uneven and are 7 and 4, respectively.

Exploited species

Numerous exploited species were recorded on transects in the CGCMR (Table 6). Most of these species were either not recorded or were recorded in lower abundances on transects at external reference sites, although comparisons would be more robust with more survey effort. The most notable of the exploited species present in the CGCMR were: mulloway (*Argyrosomus japonicus*), teraglin (*Atractoscion aequidens*), samson fish (*Seriola hippos*), yellowtail kingfish (*Seriola lalandi*) and highfin amberjack (*Seriola rivoliana*), which are not usually common or abundant on inshore reefs, but were clearly attracted to the large scale structure of the Cod Grounds pinnacles. These species were all either only recorded or recorded in greatest abundance at the main pinnacles (8CG) or Steve's Bommie (10CG), another pinnacle in close proximity). The only exploited species that is not commonly seen on inshore reefs and was here recorded only at reference sites was pearl perch (*Glaucosoma scapulare*). This species is also often associated with pinnacles and reef areas arising from deeper water (McKay, 1997), and has been overharvested by commercial fishing along the NSW coast.

Plate 1. Examples of exploited species recorded in surveys of the CGCMR and nearby reference sites.



Seriola lalandi

Glaucosoma scapulare

Seriola rivoliana

Table 6. Frequency (number of transects – F), mean abundance (N), mean biomass (B) and mean biomass of large individuals (> 40 cm TL) (B>40) of commercially or recreationally exploited fish species recorded on transects in the CGCMR (abbreviated to CG) and at external reference sites (Ref). Mean abundances are across all transects, but mean biomass values relate to only sites where the species was recorded; biomass estimates are in kg.

Species	F		N		B		B>40	
	CG	Ref	CG	Ref	CG	Ref	CG	Ref
Acanthopagrus australis	6	0	2.3	0	2.20			
Achoerodus viridis	6	1	0.7	0.1	4.30	1.42	4.88	1.42
Argyrosomus japonicus	1	0	2.2	0	586.34		586.34	
Atractoscion aequidens	1	0	31.7	0	276.46		59.47	
Cheilodactylus fuscus	13	4	31.2	1.4	16.68	1.18	2.99	
Chrysophrys auratus	12	2	4.2	0.3	2.75	0.22	3.67	
Dinolestes lewini	3	0	21.9	0	67.19			
Elagatis bipinulata	1	0	0.3	0	3.26			
Glaucosoma scapulare	0	2	0	4.1		8.10		
Nemadactylus douglasi	5	4	3.6	2.7	3.30	2.92		1.78
Orectolobus halei	4	2	0.3	0.4	202.46	97.59	202.46	97.59
Orectolobus maculatus	2	1	0.1	0.1	99.67	42.05	99.67	42.05
Pseudocaranx georgianus	3	0	0.5	0	1.21			
Rhabdosargus sarba	5	1	1.9	1	1.88	0.89		
Seriola hippos	2	0	1	0	17.00		15.33	
Seriola lalandi	3	0	1.9	0	26.40		25.01	
Seriola rivoliana	1	0	0.2	0	2.82		1.19	
Trachurus novaezelandiae	2	0	1.3	0	1.29			
Carangoides chrysophrys	1	0	0.1	0	1.74			

Rare species

Two species that are considered rare in NSW were recorded on transects in the CGCMR: grey nurse sharks (*Carcharias taurus*), which are listed as ‘critically endangered’ under the EPBC Act and protected around Australia, and black cod (*Epinephelus daemelii*), which have been totally protected in NSW waters since 1983, and are listed as ‘Vulnerable’ under the NSW Fisheries Management Act and by Pogonoski *et al*. (2002) in their threat assessment of Australian fishes.

Three grey nurse sharks, estimated at ~2 m (x 2 individuals) and 2.5 m, were recorded on a transect at the Cod Grounds pinnacles site (8CG), and an additional 15 individuals were observed at this site outside of the 5 m-wide fish block, in the area known as the shark gutter. Two other individuals were recorded (one individual ~2.5 m) on a transect at one of the external reference sites – “Z-3” (4CG), which is just over 2 km from the CGCMR boundary (and therefore over 3 km from the main pinnacles), and another observed off-transect at the SE Lumps site (11CG), within the CGMR. Two black cod estimated at 50 cm each were recorded at the SW flats site (3CG), which is ~350 m from the main Cod Grounds pinnacles and within reserve boundaries.

A pipehorse, *Solegnathus dunckeri* (Plate 2) was also observed during the surveys, off-transect at 7CG. Few data are available for this species, which it is usually known from by-catch of the Queensland East Coast Otter Trawl Fishery, taken from depths between 75 and 140 m (Kuiter 2009). Anecdotal evidence indicates that this species has been observed in the area previously, which is significant considering that the entire area is considerably shallower than its known depth range.

Plate 2. Rare species recorded in surveys of the CGCMR and nearby reference sites

Solegnathus dunckeri. Photo: Simon Talbot ©

Carcharias taurus. Photo: Andrew Green

3.2 MOBILE MACROINVERTEBRATE AND CRYPTIC FISH SURVEYS

A total of 35 mobile macroinvertebrate species were recorded, with 29 of these found on transects inside the CGCMR. The most abundant species were the spiny sea urchin (*Centrostephanus rodgersii*), orange feather star (*Cenolia trichoptera*) and eastern slate-pencil urchin (*Phyllacanthus parvispinus*), and the most frequently recorded, *C. trichoptera*, the mollusc *Astralium tentoriformis* and *C. rodgersii* (see Table 7). The mobile macoinvertebrate community was overwhelmingly dominated by echinoderms (Table 8), with either *C. rodgersii* or *P. parvispinus* the dominant species at the majority of sites.

Table 7. Total abundance and frequency of occurrence of mobile macroinvertebrates recorded on 24 transects (18 inside the CGCMR and six at external reference sites) at 11 sites (7 inside the CGCMR and four at external reference sites), representing 2,400 m^2 of reef.

Species	Transects	Abundance
Crustaceans		
Pagurus sinuatus	1	3
unidentified hermit crab	6	9
Echinoderms		
Astrosierra amblyconus	3	3
Cenolia glebosus	1	1
Cenolia trichoptera	19	803
Centrostephanus rodgersii	13	3511
Conocladus australis	2	2
Echinaster colemani	2	5
Echinostrephus sp.	2	2
Fromia polypora	9	15
Ophidiaster confertus	2	2
Pentagonaster dubeni	9	15
Petricia vernicina	3	3
Phyllacanthus parvispinus	13	715
Plectaster decanus	8	10
Prionocidaris callista	12	175
Pseudoboletia indiana	1	1
Temnopleurus toreumaticus	1	1
Tripneustes gratilla	4	4
unidentified crinoid 1	1	1
unidentified crinoid 2	2	37
Molluscs		
Astralium tentoriformis	16	183
Chromodoris splendida	1	1
Cymbiola magnifica	1	1
Dicathais orbita	1	1
Glossodoris atromarginata	1	1
Hypselodoris bennetti	1	1
Hypselodoris bertschi	1	1
Muricid sp. 1	1	2
Neodoris chrysoderma	3	3
Pteraeolidia ianthina	5	13
Ranella australasia	1	3
Saginopterum ornatum	3	3
Sassia parkinsonia	2	6
unidentified nudibranch	2	2

Table 8. Species richness and total abundance of mobile macroinvertebrates by taxonomic group on transects inside the CGCMR and at external reference sites.

Site	Depth (m)	Species	Abundance	Urchins	Other echinoderms	Crustaceans	Molluscs
1CG	27	3	341	318	0	1	22
1CG	31	3	70	69	1	0	0
2CG	28	7	325	290	17	3	15
2CG	29	2	266	265	1	0	0
2CG	36	5	39	26	11	0	2
3CG	26	4	354	330	1	0	23
3CG	27	6	322	283	17	0	22
4CG	29	8	199	106	90	0	3
4CG	29.5	9	211	65	133	0	13
5CG	42	4	12	7	1	3	1
6CG	29	10	272	208	54	0	10
6CG	29.5	14	472	245	179	2	46
7CG	35	9	79	46	19	1	13
8CG	25	8	424	409	4	1	10
8CG	26	6	404	378	14	0	12
8CG	32	9	29	18	8	0	3
8CG	36	4	44	30	12	0	2
9CG	26	6	690	481	198	0	11
9CG	27	6	458	377	79	0	2
10CG	30	5	140	133	6	0	1
10CG	31	10	136	108	20	1	7
10CG	36.5	4	38	22	16	0	0
11CG	29	5	164	150	13	0	1
11CG	33	6	50	45	3	0	2
$\bar{x}$ 100m2	**30.4**	**6.4**	**230.8**	**183.7**	**37.4**	**0.5**	**9.2**

Numerous differences between transects were identified in mobile macorinvertebrate univariate metrics (Table 9). There were significantly less species, lower total mobile invertebrate abundance and greater *Centrostephanus rodgersii* abundance on transects inside the CGCMR (Fig. 4). This is likely related to differences in the depth of transects surveyed between CGCMR sites and reference sites. Regardless of location, mobile invertebrate abundance, urchin abundance and *C. rodgersii* abundance all decreased with increasing depth. *Centrostephanus rodgersii* numbers were clearly largely responsible for the significance of these patterns, being restricted to shallower sites (<31 m) inside the CGCMR. No transects shallower than 29 m were surveyed outside the CGCMR, and no *C. rodgersii* were recorded on any transects at external reference sites.

Table 9. Results of ANCOVAs of important mobile macroinvertebrate community metrics with location (sites inside the CGCMR or external reference sites) as an independent factor and depth as a continuous covariate. Degrees of freedom for these factors and error are 1, 1 and 21 respectively.

Variable	Location MS	F	P	Depth MS	F	P	Error MS
Number of species	68.158	13.027	0.002	16.628	3.178	0.089	5.232
Abundance (total)	0.886	6.098	0.022	22.332	153.712	<0.001	0.145
Abundance (urchins)	0.013	0.072	0.791	24.303	129.213	<0.001	0.188
Abundance (*C. rodgersii*)	34.749	13.971	0.001	59.917	24.09	<0.001	2.487

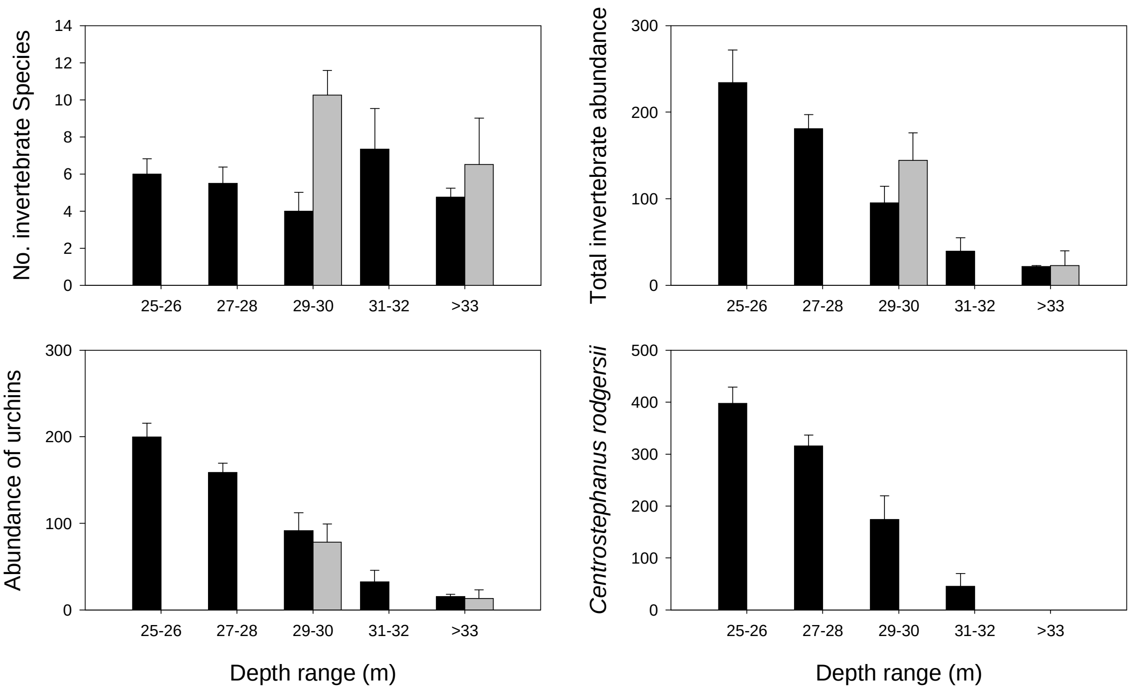


Figure 4. Variation in the species richness and abundance of the mobile macroinvertebrate community censused, and abundance of all urchins and just *Centrostephanus rodgersii* on transects at different depths, inside the CGCMR (black fill) and at external reference sites (grey fill). Data have been binned into five depth categories, with sample sizes of 4, 4, 3, 3 and 4 transects for CGCMR, respectively, and 4 and 2 for external reference sites, which only had transects in the 29-30 m and > 33 m categories. Y-axes represent mean values (+SE) per transect (100 m^2).

Cryptic fishes

Thirteen species of cryptic fish were recorded along the 1 m blocks surveyed for macroinverebtrates and cryptic fishes. These largely consisted of species typical of inshore reef habitat in the area, with the half-banded sea perch (*Hypoplectrodes maccullochi*) the most frequently recorded (18 of 24 transects) and most abundant (average 6.4 individuals per transect on which it was recorded) cryptic fish species, followed by the red rock cod, (*Scorpaena cardinalis*) (12 transects, 1.25 individuals). One each of the warmer-water species blotched hawkfish (*Cirrhitichthys aprinus*), common lionfish (*Pterois volitans*) and variegated lizardfish (*Synodus variegatus*) were also recorded.

3.3 Sessile biota

Forty-eight taxa or cover categories were identified in photo-quadrats inside the CGCMR and at external reference sites. These taxa/categories and their frequency of occurrence and mean cover values are provided in Table 10. Little or no foliose macroalgal cover was evident at any sites, with exposed crustose coralline algae (CCA) dominating overall cover (overall average 57% cover and recorded on all 24 transects), followed by a fine sediment/turf matrix (11%).

No significant differences were detected in the number of sessile invertebrate and algal taxa/categories, % cover of CCA, bare rock or overall sessile invertebrates (e.g. sponges, ascidians, corals and anemones) between transects surveyed inside and outside the CGCMR (Table 11). All of these metrics, with the exception of sessile invertebrate cover, differed significantly with depth.

Significantly greater cover of CCA and bare rock was found in shallower sites surveyed and less taxa/groups of sessile organisms (Fig. 5). These characteristics all relate to urchin barrens habitat, and are in agreement with results of the mobile macroinvertebrate surveys, which showed higher densities of *Centrostephanus rodgersii* (the main barrens-forming urchin species) on shallower transects. Transects in the 29-30 m depth category appeared to have intermediate values of these metrics. It was apparent whilst undertaking surveys that this was typically the lower depth range of the extent of urchin barrens. Even though overall sessile invertebrate cover did not change significantly with depth, the composition of taxa present did differ, as well as the diversity of taxa (as indicated by the significant effect of depth on the number of taxa/groups recorded). Multivariate analyses (below) clearly depict this compositional change.

Table 5. Sessile community taxa/groups, frequency (number of transects - F) and average percentage cover per transect, taken from photo-quadrats on 24 transects (18 inside the CGCMR and six at external reference sites) at 11 sites (Seven inside the CGCMR and four at external reference sites), representing > 60 m^2 of reef.

Taxon	Order	F	CGCMR	Ref	Taxon	Order	F	CGCMR	Ref
Macroalgae					**Other encrusting invertebrates cont.**				
Codium sp.	Chlorophyta	7	0.02	0.28					
Dictyotalean sp.	Heterokontophyta	2	0.17	0.00					
Lobophora variegata	Heterokontophyta	10	0.38	0.15	Unidentified encrusting ascidians	Aplousobranchia/ Stolidobranchia	8	0.19	0.15
Unidentified foliose red algae	Rhodophyta	13	0.69	0.37					
Peyssonnelia novaehollandae	Rhodophyta	15	0.72	0.89	Soft erect bryozoans	Cheilostomata	9	0.14	0.09
Encrusting *Peyssonnelia* spp. /*Hildenbrandia* spp.	Rhodophyta	20	1.25	2.90	*Steginoporella* sp.	Cheilostomata	4	0.03	0.43
					Triphyllozoon sp.	Cheilostomata	7	0.04	0.22
Crustose coralline algae	Rhodophyta	24	60.04	47.79	*Echinoclathria leporina*	Porifera	8	0.19	0.09
Corallines (branched)	Rhodophyta	11	0.45	1.41	*Holopsamma laminaefavosa*	Porifera	2	0.00	0.06
					Sponge (cup)	Porifera	6	0.06	0.40
Corals and other cnidarians					Sponge (encrusting)	Porifera	20	1.98	5.08
Drifa spp.	Alcyonacea	7	0.05	4.52	Sponge (erect branching)	Porifera	8	0.19	0.40
White-branched Alcyonacean	Alcyonacea	8	0.29	0.12	Sponge (erect simple)	Porifera	20	1.52	2.96
Unidentified Alcyonaceans	Alcyonacea	2	0.02	0.03	Sponge (plate)	Porifera	6	0.24	0.19
Mopsea sp.	Alcyonacea	8	0.79	0.31	Sponge sp.1	Porifera	2	0.02	0.00
Other gorgonians	Alcyonacea	4	0.05	0.06	Sponge sp.2	Porifera	9	0.06	0.34
Sphaerokodisis australis	Alcyonacea	3	0.10	0.28	Sponge sp.3	Porifera	5	0.12	1.00
Unidentified sea whips	Alcyonacea	2	0.02	0.00	*Tethya* spp.	Porifera	6	0.02	0.25
Balanophyllia bairdiana	Scleractina	6	0.05	0.09	*Hydroidea* sp.	Hydroida	9	0.18	0.43
Plate coral	Scleractina	5	0.10	0.03	Barnacles	Sessilia	21	3.40	0.71
Culicia sp.	Scleractina	15	4.87	0.06	Serpulid worms	Polychaeta	9	0.07	0.46
Anemones	Actiniaria	3	0.01	0.06					
Zoanthids	Zoanthinaria	19	1.34	2.41					
					Bare substrate categories				
Other encrusting invertebrates					Pebble		6	0.07	0.00
Botrylloides sp.	Stolidobranchia	7	0.07	0.30	Rock		19	1.34	0.34
Cnemidocarpa pedata	Stolidobranchia	7	0.03	0.16	Sand		23	8.65	4.80
Pyura spinifera	Stolidobranchia	9	0.05	1.15	Sediment/turf matrix		19	8.81	17.15
Didemnid spp.	Aplousobranchia	3	0.04	0.00	Shell fragments		14	0.76	0.49
Unidentified ascidians	Aplousobranchia/ Stolidobranchia	16	0.35	0.58					

Table 11. Results of ANCOVAs of sessile community metrics with location (sites inside the CGCMR or external reference sites) as an independent factor and depth as a continuous covariate. Degrees of freedom for these factors and error are 1, 1 and 21 respectively.

Variable	Location			Depth			Error
	MS	F	P	MS	F	P	MS
Number of taxa/groups	117.045	2.506	0.128	697.169	14.929	0.001	46.698
% crustose coralline algae	0.001	0.005	0.945	1.288	10.698	0.004	0.120
% bare rock	1.911	1.497	0.235	5.868	4.597	0.044	1.277
% sessile invertebrate	0.743	1.797	0.194	0.064	0.155	0.697	0.413

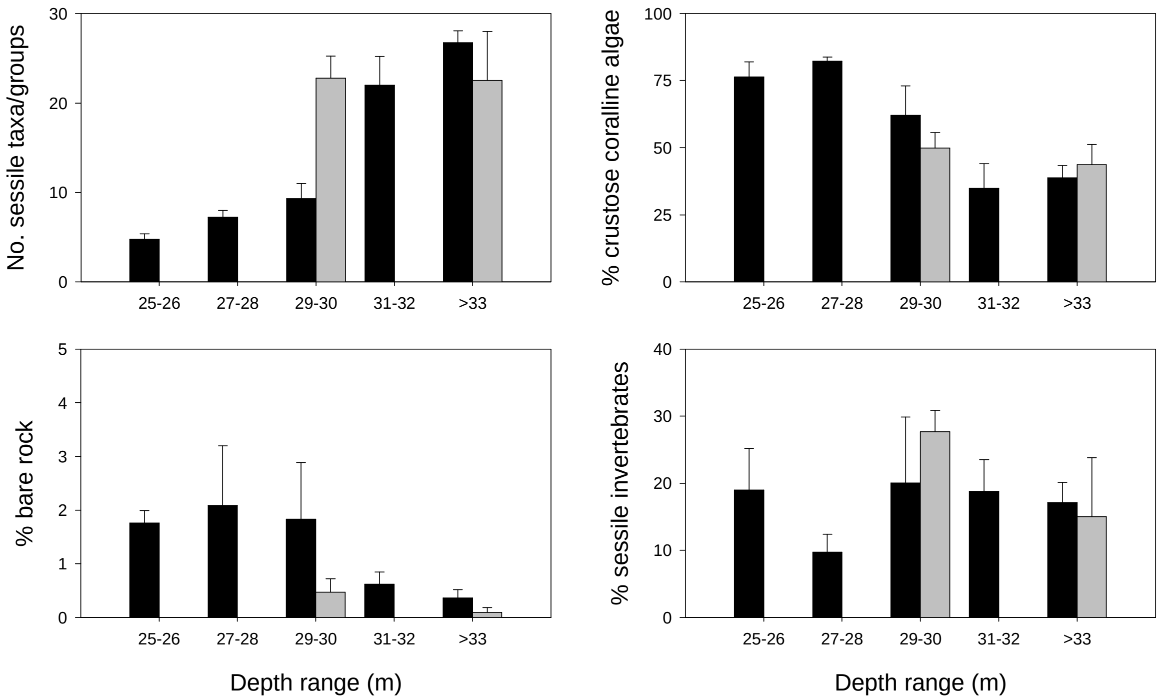


Figure 5. Variation in the number of taxa/biotic groups, and the percentage cover of crustose coralline algae, bare rock and combine sessile invertebrates (e.g. sponges, ascidians, corals and anemones) recorded in photoquadrats of the sessile community on transects at different depths, inside the CGCMR (black fill) and at external reference sites (grey fill). Data have been binned into five depth categories, with sample sizes of 4, 4, 3, 3 and 4 transects for CGCMR, respectively, and 4 and 2 for external reference sites, which only had transects in the 29-30 m and > 33 m categories. Y-axes represent mean values (+SE) per transect (~ 2.5 m^2).

3.4 COMMUNITY TYPES

Fish community

The fish community loosely fell into two groups of transects, with Principal Coordinates Analysis (PCO) revealing that deeper transects (> 29 m depth) both inside and outside the CGCMR were characterised by more white ear (*Parma microlepis*), half-banded sea perch (*Hypolectrodes maccullochi*) and eastern hulafish (*Trachinops taeniatus*), while shallower transects (≤29 m) were characterised by the presence of bream (*Acanthopagrus australis*) and eastern talma (*Chelmonops truncatus*) inside the CGCMR and high abundances of silver sweep (*Scorpis lineolata*) and mado (*Atypichthys strigatus*) on transects outside the reserve (Fig 6). The latter two highly abundant species appear responsible for all the external reference transects lying to the same side of the two major groupings in the plot, with low PCO axis 2 values.

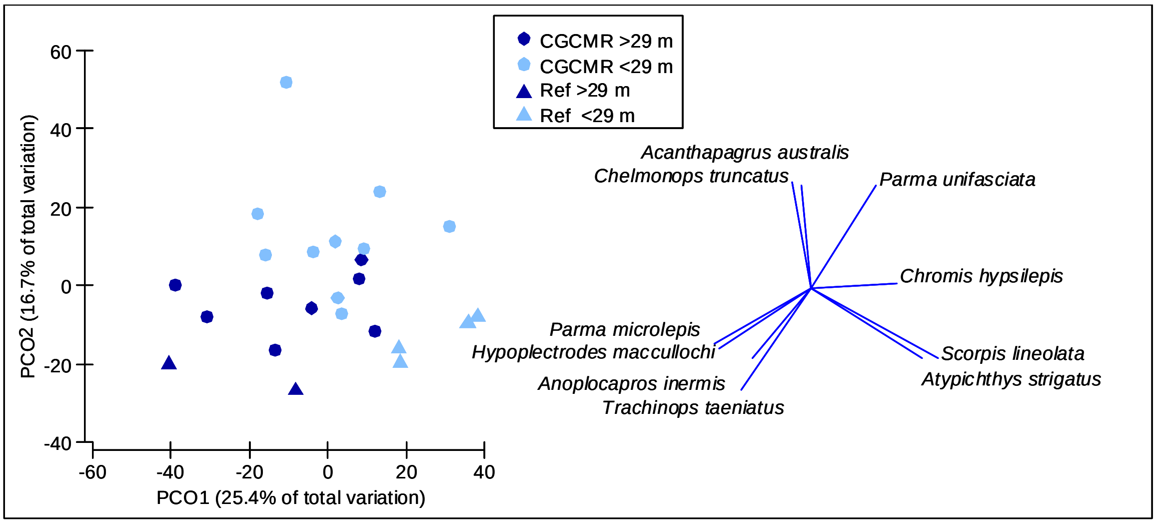


Figure 6. PCO plot and vector diagram of fish community data from transects surveyed inside the Cod Grounds Commonwealth Marine Reserve (CGCMR) and at external reference sites (Ref) at different depths.

Mobile macroinvertebrate community

The three urchin species; *Centrostephanus rodgersii*, *Phyllacanthus parvispinus* and *Prionocidaris callista*, were prominent in separating transects based on the invertebrate community data, which appeared to fall into two clear groups and one more loose grouping (Fig. 7). The shallower of the transects surveyed (≤29 m) were dominated by *C. rodgersii* with few, if any, *P. parvispinus* or *P. callista*. Transects between 29 and 32 m were dominated by *P. parvispinus* and had the greatest diversity of other mobile invertebrate species, and transects below 32 m were dominated by *P. callista* and had very few other mobile invertebrates recorded. The most other species with high correlations to the first PCO axis were associated with the *P. parvispinus*-dominated middle depth range.

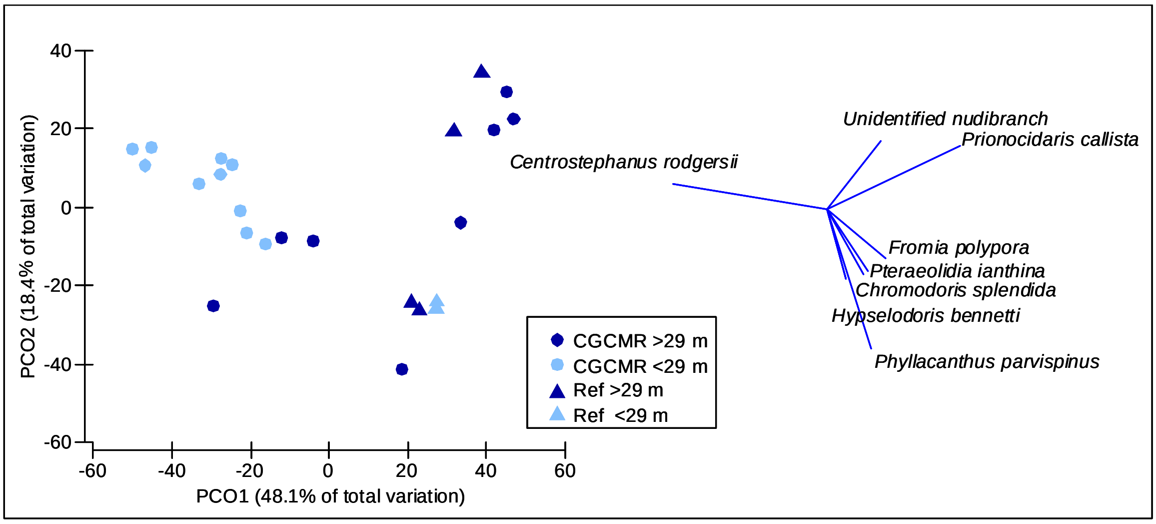


Figure 7. PCO plot and vector diagram of mobile macroinvertebrate community data from transects surveyed inside the Cod Grounds Commonwealth Marine Reserve (CGCMR) and at external reference sites (Ref) at different depths.

Sessile community

Sessile communities in the CGCMR and nearby reference sites also clearly separated into distinct groups (Fig 8); transects that were characterised by ‘urchin barrens’, with fewer sessile taxa present and dominated by crustose coralline algae, and those that were characterised by a diverse assemblage of sessile invertebrates such as sponges, ascidians, soft corals and occasional hard corals. Plates 3 and 4 show typical photo-quadrats taken in these two sessile community types.

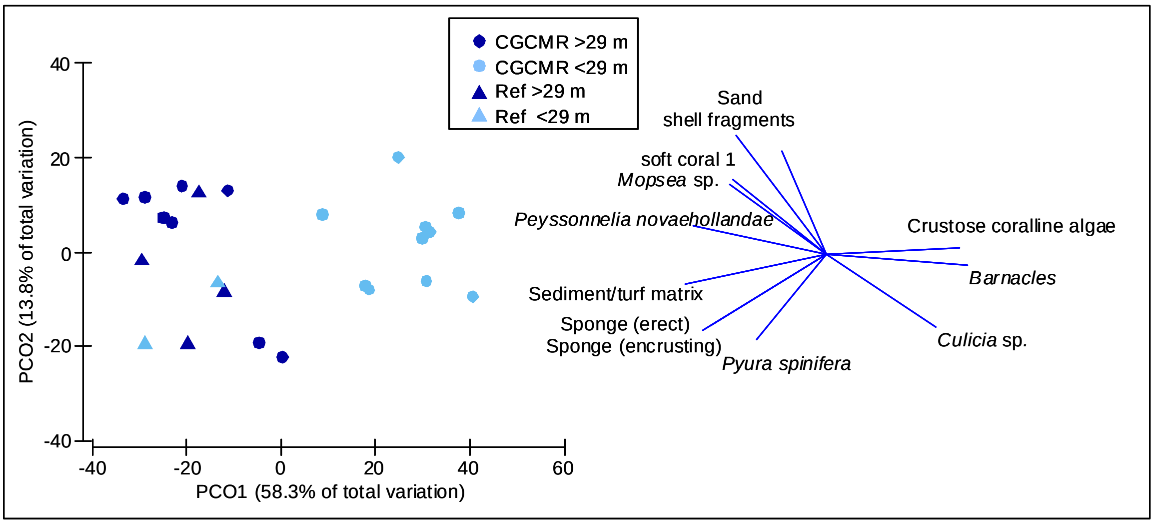


Figure 8. PCO plot and vector diagram of sessile community data from transects surveyed inside the Cod Grounds Commonwealth Marine Reserve (CGCMR) and at external reference sites (Ref) at different depths.

Plate 3. Examples of benthic photo-quadrats of ‘urchin barrens’ habitat that was typical of transects shallower than 29 m in the CGCMR.

Plate 4. Examples of benthic photo-quadrats of diverse sessile invertebrates typical of deeper transects inside the CGCMR and at external reference sites.

Overall reef assemblage and community types

When data from all surveyed components of the reef assemblage were combined together, three distinct community types were evident (Fig 9). The first included only transects that were surveyed in 29 m depth or shallower, and directly corresponded to the groups identified as an 'urchin barren' community in both analysis of sessile and mobile macroinvertebrate data separately. This 'urchin barren' community is typical of the vast majority of inshore reef areas along the entire NSW coast.

The other grouping that was consistent in the separate MDS plots above and was characterised by slightly more diverse sessile cover and very few if any *Centrostephanus rodgersii*, actually split into two clear groupings in this overall analysis. One of these included only transects surveyed in depths greater than (or equal to in one case) 31 m, both inside the CGCMR and at external reference sites. This community type consisted of a more diverse sessile community (and larger patches of sand over the reef), and the presence of the urchin *Prionocidaris callista*, and more abundant half-banded sea perch (*Hypoplectrodes maccullochi*). The other community type included transects surveyed in the narrow depth range between those of the other groupings (29-31 m), and was characterised by the abundant *Phyllacanthus parvispinus*, stalked ascidians (sea tulips, *Pyura spinifera*) and mado (*Atypichthys strigatus*).

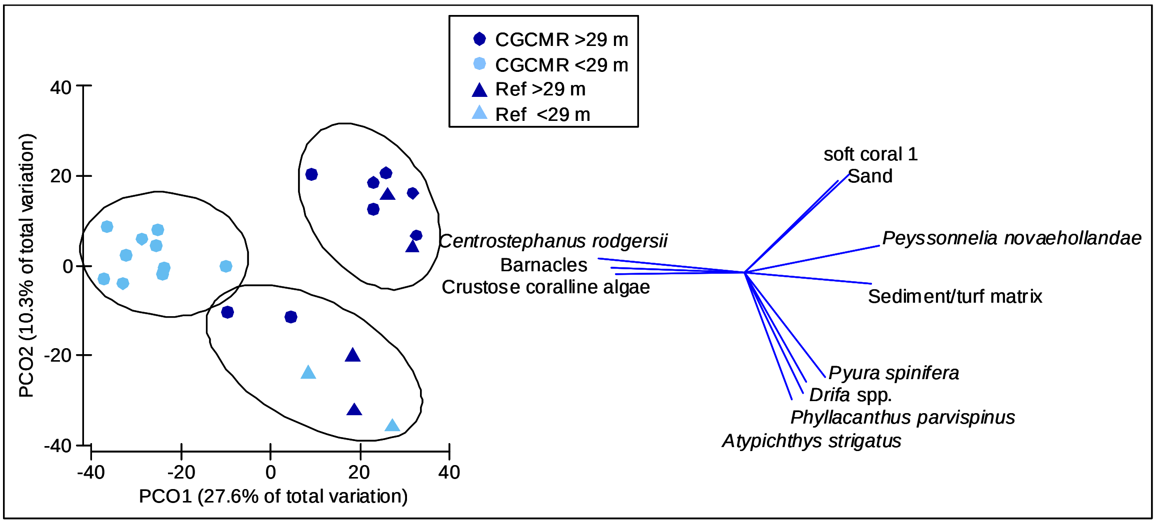


Figure 9. PCO plot and vector diagram of overall community data from transects surveyed inside the Cod Grounds Commonwealth Marine Reserve (CGCMR) and at external reference sites (Ref) at different depths. Based on combined, standardised and log(x+1) transformed

fish, macroinvertebrate and sessile cover data. Ellipses have been drawn around transects that fall into the three community types mentioned in the text.

Clearly, depth greatly influenced the nature of the biotic communities in the CGCMR and at external reference sites. As is evident from the PCO plots above (Fig 9), changes in flora and fauna with depth were not gradual, and for some components there were clear demarcations at particular depths. Each one of the community types identified in the overall analysis was dominated by a different species of sea urchin, and a different type of sessile cover. Figure 10 summarises the most prominent changes in the overall communities with depth.

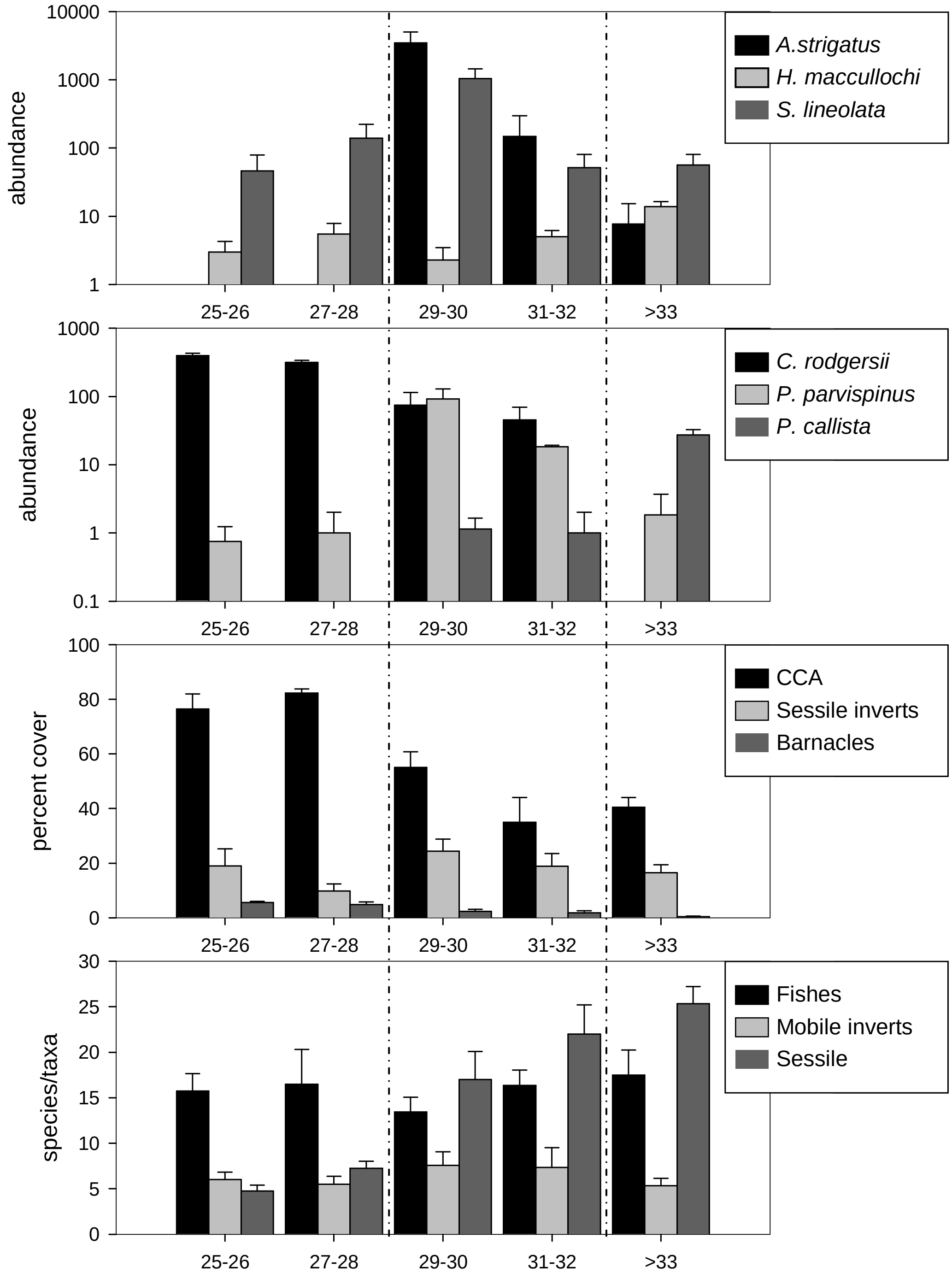


Figure 10. Variation in the reef assemblage with depth. From top to bottom, plots display overall average (+ SE) values per transect in important fishes, mobile macroinvertebrates, sessile cover categories and taxonomic richness. The dashed vertical lines represent rough boundaries for community types identified in multivariate analyses. Note that y-axes are on a log scale for the fish and macroinvertebrate plots (top two). See text for full species names.

4. DISCUSSION

The baseline survey of reef biota in the CGCMR and at nearby external reference sites revealed the following key features of local floral and faunal communities:

- Domination by cool temperate species
- Distinctly different community types at different depths surveyed
- Little or no macroalgal cover, and encrusting algae and sessile invertebrates
- Very high biomass of fishes present
- High abundance of exploited species, particularly large pelagic fishes
- Presence of some rare and threatened species, including numerous grey nurse sharks

Perhaps the most obvious feature of the reef communities in the CGCMR was that strikingly different community types existed at different depths. The community types represented one that is typical of inshore reef habitat in NSW (an urchin barren state) and two others that are generally found in depths beyond those at which kelp persists. The depth range over which the community types changed was very narrow, resulting in fairly sharp ecotones. Such distinct changes, and patterns in the species and abundance of urchins recorded, clearly indicate the importance of urchins in driving these community types. Urchins are known to often be dominant grazers in reef communities and high abundance of the spiny sea urchin (*Centrostephanus rodgersii*), is well known to cause “barrens” along the NSW coast, where macroalgal cover is overgrazed, which then has flow on effects on species in the system (Andrew and Underwood, 1989; Andrew and O'Neil, 2000; Ling, 2008).

The sessile communities in areas where the urchins *Phyllacanthus parvispinus* and *Prionocidaris callista* dominated were far more diverse than the bare, crustose coralline-dominated areas where *C. rodgersii* was abundant, although the effect of urchin species can not be separated from the effect of their abundance, as *C. rodgersii* abundance was comparatively much higher. No urchin barrens were observed on transects at external reference sites, but this is likely to be due to the shortage of reef shallower than 30 m available to survey outside but near the CGCMR.

Fish biomass averaged 272.4 kg per transect across all the sites surveyed, with some transects possessing estimated fish biomass in excess of 1 tonne. These figures are very high when compared to Lord Howe Island inshore reefs, for example, which averaged ~ 50 kg per transect in surveys undertaken in summer 2008 (Edgar *et al*., 2006; Edgar *et al*., *in press*) using the same methods as the CGCMR baseline surveys reported here. Massive numbers of planktivorous fishes such as mado (*Atypichthys strigatus*) and silver sweep (*Scorpis lineolata*) and reasonable numbers of larger-bodied higher carnivores such as wobbegong sharks (*Orectolobus* spp.) and mulloway (*Argyrosomus japonicus*) were responsible for the extraordinarily high fish biomass observed. It is likely that both the structure of the reef habitat surveyed (which represented those patches of reef that rose the furthest from the bottom in the offshore environment), and perhaps even oceanographic effects related to this (e.g. possibly upwelling of nutrient rich water, resulting in higher local plankton availability), are responsible for the high fish biomass present.

Another important feature of the reef communities surveyed was the presence of rare species. A relatively high abundance of grey nurse sharks (*Carcharias taurus*) was observed at the main Cod Grounds pinnacles (site 8CG). These pinnacles clearly represent an important aggregation site for this species. Although it is widely distributed, only 19 recent aggregation sites are known on the east coast of Australia (Schirmer *et al*., 2004), and the regularity of occupation of these has been reported to be relatively low. From extensive monitoring of known aggregation sites along the NSW coast, Otway *et al.* (2003) found no sharks present on 64% of surveys. The Cod Ground pinnacles was one of only two sites where sharks were observed on every occasion. Although the pinnacles themselves appear to be the key aggregation site, the sharks also use the broader area, as evidenced by sightings of single individuals (one on transect and another off-transect) at a nearby smaller pinnacle within the reserve and at an external reference site.

Other observations of rare species were the black cod (*Epinephelus daemelii*) and the deep-water pipehorse, *Solegnathus dunckeri*. Only two black cod were recorded or seen during the baseline surveys, despite the area being named after this species, and which was reportedly previously common in the area (Pogonoski *et al*., 2002). Continued monitoring through the long-term will establish whether this species responds to the protection of the area around the pinnacles by increasing in abundance. Greater survey effort, particularly in deeper areas of the reserve and nearby reefs, is required to determine whether the observation of *S. dunckeri* was an unusual occurrence, or whether this region represents an unusual area where it occurs shallower than throughout the rest of its range. Anecdotal evidence by members of the Port Macquarie Underwater Research Group (PURG) suggests that the latter may well be possible.

Whilst the CGCMR baseline survey represented the first step in recording the reef biota in a consistent and quantitative manner, there were some limitations that are important to recognise. Due to timing and logistical reasons, the survey was limited to 24 transects and 11 sites. Although this is a substantial effort given that survey time per dive is effectively less than half of that available in water <18 m deep, it would be ideal to survey a greater number of sites than what was possible, particularly at sites located outside the CGCMR. The limited number of surveys at sites outside the reserve largely reflected the lack of reef available nearby in depths of less than 30 m (and surveyable using open circuit SCUBA), but also the need to prioritise data collection within the reserve given the limited time available. The currently low number of external reference sites made comparisons of surveys inside and outside the reserve difficult, and surveying similar habitat in appropriate depths (which will require travel further from the CGCMR boundaries than was undertaken as part of the current surveys) should be one of the priorities of future surveys, particularly in the coming years (see recommendations below). Much of the reef within the CGCMR boundaries that lies shallower than 30 m (and thus possible to survey using standard open circuit SCUBA) was surveyed, but only seven transects were surveyed in the substantial areas of reef deeper than 30 m that occur within the reserve. Clearly more survey effort is also desirable in these areas, but would require the use of closed circuit (rebreather), as was used for the deeper transects undertaken for this baseline survey.

The use of closed circuit units was necessary in the current baseline surveys (and will always be necessary to survey the deeper parts of the CGCMR and nearby reefs), but may result in particular biases in the data collected, as compared to surveys in shallower parts where open circuit SCUBA was used. The major differences expected would be in the number, and in some cases species, of fish recorded as a result of the lack of disturbance by bubbles created by divers on open circuit. This bias is unlikely to have influenced the conclusions of community types varying with depth, however, as it would have no bearing on mobile macroinvertebrate or sessile communities recorded, and the greatest depth-related differences occurred in these taxonomic groups. The bias is also unlikely to affect interpretation of future monitoring data, as it should remain consistent in time due to the limitations imposed by depth on bottom times.

4.1 Marine Park zoning

The CGCMR boundary currently encompasses the bulk of the reef habitat within the larger area around the main Cod Grounds pinnacles and, most notably, the pinnacles themselves. The pinnacles clearly support a reef assemblage that is not typical of many other reefs along the coast, attracting large numbers of exploited pelagic species and a substantial aggregation of grey nurse sharks. Although the community type observed in the majority of the reef area within the reserve that is less than 30 m closely resembles that typical of inshore reefs along the NSW coast, these areas still contained a greater biomass of fishes than is present even at Lord Howe Island reefs. Because of the large biomass of exploited species, including large wobbegong sharks and the pelagic carangids (e.g. *Seriola lalandi* and *S. rivoliana*), the reserve boundaries protect valuable marine resources that are becoming increasingly rare in other parts of the Australian coast.

However, there are other sites of high conservation value outside the reserve boundaries. Observations at external reference sites surveyed a few kilometres to the south of the reserve boundary included extraordinarily high biomass and abundance of fishes and a rare pipehorse, *Solegnathus dunckeri*. Although the observation of a single deep-water pipehorse is not necessarily sufficient evidence on which to base the expansion of current reserve boundaries, pipehorses have been previously sighted in the area (although unconfirmed as this species). Combined with the other values (e.g. diverse sessile communities, the use of the broader area by grey nurse sharks, value of an expanded buffer zone around the pinnacle), further surveys and exploration of adjacent reef areas are clearly warranted, with the potential for expanding reserve boundaries. In particular, the extensive reef area to the immediate south of the CGCMR should be investigated.

Most of the statistically significant differences in univariate metrics that were observed between transects within the CGCMR boundaries and external reference sites can reasonably be attributed to biases in the habitat type surveyed (i.e. the lack of available sites with a similar depth range outside the reserve), as discussed above. Indeed, differences between sites that can be attributed to its protection would not be expected within such a short time frame since declaration (Edgar *et al.*, in press) and only pre-existing differences in assemblages might be evident. However, if only transects surveyed in the same depth ranges were considered in comparisons (i.e. only transects in 29-30 and >33 m), then the external reference sites had a greater diversity and cover of sessile invertebrates, greater diversity and abundance of mobile invertebrates, and a much higher abundance and biomass of total fishes.

Additional information on the deeper patches of reef (>30 m) inside and outside the CGCMR would be valuable and assist in determining whether an increase in the size of the CGCMR would add substantially to the community types represented and the overall conservation value of the reserve. Due to logistic and safety reasons, this would most likely need to be undertaken using closed-circuit (rebreather) systems or remotely-operated cameras, video or ROV (remotely operated underwater vehicle).

4.2 THREATS

Continued illegal fishing is likely to be the major threat to the reef assemblage in the CGCMR. Due to its position (~7 km offshore) and relatively small size (and hence difficulty in knowing whether a boat is fishing within the reserve unless observed from a close vantage), this reserve is very hard to police. Two boats were observed bottom fishing within the reserve boundaries, and one large yacht seen trolling through the reserve during four and a half survey days in and near the reserve. Numerous large fishing sinkers were also observed on the bottom within the reserve, many appearing to be fairly recent, with little growth or corrosion. Clearly, given the small size of this reserve, only a relatively small amount of illegal fishing would have major consequences with respect to recovery of faunal and floral populations. Expanded boundaries would provide a greater buffer against fishing-induced impacts and reduce the likelihood that the CGCMR becomes a 'paper park'.

Fishing is known to have substantial and far reaching impacts on reef communities, with the removal of large predatory fishes and invertebrates having flow on effects on reef communities (Pauly *et al*., 1998; Shears and Babcock, 2002; Myers and Worm, 2005). In NSW, removal of large predators of urchins, for example blue groper (*Achoerodus viridis*) and pink snapper (*Chrysophrys auratus*), may cause increasing abundances of urchins species, which in turn can affect densities of algae and invertebrates. Although the CGMCR surveys revealed a high biomass of higher carnivores, relatively few snapper and blue groper were recorded, particularly in comparison to what might be expected at inshore areas of the NSW coast. If low densities of such predators are related to past (and present) fishing pressure, then protection of the CGCMR has the potential over the long-term to promote recovery of diverse sessile communities in the shallow parts of the reserve that are currently urchin barrens. In fact, it is even possible that recovery of these areas may result in the addition of a new community type if larger foliose macroalgae are able to grow in these areas. However, if low densities of these predatory species is the result of natural processes and local habitat characteristics, which is possible for *A. viridis*, but unlikely for *C. auratus* (which represented the greatest commercial catch in the area before declaration of the CGCMR), then protection of the area may not result a habitat change from barrens.

Climate change represents an unknown threat to the CGCMR. Very few species with warmer-water affinities were observed during the baseline survey, suggesting that the warm East Australian Current may have less impact on the local area than on other parts of the NSW coast, even those further south and closer inshore. Only continued monitoring will be able to establish patterns in the habitation, establishment and abundance of warmer water species or the abundance or continued presence of cooler water species. Whilst climate change may not currently pose a greater threat than fishing, it has potential to substantially alter the community types through the long term.

Pollution does not appear to be a major threat. Benthic photo-quadrats revealed no evidence of filamentous/opportunist algae or other pollution associated taxa. Due to the distance offshore (~7 km) and depth of the reef, pollution and catchment runoff effects are unlikely to cause substantial or lasting impacts on the CGCMR. Impacts of temporary light reduction that may occur during extreme runoff events are unlikely to be great because the benthic community largely consisted of non-photosynthetic taxa, with coral and macroalgal cover fairly minimal. Species and individuals present in the CGCMR generally appear well adapted to low light levels.

No introduced taxa were recorded during the surveys, and therefore this potential threat does not appear to pose a major risk to local reef communities. Early detection of any introduced species establishing in the reserve should be possible with regular monitoring.

5. RECOMMENDATIONS

Now that a valuable baseline has been established, we recommend continued monitoring of the CGCMR to allow assessment of changes in reef communities, including any changes associated with climate change as well as recovery from impacts of fishing. Future monitoring ideally should be undertaken using the same methods, with resurvey of transects at the same geo-referenced sites and depths, and at a similar time of year to minimise seasonal effects in long-term population trends. Monitoring should occur at intervals of one to three years initially until patterns associated with recovery from fishing stabilise, then perhaps at five-yearly intervals subsequently.

We also recommend that additional sites be incorporated in the monitoring program the next time the CGCMR reefs are surveyed. Analyses would clearly benefit from additional external reference sites, and more importantly, reference sites with a similar depth range to sites that were surveyed within the boundaries of the marine reserve. This deficiency arose from the difficulty in finding suitable reef with appropriate depth within close proximity to the CGCMR. Additional external reference sites should be identified further afield as necessary, with promising locations being Mermaid reefs to the south and perhaps some of the more inshore patches of reef between Laurieton and Port Macquarie. At least six transects (but preferably more) should be surveyed in depths between 25 and 29 m in these areas. Additional sites could also usefully be added within the CGCMR in depths > 30 m if skilled personnel and appropriate resources are available. The addition of these new sites outside the reserve and deeper transects inside the reserve will provide much greater power for detecting change inside the reserve relative to outside.

We also propose that an additional method be added to the survey protocol to provide complimentary data for monitoring the grey nurse shark aggregation. This would only be required at the Cod Grounds pinnacles site (8CG) and involve a timed swim around the main pinnacles to count and sex any grey nurse sharks present. Fifteen minutes dive time is sufficient to undertake this in a safe and repeatable manner.

A set of univariate indicators is proposed here to establish the presence and magnitude of future change in the CGCMR reef communities. These indicators and current values are shown in Table 12. As the number of sites is not large, indicators should be calculated for each transect so that variation between sites and depths can be considered in analysis of changes in their values with time. Whilst the magnitude of change in each of these indicators will become evident over time, it must be noted that reasonably large variation may occur in some of these in any one year due to the oceanic nature and local characteristics of the reef. For example, whilst exploited fish abundance and biomass are key indicators of fishing impacts and changes associated with fishing, the mobile nature of schools of exploited pelagic fishes means that large changes can occur over periods of minutes. Consequently, long time scales will be required to identify real change in these indicators. Conversely, the abundance of *Centrostephanus rodgersii* and % cover of CCA are less likely to vary at such a large scale, with only relatively small changes in these through time interpretable as important change.

Table 12. Proposed indicators for continued monitoring of the CGCMR. Values are totals per transect, except % crustose coralline algal cover (%CCA), which is mean cover per transect, and Size Spectra (SS) parameters, which were based on data from all transects at each site.

SITE	Depth	Abundance of exploited fishes	Biomass of exploited fishes (kg)	Threatened species	*C. taurus*	*E. daemelii*	Fish species	*C. rodgersii*	% CCA	SS Slope	SS intercept
1CG	27	9	296.67				9	318	82.52	-3.045	1.158
1CG	31	29	42.94				21	52	47.50		
2CG	28	1	0.21				12	290	78.07	-7.483	2.2315
2CG	29	0	0.00				6	265	80.79		
2CG	36	54	68.29				23		48.38		
3CG	26	447	174.93				21	329	87.80	-8.123	3.752
3CG	27	414	495.30	1		2	26	282	82.81		
4CG	29	1	42.05				10		60.66	-11.528	3.173
4CG	29.5	10	157.68	1	1		16		58.64		
5CG	42	2	0.58				14		51.18	-3.552	0.793
6CG	29	2	42.49				12		37.36	-12.597	3.113
6CG	29.5	8	3.32				16		42.78		
7CG	35	49	26.47				18		36.14	-10.036	2.694
8CG	25	7	4.09				13	406	83.61	-5.356	1.572
8CG	26	36	48.57	1	3		16	377	64.20		
8CG	32	4	2.15				13		17.24		
8CG	36	1	1.49				10		40.40		
9CG	26	6	1.67				13	479	70.00	-7.292	1.791
9CG	27	10	43.86				19	373	85.58		
10CG	30	216	438.68				18	116	42.51	-6.775	2.194
10CG	31	20	12.34				15	84	40.00		
10CG	36.5	622	870.91				20		26.71		
11CG	29	6	1.33				16	140	62.74	-7.347	2.076
11CG	33	12	8.84				20		39.82		

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Appendix 1. Data from fish surveys pg 1: transects inside the CGCMR.

SITE	**1CG**	**1CG**	**2CG**	**2CG**	**2CG**	**3CG**	**3CG**	**8CG**	**8CG**	**8CG**	**8CG**	**9CG**	**9CG**	**10CG**	**10CG**	**10CG**	**11CG**	**11CG**
Depth of Transect	**27**	**31**	**28**	**29**	**36**	**26**	**27**	**25**	**26**	**32**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Acanthopagrus australis	5					20	4			2			6	5				
Acanthistius ocellatus														1				
Achoerodus viridis		4			4		1			1				2		1		
Anoplocapros inermis																		
Argyrosomus japonicus																40		
Atractoscion aequidens																570		
Atypichthys strigatus				20										105	443			
Aulopus purpurissatus								1									1	
Bodianus frenchii					1													
Caesioperca lepidoptera																1		
Carcharias taurus									3									
Centroberyx affinis															12			
Chaetodon guentheri							1											
Cheilodactylus fuscus		5			6	294	34	1	3	1	1		2	205		1	3	6
Cheilodactylus vestitus									1									
Chelmonops truncatus	1																	
Chromis hypsilepis		50	219	200	150	120	231	150	85		30	140	10		63	50	33	2
Chrysophrys auratus	2	3			24	6	19	2	5				1	2		6	3	2
Coris dorsomacula							4					1						
Coris picta		1	11	1	13	5	2	15	7	2	1	9	6	1	2	5	12	3
Dicotylichthys punctulatus																		
Dinolestes lewini						30	345								20			
Elagatis bipinnulata						5												
Enoplosus armatus		1			2	2	2						7	3	30	4	2	2
Epinephelus daemelii							2											
Epinephelus undulatostriatus														3				
Eubalichthys bucephalus															1			
Eubalichthys mosaicus		1																
Fistularia commersonii		1																
Fistularia petimba													1					
Glaucosoma scapulare																		
Heterodontus portusjacksoni					1													

Appendix 1. Data from fish surveys pg 2: transects inside the CGCMR.

SITE	**1CG**	**1CG**	**2CG**	**2CG**	**2CG**	**3CG**	**3CG**	**8CG**	**8CG**	**8CG**	**8CG**	**9CG**	**9CG**	**10CG**	**10CG**	**10CG**	**11CG**	**11CG**
Depth of Transect	**27**	**31**	**28**	**29**	**36**	**26**	**27**	**25**	**26**	**32**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Hypoplectrodes annulatus																		
Hypoplectrodes maccullochi	2	5	6		5		2	2	6	3	18	4	12		7	11	5	23
Lotella rhacina		1	2			1	1				2	1	1					
Mecaenichthys immaculatus		3			2												4	
Meuschenia freycineti					3					1			1	1				
Meuschenia scaber					5					3						5	2	3
Meuschenia trachylepis		1																
Nelusetta ayraudi																		1
Nemadactylus douglasi					2	55	1									3		3
Notolabrus gymnogenis		1	2		8			2	3	2		5	2		2	3	4	9
Ophthalmolepis lineolata	1	4	6		8	1	14	2		4	8	4	1	2	1	12	8	14
Orectolobus halei	1						1						1	2				
Orectolobus maculatus	1						1											
Paracaesio xanthura						100												
Parma microlepis		1			8			10		3	12				1	9		6
Parma unifasciata	28	13	12	10	3	14	8	18	13	4		24	27	8	5		12	15
Parupeneus spilurus	8	1		20	6	1	1	2		2	5	14	1		1	1	9	5
Pempheris affinis			1			2	7		1					5				
Pempheris compressa							6							220			2	
Plagiotremus tapeinosoma									1				1					
Prionurus maculatus						2												
Prionurus microlepidotus						1	7		1								1	
Pseudocaranx georgianus			1			2						6						
Pseudocoris yamashiroi													1					
Rhabdosargus sarba					4	20	8									1		1
Scorpaena cardinalis							1					3				1		1
Scorpis lineolata		102	220	40	151	21	335		145			18		10	53	50	37	38
Seriola hippos		5			13													
Seriola lalandi		8			1				26									
Seriola rivoliana								4										
Suezichthys arquatus																		2
Trachichthys australis																		1

Appendix 1. Data from fish surveys pg 3: transects inside the CGCMR.

SITE	**1CG**	**1CG**	**2CG**	**2CG**	**2CG**	**3CG**	**3CG**	**8CG**	**8CG**	**8CG**	**8CG**	**9CG**	**9CG**	**10CG**	**10CG**	**10CG**	**11CG**	**11CG**
Depth of Transect	**27**	**31**	**28**	**29**	**36**	**26**	**27**	**25**	**26**	**32**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Trachinops taeniatus			130		40		5	60	50	25	70	68	6	40	18	40		31
Trachurus novaezelandiae		4				20												
Carangoides chrysophrys									2									
Unidentified Labrid spp.														1				
Upeneichthys lineatus			1								1		1					

Appendix 1. Data from fish surveys pg 4: transects at external reference sites.

SITE	4CG	4CG	5CG	6CG	6CG	7CG
Depth of Transect	**29**	**29.5**	**42**	**29**	**29.5**	**35**
Acanthopagrus australis						
Acanthistius ocellatus				1		
Achoerodus viridis						1
Anoplocapros inermis			1			1
Argyrosomus japonicus						
Atractoscion aequidens						
Atypichthys strigatus	8000	2290		4400	9580	46
Aulopus purpurissatus					1	
Bodianus frenchii						1
Caesioperca lepidoptera						
Carcharias taurus		1				
Centroberyx affinis						
Chaetodon guentheri						
Cheilodactylus fuscus			1	1	1	7
Cheilodactylus vestitus						
Chelmonops truncatus						
Chromis hypsilepis	210	260		1	52	
Chrysophrys auratus		1			1	
Coris dorsomacula						
Coris picta	4		1			3
Dicotylichthys punctulatus					1	
Dinolestes lewini						
Elagatis bipinnulata						
Enoplosus armatus	2	2	2	3	1	
Epinephelus daemelii						
Epinephelus undulatostriatus						
Eubalichthys bucephalus						
Eubalichthys mosaicus						
Fistularia commersonii		1				
Fistularia petimba						
Glaucosoma scapulare		1				28
Heterodontus portusjacksoni						

SITE	4CG	4CG	5CG	6CG	6CG	7CG
Depth of Transect	**29**	**29.5**	**42**	**29**	**29.5**	**35**
Hypoplectrodes annulatus			1			
Hypoplectrodes maccullochi		1	14	2	8	12
Lotella rhacina		2	2			
Mecaenichthys immaculatus			7		1	1
Meuschenia freycineti						
Meuschenia scaber	2		2			
Meuschenia trachylepis						
Nelusetta ayraudi						
Nemadactylus douglasi		6	1		6	6
Notolabrus gymnogenis	2	3		1	2	1
Ophthalmolepis lineolata	2	1	1	3	5	6
Orectolobus halei		2		1		
Orectolobus maculatus	1					
Paracaesio xanthura						
Parma microlepis			1			6
Parma unifasciata	10	6		21	13	
Parupeneus spilurus						1
Pempheris affinis						
Pempheris compressa		260			1	
Plagiotremus tapeinosoma						
Prionurus maculatus						
Prionurus microlepidotus						
Pseudocaranx georgianus						
Pseudocoris yamashiroi						
Rhabdosargus sarba						7
Scorpaena cardinalis			3			
Scorpis lineolata	2500	1140		1400	2180	98
Seriola hippos						
Seriola lalandi						
Seriola rivoliana						
Suezichthys arquatus						
Trachichthys australis						

Appendix 1. Data from fish surveys pg 5: transects at external reference sites.

SITE	**4CG**	**4CG**	**5CG**	**6CG**	**6CG**	**7CG**
Depth of Transect	**29**	**29.5**	**42**	**29**	**29.5**	**35**
Trachinops taeniatus			23	50	210	315
Trachurus novaezelandiae						
Carangoides chrysophrys						
Unidentified Labrid spp.						
Upeneichthys lineatus						1

Appendix 2. Data from mobile macroinvertebrate surveys pg 1: transects inside the CGCMR.

SITE	**1CG**	**1CG**	**2CG**	**2CG**	**2CG**	**3CG**	**3CG**	**8CG**	**8CG**	**8CG**	**8CG**	**9CG**	**9CG**	**10CG**	**10CG**	**10CG**	**11CG**	**11CG**
Depth of transect	**27**	**31**	**28**	**29**	**36**	**26**	**27**	**25**	**26**	**32**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Astralium tentoriformis	22		15			23	17	7	12			10	2	1	7			2
Astrosierra amblyconus										1					1	1		
Cenolia glebosus			1															
Cenolia trichoptera			14		10		15	4	12	1	12	195	75	6	16	14	11	2
Centrostephanus rodgersii	318	52	290	265		329	282	406	377			479	373	116	84		140	
Chromodoris splendida										1								
Conocladus australis										1					1			
Cymbiola magnifica												1						
Dicathais orbita											1							
Echinaster colemani			1							4								
Echinostrephus sp.																		1
Fromia polypora									1						2	1	2	
Glossodoris atromarginata																		
Hypselodoris bennetti										1								
Hypselodoris bertschi																		
Muricid sp. 1																		
Neodoris chrysoderma											1							
Ophidiaster confertus						1												
Pagurus sinuatus			3															
Pentagonaster dubeni			1				2					3	3					1
Petricia vernicina													1					
Phyllacanthus parvispinus		17						1		18		2	4	16	20		10	11
Plectaster decanus		1		1	1				1	1								
Prionocidaris callista					26						30			1	3	22		33
Pseudoboletia indiana								1										
Pteraeolidia ianthina										1							1	
Ranella australasia								3										
Saginopterum ornatum					1													
Sassia parkinsonia					1		5											
Temnopleurus toreumaticus								1										
Tripneustes gratilla						1	1		1						1			
Unidentified crinoid 1																		

Appendix 2. Data from mobile macroinvertebrate surveys pg 2: transects inside the CGCMR.

SITE	**1CG**	**1CG**	**2CG**	**2CG**	**2CG**	**3CG**	**3CG**	**8CG**	**8CG**	**8CG**	**8CG**	**9CG**	**9CG**	**10CG**	**10CG**	**10CG**	**11CG**	**11CG**
Depth of transect	**27**	**31**	**28**	**29**	**36**	**26**	**27**	**25**	**26**	**32**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Unidentified crinoid 2																		
Unidentified hermit crab	1							1							1			
Unidentified nudibranch																		

Appendix 2. Data from mobile macroinvertebrate surveys pg 3: transects at external reference sites

SITE Depth of transect	4CG 29	4CG 29.5	5CG 42	6CG 29	6CG 29.5	7CG 35
Astralium tentoriformis	3	12		7	33	10
Astrosierra amblyconus						
Cenolia glebosus						
Cenolia trichoptera	74	130		25	172	15
Centrostephanus rodgersii						
Chromodoris splendida						
Conocladus australis						
Cymbiola magnifica						
Dicathais orbita						
Echinaster colemani						
Echinostrephus sp.		1				
Fromia polypora	1	1	1	3	3	
Glossodoris atromarginata					1	
Hypselodoris bennetti						
Hypselodoris bertschi				1		
Muricid sp. 1					2	
Neodoris chrysoderma				1		1
Ophidiaster confertus	1					
Pagurus sinuatus						
Pentagonaster dubeni	2	1			1	1
Petricia vernicina				1	1	
Phyllacanthus parvispinus	102	63		207	244	
Plectaster decanus		1			1	3
Prionocidaris callista	4	1	7	1	1	46
Pseudoboletia indiana						
Pteraeolidia ianthina		1			9	1
Ranella australasia						
Saginopterum ornatum				1	1	
Sassia parkinsonia						
Temnopleurus toreumaticus						
Tripneustes gratilla						

SITE Depth of transect	4CG 29	4CG 29.5	5CG 42	6CG 29	6CG 29.5	7CG 35
Unidentified crinoid 1					1	
Unidentified crinoid 2	12			25		
Unidentified hermit crab			3		2	1
Unidentified nudibranch			1			1

Appendix 3. Data from sessile cover photo-quadrats pg 1: transects inside the CGCMR.

SITE	**1CG**	**1CG**	**2CG**	**2CG**	**2CG**	**3CG**	**3CG**	**8CG**	**8CG**	**8CG**	**8CG**	**9CG**	**9CG**	**10CG**	**10CG**	**10CG**	**11CG**	**11CG**
Depth of transect	**27**	**31**	**28**	**29**	**36**	**27**	**26**	**25**	**32**	**26**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Anemones	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ballanophyllia bairdiana	0.00	0.00	0.00	0.26	0.09	0.00	0.00	0.00	0.18	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barnacles	5.45	3.52	5.20	4.21	0.46	6.65	5.44	4.24	0.00	6.03	0.18	6.47	2.19	2.23	1.87	0.36	5.60	1.08
Botrylloides sp.	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00
Cnemidocarpa pedata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.19	0.18	0.00	0.00
Codium sp.	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corallines (branched)	0.00	0.93	0.00	0.00	1.11	0.00	0.00	0.00	2.54	0.00	0.55	0.00	0.00	0.61	0.00	0.00	0.00	2.34
Crustose coralline algae	82.52	47.50	78.07	80.79	48.38	82.81	87.80	83.61	17.24	64.20	40.40	70.00	85.58	42.51	40.00	26.71	62.74	39.82
Culicia sp.	2.26	0.19	7.06	3.68	0.28	2.22	2.25	2.39	0.00	26.46	0.00	17.06	0.18	11.74	10.84	0.00	0.97	0.00
Didemnid spp.	0.00	0.46	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
Drifa spp.	0.00	0.28	0.00	0.00	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Echinoclathria leporina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.73	0.00	0.00	0.00	0.19	1.26	0.77	0.18
Encrusting *Peyssonnelia* spp. /*Hildenbrandia* spp.	2.26	1.94	1.12	1.05	3.88	0.00	0.00	0.55	1.09	0.00	1.83	0.00	0.55	0.81	3.18	2.35	0.97	0.90
Dictyotalean sp.	0.00	1.39	0.00	0.00	0.00	0.00	0.00	0.00	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Holopsamma laminaefavosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroidea sp.	0.00	0.09	0.00	0.00	0.55	0.00	0.00	0.00	0.36	0.00	0.37	0.00	0.00	0.00	0.93	0.90	0.00	0.00
Lobophora variegata	0.00	3.24	0.19	0.00	0.18	0.00	0.00	0.00	1.63	0.00	0.55	0.00	0.00	0.20	0.00	0.00	0.39	0.54
Mopsea sp.	0.00	1.39	0.00	0.00	1.29	0.00	0.00	0.00	3.45	0.00	0.55	0.00	0.00	0.00	0.19	5.60	0.00	1.80
Other gorgonians	0.00	0.19	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00
Pebbles	0.00	0.09	0.00	0.00	0.18	0.18	0.00	0.18	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.18
Peyssonnelia novaehollandae	0.00	0.65	0.19	0.00	2.31	0.00	0.00	0.00	1.27	0.00	1.83	0.00	0.00	0.61	0.75	2.35	0.00	3.06
Plate coral	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.00	0.55	0.00	0.00	0.00	0.00	0.18	0.00	0.18
Pyura spinifera	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.18	0.00	0.18
Rock	4.32	0.74	0.00	0.00	0.74	0.37	1.13	2.21	0.18	1.95	0.00	1.76	3.65	1.82	0.93	0.36	3.67	0.36
Sand	2.44	17.78	0.93	0.00	11.82	3.88	2.81	3.68	33.03	0.58	20.48	1.57	4.93	0.20	0.75	25.99	4.63	20.18
Sediment/turf matrix	0.00	10.83	4.65	7.89	11.45	0.00	0.00	0.00	18.15	0.00	21.39	0.98	0.36	12.35	26.36	16.43	15.64	12.07
Serpulid worms	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.18
Shell fragments	0.00	1.67	0.00	0.00	3.23	0.00	0.56	0.37	2.72	0.00	0.00	0.20	1.82	0.00	0.00	0.36	1.74	1.08
Soft erect bryozoans	0.00	1.02	0.00	0.00	0.09	0.00	0.00	0.00	0.36	0.00	0.18	0.00	0.00	0.00	0.19	0.54	0.00	0.18
Sphaerokodisis australis	0.00	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.26	0.00	0.00

Appendix 3. Data from sessile cover photo-quadrats pg 2: transects inside the CGCMR.

SITE	1CG	1CG	2CG	2CG	2CG	3CG	3CG	8CG	8CG	8CG	8CG	9CG	9CG	10CG	10CG	10CG	11CG	11CG
Depth of transect	**27**	**31**	**28**	**29**	**36**	**27**	**26**	**25**	**32**	**26**	**36**	**26**	**27**	**30**	**31**	**36.5**	**29**	**33**
Sponge (cup)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.36	0.00	0.54
Sponge (encrusting)	0.38	2.22	1.49	2.11	1.94	0.18	0.00	0.00	3.81	0.39	2.93	0.00	0.00	10.93	2.80	2.35	1.16	2.88
Sponge (erect branching)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.18	0.00	0.00	0.00	0.00	1.62	0.00	0.90
Sponge (erect simple)	0.38	2.04	0.93	0.00	1.85	0.18	0.00	0.00	1.45	0.00	2.38	1.57	0.18	6.28	5.23	2.53	0.58	1.80
Sponge (plate)	0.00	0.00	0.00	0.00	1.75	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	1.99	0.00	0.36
Sponge sp.1 (frilly yellow erect sponge)	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
Sponge sp.2 (grey erect sponge)	0.00	0.00	0.00	0.00	0.37	0.18	0.00	0.00	0.18	0.00	0.18	0.00	0.00	0.00	0.00	0.18	0.00	0.00
Sponge sp.3 (encrusting iridescent blue sponge)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.62
Steginoporella sp.	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36
Tethya spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.18
Triphyllozoon sp.	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00
Unidentified alcyonaceans	0.00	0.37	0.00	0.00	0.55	0.00	0.00	0.00	0.91	0.00	1.65	0.00	0.00	0.00	0.00	1.81	0.00	0.36
Unidentified ascidians	0.00	0.00	0.19	0.00	1.29	0.00	0.00	0.37	0.36	0.00	0.37	0.00	0.18	0.00	0.93	0.36	0.77	1.44
Unidentified encrusting ascidians	0.00	0.19	0.00	0.00	0.55	1.66	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.72	0.00	0.18
Unidentified foliose red algae	0.00	0.46	0.00	0.00	3.42	0.00	0.00	0.00	4.72	0.00	1.46	0.00	0.00	1.21	0.00	0.90	0.00	0.18
Unidentified sea whips	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.18
Unidentified zoanthids	0.00	0.37	0.00	0.00	0.09	1.66	0.00	2.39	1.09	0.39	0.37	0.39	0.00	8.50	3.55	0.72	0.19	4.32

Appendix 3. Data from sessile cover photo-quadrats pg 3: transects at external reference sites.

SITE	4CG	4CG	5CG	6CG	6CG	7CG
Depth of transect	**29.5**	**29**	**42**	**29.5**	**29**	**35**
Anemones	0.00	0.00	0.18	0.19	0.00	0.00
Ballanophyllia bairdiana	0.00	0.00	0.00	0.00	0.18	0.37
Barnacles	2.94	0.36	0.00	0.76	0.18	0.00
Botrylloides sp.	0.37	0.00	0.00	0.19	1.08	0.19
Cnemidocarpa pedata	0.18	0.00	0.00	0.38	0.18	0.19
Codium sp.	0.37	0.00	0.18	0.38	0.54	0.19
Corallines (branched)	0.74	0.36	0.00	2.47	4.51	0.37
Crustose coralline algae	58.64	60.66	51.18	42.78	37.36	36.14
Culicia sp.	0.37	0.00	0.00	0.00	0.00	0.00
Didemnid spp.	0.00	0.00	0.00	0.00	0.00	0.00
Drifa spp.	5.70	6.38	0.00	8.37	6.14	0.56
Echinoclathria leporina	0.18	0.00	0.00	0.00	0.36	0.00
Encrusting *Peyssonnelia* spp. /*Hildenbrandia* spp.	1.65	1.64	8.20	1.14	3.07	1.69
Dictyotalean sp.	0.00	0.00	0.00	0.00	0.00	0.00
Holopsamma laminaefavosa	0.00	0.00	0.00	0.19	0.18	0.00
Hydroidea sp.	0.00	0.00	0.55	0.57	1.44	0.00
Lobophora variegata	0.55	0.36	0.00	0.00	0.00	0.00
Mopsea sp.	0.00	0.00	0.00	0.00	0.00	1.87
Other gorgonians	0.00	0.00	0.00	0.00	0.00	0.37
Pebbles	0.00	0.00	0.00	0.00	0.00	0.00
Peyssonnelia novaehollandae	0.92	0.18	1.46	0.95	0.54	1.31
Plate coral.	0.00	0.00	0.18	0.00	0.00	0.00
Pyura spinifera	0.55	0.91	0.00	3.42	1.44	0.56
Rock	0.55	0.18	0.18	1.14	0.00	0.00
Sand	2.21	3.46	13.30	1.33	2.17	6.37
Sediment/turf matrix	7.72	12.39	17.85	16.54	18.41	29.96
Serpulid worms	0.55	0.73	0.00	0.38	0.90	0.19

SITE	4CG	4CG	5CG	6CG	6CG	7CG
Depth of transect	**29.5**	**29**	**42**	**29.5**	**29**	**35**
Shell fragments	0.92	0.73	1.09	0.19	0.00	0.00
Soft erect bryozoans	0.37	0.00	0.18	0.00	0.00	0.00
Sphaerokodisis australis	0.00	0.00	0.00	0.00	0.00	1.69
Sponge (cup)	0.18	0.00	0.36	0.00	0.00	1.87
Sponge (encrusting)	3.86	6.92	1.82	7.22	5.42	5.24
Sponge (erect branching)	0.37	0.36	0.00	0.00	1.08	0.56
Sponge (erect simple)	2.02	1.28	1.09	4.18	3.97	5.24
Sponge (plate)	0.00	0.00	0.00	0.00	0.18	0.94
Sponge sp.1 (frilly yellow erect sponge)	0.00	0.00	0.00	0.00	0.00	0.00
Sponge sp.2 (grey erect sponge)	0.18	0.00	0.18	0.57	0.00	1.12
Sponge sp.3 (encrusting iridescent blue sponge)	0.00	0.00	0.00	0.38	5.42	0.19
Steginoporella sp.	2.21	0.00	0.00	0.00	0.00	0.37
Tethya spp.	0.18	0.00	0.00	0.38	0.54	0.37
Triphyllozoon sp.	0.18	0.00	0.36	0.00	0.18	0.56
Unidentified Alcyonaceans	0.00	0.00	0.36	0.00	0.18	0.37
Unidentified ascidians	0.18	0.36	0.73	0.57	1.08	0.56
Unidentified encrusting ascidians	0.37	0.55	0.00	0.00	0.00	0.00
Unidentified foliose red algae	0.92	0.18	0.36	0.19	0.36	0.19
Unidentified sea whips	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified zoanthids	3.86	2.00	0.18	5.13	2.89	0.37