

Current status of coral reef health around the Koh Rong Archipelago, Cambodia

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Abstract

Coral reef health is known to be in decline globally yet there is paucity of knowledge about the health of Cambodia's reefs. The Fisheries Administration aims to establish the country's first Marine Fisheries Management Area to protect their coral reef systems, and baseline data on current reef health were required. This study was carried out in the Koh Rong Archipelago between 2010 and 2014 with the objective of evaluating coral reef health to inform management approaches in the area. The survey methods were closely based on those of Reef Check, entailing the use of underwater transects to determine the density and diversity of corals, fish and invertebrates. An assessment of physical stressors on the reef was also undertaken. Fish diversity was found to be uniform throughout the survey area but there were localised pockets of higher density. Invertebrate diversity was also uniform, with little variation in density between sites. Hard coral communities were dominated by massive *Porites* spp. with zero incidences of coral disease noted. For the future, recommended monitoring tools in the Marine Fisheries Management Area include deploying permanent survey transects and thermal data loggers, and carrying out health survey assessments of the coastal mangrove forests and seagrass beds. It is also important to locate fish spawning sites, determine coral recruitment success, and quantify the impacts of sedimentation. Filling these knowledge gaps will provide further insights into the ecological stability of the archipelago's reef health, aiding future management strategies.

Keywords

Abundance, conservation, diversity, fish, invertebrates, marine protected area.

Introduction

Monitoring the health of coral reef ecosystems is not new, but a unified set of parameters to measure health has never been recognised. Over the past 40 years, a multitude of reef assessment methods have been designed by Risk (1972), Bryant *et al.* (1998), Downs *et al.* (2005) and Bruno *et al.* (2009), to name just a few. Collaborative discussions between marine biologists and resource stakeholders resulted in the

creation of the Global Coral Reef Monitoring Network (GCRMN) in 1995 under the International Coral Reef Initiative. The GCRMN promotes coral reef research and monitoring to inform national decision-makers about coral reef management, and strengthen understanding of global coral reef health. Coral reef assessments focus on descriptions of reef health and ecosystem responses at population and community

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levels, primarily with regard to coral cover, species abundance and population dynamics, covering an array of fish and invertebrate taxa (Risk *et al.*, 2001). Some approaches, such as those of the Caribbean Coastal Marine Productivity Programme (1997), take into account land–sea interactions, while others focus on patterns of change in community structure across a region by appraising taxonomic assemblages (Ginsberg *et al.*, 2000). The international NGO Reef Check aims to create a global database of wide ranging coral reef ecosystem health assessments (Hodgson, 2000), creating a snapshot-in-time of an array of key marine taxa in each location.

To date, few if any global reef monitoring programmes have successfully unearthed the large-scale mechanistic processes causing reef deterioration (Downs *et al.*, 2005). When assessing the health of a coral reef ecosystem, it is of paramount importance to monitor not only biological diversity and abundance, but also chronic and acute threats, and management actions. By focusing on these three areas—ecology, threats and management—it is possible to describe the current health status of a system and predict potential future health risks.

Management of coral reefs can range from protecting a single threatened coral colony to the creation of vast marine protected area (MPA) networks. In Cambodia, the first Marine Fisheries Management Area (MFMA)—a national term for a specific type of multiple-use MPA—is currently being established in the Koh Rong Archipelago by the Fisheries Administration (FiA) of the Royal Government of Cambodia (Fig. 1). The proposed MFMA has the potential to set a benchmark and framework for future marine conservation and protection measures along the country's coastline.

Globally, coral reef health is in decline. Previous studies have indicated that 58–70% of global reefs are threatened (Downs *et al.*, 2005) and this figure is likely to be even higher today. Therefore, it is of principal importance to gain an understanding, on a regional scale, of the health status of coral reef ecosystems and how best to protect them.

The FiA were aware of this in 2009 when they invited Coral Cay Conservation (CCC) to begin biophysical surveys of coral reefs in the Koh Rong Archipelago. The biodiversity and health of coral reef ecosystems along the Cambodian coastline are poorly understood, with a distinct paucity of information on marine habitats. Data from surveys conducted by CCC are now being used to describe the current

health of Cambodian coral reefs, and to aid the zoning of the proposed MFMA.

In 2010 and 2011, a preliminary investigation was carried out on a portion of the reefs that are the focus of this study. Van Bochove *et al.* (2011) noted that anthropogenic impacts were generally low, although evidence of fishery-related stressors was reported, including the depletion of key fish families. Sedimentation and siltation were recorded to be particularly severe in certain areas, perhaps due to seasonal rains. A mean hard coral cover of 25% was recorded in the sites surveyed, with rock and sandy substrates also common. In the study by van Bochove *et al.* (2011), commercially valuable fish families were identified as Serranidae, Scaridae, Lutjanidae, Haemulidae, Sphyraenidae and Carangidae. The population structure of these fish was also recorded in the area by Marine Conservation Cambodia (2011) and Savage *et al.* (2013). Thauung (2013) assessed spatial distribution of reef fish and invertebrates around Koh Rong, and Longhurst & Clay (2013) used CCC data to identify priority reef areas for conservation in the Koh Rong Archipelago.

Here we investigate the current health status of coral reefs around the Koh Rong Archipelago, and outline the threats that could directly affect the quality of ecosystem function and resource provision. We also suggest future management strategies in line with the proposed MFMA (Fig. 1) that could support ambitious national targets, such as allocating approximately 500 ha of coral reefs to an appropriate form of sustainable management by the end of 2015 (Fisheries Administration, 2011). The MFMA will reportedly entail 468 ha of coral reef, or 17% of the country's coral reefs, being brought under better protection (based on the estimated national total reef area of 2,806 ha: Mangroves for the Future, 2013).

Methods

Study area and field surveys

Surveys were undertaken by CCC staff and volunteers around three islands: Koh Rong, Koh Rong Sanloem and Koh Koun (Fig. 1). These are the largest islands of the Koh Rong Archipelago. For this paper, data will be presented from Koh Rong (10°42'N 103°14'E) and Koh Koun (10°37'N 103°19'E) only. Data from Koh Rong Sanloem are not included because research here is still ongoing.

The methods we used were closely based on those of Reef Check (Hodgson *et al.*, 2006). A few adjustments were made however, to overcome our low number of surveyors (e.g. we allowed a single diver to collect all invertebrate data on a transect, instead of the recommended two divers) and to make the surveys more applicable to local reefs (such as a slight change in indicator taxa, e.g. collector urchins *Tripneustes* spp. and flamingo tongues *Cyphoma gibbosum* were removed from the standard Reef Check list, while monocle bream *Scolopsis* spp. and jacks [Carangidae] were added, amongst others). Health parameters were closely based on the requisites for Reef Check, with key survey taxa including fish (Appendix 1) and invertebrates (Appendix 2), and substrate classification (Appendix 5).

Records were also taken of 'impacts', such as physical damage, general trash, fishing trash and disease prevalence (Appendix 3). Ancillary data were collected at every site to create a near-complete picture of potential stressors on the surveyed reefs.

Data were collected over four years from 2010–2014, with surveys carried out year-round. Sites were selected at c. 500 m intervals around the islands. The objective of this survey was to gain a comprehensive dataset pertaining to the entire archipelago's reef system. Data from van Bochove *et al.* (2011), collected between February 2010 and February 2011,

were incorporated. Seventy sites were surveyed and every site had four spatial replicates (Fig. 2), giving a grand total of 280 transects. Given the low taxonomic specificity in these methods (typically to family level), these spatial replicates were sufficient to capture the variation within one site, thus arguing that pseudoreplication was not a problem (Hodgson & Stepath, 1998). Every site was surveyed twice during the four-year survey period. Transects were deployed at depths of between 2 and 5 m depending on substrate topography. Every transect was orientated parallel to the shoreline, whilst keeping within the specified depth range. Data from all replicates were pooled for each site. Although permanent markers were not deployed, repeat surveys were carried out in the same area, guided by local landmarks and global positioning system coordinates.

Fish

Using a 20 x 5 x 5 m belt transect parallel to the shore, target species of fish were identified and counted (Appendix 1). Surveyors waited for 1 minute at the start of each survey and subsequently every 5 m along the transect to allow fish to return and disturbed sediment to settle. Fish were surveyed on the 'outward' direction of the survey dive, followed by the collection of invertebrate, impact and substrate data on the 'homeward' portion of the same transect.

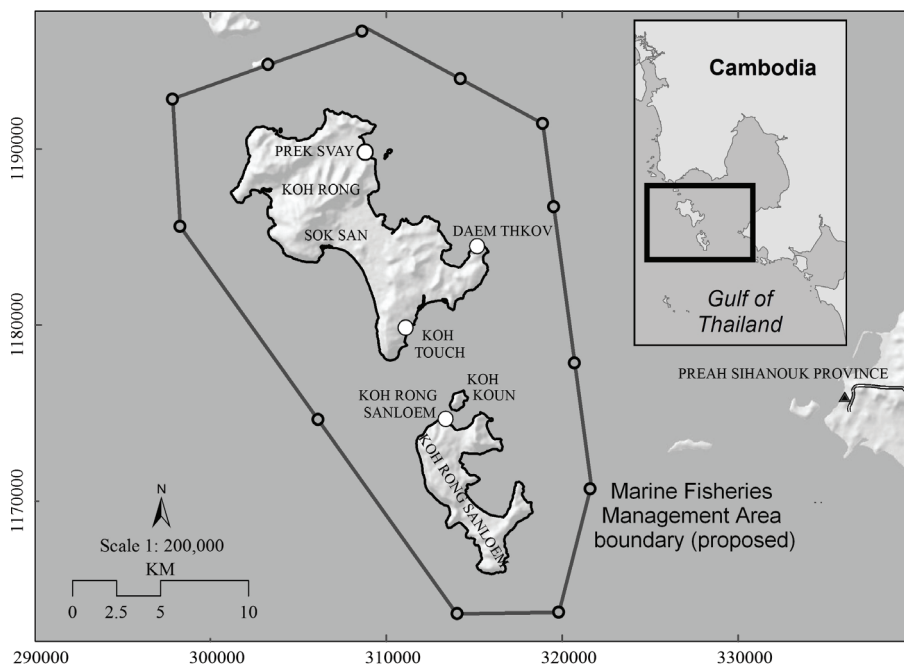


Fig. 1 Location and proposed border of the Marine Fisheries Management Area in the Koh Rong Archipelago.

Invertebrates and impacts

Using a 20 x 5 m belt transect in every survey site, the surveyors recorded the presence of each invertebrate target species shown in Appendix 2.

Incidence of impacts (Appendix 3) was also noted in the same belt transects. Where trash was found, we assigned a 'scale of impact' for general trash, and a separate ranking for fishing trash: *low* = 1 incidence of trash; *medium* = 2–4 incidences of trash; and *high* = 5 or more incidences.

Substrates

Using a 20-m point-intercept transect in every survey site, substrate was recorded at 50 cm intervals and classified according to Appendix 5. Substrates were grouped into categories for analysis: *Hard coral* encompassed all living hard corals; *Rock* encompassed bedrock, dead coral and recently killed coral (these were not differentiated in this study); *Unamalgamated substrate* encompassed sand, silt and rubble; *Other living substrate* encompassed any other living organisms, including soft corals, sponges, nutrient indicator algae, anemones, corallimorphs, zoanthids, *Halimeda* spp. and tunicates.

New coral recruits (colonies of <5 cm diameter, with the exception of *Pseudosiderastrea* spp. which naturally grow in small colonies) were also noted.

Ancillary data

At every survey site, distance from the nearest river mouth and river mouth width were estimated, as were distance from the nearest settlement and the settlement's size (human population size). Water temperatures were measured before each dive, both at the surface and at a depth of 3 m, using personal

dive computers. Identification of indicator taxa was confirmed using Allen *et al.* (2005) and Humann & Deloach (2010), when necessary.

Data analysis

The field data were entered into a Microsoft Excel database. Shannon's Index was used to quantify the diversity of fish and invertebrates on each transect. Maps were created using the software ArcGIS (ESRI Inc., Redlands, California, USA).

Results

Fish

The relative abundance of fish was highly variable (Fig. 3a). There were noticeable 'hotspots' to the north-west of Koh Rong, where mean density ranged from 161–200 individuals per 500 m³. Fish densities across the remainder of Koh Rong were noticeably lower, with only 0–120 individuals per 500 m³.

Fish diversity, quantified using Shannon's Index, was more uniform across the survey area (Fig. 3b). Whilst Koh Koun and northern Koh Rong displayed the highest index scores, of between 1.75 and 2.00, the remainder of the survey sites displayed a lower but uniform range. It was noticeable that the northwest coast of Koh Rong had both high fish density and high diversity.

Local commercially valuable species were in the families Siganidae, Lutjanidae, Nemipteridae, Lethrinidae, Carangidae, Sphyraenidae, Scaridae, and Haemulidae. The Haemulidae (sweetlips) were the most common, comprising 31% of all commercial fish in the archipelago, followed by Siganidae (rabbitfish) at 24% and Lutjanidae (snapper) at 20%. These

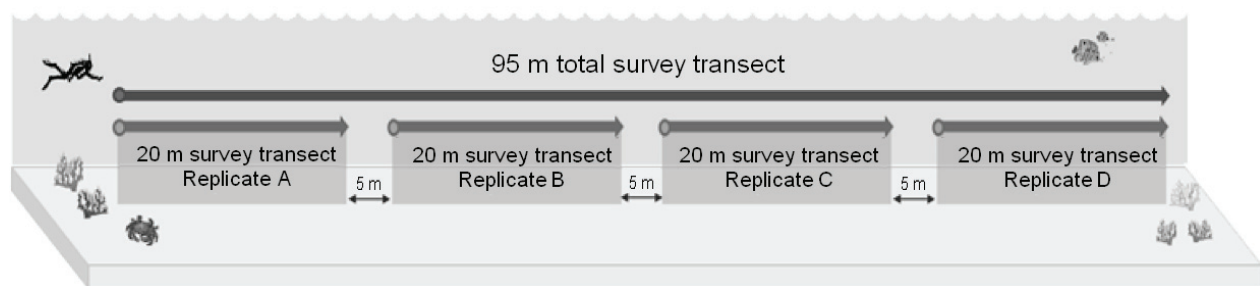


Fig. 2 Spatial distribution of transect replicates ($n = 4$) for each site (Mag Aoidh *et al.*, in prep.). The diagram is only indicative and not to scale.

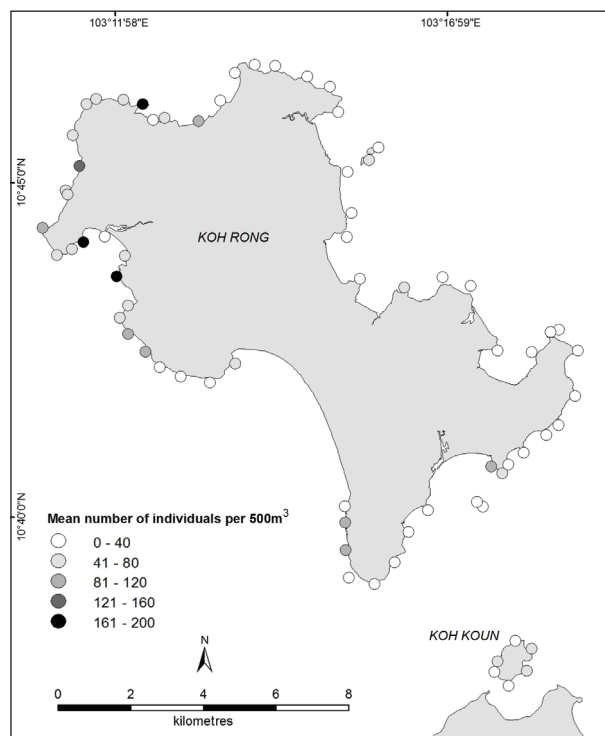


Fig. 3 (a) Fish density (individuals per 500 m³) in the Koh Rong Archipelago.

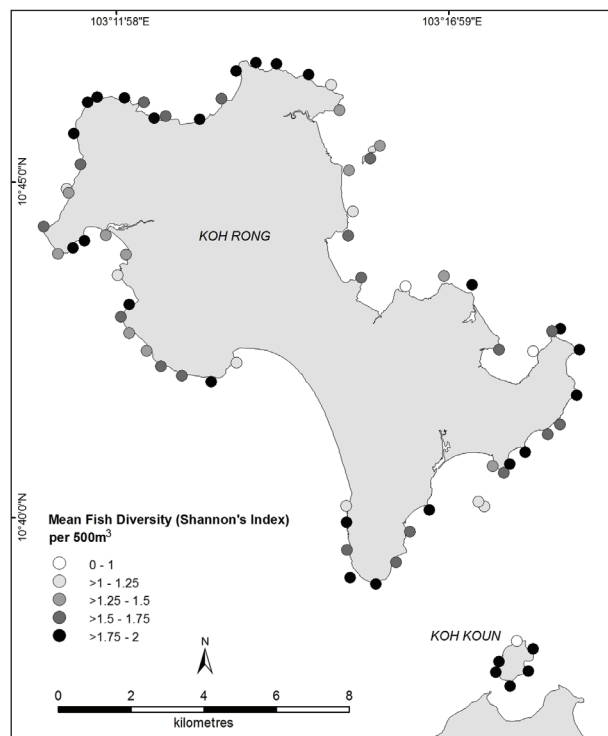


Fig. 3 (b) Fish diversity in the Koh Rong Archipelago, measured using Shannon's Index (per 500 m³).

three families were the most abundant commercially valuable fish ($n = 2,328$ fish).

Invertebrates

The overall density of invertebrates (pooling all species, but discarding the highly abundant *Diadema* spp. to avoid skewed outputs) was relatively similar across all sites with a typical range of 0–105 individuals per 100 m² (Fig. 4a). There was one notable exception to the south of Koh Rong, which had an elevated density of 141–175 individuals per 100 m².

Invertebrate diversity (Shannon's Index) was higher at the southern tip of Koh Rong (Fig. 4b). Invertebrate diversity was generally lower on the eastern sides of Koh Rong and Koh Koun, where there was a higher incidence of sandy/silty substrates and a lower incidence of rock/hard coral (Fig. 6).

Density of *Tridacna* spp. is a good indicator of water quality and reef health (Neo *et al.*, 2015) because clams are susceptible to increased water temperature, nutrient loading and poor water quality. During the four-year survey, 98 clams were noted, with a maximum of five clams per transect. *Diadema* spp. density was highly variable across the survey sites

($n = 6,965$ individuals): their density ranged from 0–7 individuals per m². Only four lobsters were seen during the survey, all on the same transect.

Impacts

With regard to physical impacts on the reef, there were two incidences of high impact fishing trash (such as ghost traps, fishing nets and rope), 10 incidences of medium impact fishing trash, and 24 incidences of low impact fishing trash (out of 70 sites). In addition, there were two incidences of high impact general trash (such as tin cans, clothing and construction materials), five incidences of medium impact general trash and 12 incidences of low impact general trash ($n = 70$ sites).

Even though we searched for signs of both black band and white band diseases, no incidences were noted during the four-year survey. Furthermore, there were only four incidents of anchor damage and one case of dynamite damage recorded during this study.

Substrates

Unamalgamated substrates were more common on the eastern side of Koh Rong and Koh Koun. Conversely, hard coral and rocky substrates were more common

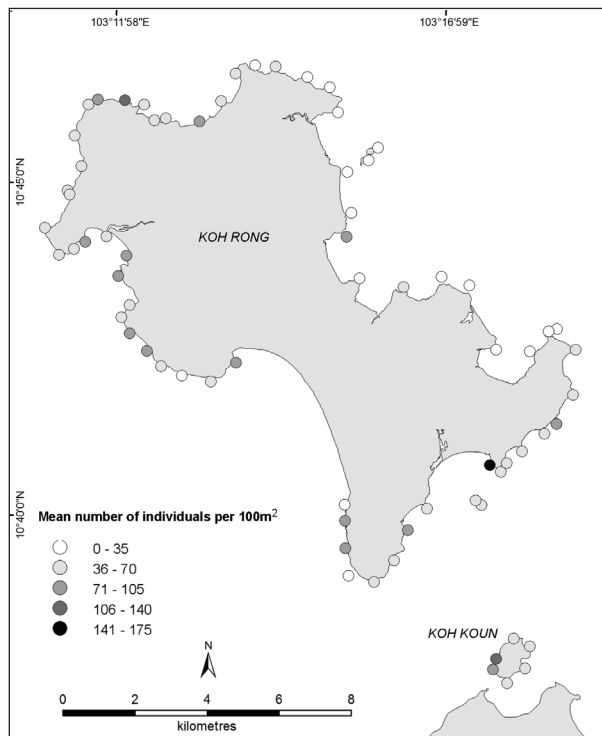


Fig. 4 (a) Invertebrate density (individuals per 100 m²) in the Koh Rong Archipelago, excluding *Diadema* spp.

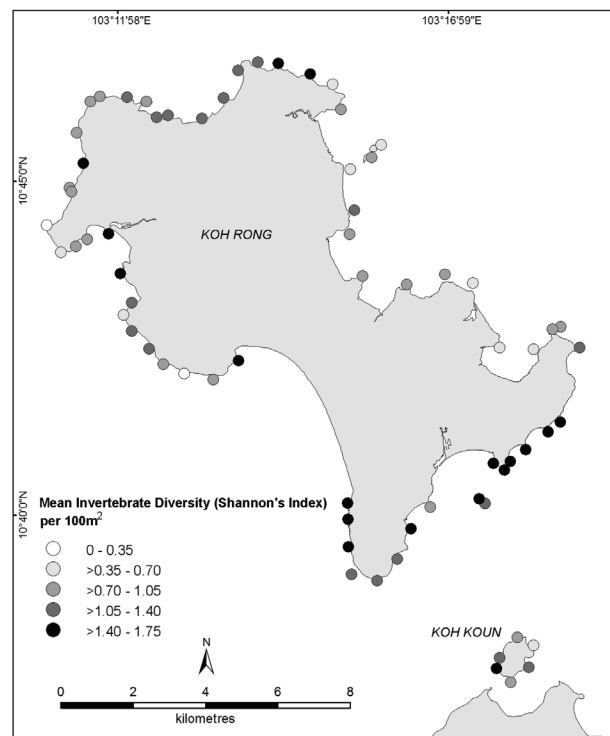


Fig. 4 (b) Invertebrate diversity in the Koh Rong Archipelago, measured using Shannon's Index (per 100 m²).

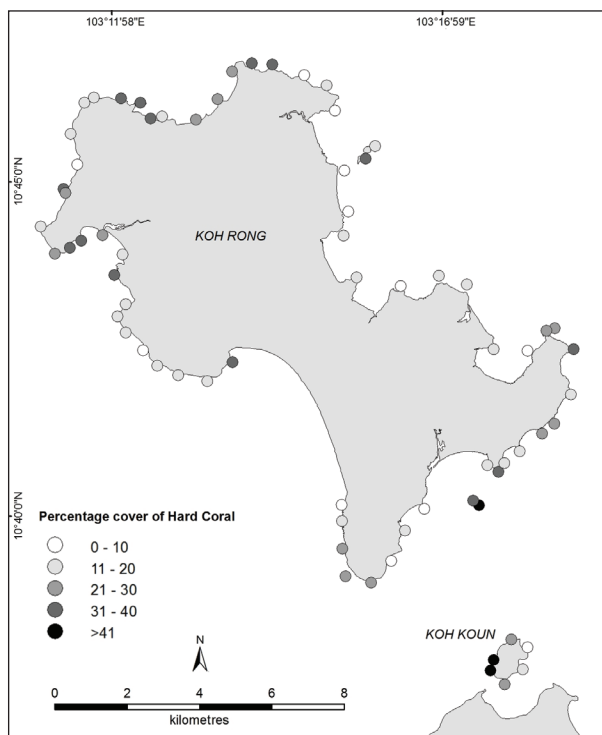


Fig. 5 Percentage cover of hard corals across the Koh Rong Archipelago.

on the northwestern reefs (Fig. 6). Koh Koun had low incidence of unamalgamated substrates and high hard coral cover (>41%), especially on the western reefs (Fig. 5).

Coral communities were dominated by massive and encrusting lifeforms (representing 47% and 25% of total hard corals respectively). Massive *Porites* spp. were the dominant coral species recorded (37% of total corals recorded). *Diploastrea heliophora* and *Favites* spp. were the next most common, at 10% and 9% respectively (Fig. 7).

Discussion

Fish

Fish abundance and diversity are good indicators of reef health (Hourigan *et al.*, 1988). A high abundance and high diversity of fish species indicates that the surrounding reef system is providing enough resources for their continued recruitment, growth and survival. Areas with fewer fish, such as the eastern side of Koh Rong, may be indicative of a poorer quality reef system or, on the other hand, it may also

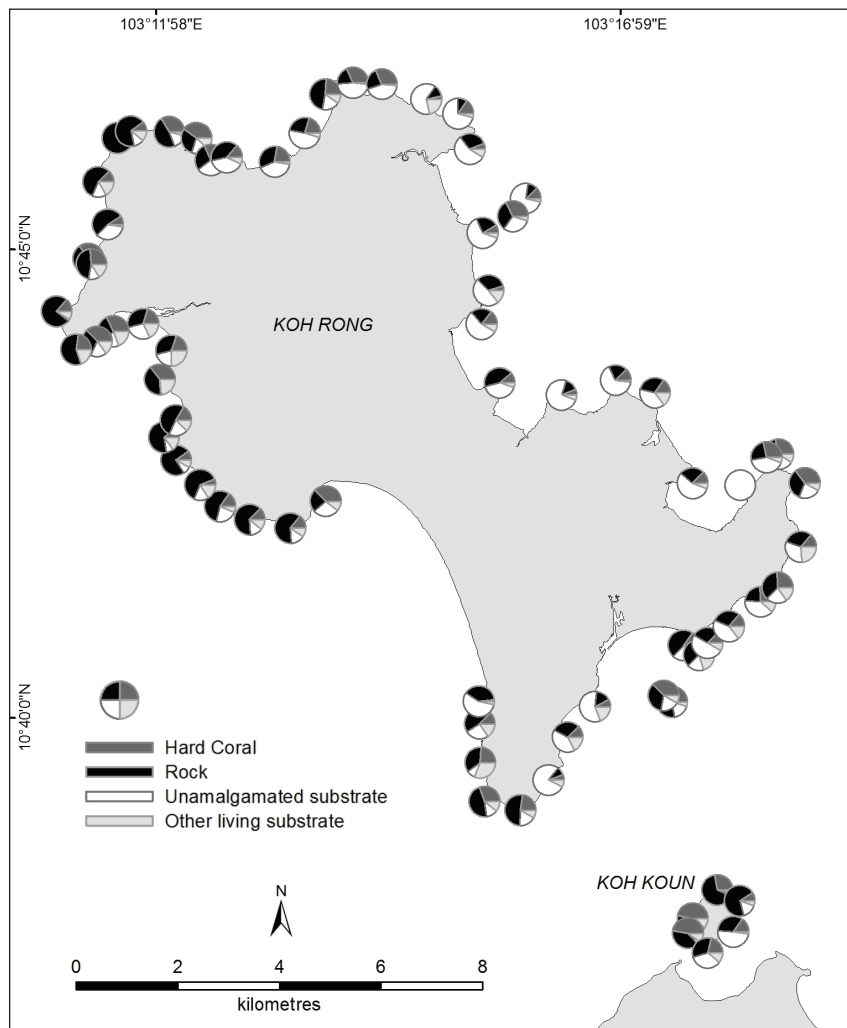


Fig. 6 Substrate composition across the Koh Rong Archipelago, showing rockier habitats to the west and more sandy/silty (unamalgamated) habitats to the east. Refer to the methods section for substrate classifications.

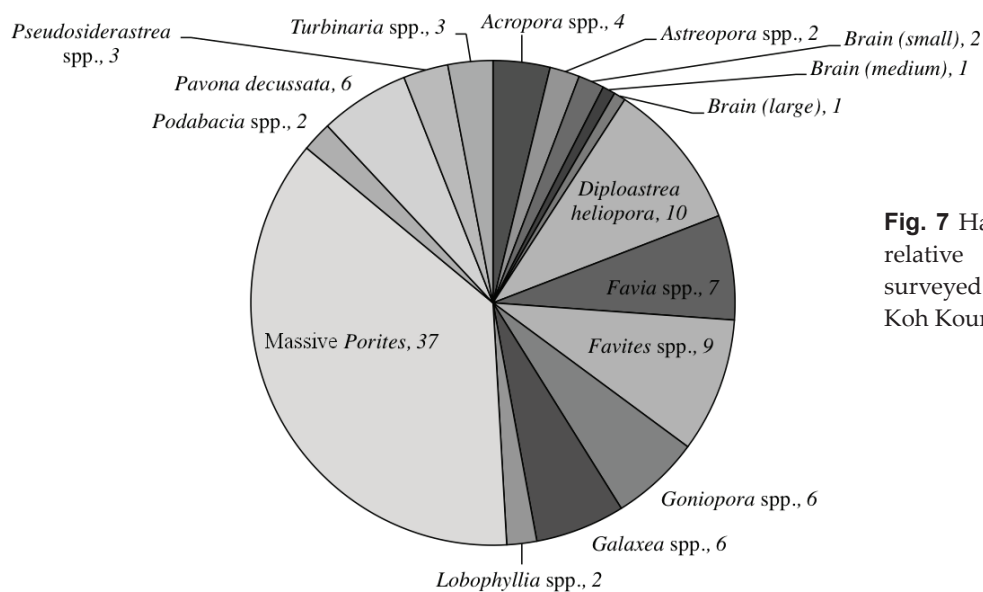


Fig. 7 Hard coral species and their relative abundance in the areas surveyed around Koh Rong and Koh Koun.

relate to natural variation in benthic topography and substrates. Many reef fish rely on corals and algae as a source of food: thus, if there is little coral growth there are likely to be fewer fish.

Sweetlips, rabbitfish and snappers are the most abundant commercially valuable fish species in the Koh Rong Archipelago. In comparison to published studies of reefs in other countries in Southeast Asia, the abundance of commercial fish in the Koh Rong Archipelago ranks first for parrotfish, second for groupers, and third for snappers and sweetlips (Table 1). This could be an important sign of good reef health, demonstrating that certain commercial species are not being overharvested. In Cambodia, local communities rely on reef fish as a source of income and food (Ouk *et al.*, 2011). The species caught reportedly have not changed over time, but in interviews with small-scale fishers, 95% perceived that their catches had declined (Leng, 2013), highlighting the urgency of avoiding further declines.

Invertebrates

Invertebrates are fundamental to the health of a coral reef. They enhance the resilience of reef ecosystems (Hoegh-Guldberg *et al.*, 2007), and through feeding on algae, act as ecosystem engineers, enabling the recruitment of crustose coralline algae and coral larvae (Todd, 1998).

Invertebrate density and diversity are relatively uniform across the archipelago, with the exception of one notably higher density site to the south of Koh Rong. Whilst invertebrate density appeared similar to sites surveyed in other parts of Southeast Asia (Table 2), we expected to see more holothuroids (sea cucumbers) on the Cambodian reefs. Sea cucumbers are integral to coral reef health because they recycle nutrients through a process of sediment bioturbation (Thorne *et al.*, 2013). Holothurians and *Tridacna gigas* are regarded as useful indicators of anthropogenic threats because trends in their abundance reflect

Table 1 The density of fish (individuals per 500 m³) in key commercial families in four Southeast Asian countries and the Koh Rong Archipelago in Cambodia. 'Rank' indicates the archipelago's position in relation to the other countries (on a scale of 1–5, where 1 is highest) for each taxon. Data for the other countries were collated from Chelliah *et al.* (2012).

Fish	Koh Rong Archipelago	Brunei	Philippines	Thailand	Malaysia	Rank
Lutjanidae (snappers)	7	1.45	2.14	20.63	11.13	3
Serranidae (groupers)	2	0.19	0.18	7.68	0.71	2
Chaetodontidae (butterflyfish)	3	1.73	12.57	6.2	4.47	4
Haemulidae (sweetlips)	0.13	0.26	0.06	0.02	0.25	3
Scaridae (parrotfish)	12	1.63	2.19	6.34	2.53	1

Table 2 The density of invertebrates (individuals per 100 m²) in four Southeast Asian countries and the Koh Rong Archipelago in Cambodia. 'Rank' indicates the archipelago's position in relation to the other countries (on a scale of 1–5, where 1 is highest) for each taxon. Data for the other countries were collated from Chelliah *et al.* (2012).

Invertebrates	Koh Rong Archipelago	Brunei	Philippines	Thailand	Malaysia	Rank
<i>Diadema</i> spp.	94	0.02	19.45	94.74	35.36	2
<i>Echinotrix</i> spp.	0.02	0	0.01	0	0	1
<i>Holothuria</i> spp.	0	0.5	0.02	1.61	1.56	5
<i>Acanthaster planci</i>	0.04	0.03	0.39	0.15	0.21	3
Nephropidae	0.03	0.04	0.03	0.2	0.01	3
<i>Tridacna gigas</i>	2	0.17	2.5	14.96	1.72	3

intensity of harvesting (Hopkins, 2009). *Tridacna* spp. have ecologically important roles as food providers, sources of shelter and reef builders (Neo *et al.*, 2015), and therefore a high density of these animals could be a good sign of a healthy reef. A deficit of *Tridacna* spp., on the other hand, could indicate a reef with reduced ecological functionality (Neo *et al.*, 2015).

The relatively high abundance of nudibranchs across the Koh Rong Archipelago and recent observations of nudibranch recruitment (Thorne, pers. obs.) indicate that water temperatures have remained comparatively stable since the May–October 2010 bleaching event (van Bochove *et al.*, 2011). Many nudibranch species have high thermal sensitivity (Clark, 1975), and overheating leads to lower fertility, bleaching of internal zooxanthellae, and death. Water temperature should be monitored using data loggers to ascertain the temporal trends. If another bleaching event occurs, these data would increase understanding of the reefs' resilience to, and potential impacts from, one of the causes of coral bleaching.

Diadema spp. (long-spined sea urchins) are important grazers of algae on coral reefs (Hoegh-Guldberg *et al.*, 2007). According to data collected during this study, sites across the Koh Rong Archipelago have up to seven individuals per m². This could be a sign that fishing pressure is high and herbivorous fish have been removed, resulting in an explosion of the urchin population. Or this could be a sign of high algal growth rates, thus supporting a high-density population of urchins. The urchins feed upon filamentous and macro algae, creating space for the recruitment of coral larvae (Carpenter, 1990). *Diadema* spp. show a preference for sheltered habitats among boulders where they can avoid predators and strong currents (Foster, 1987).

Substrates

There is a greater abundance of silt, sand and rubble on the eastern coastline of this archipelago, with a greater incidence of hard coral and rock substrates to the west. The abundance of invertebrates and fish mirrors this pattern. With fewer rocky outcrops for coral larvae to recruit upon, and fewer coralline structures for invertebrates to inhabit, there are consequently fewer fish. This is likely to be due to a paucity of their required food sources. Herbivorous fishes, like herbivorous invertebrates, require an abundance of specific algae in line with their digestive capabilities (Ogden & Lobel, 1978). Many of these algae grow on rocky substrates.

Hard corals are known to settle most efficiently on the upper surface of a rocky, coralline substrate, yet it is also known that the survival of coral recruits is greater on vertical surfaces (Birkeland, 1977). The benthic topography of Koh Koun and northwestern Koh Rong, where coral abundance is highest, is characterised by boulder-like and rocky outcrops. Based on the theory that sizeable horizontal and vertical surfaces promote the settlement of coral larvae, spatial variation in substrates may explain why hard coral cover and reef fish diversity varies from east to west in this archipelago (Thaung, 2013). Supporting this interpretation is evidence that coral larvae have very poor survival rates on unconsolidated substrates (Richmond, 1997), which are more predominant on the eastern side of the archipelago.

According to data from this study, coral composition leans heavily towards the massive growth forms, namely *Porites* spp., *Diploastrea heliophora*, *Favites* spp. and *Favia* spp. These are more stress-tolerant than branching corals (Edinger & Risk, 2000), such as *Acropora* spp. and *Tubastrea micrantha*, which are much scarcer in the archipelago. Reef systems that have an abundance of massive, stress-tolerant growth forms usually have few branching or foliose corals (Rodgers, 1990) as a result of sedimentation (Pastorak & Bilyard, 1985). An initial study of sedimentation around Koh Rong Sanloem (Yim, 2014) found that sediment rates appeared to vary greatly between sites. The greater incidence of massive corals in the Koh Rong Archipelago may be a result of high rates of sedimentation, preventing branching corals from thriving in these waters, or may be indicative of the boulder-like substratum, which tends to favour the recruitment of massive and encrusting corals (Birkeland, 1977). Yim (2014) also noted that turbidity might have more effect on reef health than sedimentation rates.

Coral and invertebrate diversity were found to be relatively uniform across the archipelago. In areas where corals are able to recruit successfully—i.e. where rocky and consolidated substrates are prevalent—their abundance and diversity appear stable. Fish diversity is also uniform throughout the archipelago. What is of concern, however, is the generally low density of fish found throughout the archipelago. There is enough reef habitat for the fish to reside in, enough invertebrates and algae for them to feed upon, and few natural large predators. As such, it could be assumed that the only remaining explanation for the low fish density is human exploitation through overfishing. Parrotfish are still abundant in the archi-

pelago, however, in comparison to other countries within Southeast Asia (Table 1), but are not necessarily targeted by local fishers. The shortage of commercially important holothurians and certain benthic invertebrates, such as lobsters, could be indicative of overharvesting (van Bochove *et al.*, 2011; Table 2). The noticeable lack of lobsters in our survey area, despite large areas of apparently suitable rocky habitat, could be due to ongoing overfishing in the area.

Implications of findings

The Koh Rong Archipelago is utilised by numerous stakeholders including businesses (mainly dive centres and coastal resorts) and local communities. Leaseholders now have agreements to develop large sections of the islands, which will undoubtedly have an impact on the adjacent reef systems over the coming years, such as increased terrestrial run-off (Skopal *et al.*, 2010). Tourism in the area is on the increase (Mulligan & Longhurst, 2014) and recreational diving is becoming ever more prevalent. This presents both threats and opportunities for the sustainable use of marine habitats, and the FiA hope to strengthen fisheries management by means of existing legislation in an attempt to protect the reefs within the archipelago. This will be enacted in the form of the Koh Rong Archipelago MFMA.

Data presented in this paper have already been used by the FiA to develop a zonation map to improve management of activities within the MFMA (Boon *et al.*, 2014). The proclamation of the MFMA will be a significant step forward in promoting sustainable resource use and may allow currently overexploited fauna to recuperate and their populations to expand.

Measuring the effectiveness of the MFMA is key for the FiA to determine progress towards their national target of 500 ha of coral reefs under an “appropriate form of sustainable management”. Changes in reef health and species composition can take time (Savage *et al.*, 2013) and, in the short-term, resource users are likely to be adversely affected (Scholz *et al.*, 2004; Mascia *et al.*, 2010; Pedju & Orams, 2013). A recent study in this area of finfish fishers and gleaners found they generally expected conservation zones in the MFMA to increase the number and size of fish, although 21.5% of interviewers thought conservation zones would negatively affect their access to fishing sites (On, 2014).

To monitor changes in reef health around the Koh Rong Archipelago after the MFMA is established, we

recommend that permanent transects are deployed at selected sites. The sites can be determined in accordance with the FiA zonation scheme and with the specific objectives and indicators for the MFMA. All data from the permanent transects, and the data from this study, should be openly available to the FiA for their use and dissemination. To facilitate this, training is being provided by the Song Saa Foundation to educate government officials in data analysis and Reef Check survey methods. The vision of the MFMA is not only to conserve threatened species in the area, such as the Critically Endangered hawksbill turtle *Eretmochelys imbricata*, but to conserve key habitats (mangroves, corals and seagrasses) and establish sustainable fishing practices to safeguard commercial fish species.

Baseline datasets are vital to determine management effectiveness and to inform future management actions (Savage *et al.*, 2013). Quantifying the changes in reef health and population composition may also help to show resource users and stakeholders that there are significant benefits to strengthening marine protection, despite potential short-term commercial losses for fishers (reduced access to key fishing grounds) and dive centres (reduced access to favourite dive sites). With Koh Koun displaying a high diversity of fish and invertebrates, and a high abundance of corals, this is certainly a hotspot for marine life in the archipelago. Likewise, the northwest of Koh Rong also demonstrated a high abundance and diversity of key taxa. These areas therefore merit particular attention to ensure their reefs are adequately protected.

Knowledge of specific ecological phenomena in the area is still relatively limited. For example, the locations of fish spawning sites, coral recruitment success, and the impacts of sedimentation rate and turbidity on coral reefs require further study. Filling these knowledge gaps would provide further insights into the ecological stability and resilience of the archipelago's reefs, and would aid future management strategies. The composition of fish species and fish assemblage patterns vary greatly between near shore habitats (Sichum *et al.*, 2013), it is also important to collect biodiversity and health data in the habitats adjacent to the coral reefs, namely mangroves and seagrasses. Whilst some studies have already been completed for these habitats (e.g. Leng *et al.*, 2014; Mulligan & Longhurst, 2014), there is need for further research to ascertain the health of these important ecosystems.

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Appendix 1

Checklist of target fish in the Koh Rong Archipelago, showing mean family density (individuals per 500 m³) on transects in 70 sites, and whether the taxon was confirmed to be present during the study

Fish	Mean family density per 500 m ³	Observed during study
Lutjanidae (Snapper)	7	Yes
<i>Lutjanus decussatus</i>		Yes
<i>Lutjanus bohar</i>		Yes
<i>Lutjanus fulvus</i>		Yes
(All other Lutjanidae)		Yes
Nemipteridae (monocle bream)	4	Yes
<i>Scolopsis bilineatus</i>		Yes
<i>Scolopsis ciliatus</i>		Yes
Lethrinidae (emperors)	0.2	Yes
Carangidae (jack)	0.1	Yes
Sphyraenidae (barracudas)	1	No
<i>Sphyraena obtusata</i>		Yes
<i>Sphyraena barracuda</i>		Yes
(All other Sphyraenidae)		No
Serranidae (groupers)	2	Yes
<i>Cromileptes altivelis</i>		Yes
<i>Cephalopholis boenak</i>		Yes
<i>Cephalopholis argus</i>		Yes
<i>Cephalopholis formosa</i>		Yes
<i>Plectropomus areolatus</i>		Yes
<i>Epinephelus merra</i>		Yes
(All other Serranidae)		No
Sygnathidae (seahorses/pipefish)	0	No
Muraenidae (moray eels)	0	No
Chaetodontidae (butterflyfish)	3	Yes
<i>Chelmon rostratus</i>		Yes
<i>Heniochus acuminatus</i>		Yes
<i>Chaetodon octofasciatus</i>		Yes
Siganidae (rabbitfish)	8	Yes
<i>Siganus corallinus</i>		Yes
<i>Siganus virgatus</i>		Yes
<i>Siganus javus</i>		Yes

Fish	Mean family density per 500 m ³	Observed during study
<i>Siganus guttatus</i>		Yes
Pomacentridae (damselfish)	0.1	Yes
Amphiprioninae		Yes
Haemulidae (sweetlips)	0.4	Yes
Hemiscyliidae (bamboo sharks)	0	No
Dasytidae (blue-spotted ribbontail rays)	0	No
Holocentridae (soldierfish/squirrelfish)	3	Yes
Mullidae (goatfish)	1	Yes
Scaridae (parrotfish)	12	Yes

Appendix 2

Checklist of target invertebrate taxa documented in the Koh Rong Archipelago, showing mean invertebrate density (individuals per 100 m²) on transects in 70 sites, and whether the taxon was confirmed present during the study.

Invertebrates	Mean incidence per 100 m ²	Observed during study
Annelida (Segmented worms)		
<i>Spirobranchius</i> spp.	26	Yes
<i>Sabellastarte</i> spp.	8	Yes
Platyhelminthes (Flatworms)	0.3	Yes
Cephalopoda (Cephalopods)		
Teuthida (Order)	0	No
Octopoda (Order)	0	No
<i>Sepia</i> spp.	0	No
Gastropoda (Gastropods)		
<i>Calliosoma</i> spp.	0	No
<i>Drupella</i> spp.	6	Yes
Nudibranchia	3	Yes
Cypraeidae	2	Yes
(All other gastropods)	5	Yes
Bivalvia (Bivalves)		
<i>Tridacna</i> spp.	2	Yes
Crustacea (Crustaceans)		
<i>Stenopus hispidus</i>	0	No
Nephropidae	0.2	Yes

Invertebrates	Mean incidence per 100 m ²	Observed during study
Echinodermata (Echinoderms)		
<i>Acanthaster planci</i>	0.1	Yes
<i>Culcita novaguinea</i>	0.1	Yes
<i>Protoreaster nodosus</i>	0	No
<i>Diadema</i> spp.	94	Yes
<i>Echinotrix</i> spp.	0.3	Yes
Crinoidea	1	Yes
<i>Thelenota ananas</i>	0	No
<i>Stichopus chloronotus</i>	0	No
<i>Holothuria edulis</i>	0	No

Appendix 3

Incidences of impacts recorded on 20 x 5 m belt transects in 70 survey sites in the Koh Rong Archipelago..

Impacts	Total incidences during study	Observed during study
Anchor damage	4	Yes
Dynamite damage	1	Yes
General trash	111	Yes
Fishing trash (nets, rope, traps, etc.)	217	Yes
Coral disease (white band and black band)	0	No

Appendix 4

Checklist of target corals in the Koh Rong Archipelago, showing the mean frequency of corals on transects and whether the taxon was documented during the study.

Corals	Mean incidence per 20 m	Observed during study
<i>Acropora</i> spp.	0.4	Yes
<i>Astreopora</i> spp.	0.1	Yes
<i>Porites</i> spp.	2.6	Yes
<i>Goniopora/Alveopora</i> spp.	0.4	Yes
<i>Pavona decussata</i>	0.4	Yes
<i>Ctenactis echinata</i>	2.1	Yes

Corals	Mean incidence per 20 m	Observed during study
<i>Herpolitha limax</i>	0	No
<i>Polyphyllia talpina</i>	0	No
<i>Podabacia</i> spp.	0.1	Yes
<i>Galaxea</i> spp.	0.5	Yes
<i>Pectinia</i> spp.	0	No
<i>Lobophyllia</i> spp.	0.1	Yes
<i>Diploastrea heliopora</i>	0.7	Yes
<i>Echinopora</i> spp.	0.04	Yes
<i>Euphyllia</i> spp.	0	No
<i>Plerogyra</i> spp.	0	No
<i>Tubastrea micrantha</i>	0	No
<i>Turbinaria</i> spp.	0.2	Yes
<i>Pseudosiderastrea</i> spp.	0.2	Yes
Brain coral (small, medium, large)	0.4	Yes (all three)
<i>Tubipora</i> spp.	0	No
<i>Millepora</i> spp.	0	No
<i>Heliopora</i> sp.	0	No
<i>Favia</i> spp.	0.5	Yes
<i>Favites</i> spp.	0.7	Yes

Appendix 5

Checklist of target substrates in the Koh Rong Archipelago, showing whether the substrate was observed during the survey.

Substrates	Observed during study	Substrates	Observed during study
Rock (geo-bedrock and dead coral)	Yes	Sponge	Yes
Rubble	Yes	Recently Killed Coral (RKC)	Yes
Sand	Yes	Anemone	Yes
Silt	Yes	Zoanthids	Yes
Nutrient Indicator Algae (NIA)	Yes	Corallimorphs	Yes
Hard coral (detailed above)	Yes	<i>Halimeda</i> spp.	No
Soft coral	Yes	Tunicates	Yes