2016 Biodiversity Surveys of the Cod Grounds and Pimpernel Rocks Commonwealth Marine Reserves

REEF LIFE SURVEY

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Report to Parks Australia, Department of the Environment

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Images

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List of acronyms

ACRONYM	EXPANDED
AMP/CMR	Australian Marine Park/ Commonwealth Marine Reserve
RLSF	The Reef Life Survey Foundation
MPA	Marine Protected Area
IUCN	International Union for Conservation of Nature
RLS	Reef Life Survey
EEZ	Exclusive Economic Zone
CTI	Community Temperature Index

Executive summary

The Cod Grounds Commonwealth Marine Reserve (CMR) is located in Commonwealth waters approximately four nautical miles off the coast of New South Wales, encompassing three underwater pinnacles rising to ~18 m depth from a seabed 40 m deep. This CMR is highly protected by a Marine National Park Zone (IUCN II). The Solitary Islands are protected within NSW State waters within the boundaries of the Solitary Islands Marine Park, with areas further than 3 nautical miles from the islands protected by the Solitary Islands Commonwealth Marine Reserve. Most of this CMR is classified as Multiple Use or Special Purpose Zone (IUCN VI), but Pimpernel Rock is highly protected by a Marine National Park Zone (IUCN II).

Pimpernel Rock is a submerged pinnacle that rises from the ocean floor to within 10 m of the surface. It is an extremely significant feature of the Solitary Islands CMR, as it attracts large pelagic fishes, marine mammals, grey nurse sharks *Carcharias taurus*, black cod *Epinephelus daemelii*, and marine turtles. Both the Cod Grounds and Pimpernel Rock CMRs are primarily recognised for providing key habitat for grey nurse sharks and black cod, which are protected under both NSW State and Commonwealth legislation. This report describes patterns of reef biodiversity in the Cod Grounds and Pimpernel Rock CMRs and at a number of external reference sites. It follows the 2009 baseline survey on the condition and biodiversity values of the Cod Grounds CMR.

The surveys of the Cod Grounds and Solitary Islands revealed:

- a dominance of temperate species in deeper areas, with more subtropical species in the shallows;
- distinct depth stratification;
- very high fish biomass, including exploited fish species; and
- a high abundance of grey nurse sharks during recent surveys of the CGCMR.

Depth stratification was found across all surveyed communities, including fishes, invertebrates and benthos. Previous studies, including the Cod Grounds baseline survey, have also noted depth structuring along narrow bands, driven to some degree by the distribution and abundance of grazing sea urchins. Spatial differences were also apparent between the Cod Grounds, Pimpernel Rock and the Solitary Islands sites. The Solitary Islands sites chosen as reference sites for the CMR (Pimpernel Rock) were as similar as possible in wave exposure and underlying habitat structure, however, they were much shallower than the Cod Grounds and Pimpernel Rock sites. The fish community at the Solitary Islands reference sites were more similar to those found in subtropical and tropical waters further north than to the largely temperate species found at depth in the CMRs. Ultimately, given the strong effects of depth on reef communities in this region, deeper sites would be ideal to provide reference sites for Pimpernel Rock. However, the pinnacles of Pimpernel Rock and the Cod Grounds are geomorphologically unique, also making it difficult to find appropriate reference sites outside the CMR, and meaning that trends through time within these CMRs will need to be carefully interpreted in light of broader regional change.

Pimpernel Rock and some of the Cod Grounds sites had very high biomass of fishes; in a number of cases this was driven by very large schools of planktivores, and in some cases also high abundances of carnivores and sharks. In the Cod Grounds, the highest biomass values were recorded at the reference sites in 2009, but in the CMR sites in 2016. Although possible, it is unlikely that successful protection of the CMR has displaced fishing effort to areas outside the CMR, because analysis of large and exploited fish species indicated that both had marginally higher biomass in the CMR than at reference sites, but not significantly so. The high abundance of the grey nurse sharks, especially during the 2016 surveys, suggests that the east coast population is benefiting from national regulations for no-take protection.

RECOMMENDATIONS

- Undertake ongoing ecological monitoring at intervals of 1-3 years to build up a temporal dataset to assess changes relative to data provided by this survey, with results reported using a logistically manageable set of sensitive biodiversity indicators;
- Incorporate additional sites for monitoring, especially additional control sites outside the CMRs, in comparable habitats and depths;
- Include timed swims around the pinnacles for more accurate assessment of the grey nurse shark population;
- Undertake monitoring of potential impacts, including dedicated surveys of fishing catch and effort in the general area by recreational and commercial fishers, (e.g. AFMA data) and reporting mechanisms for pollution, shipping, interactions with megafauna and plastic marine debris;
- Undertake regular monitoring of physical characteristics – seasonal reporting of water quality, nutrients, turbidity, light and other physical parameters that support ecological processes;
- Through the longer term, consider establishing a buffer zone around the CMR boundaries.

1 Introduction

The Cod Grounds Commonwealth Marine Reserve (CMR) is located in Commonwealth waters approximately four nautical miles off the coast of Laurieton, New South Wales, Australia, encompassing three underwater pinnacles rising to ~18 m depth from a seabed approximately 40 m deep (Davies et al. 2008). The Cod Grounds CMR was established primarily due to its value as habitat for grey nurse sharks (*Carcharias taurus*) and black cod (*Epinephelus daemelii*), which are protected under both NSW State and Commonwealth environmental legislation. The complex geomorphology within the Cod Grounds CMR forms a variety of distinctive habitats including steep outcrops, shallow gutters, boulder/cobble slopes, and sand expanses; four substratum types (solid consolidated bedrock outcrop, unconsolidated boulder and cobble, cobbles partially covered by sand, and rippled fine sand with variable amounts of shell grit), and at least two geological facies have been classified from habitat mapping of the area (Davies et al. 2008).

The Solitary Islands are protected within NSW State waters within the boundaries of the Solitary Islands Marine Park, with areas further than 3 nautical miles from the islands protected by the Solitary Islands CMR. Most of this CMR is classified as Multiple Use or Special Purpose Zone (IUCN VI), but Pimpernel Rock is highly protected by a Marine National Park Zone (IUCN II). Pimpernel Rock is a submerged pinnacle that rises from the ocean floor to within a few meters of the surface, and is the most significant feature of the Solitary Islands CMR, as it attracts large pelagic fish, grey nurse sharks *Carcharias taurus*, black cod *Epinephilus daemelii*, marine mammals and turtles (Commonwealth of Australia 2001b). Similarly to the Cod Grounds CMR, the deeper areas of the Solitary Islands CMR have steep slopes and deeply scoured gutters, with a variety of geomorphological features (Ingleton et al. 2007).

The highly complex habitats of the Cod Grounds and Pimpernel Rocks interact with the East Australian Current (EAC), the largest ocean current along the east coast of Australia. The EAC is the southern arm of the bifurcation of the westward-flowing Southern Equatorial Current, which enters the Coral Sea region from the Pacific Ocean. The EAC flows southwards in a series of eddies and areas of upwelling, drawing nutrient rich water from a depth of at least 200 m. The EAC, its upwellings, interactions with the structurally complex seabed, and transport of warmer waters and tropical larvae, promote a rich flora and fauna within the Cod Grounds and Solitary Islands CMRs (Oke and Middleton 2001; Brewer et al. 2007). Offshore reefs are low outcrops made of rubble and broken rock in waters deeper than 35m, dominated by sponges, soft corals and encrusting algae. Deep midshelf reefs in the Solitary Islands CMR host a high diversity of marine life. Three submerged pinnacles with steep slopes are encrusted with algae, sponges and ascidians (Commonwealth of Australia 2001b).

Prior to the establishment of the Cod Grounds CMR in 2007, this area supported a multi-species fishery for a number of decades. Of the 20 main target species in the region, the highest catches were reported for snapper (*Chrysophrys auratus*), bonito (*Sarda australis*), sweep (*Scorpis lineolata*) and silver trevally (*Pseudocaranx dentex*); commercial catches were high and recreational catches, albeit unrecorded, were also thought to be high (Schirmer et al. 2004). Grey nurse sharks are thought to have been part of the recreational catch in the past (Commonwealth of Australia 2001a).

The Cod Grounds CMR is now managed as a no-take zone, or an International Union for Conservation of Nature (IUCN) Category 1a Sanctuary Zone. Unfortunately, there has been evidence of illegal fishing, which is of concern because of the small size of the Reserve, as the removal of even a few individuals of important species may have large ecological repercussions. For instance, the removal of large predators of urchins, such as blue groper (*Achoerodus viridis*) and pink snapper (*Chrysophrys auratus*), may cause increasing abundances of urchins, which in turn can affect densities of algae and invertebrates and create 'urchin barrens' (Stuart-Smith et al. 2009).

Previous studies have focused on the grey nurse shark (Otway et al. 2003); together with Pimpernel Rocks, the Cod Grounds CMR is thought to attract over 16% of the grey nurse shark population off the coast of NSW (Commonwealth of Australia 2001a). In 2009, Reef Life Survey (RLS) conducted the most comprehensive biodiversity survey in the Cod Grounds CMR to that time, laying down a baseline from which future changes and dynamics can be measured. The baseline survey documented and described the key ecological features of the Cod Grounds CMR and surrounding habitats, including the dominance of cool temperate species, distinct depth zonation of benthos, the general paucity of benthic biota, very high fish biomass and abundance of large pelagic fishes exploited elsewhere, and the presence of a number of rare and threatened species (Stuart-Smith et al. 2009).

The shallowest benthic communities were typical of urchin barrens found elsewhere in NSW, with a high abundance of the barrens-forming urchin *Centostephanus rodgersii* (Rule and Smith 2007); deeper areas hosted at least 48 taxa or cover categories of sponges, ascidians, soft corals and hard corals. Urchin grazing was considered the key driver of the distinctive zonation of the benthic community into depth bands (Stuart-Smith et al. 2009). The fish community was also partitioned between shallow and deep assemblages. Species encountered primarily in the Cod Grounds CMR, apart from rare species, include those typically aggregating around prominent undersea features, such as highfin amberjack (*Seriola rivoliana*), yellowtail kingfish (*Seriola lalandi*) and rainbow runner (*Elagatis bipinnulata*). High densities of large wobbegong sharks (*Orectolobus halei* and *O. maculatus*) were also recorded. Average abundance and biomass of fishes, especially exploited species, were significantly higher inside the Cod Grounds CMR than at nearby fished reference sites.

The shallow habitats of the Solitary Islands have been subject to abundant research, but the deeper areas and Pimpernel Rock itself have received less attention. The NSW Marine Park Authority and others have classified the habitats around Pimpernel Rock into three broad depth-related zones: 1) 10 m to 18 m water depth: dominated by barnacles and sea urchins, with patches of cunjevoi (*Pyura stolonifera*), encrusting sponges and filamentous algae; 2) 18 m to 30 m: high percent cover of *P. stolonifera*, with hydrozoan epiphytes and some gorgonians; and 3) > 30 m depth: dominated by the stalked ascidian *Pyura spinifera*, sponges and sea whips (The Ecology Lab 2006). More recently, small patches were found to be dominated by specific biota, whereas at broader scales the benthic community was dominated by either coral and/ or other mixed invertebrate communities or macroalgae, in particular the kelp *Ecklonia radiata* (Malcolm et al. 2010). Species richness, taxonomic composition and diversity were found to increase with depth, with the highest species richness recorded at the 50 m depth contour within the Solitary Islands CMR. Fish communities were also found to be diverse, with a combination of reef-associated and pelagic species (Malcolm et al. 2010).

This report describes patterns of reef biodiversity in the Cod Grounds CMR and at a number of external reference sites. It follows from the 2009 baseline survey on the condition and biodiversity values of the Cod Grounds CMR. The survey is part of the ongoing performance assessment program for the Cod Grounds CMR, which will determine its effectiveness in protecting key species and ecological communities within its boundaries. Additionally, this report describes ecological communities at Pimpernel Rock and associated external reference sites.

2 Methods

Field surveys at the Cod Grounds and Pimpernel Rock were conducted from 18th to 21st April 2016 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, along six transects at four sites outside the CGCMR, and four transects at Pimpernel Rock (Figure 1). Additional data from 29 previously surveyed transects at five sites in the State-managed Solitary Islands Marine Park were used as reference sites for Pimpernel Rock, chosen for similar habitat (although at shallower depths). 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 depths both inside and outside the CGCMR and around the Pimpernel Rock pinnacle, 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.

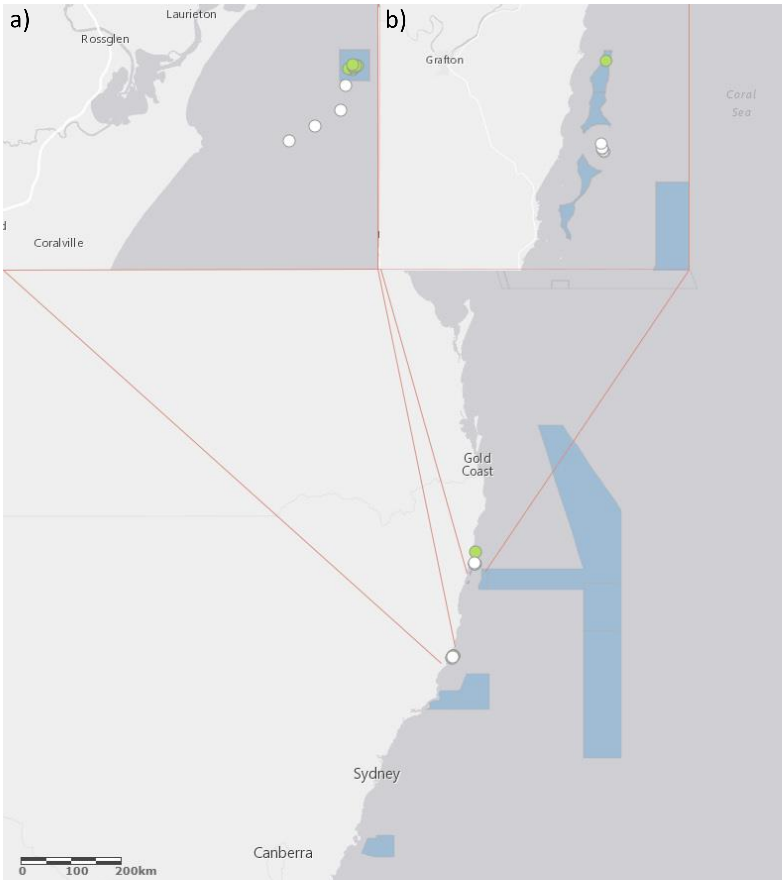

Figure 1. Map of a) Cod Grounds and Pimpernel Rocks, and b) Solitary Islands sites surveyed from 2009 - 2016.

Table 1. Site details including marine park zone (CGCMR: Cod Grounds Commonwealth Marine Reserve; SICMR: Solitary Islands Commonwealth Marine Reserve; Ref: Reference site outside reserve), geographical coordinates (datum = WGS84), depth of transect line, for each site surveyed. For the Cod Grounds, Date and Depth columns separate the original baseline surveys from the more recent follow-up surveys.

SiteCode	CMR	Site name	Latitude	Longitude	Date (baseline)	Depth	Date (repeat)	Depth
CG1	**CGCMR**	Nth of Pinnacles (662)	**-31.6821**	152.90948	**14-05-09**	27	**21-04-16**	26
CG1	**CGCMR**	Nth of Pinnacles (662)	**-31.6821**	152.90948	**14-05-09**	31	**21-04-16**	27
CG2	**CGCMR**	Cod Gardens (CODGAR)	**-31.6813**	152.91078	**12-05-09**	29	**18-04-16**	28
CG2	**CGCMR**	Cod Gardens (CODGAR)	**-31.6813**	152.91078	**14-05-09**	28	**18-04-16**	29
CG2	**CGCMR**	Cod Gardens (CODGAR)	**-31.6813**	152.91078	**14-05-09**	36		
CG3	**CGCMR**	SW flats (66B)	**-31.6831**	152.90585	**14-05-09**	26	**19-04-16**	25
CG3	**CGCMR**	SW flats (66B)	**-31.6831**	152.90585	**14-05-09**	27	**19-04-16**	26
CG4	**Ref**	Z - 3 (666)	**-31.708**	152.90093	**15-05-09**	29		
CG4	**Ref**	Z - 3 (666)	**-31.708**	152.90093	**15-05-09**	29.5		
CG5	**Ref**	Deep Wall (665)	**-31.6934**	152.90375	**15-05-09**	42		
CG5	**Ref**	Deep Wall (665)	**-31.6934**	152.90375	**15-05-09**	29		
CG5	**Ref**	Deep Wall (665)	**-31.6934**	152.90375	**15-05-09**	29.5		
CG6	**Ref**	Z - 1 - 28 (M2-28)	**-31.717**	152.88254			**19-04-16**	28
CG6	**Ref**	Z - 1 - 28 (M2-28)	**-31.717**	152.88254			**19-04-16**	29
CG7	**Ref**	Leahs Lumps (L-BUMP)	**-31.7258**	152.86517	**15-05-09**	35	**19-04-16**	38
CG8	**CGCMR**	Cod Grounds Pinnacles	**-31.6821**	152.90948	**16-05-09**	25	**21-04-16**	25
CG8	**CGCMR**	Cod Grounds Pinnacles	**-31.6821**	152.90948	**16-05-09**	32		
CG8	**CGCMR**	Cod Grounds Pinnacles	**-31.6821**	152.90948	**16-05-09**	36		
CG8	**CGCMR**	Cod Grounds Pinnacles	**-31.6821**	152.90948	**17-05-09**	26		
CG8	**CGCMR**	Cod Grounds Pinnacles	**-31.6825**	152.90945			**18-04-16**	27
CG9	**CGCMR**	Geek Flats (667)	**-31.6807**	152.90872	**16-05-09**	26	**21-04-16**	28

SiteCode	CMR	Site name	Latitude	Longitude	Date (baseline)	Depth	Date (repeat)	Depth
CG9	**CGCMR**	Geek Flats (667)	**-31.6807**	152.90872	**16-05-09**	27		
CG10	**CGCMR**	Steves Bommie (668)	**-31.6815**	152.91196	**17-05-09**	30	**21-04-16**	36
CG10	**CGCMR**	Steves Bommie (668)	**-31.6815**	152.91196	**17-05-09**	31		
CG10	**CGCMR**	Steves Bommie (668)	**-31.6815**	152.91196	**17-05-09**	36.5		
CG11	**CGCMR**	SE lumps (66A)	**-31.6841**	152.90851	**17-05-09**	29	**19-04-16**	30
CG11	**CGCMR**	SE lumps (66A)	**-31.6841**	152.90851	**17-05-09**	33		
PIMP1	**SICMR**	Pimpernel Rock	**-29.6981**	153.39755	**20-04-16**	14		
PIMP1	**SICMR**	Pimpernel Rock	**-29.6981**	153.39755	**20-04-16**	26		
PIMP1	**SICMR**	Pimpernel Rock	**-29.6981**	153.39755	**20-04-16**	35		
PIMP1	**SICMR**	Pimpernel Rock	**-29.6981**	153.39755	**20-04-16**	38		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**06-06-08**	6		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**06-06-08**	6.1		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**06-06-08**	8		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**06-06-08**	10		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**06-06-08**	12		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**15-03-09**	8		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**21-08-09**	8		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**21-08-09**	12		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**21-08-09**	14		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**05-06-11**	14		
SI1	**Ref**	Elbow Cave Mooring N Solitary Is	**-29.9304**	153.38984	**26-04-13**	10		
SI13	**Ref**	South End Nth Solitary	**-29.9331**	153.392562	**22-08-09**	9		
SI13	**Ref**	South End Nth Solitary	**-29.9331**	153.392562	**22-08-09**	15		
SI13	**Ref**	South End Nth Solitary	**-29.9331**	153.392562	**22-08-09**	16.6		

SiteCode	CMR	Site name	Latitude	Longitude	Date (baseline)	Depth	Date (repeat)	Depth
SI14	**Ref**	Fish Soup	**-29.9127**	153.38342	**22-08-09**	7		
SI14	**Ref**	Fish Soup	**-29.9127**	153.38342	**22-08-09**	8		
SI14	**Ref**	Fish Soup	**-29.9127**	153.38342	**22-08-09**	10.1		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**06-06-08**	10		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**06-06-08**	11		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**06-06-08**	11.1		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**06-06-08**	12		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**06-06-08**	13.5		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**21-08-09**	10		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**21-08-09**	11		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**21-08-09**	14		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**23-06-11**	11		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**01-10-11**	10		
SI2	**Ref**	Anemone Bay N Solitary Is	**-29.9231**	153.38809	**26-04-13**	12		
SI23	**Ref**	Canyons North Solitary	**-29.9251**	153.38679	**15-03-09**	14		

FISH SURVEYS (METHOD 1)

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 divers swam slowly along opposite sides of the line. Size-classes of total fish length (from snout to tip of tail) used were 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.

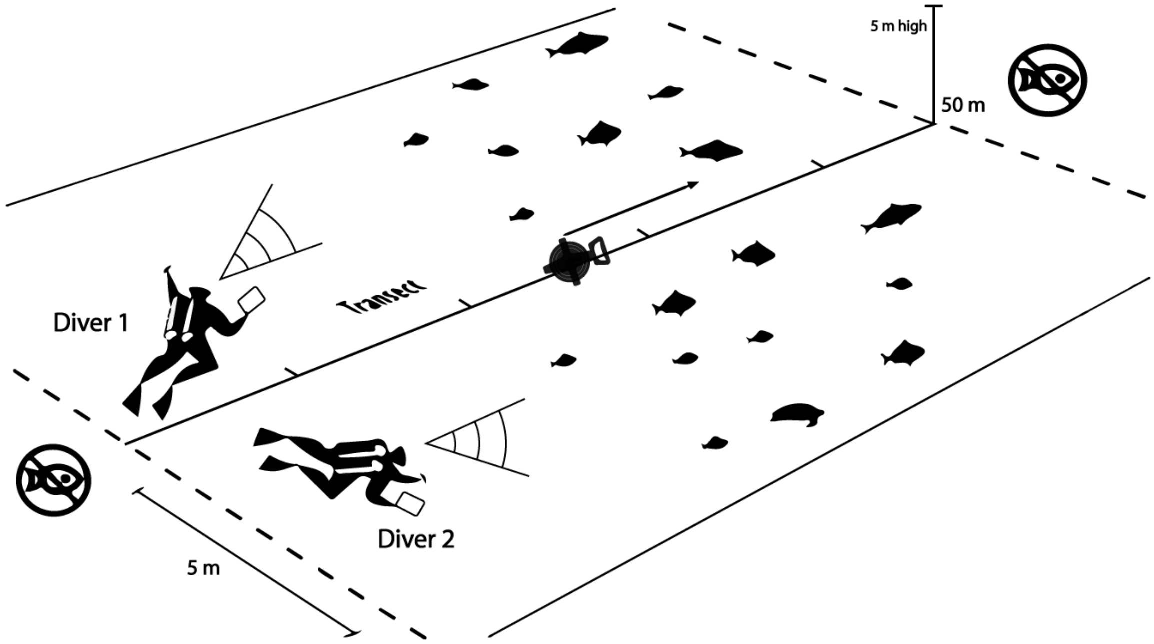

Figure 2. Stylised representation of method 1 survey technique

MACROINVERTEBRATE AND CRYPTIC FISH SURVEYS (METHOD 2)

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) were censused along the same transect lines set for fish surveys. Divers swam 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.

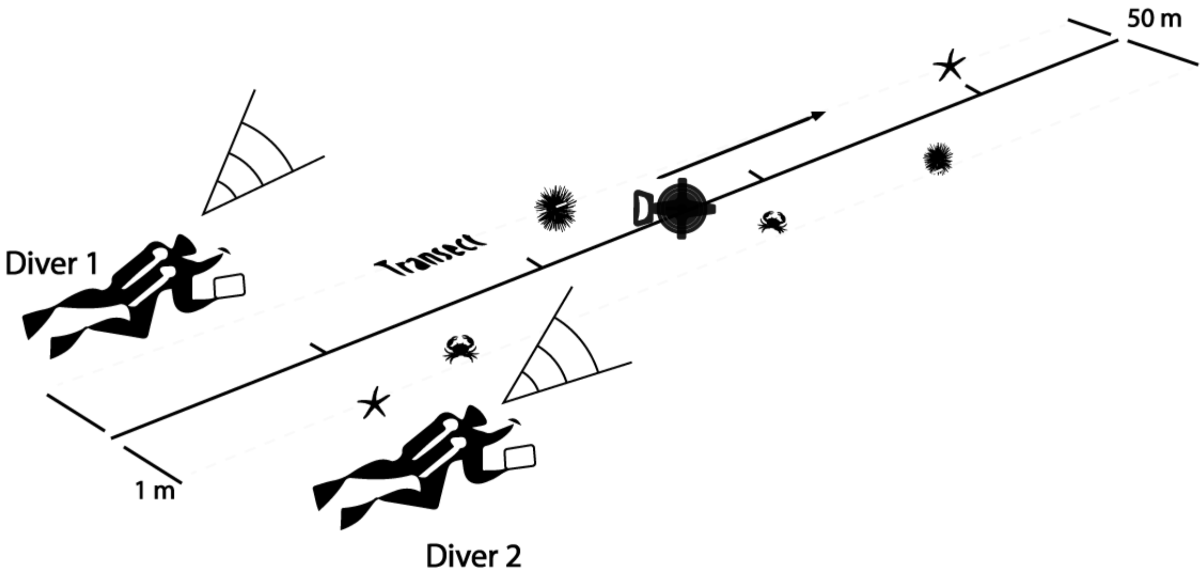

Figure 3. Stylised representation of method 2 survey technique

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 was 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. The percentage cover of different macroalgal, coral, sponge and other attached invertebrate species in photo-quadrats was digitally quantified in the laboratory using the Coral Point Count with Excel extensions (CPCe) software (Kohler and Gill 2006). A grid of 5 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.

STATISTICAL ANALYSES

At most sites, multiple transects were surveyed at different depths (see Table 1). Because of clear depth stratification over the large range of depths covered (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 the summed value(s) of the two blocks per transect (i.e. giving values per 500 m2 for fishes and per 100 m2 for mobile macroinvertebrates).

Separate univariate analyses and data exploration techniques were used for fish, mobile macroinvertebrate communities, cryptic fishes and sessile communities. 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.

Univariate metrics were applied 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.

To explore patterns in fish community trophic structure, the abundance and biomass of fishes in different trophic groups (planktivores, grazers, farmers, carnivores, piscivores, benthic invertivores and corallivores) were estimated. Biomass estimates were made for each species on each transect 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 2016). Community characteristics and relationships between transects were explored using Multidimensional Scaling (MDS) plots based on Bray-Curtis similarity matrices. Data for fish, mobile macroinvertebrate and sessile communities were considered separately, with a square root transformation applied to all data.

3 Results

FISH SURVEYS

Overall, 218 species of fish were recorded on the transects; 186 of these occurred in the SICMR and its reference sites. Similar numbers of species were recorded in the CGCMR in 2009 and 2016: 66 and 65, respectively (APPENDIX 1). The five most abundant species in the CGCMR in 2009 were *Chromis hypsilepis* (one-spot puller), *Scorpis lineolata* (silver sweep), *Trachinops taeniatus* (eastern hulafish), *Atractoscion aequidens* (teraglin) and *Atypichthys strigatus* (mado). Similar species were among the most abundant in 2016 (with *Parma unifasciata*), but abundances were approximately three times as high for the top two species. The reference sites were also dominated by the same species, but abundance was higher in 2009 than 2016. Pimpernel Rock in the SICMR had similar dominant species (top five: *Scorpis lineolata*, *Atypichthys strigatus*, *Trachinops taeniatus*, *Pempheris affinis* (black-tipped bullseye) and *Pseudanthias rubrizonatus* (lilac-tipped basslet)), whilst its reference sites hosted a mixed subtropical/temperate assemblage (top five: *Dascyllus trimaculatus* (three-spot damsel), *Thalassoma lunare* (moon wrasse), *Amphiprion akindynos* (Barrier Reef anemonefish), *Scorpis lineolata*, *Parma unifasciata* (girdled parma)).

The fish community varied both spatially and temporally; spatial differences occurred primarily between the CMRs and reference sites and between the Cod Grounds and Solitary Islands, and the community shifted in the CGCMR between 2009 and 2016 (Figure 4). In 2009, sites inside and outside the CGCMR were distinguished by higher proportional biomass of *Scorpis lineolata*, *Atypichthys strigatus*, *Pempheris compressa* (small-scale bullseye), and *Anoplocarpus inermis* outside the CMR, and higher biomass of *Orectolobus maculatus* (spotted wobbegong), *Coris dorsomacula* (pale-barred coris), *Seriola lalandi* (yellow-tail kingfish) and *Scorpaena jacksoniensis* (eastern red scorpionfish) inside the CMR.

Changes in the CGCMR between 2009 and 2016 reflected a shift in the community inside the CMR towards the community structure recorded at the shallowest reference sites outside the reserve (which were most comparable in habitat). These changes were driven by increasing dominance of the species previously dominant outside the CMR, combined with other species such as *Chromis hypsilepis*, *Prionurus microlepidotus* (sawtail), *Pagrus auratus* (pink snapper) and *Parma unifasciata*. Despite these changes, the similarity of most sites between years tended to be greater than between sites in any year, which is quite remarkable given the close proximity of the majority of sites inside the CGCMR. This can be interpreted as suggesting relative stability between years in overall community structure at many of the sites (although note changes in biomass outlined below).

The Cod Grounds and Pimpernel Rock sites had significantly different fish assemblages from those recorded in the Solitary Islands reference sites, and were more similar to each other, despite being >200 km apart. The Solitary Islands reference sites were characterised by a mixed community of subtropical and temperate reef fishes typical of shallow water, with some tropical species also driving the difference. In contrast, the Pimpernel Rock site (SICMR) was similar to the Cod Grounds sites (both CMR and reference sites) in the dominance of temperate species such as *Orectolobus halei*, *Atypichthys strigatus* and *Scorpis lineolata*. The key reason for greater similarity of Cod Grounds and Pimpernel surveys than between Pimpernel Rock and the Solitary Islands reference sites is likely a lack of suitable reference sites in the Solitaries with surveys done in water deeper than ~16 m. A number of the shallow water species at the Solitaries sites were absent or not common along the deeper transects at Pimpernel Rock and the Cod Grounds.

Fish abundance and biomass were significantly higher at Pimpernel Rock than at the Solitary Islands reference sites, but species richness was similar (Figure 5). There were significant changes in the Cod Grounds CMR and reference sites between survey years. Abundance and biomass declined between 2009 and 2016 at reference sites, and increased at CMR sites. The change was only significant for abundance at the CMR sites, due to the high variability between transects. Species richness was similar between the Cod Grounds CMR and reference sites, and between years. The Pimpernel Rock site also stood out in its biomass of large fishes (>40 cm total length) and species commonly exploited by commercial and recreational fisheries (Figure 6). The Solitary Islands reference sites had the lowest biomass of both categories. Biomass in the CGCMR was slightly higher than its reference sites, but the high variability precluded significant results, and no clear temporal patterns were evident.

Depth was a significant factor for most of the fish metrics (Table 2). This may have been most strongly driven by the fact that the Solitary Islands reference transects were much shallower (<17 m) than all but one of the other transects (>25 m). The difference in reef community structure between the Solitary Islands sites and all other sites must be viewed with the effects of depth in mind. There was a trend of higher abundance at intermediate depths, and higher biomass with increasing depth, but no depth-related pattern in fish species richness. The biomass trend was driven by large-bodied fishes and exploited species, especially in the CMRs. In contrast, the highest numbers of species were recorded at depths shallower than 25 m, which were surveyed only at the SI reference sites and one transect at Pimpernel Rock. There were no consistent differences in species richness between the CGCMR and reference sites (Figure 7).

No clear differences were detected in trophic groups between CMRs and their reference sites, with high variability in trophic group biomass between transects (Table 3). CMR was a significant factor only for planktivores and carnivores. In the Cod Grounds, there was a significant CMR x Year interaction for planktivores. Planktivores, carnivores and piscivores dominated fish biomass throughout the CGCMR, SICMR and reference sites; they were especially important in the SICMR (Figure 8a). The CGCMR tended towards higher biomass of almost all groups than the reference sites, but variability was too high for any differences to be significant. The SI reference sites tended to have the lowest biomass of most groups, except for invertivores, omnivores and farmers, for which biomass was roughly even across the locations.

Fish biomass of the different trophic groups did not change significantly over time in the Cod Grounds, except for planktivores, which increased significantly in the CGCMR between 2009 and 2016 (Figure 8b). The key differences in biomass between 2009 and 2016 in the Cod Grounds and in relation to changes between CMR and reference sites appeared to be related to huge schools of planktivores, which dominate by biomass, being more common on reference sites in 2009 and at CMR sites in 2016. Thus, the largest biomass differences observed do not likely represent a reserve effect, but most probably shifting or patchy schools of planktivores (which may be driven by current direction and flow), rather than trends in targeted species recovery or loss. An exception is the reduced biomass of carnivores at reference sites between surveys – less than half the biomass of this trophic group was recorded at sites outside the reserve in 2016 than in 2009. This was most likely driven by changes in the biomass of *Orectolobus halei* (banded carpet shark, declined by 223 kg or 58%), *O. maculatus* (spotted wobbegong, declined by 67 kg or 66%), and to a lesser degree by *Pagrus auratus* (silver seabream, declined by 4 kg or 53%) and *Acanthopagrus australis* (surf bream, declined by 7 kg or 32%).

The two key species targeted for protection by the Cod Grounds CMR and Pimpernel Rock, the grey nurse shark and black cod, were sighted on multiple transects during the surveys. Solitary Islands reference sites were the most depauperate in this regard; only one black cod was recorded, and no grey nurse sharks. In contrast, transects at Pimpernel Rock yielded 3 black cod and 8 grey nurse sharks. A similar pattern occurred in the Cod Grounds; only one grey nurse shark was recorded on the transects at reference sites in 2009, and no black cod. In the CGCMR, there were 2 records of black cod in 2009, but none in 2016. Three grey nurse sharks were sighted in 2009, and 12 in 2016. Black cod and grey nurse sharks were also recorded when they were seen outside of the transects. This revealed an additional two grey nurse sharks at the Solitary Islands reference sites, one black cod in the SICMR, and 21 grey nurse sharks in the CGCMR.

The pipehorse *Solegnathus dunckeri* was recorded once in 2016, as it was during the 2009 surveys, along a transect within the CGCMR (Stuart-Smith et al. 2009). All records of this species in and outside the CMR have been much shallower than its usual recorded depth range, which is 75-140 m (Kuiter 2009). A second record from this area warrants further investigation, as it may be using these shallower habitats during specific parts of its life cycle. It is also possible that this species more frequently occurs in these depths, but is typically missed on the usual video surveys undertaken at these depths (dive surveys are not frequently undertaken deeper than 20 m by any agency).

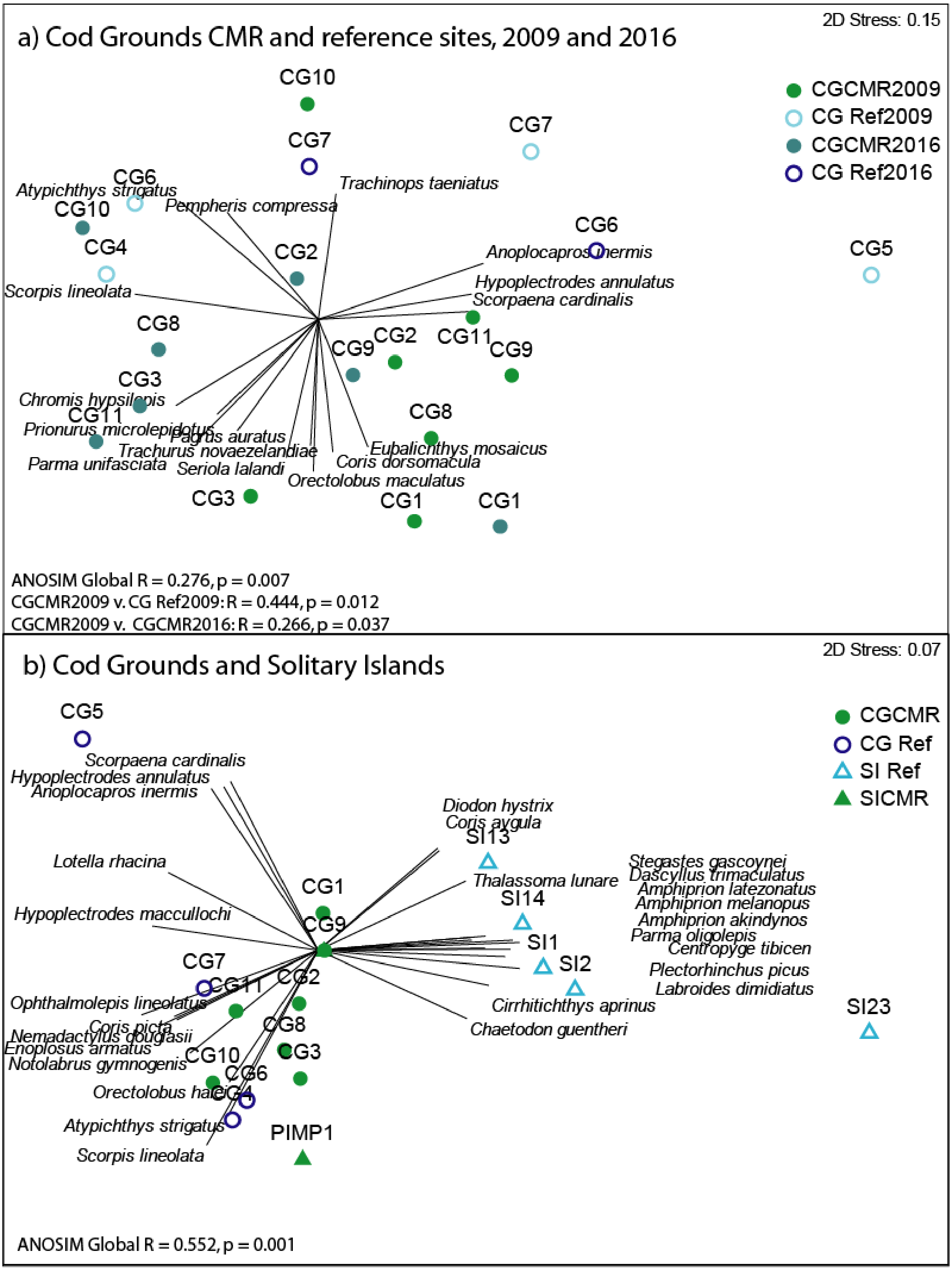

Figure 4. Multidimensional Scaling (MDS) plot of reef fish biomass in the Cod Grounds and Solitary Islands CMRs and reference sites, performed on the Bray-Curtis similarity matrix of the square-root transformed data. a) Analysis of the Cod Grounds CMR by year and CMR status, with vectors shown if they had a correlation of at least 0.5; b) analysis of both CMRs and reference sites, with years pooled for the Cod Grounds CMR, with vectors shown if they had a correlation value of at least 0.6. ANOSIM results are given for the Global R and for individual significant comparisons.

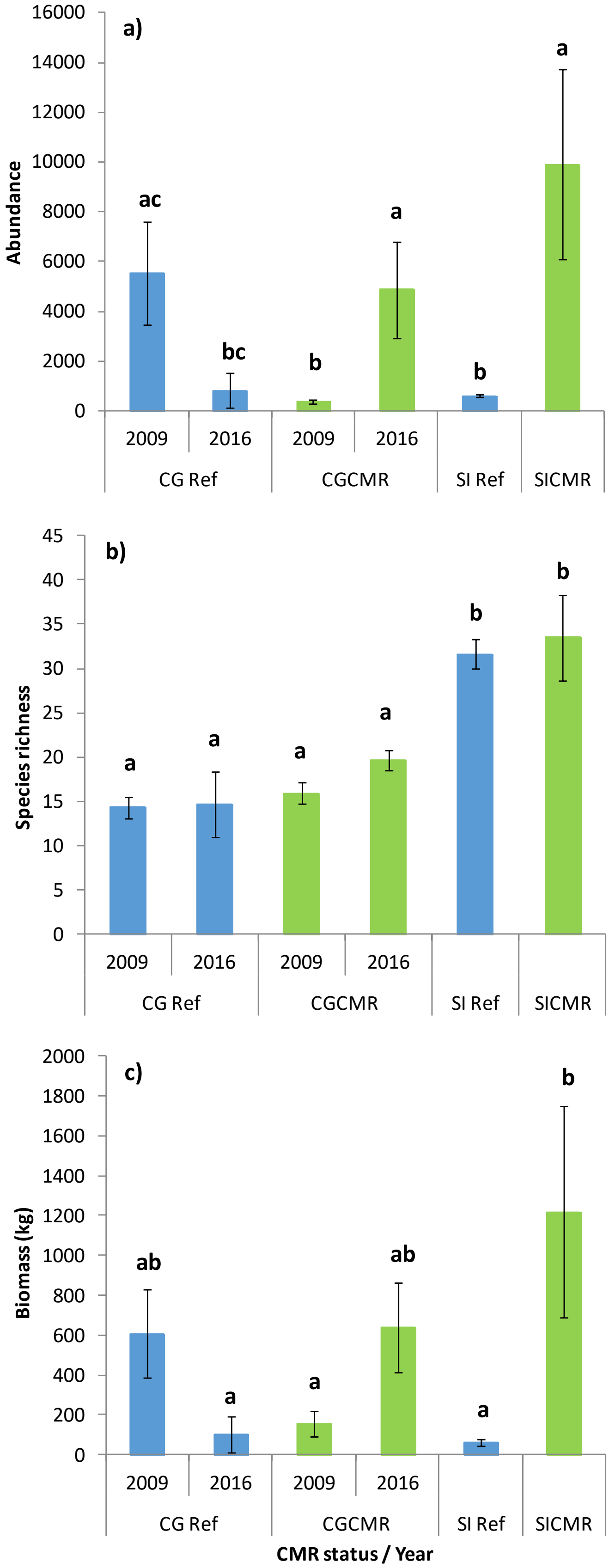

Figure 5. Total a) abundance, b) species richness and c) biomass of fishes per 500 m^2 recorded in the Cod Grounds CMR and reference sites in 2009 and 2016, and in the Solitary Islands CMR (Pimpernel Rock) and reference sites. Letters group sites that were similar, analysed by ANCOVA (with depth as a covariate) and Tukey HSD test on the log(x+1) transformed data.

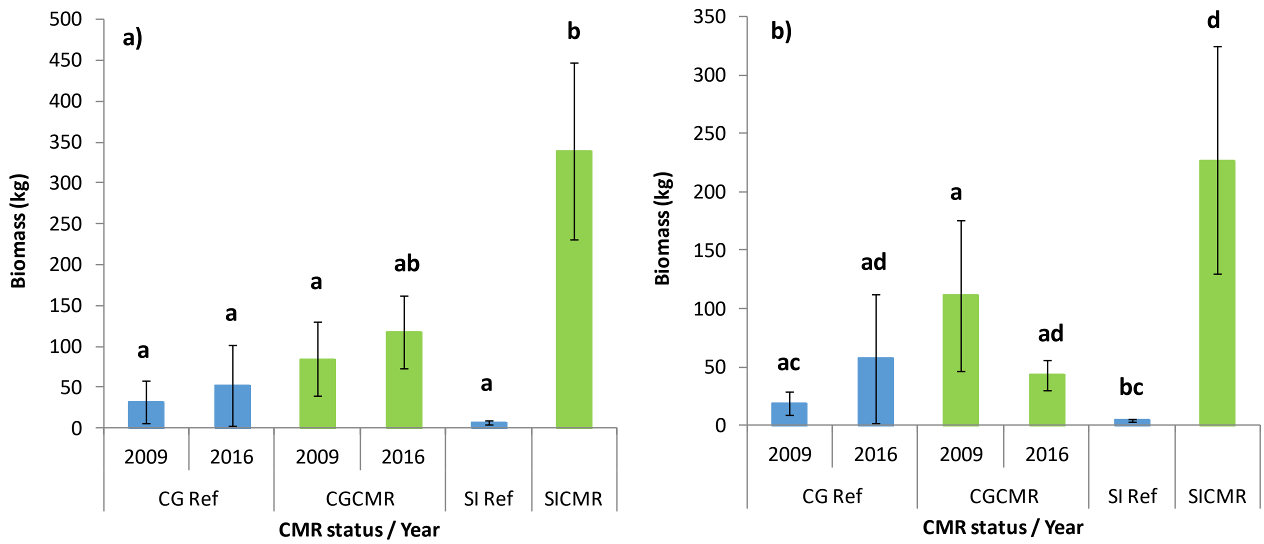

Figure 6. Biomass per 500 m^2 of a) species larger than 40 cm TL, and b) biomass of exploited species recorded in the Cod Grounds CMR and reference sites in 2009 and 2016, and in the Solitary Islands CMR (Pimpernel Rock) and reference sites. Letters group sites that were similar, analysed by ANCOVA (with depth as a covariate) and Tukey HSD test on the log(x+1) transformed data.

Table 2. Results of ANCOVAs of fish community metrics, combining location CGCMR, SICMR and reference sites for both, and time (2009 and 2016 for the CGCMR and reference sites as an independent factor and depth as a continuous covariate. Analyses were conducted on the log(x+1) transformed data.

Factor	Variable	df	MS	F	p	Error MS
CMR-Year	Abundance	5,65	2.20	9.24	<0.001	0.24
	Species richness	5,65	0.09	5.98	<0.001	0.02
	Biomass (total)	5,65	1.75	5.01	<0.001	0.35
	Biomass (>40cm)	5,65	2.54	4.49	0.001	0.57
	Biomass (exploited)	5,65	1.41	3.26	0.010	0.43
Depth	Abundance	1,65	0.48	2.01	0.161	0.24
	Species richness	1,65	0.95	60.03	<0.001	0.02
	Biomass (total)	1,65	3.83	10.98	0.002	0.35
	Biomass (>40cm)	1,65	7.33	12.95	<0.001	0.57
	Biomass (exploited)	1,65	8.89	20.56	<0.001	0.43

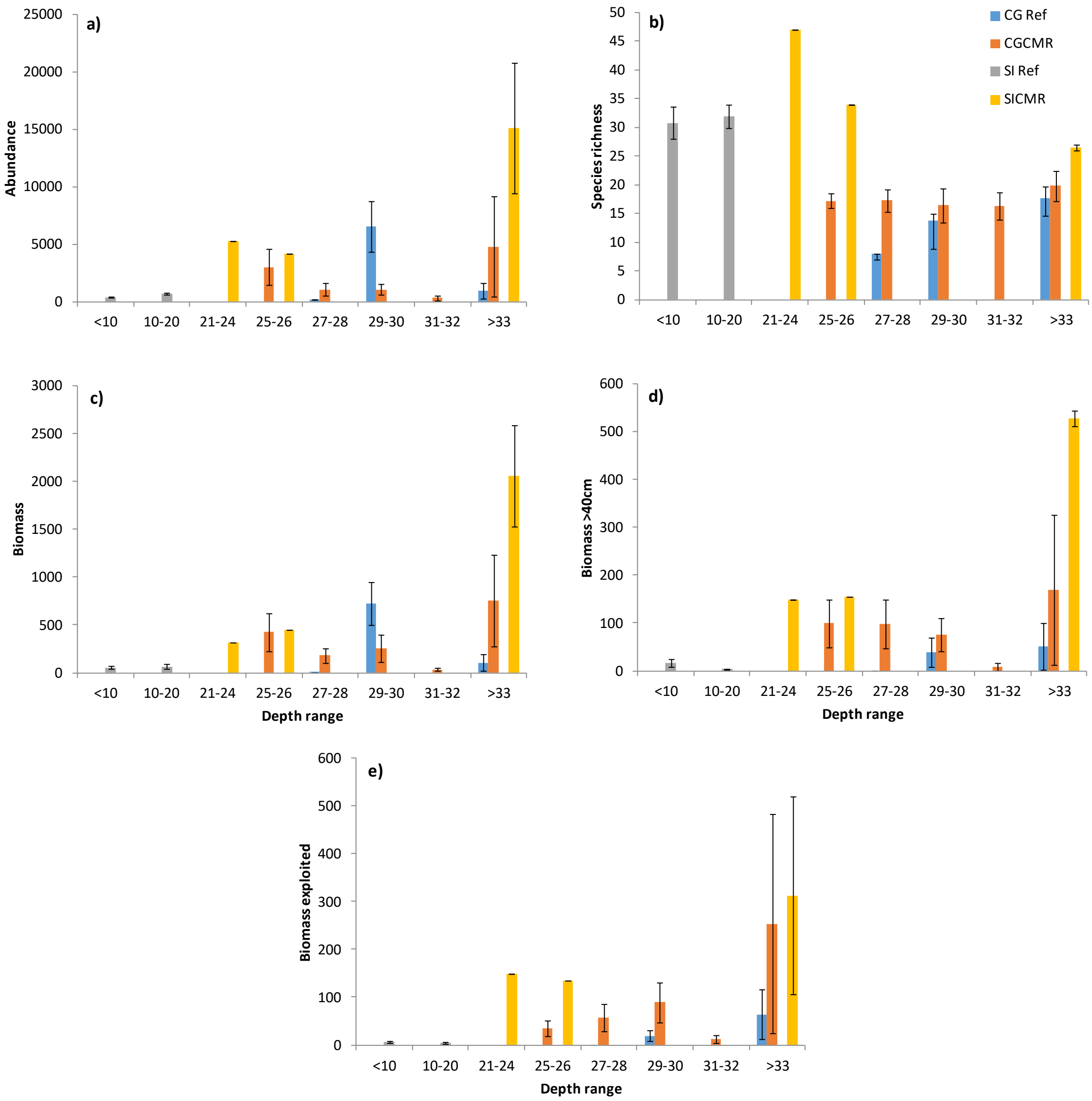

Figure 7. Variation in the species richness, abundance and biomass of the fish community recorded on transects at different depths, inside the CMRs and at reference sites. Data have been binned into depth categories, with sample sizes as follows: 1, 5 and 3 transects for Cod Grounds reference sites; 9, 8, 5, 3 and 5 transects for CGCMR; 8 and 21 transects at the SI reference sites; and 1, 1 and 2 transects in the SICMR. Y-axes represent mean values (+SE) per transect (500 m^2).

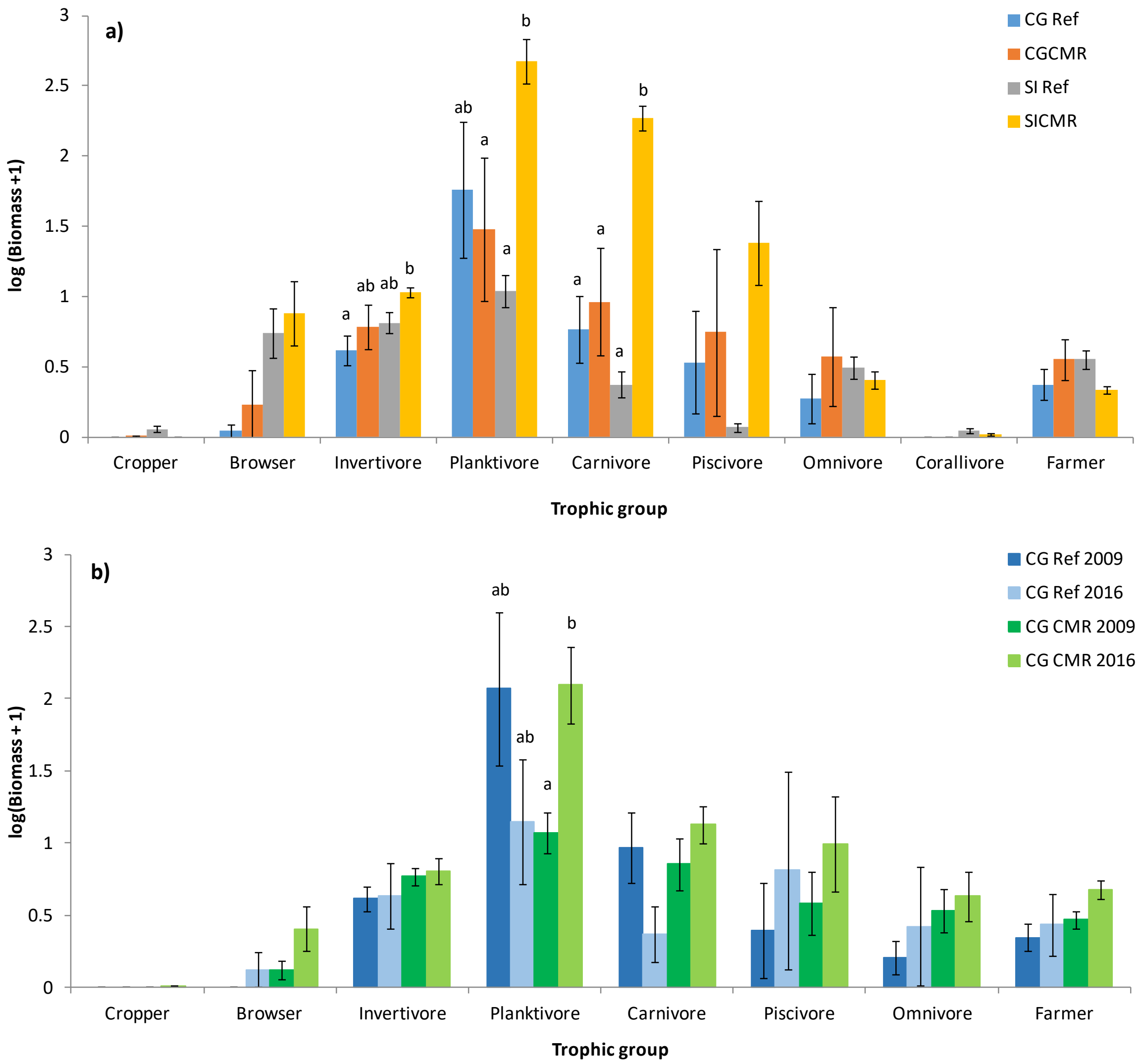

Figure 8. Distribution of trophic groups (per 500 m^2) among a) the Cod Grounds and reference sites, and the Solitary Islands and reference sites, and b) variability in the Cod Grounds CMR and reference sites between 2009 and 2016. Letters group locations with similar biomass (see relevant analysis results in Table 3); letters are omitted for trophic groups with no significant differences. Values plotted are the log(x+1) +/- 1 SE of the biomass of the groups, to visualise groups with lower biomass. There were no corallivores in the Cod Grounds; this group is omitted from b).

Table 3. Results of two ANCOVAs of trophic groups, comparing location CGCMR, SICMR and reference sites, and Year x CMR (only for the CGCMR). CMR and Depth results are only shown for the first analysis. Analyses were conducted on the log(x+1) transformed data. There were no corallivores in the Cod Grounds; this group is omitted from the second analysis. Significant results are shown in bold.

Trophic group	Factor	df	MS	F	p
Cropper	CMR	3,67	0.003	0.74	0.531
	Depth	**1,67**	**0.038**	**10.21**	**0.002**
	Year (CG only)	1,34	0.001	3.45	0.072
	CMR x Year (CG only)	1,34	0.000	0.81	0.375
Browser	CMR	3,67	0.547	1.66	0.183

	Depth	**1,67**	**5.387**	**16.36**	**<0.001**
	Year (CG only)	1,34	0.491	3.68	0.064
	CMR x Year (CG only)	1,34	0.037	0.28	0.602
Invertivore	**CMR**	**3,67**	**0.235**	**2.95**	**0.039**
	Depth	1,67	0.001	0.02	0.901
	Year (CG only)	1,34	0.083	1.46	0.235
	CMR x Year (CG only)	1,34	0.006	0.11	0.743
Planktivore	**CMR**	**3,67**	**2.321**	**3.77**	**0.015**
	Depth	**1,67**	**4.812**	**7.81**	**0.007**
	Year (CG only)	1,34	2.496	3.48	0.071
	CMR x Year (CG only)	**1,34**	**5.562**	**7.89**	**0.008**
Carnivore	**CMR**	**3,67**	**3.519**	**11.89**	**<0.001**
	Depth	**1,67**	**4.582**	**15.48**	**<0.001**
	Year (CG only)	1,34	0.003	0.007	0.934
	CMR x Year (CG only)	1,34	1.066	2.66	0.112
Piscivore	CMR	3,67	0.957	1.61	0.196
	Depth	**1,67**	**7.957**	**13.36**	**<0.001**
	Year (CG only)	1,34	1.552	1.50	0.229
	CMR x Year (CG only)	1,34	0.000	0.00	0.995
Omnivore	CMR	3,67	0.494	2.27	0.088
	Depth	1,67	0.098	0.45	0.505
	Year (CG only)	1,34	0.360	1.12	0.297
	CMR x Year (CG only)	1,34	0.005	0.02	0.905
Corallivore	CMR	3,67	0.002	0.93	0.429
	Depth	**1,67**	**0.024**	**10.26**	**0.002**
Farmer	CMR	3,67	0.146	2.23	0.092
	Depth	1,67	0.212	3.25	0.076
	Year (CG only)	1,34	0.211	3.637	0.065
	CMR x Year (CG only)	1,34	0.016	0.278	0.602

MOBILE MACROINVERTEBRATE SURVEYS

A total of 70 mobile invertebrate species were recorded during the combined 2009 and 2016 surveys, including 2 species of crustaceans, 36 species of echinoderms and 26 species of molluscs; 6 species were unidentified (Table 4). The most abundant species were all echinoderms, and the community was dominated by the spiny sea urchin *Centrostephanus rodgersii*. Other species that were particularly abundant in the Solitary Islands were the collector urchin *Tripneustes gratilla* and the difficult sea cucumber *Holothuria difficilis*. In the Cod Grounds, the second most abundant species was also the collector urchin, but this was followed by the slate pencil urchin *Phyllacanthus parvispinus*.

Community-level analysis of mobile invertebrates revealed clear groupings of sites by CMR status and year (Figure 9). CMR sites shifted slightly between 2009 and 2016 towards higher abundance of *C. rodgersii* and *T. gratilla*. Reference sites were more diverse in their invertebrate assemblages, so that changes between 2009 and 2016 were masked by high inter-site variability. CG5 and CG7 tended towards high abundance of nudibranchs, hermit crabs and pencil urchins in 2009; CG7 in 2016 and CG6 in both years had a combination of the blue dragon *Pteraeolidia ianthina*, the crinoid *Comanthus trichoptera*, the pencil urchin *Phyllacanthus parvispinus* and the sea star *Ophidiaster confertus*. This sea star species also drove a separation between the CMR site CG10 in 2016 from the other CMR sites in that year.

Most Solitary Islands reference sites were characterised by a diverse assemblage of invertebrates that was distinct from that recorded in the Cod Grounds. The exceptions were the Pimpernel Rock site in the SICMR, which was similar to the Cod Grounds, and SI23, which appeared to have relatively low abundance of most species (Figure 9). The Cod Grounds were characterised by relatively high abundance of *P. ianthina*, *Plectaster decanus*, *P. parvispinus*, *C. trichoptera* and *Astralium tentoriiforme*. The Cod Grounds reference sites were set apart from the CMR sites by a higher abundance and inter-site diversity than the CMR sites, which formed a tighter grouping, indicating a more similar assemblage.

The general pattern of invertebrate abundance and species richness was for lower density and diversity inside the CMRs, and for lower density and diversity in 2016 compared to 2009 (Figure 10). Most of these differences were not significant, due to high variability between transects and a strong effect of depth; only species richness was not significantly affected by depth (Table 5). Invertebrate abundance was highest at the Solitary Islands reference sites; Pimpernel Rock had abundances similar to the Cod Grounds. In the Cod Grounds, total abundance was similar between the CMR and reference sites in 2009, but slightly higher in the CMR than at reference sites in 2016. Species richness, on the other hand, was lower in the CMRs than at reference sites in both years, and declined in the Cod Grounds between 2009 and 2016. Urchin abundance followed the pattern observed in the total abundance. The most common species, *C. rodgersii*, was almost absent from Cod Grounds reference sites and had low abundance in the SICMR, but very high densities elsewhere (between 150 and 200 individuals / 100m^2).

Abundance values (total, urchins and *C. rodgersii*) tended to be higher overall on shallower transects, whilst species richness did not show specific depth-related trends (Figure 11). The trend of declining abundance with increasing depth was strongest in the CGCMR; for urchins and *C. rodgersii* it was also evident in the SICMR. There was no such trend apparent at the CG and SI reference sites, although these results must be interpreted with caution due to the limited depth range at the SI reference sites, and the smaller sample size at the CG reference sites.

Table 4. Total frequency of occurrence (transects) and total abundance (sum across all surveys undertaken) of mobile macroinvertebrates recorded on 71 transects (18 in the CGCMR and 6 at reference sites in 2009; 12 in the CGCMR and 3 at reference sites in 2016; 4 in the SICMR and 28 at reference sites).

Species	Transects			Abundance		
	CG 2009	CG 2016	SI	CG 2009	CG 2016	SI
Crustaceans						
Arctides antipodarum	0	0	1	0	0	1
Pagurus sinuatus	1	0	0	3	0	0
unidentified hermit crab	6	1	7	9	1	12
unidentified crab	0	0	2	0	0	2
Echinoderms						
Acanthaster planci	1	0	0	1	0	0
Antedon loveni	0	0	1	0	0	9
***Antedon* sp.**	0	2	1	0	14	40
Centrostephanus rodgersii	13	13	31	3511	1845	7135
Cladolabes schmeltzii	0	0	1	0	0	245
***Comanthus* sp.**	1	1	4	1	7	111
Comanthus trichoptera	19	9	6	803	98	124
Conocladus australis	2	0	0	2	0	0
Coscinasterias muricata	0	0	1	0	0	1
Diadema savignyi	0	0	8	0	0	19
Echinaster colemani	2	0	0	5	0	0
Echinometra mathaei	0	0	2	0	0	2
***Echinostrephus* spp.**	2	0	2	2	0	3
Echinothrix calamaris	0	0	2	0	0	2
Fromia polypora	9	0	0	15	0	0
Heliocidaris tuberculata	0	0	1	0	0	2
Himerometra magnipinna	0	0	1	0	0	2
Himerometra robustipinna	0	1	2	0	10	75
Holothuria difficilis	0	0	15	0	0	2482
Holothuria hilla	0	0	1	0	0	1
***Holothuria* sp.**	0	0	1	0	0	1
Ophidiaster confertus	2	2	24	2	2	130
Pentagonaster dubeni	9	6	4	15	7	14
Petricia vernicina	3	1	0	3	1	1
Phyllacanthus parvispinus	13	5	10	715	100	172
Plectaster decanus	7	6	0	9	15	15
Prionocidaris callista	12	0	0	175	0	0
Pseudoboletia indiana	1	0	2	1	0	3
Pseudoboletia maculata	0	0	1	0	0	4
***Tamaria* sp.**	0	0	1	0	0	2
Temnopleurus toreumaticus	1	0	0	1	0	0
Toxopneustes pileolus	0	0	2	0	0	3
Tripneustes gratilla	4	3	27	4	4	2911
Tropiometra afra	1	1	12	2	2	27
unidentified sea cucumber	0	0	3	0	0	252
unidentified crinoid	2	1	2	37	6	21
Molluscs						

Species	Transects			Abundance		
	CG 2009	CG 2016	SI	CG 2009	CG 2016	SI
Agnewia tritoniformis	0	0	1	0	0	3
***Aplysia* sp.**	0	0	3	0	0	4
Astralium tentoriiforme	16	1	4	183	1	8
Cabestana spengleri	0	0	1	0	0	5
***Chromodoris* sp.**	0	1	0	0	1	1
Conus miles	0	0	1	0	0	1
Cuthona sibogae	0	1	0	0	1	1
Cymbiola magnifica	1	0	0	1	0	0
Dicathais orbita	1	0	0	1	0	0
Doriprismatica atromarginata	1	0	2	1	0	3
Doris chrysoderma	3	0	0	3	0	0
Goniobranchus splendidus	1	0	2	1	0	3
Hexabranchus sanguineus	0	0	1	0	0	1
Hypselodoris bennetti	1	0	1	1	0	1
Hypselodoris bertschi	1	0	0	1	0	0
Mancinella alouina	0	0	1	0	0	1
Micromelo guamensis	0	0	1	0	0	1
Monoplex parthenopeus	0	0	1	0	0	1
Octopus tetricus	0	0	2	0	0	2
Ovula ovum	0	0	1	0	0	1
Pteraeolidia ianthina	5	2	0	13	2	2
Ranella australasia	1	0	1	3	0	1
Sagaminopteron ornatum	3	1	0	3	1	1
Sassia parkinsonia	2	0	0	6	0	0
Thais ambustulatus	0	0	1	0	0	3
Turbo militaris	0	0	1	0	0	1
Unidentified gastropod	1	0	1	2	0	2
Unidentified nudibranch	2	0	1	2	0	1

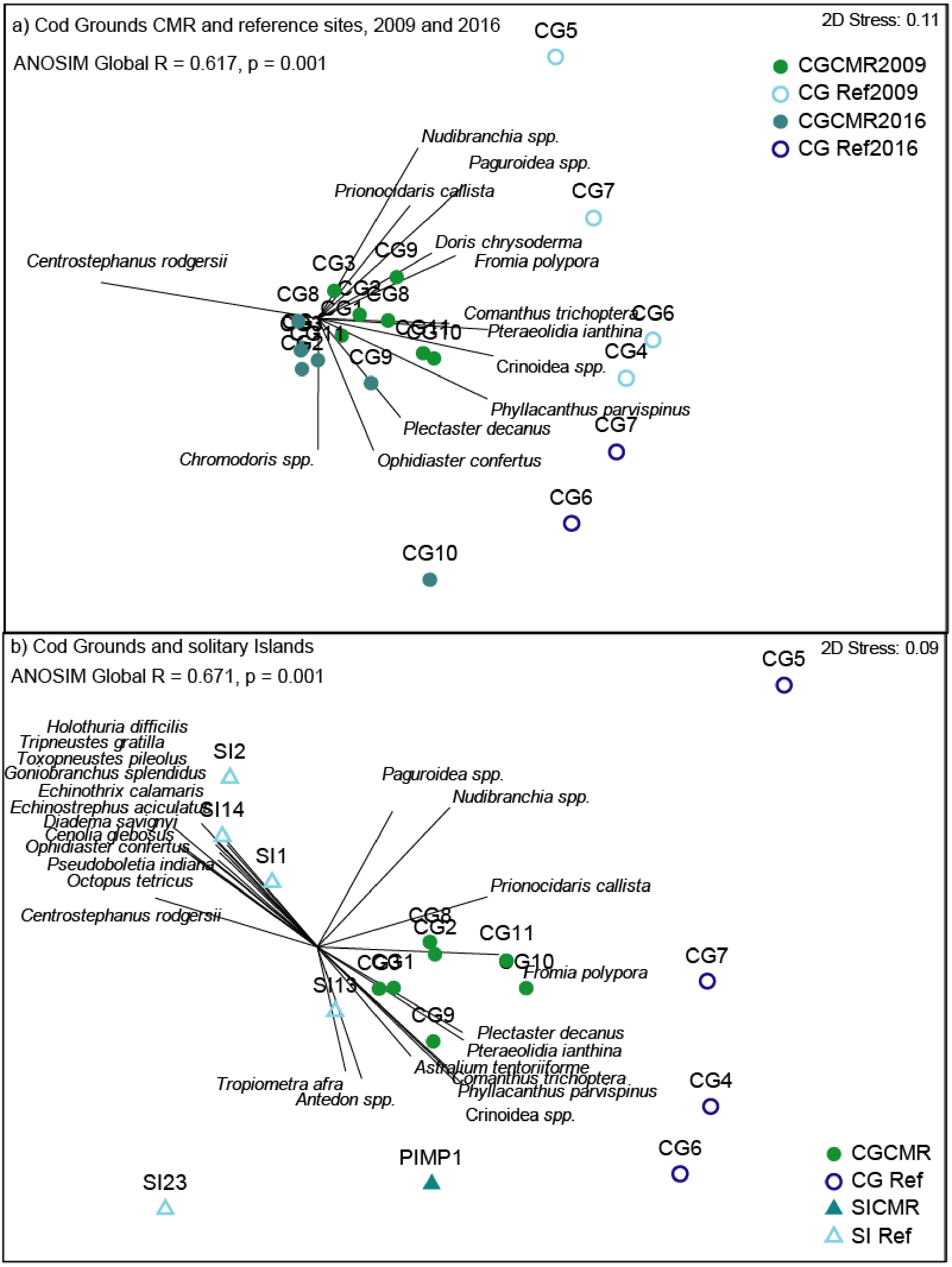

Figure 9. Multidimensional Scaling (MDS) plot of mobile invertebrate abundance in the Cod Grounds and Solitary Islands CMRs and reference sites, performed on the Bray-Curtis similarity matrix of the square-root transformed data. a) Analysis of the Cod Grounds CMR by year and CMR status, with vectors shown if they had a correlation of at least 0.5; b) analysis of both CMRs and reference sites, with years pooled for the Cod Grounds CMR, with vectors shown if they had a correlation value of at least 0.6. ANOSIM results are given for the Global R and for individual significant comparisons; for a), all comparisons were significant.

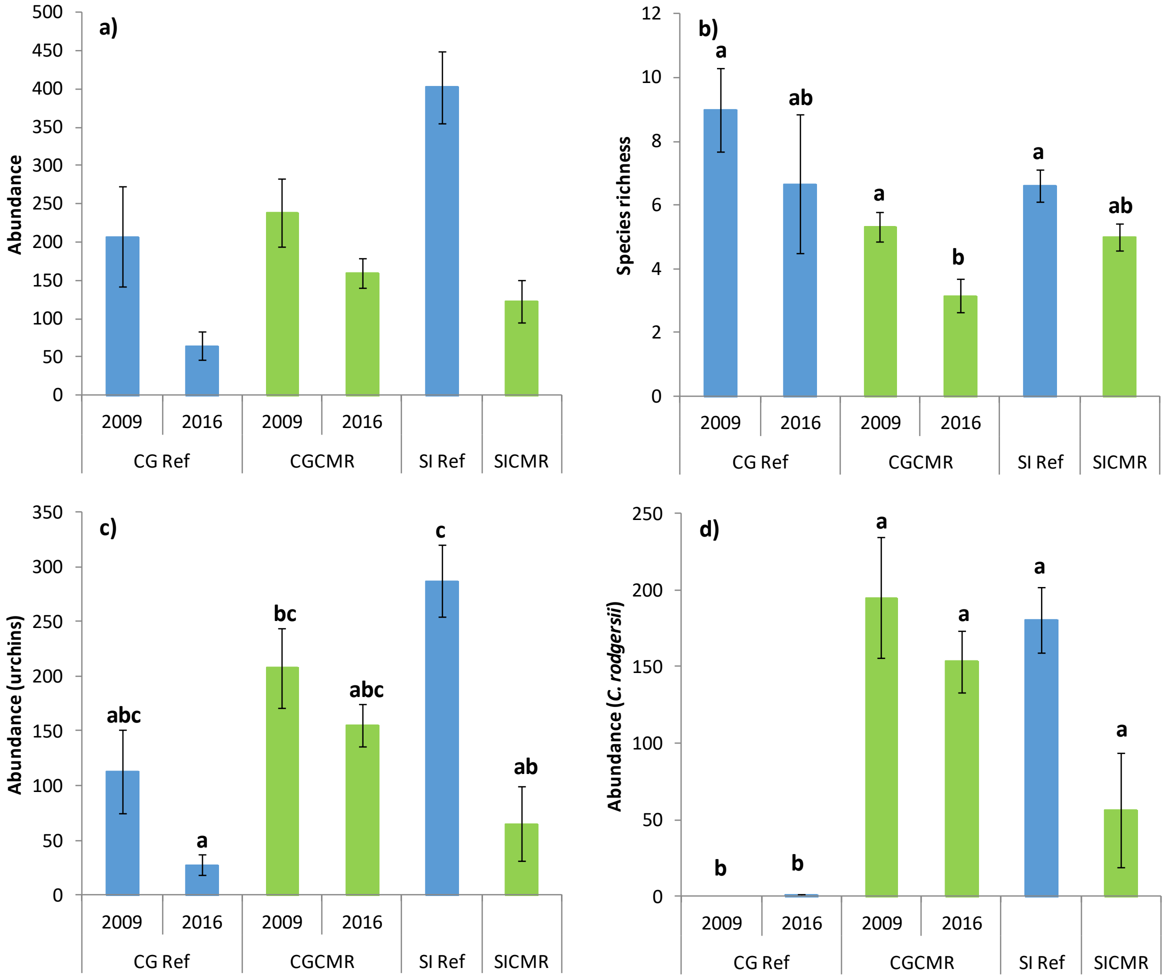

Figure 10. Total a) abundance, b) species richness and c) urchin abundance and d) *Centrostephanus rodgersii* abundance recorded in the Cod Grounds CMR and reference sites in 2009 and 2016, and in the Solitary Islands CMR (Pimpernel Rock) and reference sites (per 100 m^2). Letters group sites that were similar, analysed by ANCOVA (with depth as a covariate) and Tukey HSD test on the log(x+1) transformed data.

Table 5. Results of ANCOVAs of invertebrate community metrics, combining location CGCMR, SICMR and reference sites for both, and time (2009 and 2016 for the CGCMR and reference sites as an independent factor and depth as a continuous covariate. Analyses were conducted on the log(x+1) transformed data.

Factor	Variable	df	MS	F	p	Error MS
CMR-Year	Abundance	5,64	0.32	3.02	0.016	0.11
	Species richness		0.16	6.57	<0.001	0.02
	Abundance (urchins)		0.82	9.97	<0.001	0.08
	Abundance (*C. rodgersii*)		4.66	15.51	<0.001	0.30
Depth	Abundance	1,64	4.40	42.05	<0.001	0.11
	Species richness		0.07	2.75	0.102	0.02
	Abundance (urchins)		5.62	68.09	<0.001	0.08
	Abundance (*C. rodgersii*)		20.31	67.57	<0.001	0.30

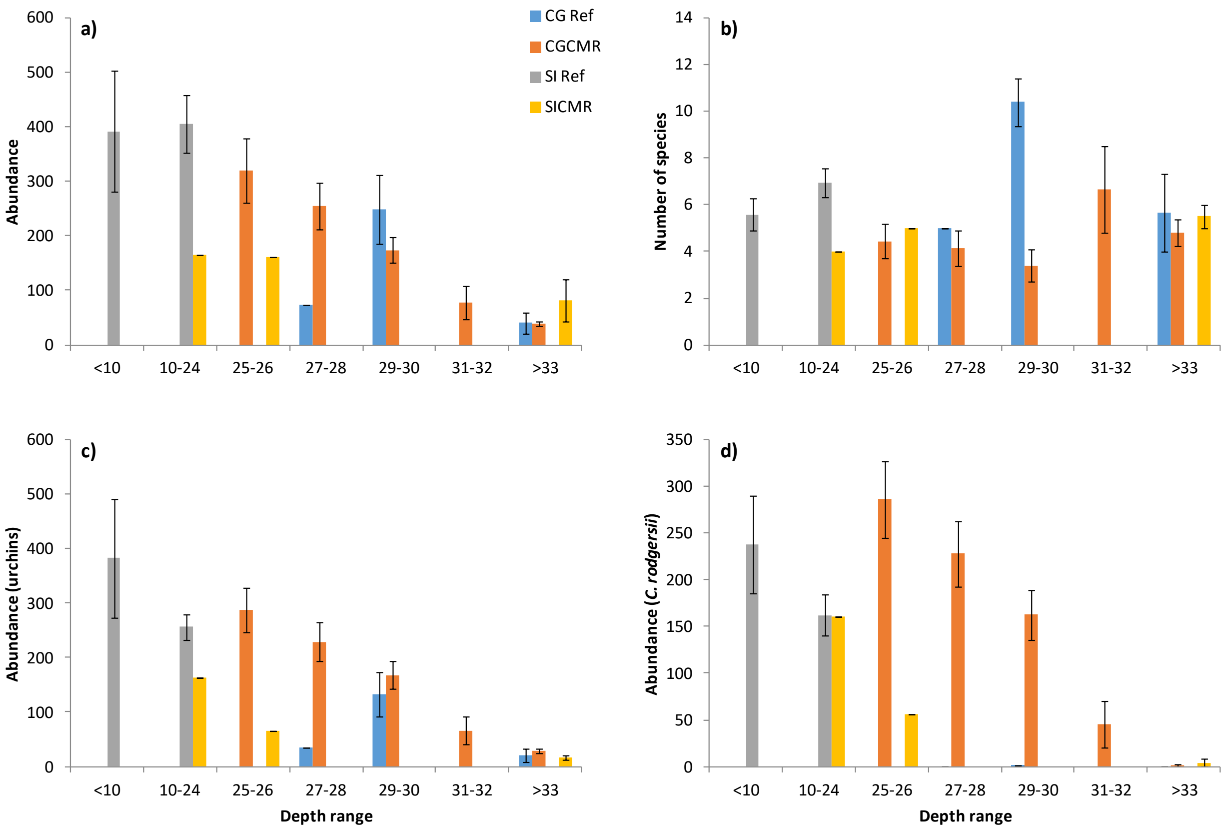

Figure 11. Variation in the a) total invertebrate abundance, b) species richness, c) urchin abundance and d) *Centrostephanus rodgersii* abundance recorded on transects at different depths, inside the CMRs and at reference sites. Data have been binned into depth categories, with sample sizes as follows: 1, 5 and 3 transects for Cod Grounds reference sites, 9, 8, 5, 3 and 5 transects for CGCMR, 7 and 21 transects at the SI reference sites and 1, 1 and 2 transects in the SICMR. Y-axes represent mean values (+SE) per transect (100 m^2).

CRYPTIC FISH SURVEYS

Using Method 2, 34 species of cryptic fish were surveyed along transects in both CMRs and reference sites. The most common species was the half-banded sea perch, *Hypoplectrodes maccullochi*, typical of inshore reef habitats in this region. In the Solitary Islands, the ringscale triplefin *Enneapterygius atrogulare* was also abundant; in the Cod Grounds, the second most abundant species was the red rock cod *Scorpaena jacksoniensis* in 2009 and the blacktip bullseye *Pempheris affinis* in 2016 (Table 6).

Table 6. Total frequency of occurrence (transects) and total abundance of cryptic fishes recorded on 71 transects (18 in the CGCMR and 6 at reference sites in 2009; 12 in the CGCMR and 3 at reference sites in 2016; 4 in the SICMR and 28 at reference sites).

	Transects						Abundance					
Species	**CG 2009**	**CG ref 2009**	**CG 2016**	**CG ref 2016**	**SI**	**SI ref**	**CG 2009**	**CG ref 2009**	**CG 2016**	**CG ref 2016**	**SI**	**SI ref**
Acanthistius ocellatus	2	0	2	1	0	0	2	0	2	1	0	0
Aspasmogaster costata	1	0	0	0	0	0	1	0	0	0	0	0
Aulopus purpurissatus	0	0	0	0	2	1	0	0	0	0	2	1
Blenniidae	0	0	0	0	1	1	0	0	0	0	1	1
Cheilodipterus macrodon	0	0	0	0	1	1	0	0	0	0	1	1
Cirrhitichthys aprinus	1	0	4	1	14	12	1	0	6	2	31	27
Cirrhitichthys falco	0	0	0	0	1	1	0	0	0	0	1	1
Cirripectes alboapicalis	0	0	0	0	1	1	0	0	0	0	1	1
Cochleoceps orientalis	1	0	0	0	0	0	2	0	0	0	0	0
Cyprinocirrhites polyactis	0	0	1	0	0	0	0	0	6	0	0	0
Dendrochirus zebra	0	0	0	0	1	1	0	0	0	0	1	1
Enchelycore sp.	0	0	0	0	2	2	0	0	0	0	2	2
Enneapterygius atrogulare	0	0	0	0	14	14	0	0	0	0	177	177
Epinephelus undulatostriatus	0	0	1	0	2	0	0	0	1	0	2	0
Gobiidae	2	0	0	0	0	0	4	0	0	0	0	0
Gymnothorax eurostus	0	0	0	0	3	3	0	0	0	0	8	8
Gymnothorax prasinus	6	1	2	1	2	1	10	1	2	1	6	5
Gymnothorax thyrsoideus	0	0	0	0	2	2	0	0	0	0	10	10
Heteropriacanthus cruentatus	0	0	0	0	1	1	0	0	0	0	1	1
Hypoplectrodes maccullochi	18	6	11	2	4	1	223	114	65	26	203	2

	Transects						Abundance					
Species	**CG 2009**	**CG ref 2009**	**CG 2016**	**CG ref 2016**	**SI**	**SI ref**	**CG 2009**	**CG ref 2009**	**CG 2016**	**CG ref 2016**	**SI**	**SI ref**
Lotella rhacina	3	1	5	2	0	0	5	1	6	2	0	0
Orectolobus halei	4	2	1	0	3	3	4	2	1	0	5	5
Ostorhinchus aureus	0	0	0	0	1	1	0	0	0	0	2	2
Ostorhinchus properuptus	0	0	0	0	1	1	0	0	0	0	2	2
Pempheris affinis	0	0	4	1	0	0	0	0	41	8	0	0
Plagiotremus laudandus	0	0	0	0	1	1	0	0	0	0	2	2
Plagiotremus tapeinosoma	0	0	1	0	0	0	0	0	1	0	0	0
Pterois volitans	1	0	0	0	0	0	1	0	0	0	0	0
Scorpaena cardinalis	12	5	0	0	12	12	25	16	0	0	26	26
Scorpaena jacksoniensis	0	0	5	0	2	0	0	0	10	0	5	0
Scorpaenodes evides	0	0	0	0	3	3	0	0	0	0	5	5
Solegnathus dunckeri	0	0	1	1	0	0	0	0	1	1	0	0
Synodus variegatus	1	0	2	1	0	0	1	0	2	1	0	0
Trachichthys australis	0	0	1	0	0	0	0	0	2	0	0	0
Trachypoma macracanthus	0	0	0	0	1	1	0	0	0	0	2	2
Trinorfolkia clarkei	0	0	0	0	1	1	0	0	0	0	6	6
Tripterygiidae	0	0	0	0	1	1	0	0	0	0	6	6

SESSILE BIOTA

In 2016, Sessile biota were examined with photoquadrats along 28 transects; nine in the Cod Grounds CMR, three at Cod Grounds reference sites, three at Pimpernel Rock and 13 at the Solitary Islands reference sites. Crustose coralline algae dominated the sessile communities overall, with an average of 43% across all transects, followed by low-lying turf at 15%.

There was a significant shift in the benthic community in the Cod Grounds CMR between 2009 and 2016, from high cover of crustose coralline algae and bare rock, to a combination of turf and bare rock. Most of the CMR sites exhibited this change, but the reference sites less so – a more diverse sessile community characterised the reference sites, and the temporal change was from a combination of algae, sponges, ascidians and soft corals to greater proportions of turf and corals. The increase in corals was driven by an increase in the temperate encrusting corals *Culcita* spp.

Among the CMRs and reference sites (with years pooled for the CGCMR), there appeared to be four distinct groups. Cod Grounds CMR sites were dominated by crustose coralline algae, Cod Grounds reference sites had higher cover of ascidians, soft corals and calcified algae. The Solitary Islands reference sites were characterised by live corals and abiotic substrata such as rock and rubble. There was only one site at Pimpernel Rock, but it was separated from the other groups by a greater proportion of macroalgae, turf and sponges (Figure 12). Separation across the x-axis is most probably driven by the depth gradient, with more diverse sessile benthos on the deeper transects to the left, and more CCA and urchin barrens to the right, in shallower habitats. The y-axis separation between years appears to reflect an increase in corals.

There was slightly higher cover of live sessile biota in the SICMR than at reference sites, and higher live cover in the CGCMR in 2016 than 2009 (Figure 13, Table 7). Differences were slight but significant, and CMR was a more important factor than depth. Benthic categories were less abundant in the CGCMR than at reference sites, and declined both in the CMR and at reference sites between 2009 and 2016. Crustose coralline algae dominated in the Cod Grounds, but decline significantly at the reference sites in 2016. Live hard coral increased at the Cod Grounds, both in the CMR and at reference sites, but only by a small amount, and this was dominated by the temperate encrusting coral *Culcita* sp. Turf and macroalgae were highly variable in cover, but turf was particularly prevalent in the SICMR (Pimpernel Rock). Depth was a significant factor only for crustose coralline algae and live hard coral cover.

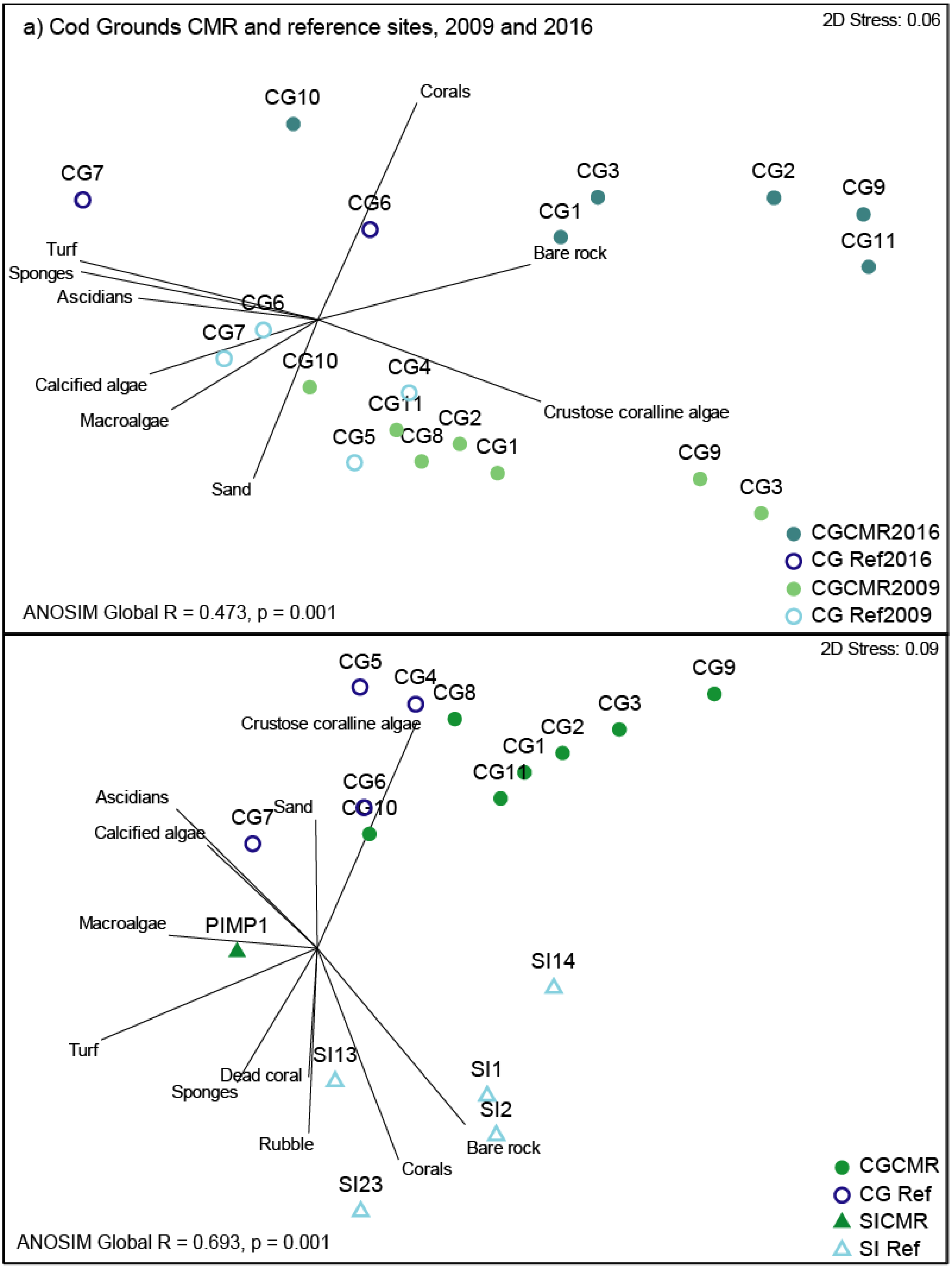

Figure 12. Multidimensional Scaling (MDS) plot of benthic community % cover in the Cod Grounds and Solitary Islands CMRs and reference sites, performed on the Bray-Curtis similarity matrix of the square-root transformed data. a) Analysis of the Cod Grounds CMR by year and CMR status, with vectors shown if they had a correlation of at least 0.5; b) analysis of both CMRs and reference sites, with years pooled for the Cod Grounds CMR, with vectors shown if they had a correlation value of at least 0.5. ANOSIM results are given for the Global R.

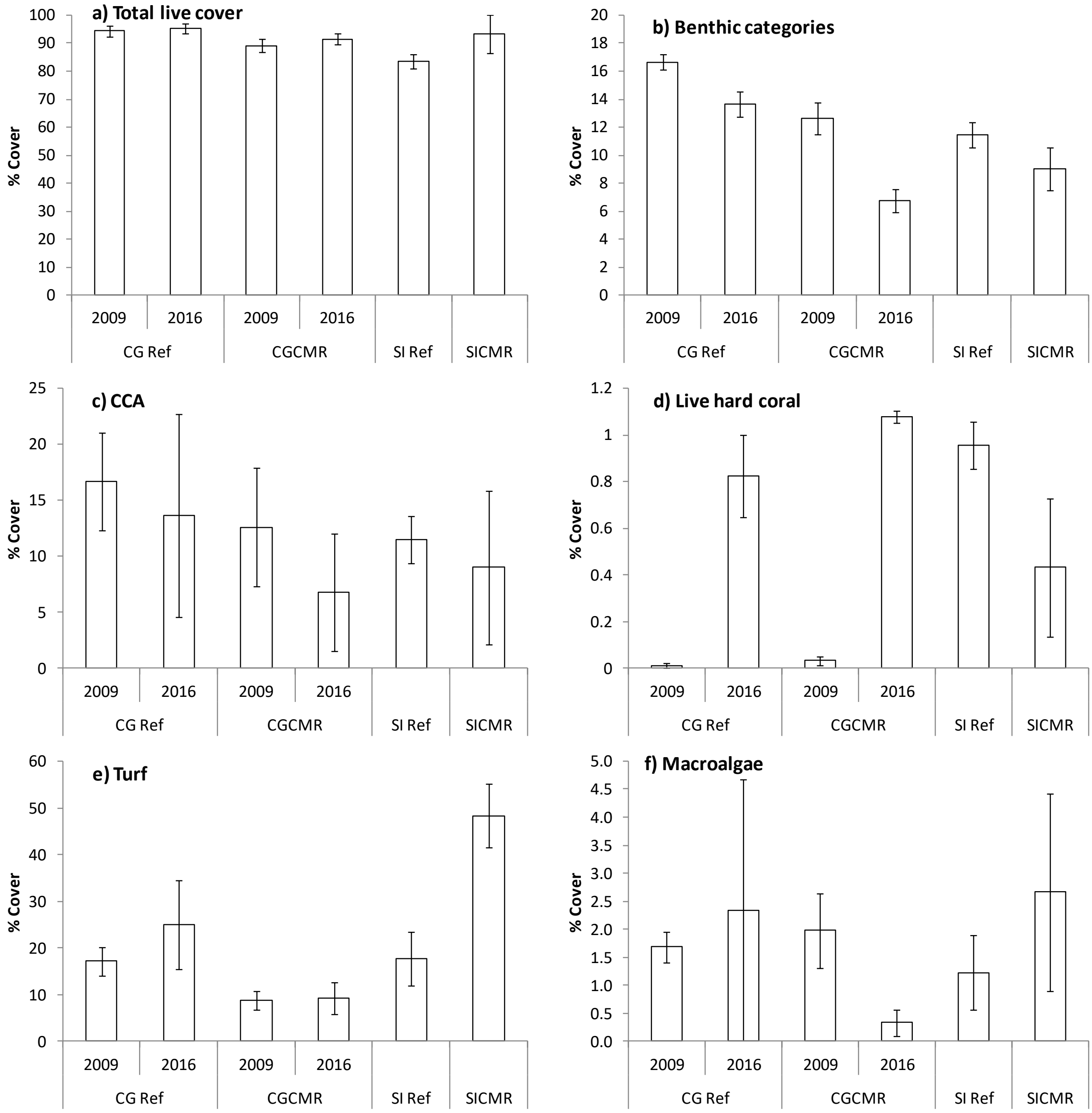

Figure 13. Percentage cover of a) total cover of live biota, b) number of benthic categories, c) crustose corralline algae, d) live hard coral, e) turf and f) macroalgae recorded on transects inside the CMRs and at reference sites, with Cod Grounds sites divided by survey year. Y-axes represent mean values (+SE) per transect (100 random points).

Table 7. Results of ANCOVAs of sessile community metrics, combining location CGCMR, SICMR and reference sites as an independent factor and depth as a continuous covariate. Analyses were conducted on the log(x+1) transformed data. Significant results are highlighted in bold.

Factor	Variable	df	MS	Error MS	F	p
CMR	**Total cover**	**3,47**	**0.0130**	**0.0015**	**8.66**	**<0.001**
	Number of categories		**0.1588**	**0.0191**	**8.31**	**<0.001**
	CCA		**1.4874**	**0.0599**	**24.83**	**<0.001**
	LHC		0.0580	0.2140	0.27	0.845

Factor	Variable	df	MS	Error MS	F	p
	Turf		**1.8377**	**0.2199**	**8.36**	**<0.001**
	Macroalgae		0.0850	0.1073	0.79	0.504
Depth	Total cover	1,47	0.0020	0.0015	1.33	0.254
	Number of categories		**0.0816**	**0.0191**	**4.27**	**0.044**
	CCA		**3.0310**	**0.0599**	**50.60**	**<0.001**
	LHC		**3.5690**	**0.2140**	**16.64**	**0.002**
	Turf		0.1511	0.2199	0.69	0.411
	Macroalgae		0.1969	0.1073	1.84	0.182

4 Discussion

The surveys of the Cod Grounds and Solitary Islands revealed some key attributes of reef communities in the CMRs and at reference sites, including:

i. a dominance of temperate species in deeper areas, with more tropical species in the shallows;

ii. distinct depth stratification;

iii. very high fish biomass, including exploited fish species;

iv. a decline at reference sites that is unlikely to be a consequence of displaced fishing effort; and

v. a high abundance of grey nurse sharks during more recent surveys of the CGCMR, suggesting a successful role in the protection of this species.

Depth stratification was found across all surveyed communities, including fishes, invertebrates and benthos. Previous studies, including the Cod Grounds baseline survey, have also noted depth structuring along narrow bands, driven largely by the distribution and abundance of different species of sea urchins (Stuart-Smith et al. 2009). On inshore reefs of NSW, sea urchins are often the dominant grazers, acting as a structuring force for populations of habitat forming organisms such as kelp (Bennett et al. 2016). Certain species, such as the dominant spiny sea urchin (*C. rodgersii*), can overgraze macroalgae to the point where they form “barrens”, which creates a bottom-up effect on the whole community (Andrew and O'Neil 2000; Ling et al. 2015).

This study detected a small reduction in urchins in the CGCMR and a shift in sessile communities, but it is unclear whether the two are related. Much of the survey effort took place at depths beyond the reach of grazing sea urchins, which have their highest densities in shallower waters (Stuart-Smith et al. 2009). However, in deeper waters, where sea urchin density is already low, a small reduction in sea urchins may be enough to lead to changes in the sessile community. It is also possible that the sessile community shift was largely affected by warming, with a higher cover of corals, but the deeper reference sites also showed a change towards less CCA and more turf and macroalgae.

Spatial differences were also apparent between the Cod Grounds, Pimpernel Rock and the Solitary Islands sites. The Solitary Islands sites chosen as reference site for the CMR (Pimpernel Rock) were as similar as possible in exposure and underlying habitat structure, however, they were much shallower than the Cod Grounds and Pimpernel Rock sites. Ultimately, given the strong effects of depth on reef communities in this region, deeper sites may be required as reference sites for Pimpernel Rock. Additionally, the pinnacles of Pimpernel Rock and the Cod Grounds are geomorphologically unique, making it difficult to find appropriate reference sites outside the CMRs. The fish community at the Solitary Islands reference sites were much more similar to those found in subtropical and tropical waters further north than to the largely temperate species found at depth in the CMRs.

Pimpernel Rock and some of the Cod Grounds sites had very high biomass of fishes; some transects had over 2.5 tonnes of fish. In a number of cases this was driven by very large schools of planktivores such as mado (*Atypichthys strigatus*) and silver sweep (*Scorpis lineolata*), and in some cases also high abundances of carnivores and sharks. In the Cod Grounds, the highest biomass values were recorded at the reference sites in 2009, but in the CMR sites in 2016. This could indicate that the successful protection of the CMR has displaced fishing effort to areas outside the CMR, but the CMR was already in place during the baseline survey (Stuart-Smith et al. 2009). However, this is not supported by the analysis of large and exploited fish species; both had marginally higher biomass in the CMR than at reference sites, but not significantly so. The high variability between transects – especially when large schools of planktivores are stochastically distributed – could mask the effect of protection. It is also possible that it will take longer to detect the effects of the CMR; large, long-lived fish species require many years of protection for detectable population recovery (Russ and Alcala 2004). Studies of MPA protection have found both rapid and delayed responses of exploited fish populations, in part depending on compliance with no-take regulations, the life history of the exploited species, and the size, age and habitat structure of the CMR (Graham et al. 2011; Green et al. 2013; Edgar et al. 2014). Furthermore, suspected illegal fishing in the Cod Grounds CMR may be delaying recovery (Stuart-Smith et al. 2009).

Illegal fishing is the major potential threat affecting communities in the CGCMR and SICMR. The CMRs lie some kilometres offshore, are small, and their boundaries may be difficult to acknowledge and police. The baseline survey in 2009 recorded fishing activities within the Cod Grounds CMR and derelict fishing gear along the transects. These CMRs encompass unique and small-scale features that are significant in the context of the surrounding habitat; they serve to aggregate fauna from a large “catchment area” and fishing impacts could therefore have wide repercussions. Given the concentration of large-bodied predators, even small amounts of fishing could result in significant biomass being removed from the system. Surveillance, enforcement and education are therefore crucial in protecting these CMRs.

The removal of top predators from a system can have top-down repercussions throughout the food web, and in extreme cases can lead to the alteration of the habitat-forming organisms themselves (Mumby et al. 2006). For instance, common target species in NSW include the urchin predators blue groper (*Achoerodus viridis*) and pink snapper (*Chrysophrys auratus*). Removing these species may cause an increase in grazing urchins, potentially leading to urchin barrens replacing habitat-forming macroalgae.

Despite similar depths, Pimpernel Rock had a more diverse sessile biota than the CGMR, including higher cover of macroalgae and turf than any of the other sites, including the shallower Solitary Island sites. Pimpernel Rock also hosts a higher biomass of large predators of both invertebrates and fishes, such as the blue groper, various snapper species, and wrasses that prey on sea urchins, especially in their juvenile stages. The longer history of protection at Pimpernel Rock may have led to a natural balance of larger fishes than the CGMR, where planktivorous and pelagic species dominate over larger reef-dwelling predators; this balance is likely to have flow-on effects down the food web to lower trophic levels and the sessile community. Additionally, Pimpernel Rock is a smaller, more isolated habitat, and the aggregations of fishes frequenting the pinnacle are likely to feed more heavily in the small area. The greater availability of habitat surrounding the CGCMR allows a greater dispersion of fishes, and lighter feeding pressure in any one area.

The typical human footprint on coastal reefs in this region, where overfishing of large fishes has probably led to larger urchin populations and the resulting urchin barrens, is reflected in the CGCMR (Ling et al. 2015).

The high abundance of the grey nurse shark *C. taurus*, especially during the most recent surveys, suggests that this population is benefiting from no-take protection. The Cod Grounds and Pimpernel Rock are well-known aggregation sites for this species, and this is one case where even a relatively small CMR appears useful in protecting a key habitat of a large-bodied predator. Known aggregations sites for this species on the east coast of Australia have seen declining numbers of individuals and lower occupancy than expected (Otway et al. 2003); this site appears to retain a significant population of grey nurse sharks, and recurring surveys will reveal whether numbers are stable or increasing. These results indicate a successful outcome of general protection for this species, both inside and outside CMRs, with a beneficial additional layer of protection added by the no-take zone.

5 Recommendations

- Undertake regular monitoring of physical characteristics – monthly or seasonal reporting of water quality, nutrients, turbidity, light and other physical parameters that support ecological processes;
- Undertake ongoing ecological monitoring at intervals of 1-3 years to build up a temporal dataset to assess changes relative to data provided by this survey, with results reported using a comprehensive suite of sensitive environmental indicators;
- Incorporate additional sites for monitoring, especially additional control sites outside the CMRs, in comparable habitats and depths;
- Include timed swims around the pinnacles for more accurate assessment of the grey nurse shark population;
- Undertake monitoring of potential impacts, including dedicated surveys of fishing catch and effort in the general area by recreational and commercial fishers, and reporting mechanisms for pollution, shipping, interactions with megafauna and plastic marine debris;
- Through the longer term, consider establishing a buffer zone around the CMR boundaries.

6 Acknowledgements

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8 Appendices

APPENDIX 1 – SPECIES LIST OF FISHES RECORDED DURING SURVEYS IN THE CGCMR, SICMR AND REFERENCE SITES, INCLUDING FREQUENCY AND AVERAGE BIOMASS (KG).

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Abudefduf bengalensis	0	0	0	0	0	1	0	0	0	0	0	7.115
Abudefduf vaigiensis	0	0	0	0	1	0	0	0	0	0	25.208	0
Acanthistius ocellatus	1	1	5	0	1	0	10.617	50.901	201.551	0	110.163	8.309
Acanthopagrus australis	6	0	3	0	0	3	429.490	0	299.844	0	0	447.509
***Acanthurid* spp.**	0	0	0	0	0	1	0	0	0	0	0	24.022
Acanthurus dussumieri	0	0	0	0	0	1	0	0	0	0	0	0.245
Acanthurus nigrofuscus	0	0	1	0	0	2	0	0	0.996	0	0	5.590
Acanthurus olivaceus	0	0	0	0	0	3	0	0	0	0	0	76.590
Acanthurus triostegus	0	0	0	0	0	1	0	0	0	0	0	1.957
Achoerodus viridis	6	1	4	1	4	3	1029.944	172.107	2300.811	344.214	5377.686	666.716
Alectis ciliaris	0	0	0	0	1	0	0	0	0	0	669.537	0
Alectis indica	0	0	0	0	0	0	0	0	0	0	0	0
Amphiprion akindynos	0	0	0	0	0	13	0	0	0	0	0	1791.119
Amphiprion latezonatus	0	0	0	0	0	13	0	0	0	0	0	204.611
Amphiprion melanopus	0	0	0	0	0	4	0	0	0	0	0	27.065
Anampses caeruleopunctatus	0	0	0	0	0	3	0	0	0	0	0	7.489
Anampses neoguinaicus	0	0	0	0	0	6	0	0	0	0	0	6.190
Anoplocapros inermis	0	2	0	0	0	0	0	34.804	0	0	0	0
Aplodactylus lophodon	0	0	1	0	0	0	0	0	17.198	0	0	31.706
Apogon limenus	0	0	1	0	0	0	0	0	2.456	0	0	0
Argyrosomus japonicus	1	0	0	0	0	0	38366.860	0	0	0	0	0

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Arothron stellatus	0	0	0	0	0	0	0	0	0	0	0	0
Atractoscion aequidens	1	0	1	1	0	0	26259.970	0	12351.720	49406.900	0	0
Atypichthys strigatus	3	5	6	3	4	4	2559.769	414992.500	45833.380	23758.250	279277.100	321.522
Aulopus purpurissatus	2	1	1	0	0	1	60.670	236.313	44.818	0	0	34.919
Aulostomus chinensis	0	0	0	1	2	2	0	0	0	10.958	196.662	16.929
Bodianus axillaris	0	0	1	0	0	2	0	0	0.077	0	0	8.231
Bodianus frenchii	1	1	0	1	1	0	56.381	169.142	0	701.254	95.687	0
Bodianus perditio	0	0	0	0	3	0	0	0	0	0	243.662	8.180
Bodianus unimaculatus	0	0	1	0	0	0	0	0	17.222	0	0	0
Brachaelurus waddi	0	0	0	1	0	0	0	0	0	96.095	0	44.864
Caesio caerulaurea	0	0	0	0	0	1	0	0	0	0	0	34.191
Caesio teres	0	0	0	0	1	1	0	0	0	0	108.468	643.715
Caesioperca lepidoptera	1	0	0	0	0	0	32.973	0	0	0	0	0
Cantherhines pardalis	0	0	0	0	0	1	0	0	0	0	0	4.535
Canthigaster callisterna	0	0	0	0	0	2	0	0	0	0	0	9.270
Canthigaster valentini	0	0	0	0	0	0	0	0	0	0	0	0.352
Carangid spp.	1	0	0	0	2	0	68.852	0	0	0	15646.650	0
Carangoides chrysophrys	0	0	0	0	2	0	0	0	0	0	640.608	0
Carangoides orthogrammus	0	0	1	0	0	0	0	0	5.912	0	0	0
Caranx sexfasciatus	0	0	0	0	0	0	0	0	0	0	0	77.129
Carcharias taurus	1	1	4	0	3	0	12596.410	16662.820	81332.530	0	109949.500	0
Centroberyx affinis	1	0	0	0	0	0	62.186	0	0	0	0	0
Centropyge bicolor	0	0	0	0	0	1	0	0	0	0	0	3.215
Centropyge tibicen	0	0	0	0	0	9	0	0	0	0	0	52.472
Centropyge vrolikii	0	0	0	0	0	1	0	0	0	0	0	4.144
Cephalopholis miniata	0	0	0	0	0	1	0	0	0	0	0	32.821
Cephalopholis urodeta	0	0	0	0	0	1	0	0	0	0	0	18.676
Chaetodon auriga	0	0	0	0	0	1	0	0	0	0	0	25.313

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Chaetodon citrinellus	0	0	0	0	0	2	0	0	0	0	0	4.086
Chaetodon flavirostris	0	0	0	0	0	3	0	0	0	0	0	22.336
Chaetodon guentheri	1	0	5	1	4	9	2.934	0	43.909	17.603	376.970	96.815
Chaetodon kleinii	0	0	0	0	2	8	0	0	0	0	50.086	88.853
Chaetodon lunulatus	0	0	0	0	0	1	0	0	0	0	0	2.296
Chaetodon mertensii	0	0	0	0	0	1	0	0	0	0	0	0.954
Chaetodon pelewensis	0	0	0	0	0	2	0	0	0	0	0	8.156
Chaetodon plebeius	0	0	0	0	0	1	0	0	0	0	0	3.247
Chaetodon rainfordi	0	0	0	0	0	1	0	0	0	0	0	2.296
***Chaetodon* spp.**	0	0	0	0	0	1	0	0	0	0	0	7.700
Chaetodon tricinctus	0	0	0	0	0	1	0	0	0	0	0	4.505
Chaetodon trifascialis	0	0	0	0	0	4	0	0	0	0	0	24.487
Chaetodon unimaculatus	0	0	0	0	0	2	0	0	0	0	0	17.052
Cheilodactylus fuscus	13	4	7	1	3	7	12049.750	788.577	10230.620	5462.589	1154.886	756.756
Cheilodactylus vestitus	1	0	2	0	1	5	10.585	0	74.840	0	218.606	169.538
Cheilodipterus macrodon	0	0	0	0	0	0	0	0	0	0	0	19.142
Chelmonops truncatus	1	0	0	0	0	0	17.490	0	0	0	0	0
Chironemus marmoratus	0	0	0	0	0	0	0	0	0	0	0	26.829
Chromis flavomaculata	0	0	0	0	1	3	0	0	0	0	9.650	5.675
Chromis hypsilepis	15	4	10	0	1	6	8233.215	8172.660	72713.370	0	40.271	503.543
Chromis margaritifer	0	0	1	0	1	3	0	0	0.028	0	0.644	2.505
Chromis viridis	0	0	0	0	0	1	0	0	0	0	0	3.374
Chromis weberi	0	0	0	0	0	1	0	0	0	0	0	0.927
Chromis xanthura	0	0	0	0	1	0	0	0	0	0	8.729	0
Cirrhilabrus punctatus	0	0	0	0	1	0	0	0	0	0	9.585	0.015
Cirrhitichthys aprinus	0	0	0	0	3	8	0	0	0	0	55.578	26.021
Cirrhitichthys falco	0	0	0	0	0	2	0	0	0	0	0	2.228
Coris aygula	0	0	0	0	0	2	0	0	0	0	0	5.958

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Coris dorsomacula	2	0	2	0	1	6	14.789	0	14.304	0	47.719	45.590
Coris gaimard	0	0	0	0	0	1	0	0	0	0	0	8.299
Coris picta	17	3	9	0	3	5	671.862	314.321	651.270	0	462.670	95.493
Ctenochaetus binotatus	0	0	0	0	0	3	0	0	0	0	0	31.469
Cyprinocirrhites polyactis	0	0	2	0	0	0	0	0	1.508	0	0	0
Dascyllus reticulatus	0	0	0	0	0	11	0	0	0	0	0	262.169
Dascyllus trimaculatus	0	0	0	0	1	13	0	0	0	0	3.3705	11995.790
Dendrochirus zebra	0	0	0	0	0	1	0	0	0	0	0	4.859
Dicotylichthys punctulatus	0	1	0	0	0	2	0	144.317	0	0	0	116.182
Dinolestes lewini	3	0	1	0	0	0	4910.969	0	1009.955	0	0	0
Diodon hystrix	0	0	0	0	0	3	0	0	0	0	0	408.101
Elagatis bipinnulata	1	0	0	0	0	0	133.427	0	0	0	0	41.769
Enoplosus armatus	10	5	9	1	1	0	219.204	143.393	363.873	29.915	223.600	0
Epinephelus daemelii	1	0	0	0	1	1	137.174	0	0	0	5729.582	105.330
Epinephelus fasciatus	0	0	0	0	1	2	0	0	0	0	48.369	28.166
Epinephelus undulatostriatus	1	0	1	0	2	0	38.771	0	89.357	0	939.676	0
Eubalichthys bucephalus	1	0	0	0	0	0	27.729	0	0	0	0	0
Eubalichthys mosaicus	1	0	1	0	0	0	6.082	0	47.989	0	0	0
Fistularia commersonii	1	1	0	0	0	0	3.245	9.734	0	0	0	1.007
Fistularia petimba	1	0	0	0	0	0	0.431	0	0	0	0	1.220
Forcipiger flavissimus	0	0	0	0	0	0	0	0	0	0	0	0.357
Glaucosoma scapulare	0	2	0	0	2	0	0	2679.215	0	0	6228.212	0
Gnathodentex aureolineatus	0	0	0	0	0	1	0	0	0	0	0	18.437
Gomphosus varius	0	0	0	0	0	1	0	0	0	0	0	0.623
Halichoeres chrysus	0	0	0	0	0	1	0	0	0	0	0	2.604
Halichoeres hortulanus	0	0	0	0	0	2	0	0	0	0	0	1.063
Halichoeres margaritaceus	0	0	0	0	0	2	0	0	0	0	0	4.964
Halichoeres nebulosus	0	0	0	0	2	10	0	0	0	0	11.830	50.411

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Hemigymnus fasciatus	0	0	0	0	0	3	0	0	0	0	0	21.543
Heniochus acuminatus	0	0	0	0	0	0	0	0	0	0	0	0
Heniochus chrysostomus	0	0	0	0	0	0	0	0	0	0	0	0.242
Heniochus diphreutes	0	0	0	0	0	3	0	0	0	0	0	99.034
Heterodontus portusjacksoni	1	0	2	0	0	0	285.806	0	452.127	0	0	0
Heteropriacanthus cruentatus	0	0	0	0	0	1	0	0	0	0	0	8.146
Hologymnosus doliatus	0	0	0	0	0	1	0	0	0	0	0	4.515
Hypoplectrodes annulatus	0	1	0	0	0	0	0	31.851	0	0	0	0
Hypoplectrodes maccullochi	15	5	8	3	4	3	175.462	103.849	207.401	88.864	105.484	11.054
Kyphosus sydneyanus	0	0	0	0	1	1	0	0	0	0	1149.455	2958.805
Labrid spp.	1	0	0	0	0	1	2.130	0	0	0	0	4.683
Labroides dimidiatus	0	0	2	0	2	15	0	0	4.661	0	24.145	35.537
Latridopsis forsteri	0	0	1	0	0	0	0	0	259.439	0	0	0
Lotella rhacina	7	2	4	2	0	0	115.501	315.282	74.400	249.612	0	0
Lutjanid spp.	0	0	0	0	0	1	0	0	0	0	0	439.470
Lutjanus adetii	0	0	0	0	0	0	0	0	0	0	0	0
Lutjanus bohar	0	0	0	0	0	0	0	0	0	0	0	2.338
Lutjanus kasmira	0	0	0	0	0	0	0	0	0	0	0	0.111
Lutjanus russellii	0	0	3	0	4	0	0	0	438.212	0	6197.014	0
Macropharyngodon meleagris	0	0	0	0	0	2	0	0	0	0	0	1.286
Macropharyngodon negrosensis	0	0	0	0	0	0	0	0	0	0	0	0.113
Mecaenichthys immaculatus	3	3	4	1	1	0	18.499	55.496	197.692	24.438	18.943	0
Meuschenia freycineti	4	0	0	0	0	0	214.940	0	0	0	0	0
Meuschenia scaber	5	2	0	0	0	0	81.330	76.377	0	0	0	0
Meuschenia trachylepis	1	0	0	0	0	1	16.391	0	0	0	0	3.704
Microcanthus strigatus	0	0	2	0	0	0	0	0	320.163	0	0	0
Mulloidichthys vanicolensis	0	0	0	0	0	1	0	0	0	0	0	51.712
Myripristis kuntee	0	0	0	0	0	1	0	0	0	0	0	9.857

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Myripristis murdjan	0	0	0	0	0	2	0	0	0	0	0	47.927
Naso unicornis	0	0	0	0	0	3	0	0	0	0	0	39.103
Nelusetta ayraudi	1	0	0	0	0	0	56.997	0	0	0	0	0
Nemadactylus douglasii	5	4	3	2	0	0	536.698	1155.326	184.966	459.938	0	0
Notolabrus gymnogenis	12	5	6	2	4	2	447.448	391.823	342.349	890.037	829.357	31.624
Ophthalmolepis lineolatus	16	6	12	3	1	0	1374.925	752.165	1653.691	1799.352	285.414	0
Orectolobus halei	4	2	6	1	3	1	17574.030	12032.420	8877.352	1249.964	13677.210	441.728
Orectolobus maculatus	2	1	1	0	1	0	5056.389	1977.446	2640.489	0	937.473	0
Orectolobus spp.	0	0	0	0	0	1	0	0	0	0	0	223.674
Ostorhinchus aureus	0	0	0	0	0	1	0	0	0	0	0	1.112
Ostorhinchus properuptus	0	0	0	0	0	1	0	0	0	0	0	0.476
Pagrus auratus	12	2	7	1	1	0	1113.369	40.650	968.350	55.189	494.201	0
Paracaesio xanthura	1	0	1	0	3	6	768.784	0	67.429	0	5485.334	723.320
Paracanthurus hepatus	0	0	0	0	0	6	0	0	0	0	0	137.344
Parachaetodon ocellatus	0	0	0	0	0	0	0	0	0	0	0	0
Paracirrhites arcatus	0	0	0	0	0	0	0	0	0	0	0	0.566
Paracirrhites forsteri	0	0	0	0	0	0	0	0	0	0	0	2.780
Paraluteres prionurus	0	0	0	0	0	1	0	0	0	0	0	0.443
Parapercis stricticeps	0	0	1	0	0	0	0	0	1.446	0	0	0
Paraplesiops bleekeri	0	0	1	0	0	0	0	0	35.380	0	0	0
Parma microlepis	8	2	1	2	0	0	821.484	92.030	19.603	880.677	0	0
Parma oligolepis	0	0	0	0	0	2	0	0	0	0	0	15.386
Parma polylepis	0	0	0	0	0	5	0	0	0	0	0	51.867
Parma unifasciata	16	4	12	3	4	14	1711.205	1359.332	4169.764	1383.406	1165.971	2111.834
Parupeneus multifasciatus	0	0	0	0	0	2	0	0	0	0	0	7.460
Parupeneus spilurus	15	1	12	2	4	12	1036.939	68.129	1013.602	299.160	1022.676	1095.750
Pempheris affinis	5	0	4	1	1	6	34.655	0	99.431	99.756	4387.119	75.644
Pempheris analis	0	0	0	0	0	0	0	0	0	0	0	13.506

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Pempheris compressa	3	2	3	1	2	0	1736.040	3687.752	135.694	49.878	413.514	9.3679
Pempheris multiradiata	0	0	0	1	0	0	0	0	0	171.310	0	0
Pempheris oualensis	0	0	0	0	0	1	0	0	0	0	0	53.035
Platax teira	0	0	0	0	0	1	0	0	0	0	0	84.151
Plectorhinchus flavomaculatus	0	0	0	0	0	4	0	0	0	0	0	305.106
Plectorhinchus gibbosus	0	0	0	0	0	1	0	0	0	0	0	134.237
Plectorhinchus picus	0	0	0	0	0	1	0	0	0	0	0	105.374
Plectroglyphidodon dickii	0	0	0	0	0	8	0	0	0	0	0	20.121
Plectroglyphidodon johnstonianus	0	0	0	0	0	1	0	0	0	0	0	3.324
Pomacanthus semicirculatus	0	0	0	0	0	0	0	0	0	0	0	38.039
Pomacentrus australis	0	0	0	0	0	2	0	0	0	0	0	1.398
Pomacentrus bankanensis	0	0	0	0	0	2	0	0	0	0	0	0.050
Pomacentrus coelestis	0	0	0	0	1	12	0	0	0	0	15.444	110.001
1Prionurus maculatus	1	0	1	0	1	5	128.635	0	193.576	0	180.861	2146.256
Prionurus microlepidotus	4	0	5	1	3	13	681.924	0	4944.698	444.582	22107.580	7801.993
Pseudanthias fasciatus	0	0	0	0	4	1	0	0	0	0	4594.649	4.479
Pseudanthias hypselosoma	0	0	0	0	2	0	0	0	0	0	573.145	0
Pseudanthias pictilis	0	0	0	0	0	1	0	0	0	0	0	2.552
Pseudanthias rubrizonatus	0	0	0	0	2	0	0	0	0	0	3158.795	0
Pseudanthias spp.	0	0	0	0	0	0	0	0	0	0	0	0.528
Pseudanthias squamipinnis	0	0	4	0	2	2	0	0	1.204	0	143.849	46.965
Pseudocaranx georgianus	3	0	0	0	0	3	137.124	0	0	0	0	1063.874
Pseudocoris yamashiroi	1	0	0	0	0	0	0.475	0	0	0	0	0
Pseudolabrus guentheri	0	0	0	0	1	3	0	0	0	0	66.854	36.536
Pseudolabrus luculentus	0	0	1	0	1	5	0	0	5.460	0	34.096	20.860
Pterocaesio chrysozona	0	0	0	0	0	1	0	0	0	0	0	16.734
Pterocaesio digramma	0	0	0	0	0	6	0	0	0	0	0	235.465
Pterois volitans	0	0	1	0	0	0	0	0	17.825	0	0	0

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Rhabdosargus sarba	5	1	8	0	0	0	521.253	148.033	553.818	0	0	0
Sarda australis	0	0	1	0	0	0	0	0	4457.053	0	0	0
Scarus chameleon	0	0	0	0	0	1	0	0	0	0	0	26.805
Schuettea scalaripinnis	0	0	0	0	0	0	0	0	0	0	0	0
Scolopsis bilineata	0	0	0	0	0	1	0	0	0	0	0	9.438
Scorpaena cardinalis	4	1	0	0	0	1	114.478	207.076	0	0	0	17.785
Scorpaena jacksoniensis	0	0	5	0	2	0	0	0	273.580	0	165.100	0
Scorpaenodes evides	0	0	0	0	0	1	0	0	0	0	0	1.960
Scorpaenodes littoralis	0	0	0	0	0	0	0	0	0	0	0	1.351
Scorpaenopsis spp.	0	0	0	0	1	0	0	0	0	0	53.476	0
Scorpis lineolata	13	5	12	2	4	12	7515.154	140647.900	372407.200	11950.840	522993.00	3069.208
Seriola dumerili	0	0	3	0	2	0	0	0	1868.785	0	3497.543	0
Seriola hippos	2	0	0	0	0	0	1005.771	0	0	0	0	0
Seriola lalandi	3	0	8	1	4	1	2888.953	0	2737.158	320.620	195589.700	17.402
Seriola rivoliana	1	0	0	0	0	1	113.565	0	0	0	0	14.163
Siganus fuscescens	0	0	0	0	0	1	0	0	0	0	0	14.328
Stegastes apicalis	0	0	0	0	0	1	0	0	0	0	0	6.450
Stegastes gascoynei	0	0	0	0	0	13	0	0	0	0	0	532.628
Stethojulis bandanensis	0	0	0	0	0	6	0	0	0	0	0	9.314
Stethojulis interrupta	0	0	0	0	0	6	0	0	0	0	0	38.226
Stethojulis strigiventer	0	0	0	0	0	1	0	0	0	0	0	2.003
Suezichthys arquatus	1	0	0	0	0	1	2.211	0	0	0	0	1.575
Sufflamen chrysopterum	0	0	0	0	0	5	0	0	0	0	0	111.949
Sufflamen fraenatum	0	0	0	0	0	3	0	0	0	0	0	46.218
Syngnathid spp.	0	0	0	0	0	1	0	0	0	0	0	0.209
Synodus variegatus	0	0	0	1	0	0	0	0	0	41.343	0	1.226
Thalassoma amblycephalum	0	0	0	0	2	8	0	0	0	0	123.849	56.784
Thalassoma jansenii	0	0	0	0	0	2	0	0	0	0	0	3.965

Species	Transects						Biomass					
	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref	CG09	CG09 ref	CG16	CG16 ref	SI	SI ref
Thalassoma lunare	0	0	0	0	2	16	0	0	0	0	71.747	2102.408
Thalassoma lutescens	0	0	0	0	2	15	0	0	0	0	627.662	958.078
Thalassoma nigrofasciatum	0	0	0	0	2	0	0	0	0	0	103.445	4.128
Thalassoma quinquevittatum	0	0	0	0	1	0	0	0	0	0	1.501	0
Thalassoma spp.	0	0	0	0	0	0	0	0	0	0	0	0
Trachichthys australis	1	0	0	0	0	0	3.612	0	0	0	0	0
Trachinops taeniatus	13	4	10	3	4	2	117.204	359.503	179.662	329.095	1218.406	43.713
Trachurus novaezelandiae	2	0	0	0	0	1	216.187	0	0	0	0	908.714
Trachypoma macracanthus	0	0	0	0	0	3	0	0	0	0	0	25.354
Upeneichthys lineatus	3	1	1	0	0	0	31.250	21.327	25.548	0	0	0
Zanclus cornutus	0	0	0	0	1	3	0	0	0	0	62.449	33.633