The status of coral reefs and seagrass meadows in the Kep Archipelago, Cambodia

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មូលន័យសង្ខេប

បរិស្ថានសមុទ្រនៅក្នុងប្រទេសកម្ពុជាទទួលរងការគំរាមកំហែងដោយសកម្មភាពនេសាទខុសច្បាប់ ដែលបានបំផ្លិចបំផ្លាញទីជម្រក និងការដកហូតធនធានហួសកម្រិត។ ពីឆ្នាំ២០១៤ ដល់ ២០១៥ និងឆ្នាំ២០១៧ ពួកយើងបានធ្វើការអង្កេតទៅលើស្ថានភាពផ្កាថ្ម ចំនួន០៣កន្លែងគឺនៅ កោះសេះ កោះម៉ាក់ប្រាង និងកោះអង្ក្រង ស្ថិតនៅក្នុងប្រជុំកោះកែប ហើយក្នុងឆ្នាំ២០១៨ យើងបានប្រមូលទិន្នន័យមូលដ្ឋាននៃស្មៅសមុទ្រនៅតាមកោះសេះ កោះពូ និងកោះទន្សាយ។ តាមការស្រាវជ្រាវក្នុងឆ្នាំ២០១៤ ដល់ ២០១៥ បានបង្ហាញពីភាពអន់ថយនៃជីវិតសត្វត្រីដែលរស់នៅក្នុងតំបន់ផ្កាថ្ម។ ទោះជាយ៉ាងណា ដង់ស៊ីតេ និងភាពចម្រុះរបស់ត្រីមានការកើនឡើងគួរឱ្យកត់សម្គាល់ក្នុងរយៈពេល០៤ឆ្នាំកន្លងមកនេះ ហើយក៏មានការកើនឡើងផងដែរនូវតម្លៃផលនេសាទគោលដៅ ដែលមានដូចជា ក្រុមត្រី lutjanids serranids carangids និង haemulids។ ពពួកត្រីប្រភេទតិណាសី មិនសូវប្រទះឃើញទេ ហើយប្រភេទកាំប្រមាសមុទ្រ(តាអន់ *Diadema* spp.) នៅតែជាប្រភេទតិណាសីដែលសម្បូរជាងគេ។ ទោះជាបែបនេះក្តី ក្រុមត្រីsiganids មានការកើនឡើងគួរឱ្យកត់សម្គាល់នៅតំបន់ផ្កាថ្មនៃកោះសេះ។ ការលូតលាស់របស់សារាយសមុទ្រមាឌធំ(macroalga) មានកម្រិតទាបនៅឆ្នាំ២០១៧(គ្របដណ្តប់១%) ហើយផ្កាថ្មរឹង(hard corals) គឺជាស្រទាប់លេចធ្លោជាងគេក្នុងគ្រប់ករណីទាំងអស់(គ្របដណ្តប់៤២.៩%)។ តំបន់ស្មៅសមុទ្រ០៣កន្លែងត្រូវបានដៅក្នុងផែនទី។ ស្មៅសមុទ្រទាំងនោះគ្របដណ្តប់លើផ្ទៃដីប្រមាណ ៧.៥គម² ដែលក្នុងនោះមានស្មៅសមុទ្រចំនួន០៩ប្រភេទត្រូវបានកត់ត្រា។ ស្មៅសមុទ្រប្រភេទ*Thalassia hemprichii* ជាប្រភេទដែលមានច្រើនជាងគេនៅក្នុងតំបន់នីមួយៗ គឺមានរហូតដល់៧៦%នៃសំណាកទាំងអស់។ យុទ្ធសាស្ត្រអភិរក្សតាមការលើកកម្ពស់ការស្តារប្រព័ន្ធអេកូឡូស៊ីសមុទ្រនៅប្រជុំកោះកែបត្រូវបានអនុវត្តនៅក្នុងឆ្នាំ២០១៨ ដោយរាប់បញ្ចូលទាំងការបង្កើតដែនគ្រប់គ្រងជលផលសមុទ្រ និងការស្តារឡើងវិញយ៉ាងសកម្ម និងកិច្ចផ្តួចផ្តើមឲ្យមានការគ្រប់គ្រងសហគមន៍។ ការសិក្សាតាមដានជាបន្តគឺជាតម្រូវការចាំបាច់ដើម្បីវាយតម្លៃអំពីប្រសិទ្ធភាពនៃកិច្ចខំប្រឹងប្រែងកន្លងមក។ យើងសូមណែនាំឱ្យមានការសិក្សាពីផលប៉ះពាល់ និងការសិក្សាស្រាវជ្រាវពីប្រភេទដែលរស់នៅតាមតំបន់ស្មៅសមុទ្រ ព្រមទាំងសិក្សាតាមដានពីសកម្មភាពនេសាទខុសច្បាប់ ដើម្បីឈានទៅដល់ការយល់ដឹងកាន់តែប្រសើរឡើងអំពីស្ថានភាព និងកត្តាគំរាមកំហែងលើបរិស្ថានសមុទ្រនៅប្រជុំកោះកែប។

Abstract

Cambodia's marine environment is threatened by illegal fishing activities that destroy habitat and overexploit resources. We investigated the status of three coral reefs fringing the Koh Seh, Koh Mak Prang and Koh Angkrong islands within the Kep Archipelago in 2014/15 and 2017 and collected baseline data on seagrass meadows adjacent to the Koh Seh, Koh Pou and Koh Tonsay islands in 2018. Surveys in 2014/15 revealed a paucity of fish life on reefs. However, total fish density and diversity increased significantly within four years and included increases of high-value fishery targets such as lutjanids, serranids, carangids and haemulids. Fish herbivores were poorly represented and the urchin *Diadema* sp. remained the dominant herbivore over time. Despite this, siganids increased significantly on the Koh Seh reef. Total

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macroalgal growth was relatively low in 2017 (1% cover) and hard corals were the dominant substrate in all cases (42.9% cover). Three seagrass meadows were mapped. These covered a total estimated area of 7.5 km^2 where nine species of seagrass were recorded. *Thalassia hemprichii* was dominant in each meadow, being present in 76% of samples. A conservation strategy to promote the recovery of marine ecosystems in the Kep Archipelago was implemented in 2018 and included the establishment of a marine fisheries management area and active restoration and community management initiatives. Monitoring is required to assess the effectiveness of this effort over time. We recommend this include impact assessments and species surveys in seagrass meadows and monitoring of illegal fishing activities to better understand the status of the marine environment of the Kep Archipelago and threats to this.

Keywords

Fishing, Gulf of Thailand, marine angiosperms, reef ecosystems.

Introduction

Fishery resources in the South China Sea (including the Gulf of Thailand) have been exploited unsustainably for decades, resulting in loss of habitat and biodiversity and altered trophic structures (Chou *et al*., 2002; UNEP, 2007b; Teh *et al*., 2017). Productivity has been particularly threatened by intensive inshore fishing and degradation of key ecosystems that support fisheries (UNEP, 2007b; Vo *et al*., 2013; Rogers *et al*., 2018). Destructive fishing methods have been identified as one of the most important drivers of degradation of marine ecosystems in the region, particularly for their contribution to the loss of coral reefs and seagrass meadows (Vo *et al*., 2013).

Coral reefs and seagrass meadows are vital to the livelihoods of many people that inhabit coastal provinces in Cambodia (UNEP, 2007a, 2008b; FAO, 2011). Small-scale fishers and commercial fisheries operate within the shallow inshore area, catching species associated with these habitats. High and low-value fish, shrimp, crab and squid are the main targets, with reef fishes being among the most valuable (UNEP, 2007a; UNEP, 2007b; Teh *et al*., 2014). Although marine fisheries only constitute approximately 20% of Cambodia's total annual fisheries production, with the majority coming from inland freshwater fisheries (Gillett, 2004; Paul & Keothyda, 2017), illegal fishing by national and foreign vessels is common and total marine fisheries catches have been estimated to be over twice the number of recorded landings (Teh *et al*., 2014). The Cambodian Fisheries Law (2006: Article 52) prohibits fishing or any form of exploitation that damages or disturbs the growth of seagrass or coral reefs. It also prohibits the use of destructive methods, including trawling of inshore fishing areas between the shore and the 20 m isobath (Article 49). However, enforcement of regulations has been generally poor and trawling and push net techniques remain among the most immediate threats to seagrass meadows. Over-fishing and destructive practices such as dynamite and cyanide fishing are also considered to present major threats to coral reefs (UNEP, 2007a, 2008b; Bobenrieth & Sun, 2012; Razak Latun *et al*., 2016; Paul & Keothyda, 2017).

Habitat destruction and other pressures have caused significant declines to Cambodia's inshore fisheries, which have been increasingly fished over time (Gillet, 2004; UNEP, 2007b; Leng, 2013). It is believed that the country's marine fisheries began declining in the 1980s when the number of trawling vessels expanded (Teh *et al*., 2014). A second expansion occurred in 1999–2000, which resulted in a high concentration of trawlers along Cambodia's coast (Gillett, 2008). As a consequence, the small-scale fishers that once dominated the inshore fishing areas are now in conflict with illegal fishers over space and resources (UNEP, 2007b; Sherman *et al*., 2007; Gillett, 2008).

The Cambodia-based NGO, Marine Conservation Cambodia (MCC) was invited by the Cambodian Fisheries Administration (FiA) to undertake research and monitoring on coral reef ecosystems and assist with the development and implementation of a conservation strategy in Kep Province in 2014. Kep is the smallest of Cambodia's four coastal provinces in terms of area and human population, although it has a relatively high population density. The mainland area is surrounded by Kampot Province, whereas the Kep Archipelago shares its eastern and southern borders with Vietnam's territorial sea. The archipelago includes 13 islands, most of which include fringing coral reefs, and has some of the most extensive and diverse seagrass meadows remaining in Cambodia (UNEP, 2008b; Vibol *et al*., 2010). Coral reefs and seagrass meadows share trophic linkages with mangroves and collectively form a significant part of the area's broader network of ecosystems (Davis *et al*., 2014). These habitats collectively provide food security and income for a large portion of the local population (UNEP, 2007a, 2008a,b; Bobenrieth & Sun, 2012; Sopanha *et al*., 2012). Crab, shrimp and finfish fisheries are among the most important fisheries in Kep, with coral reefs supporting the most valuable species (UNEP, 2007b; Rizvi & Singer, 2011). UNEP (2007a) surveyed reefs fringing the Koh Pou island group in the Kep Archipelago in 2013 and found that high-value and common fisheries targets were lacking, whereas benthic assemblages appeared to be in better condition. The depleted fish life was largely attributed to the effects of seaweed farming rather than over-fishing, although signs of destructive fishing were observed along with discarded fishing gears. The current status of reefs in the Kep Archipelago is unknown and to our knowledge, research on seagrass has yet to be conducted.

This study documents the status of three fringing reefs in the Kep Archipelago between 2014/15 and 2017 and presents baseline data on benthic assemblages and seagrass meadows collected in the archipelago in 2017 and 2018. We assess changes in the density and diversity of reef fish over time, in addition to selected indicator organisms and major functional groups of herbivore. We conclude by relating our results to conservation efforts and illegal fishing pressures in the Kep Archipelago, and by outlining a conservation strategy that came to fruition in 2018, including the establishment of the Kep Marine Fisheries Management Area (MFMA).

Methods

Study area and locations

First proposed in 2016, the Kep MFMA was established in April 2018 and encompasses 113 km^2 (Fig. 1). Three fringing reefs within the MFMA were selected by MCC and FiA based on their perceived condition. These appeared to be among the least degraded in the archipelago and were dominated by hard coral and so were regarded as potentially important to protect and most likely to respond to conservation action.

The three reefs varied in size and fringe the Koh Seh (Koh Ach Seh), Koh Mak Prang and Koh Angkrong islands (Fig. 1; Table 1). Koh Seh and Koh Angkrong are situated approximately 1 km apart and both are located approximately 3 km from Koh Mak Prang.

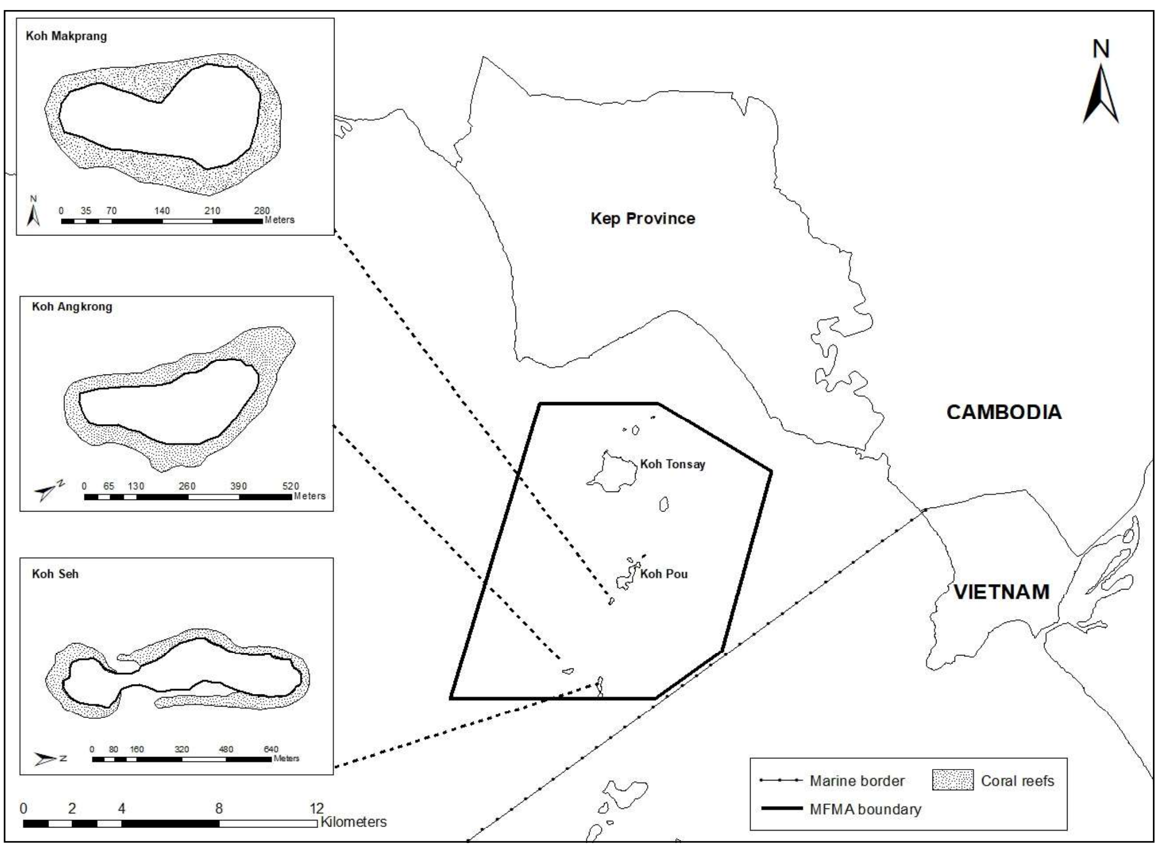

Fig. 1 The Kep Archipelago including the Koh Seh, Koh Mak Prang, Koh Angkrong, Kou Pou and Koh Tonsay islands.

Table 1 Survey effort in the Kep Archipelago in 2014/2015 and 2017.

Reef	Area (km^2)	2014/15				2017			
		Sites	Replicates	Surveys	Period	Sites	Replicates	Surveys	Period
Koh Seh	0.076	20	1	80	Mar 14	5	3	60	Apr−Dec
Koh Mak Prang	0.023	7	1	28	Jan 15	3	3	36	Apr−Aug
Koh Angkrong	0.059	9	1	36	Jan–Feb 15	3	3	36	Feb−Apr

Three seagrass meadows were selected on the basis of their being the main meadows known to local fishers within the archipelago. These are located adjacent to the Koh Seh, Koh Pou and Koh Tonsay islands. Koh Seh is situated approximately 3.8 km from Koh Pou and 7.7 km from Koh Tonsay. Koh Pou and Koh Tonsay are situated approximately 2.8 km apart (Fig. 1).

Coral reef surveys

Our procedures for collecting field data followed a modified version of the Reef Check international guidelines for coral reef monitoring, as detailed by Hodgson *et al*. (2006). Dive surveys were conducted by MCC staff and volunteers to collect data on substrates, reef impacts, fish and invertebrates. Volunteer involvement was mainly associated with the 2014 reef surveys and 2018 seagrass surveys. With the exception of pier surveys on the Koh Seh reef, 100 m belt transects were created parallel to reef crests. These were divided into four survey segments which were 5 m in width and 20 m in length and separated by 5 m intervals. As a consequence, 100 m^2 of reef was examined in each segment. Fish were recorded up to the water surface, which was ≤5 m above the transect line at all sites.

Survey effort differed between years for each of the monitored reefs (Table 1). Baseline surveys were undertaken in 2014 on the Koh Seh reef and in 2015 on the Koh Mak Prang and Koh Angkrong reefs. These included the entirety of each reef system so as to map their extent. By 2017, five survey sites had been established on the Koh Seh reef (including one pier site) and three sites on the Koh Mak Prang and Koh Angkrong reefs for monitoring purposes.

Substrate—Substrates were classified following Hodgson *et al*. (2006). Categories included live hard coral, recently killed coral, coral rubble, soft coral, nutrient indicator algae, sponges, zoanthids, rock, sand, silt/clay and other. These were recorded at 0.5 m intervals within each 20 m survey segment by lowering a plumb line at each point and registering the substrate directly beneath. Comparisons of substrates over time are not included in our study due to methodological differences between 2014/15 and 2017. Instead, substrate data collected in 2017 are presented as a baseline.

Impact assessments—The degree of coral damage and trash was recorded at each site. Categories for coral damage included boat/anchor, dynamite and other, whereas trash categories included fishing gear and other. The extent of these were recorded using the following scale: 0 = None, 1 = low (one piece/damage per 20 m survey segment), 2 = medium (two to four pieces/damage per 20 m survey segment) and 3 = high (more than four pieces/damage per 20 m survey segment).

Fish and invertebrates – Divers surveyed for indicator taxa recognised for their ecological and economic importance to the Kep Archipelago and coral reefs globally. These included the Reef Check indicator organisms, Green & Bellwood's (2009) key herbivorous fish families, and additional fish taxa selected by MCC (Appendix A). Similar taxa were monitored by van-Bochove *et al*. (2011) and Thorne *et al*. (2015) to assess the status of coral reefs in the Koh Rong Archipelago of Cambodia. Surveyors identified and counted fishes in each 20 m survey segment. A small number of trained MCC surveyors collected data from the Koh Seh reef in 2014, while one trained MCC surveyor, not present for 2014 surveys, collected data on the reefs in 2015 and 2017.

Seagrass surveys

Seagrass meadows were investigated over approximately two weeks in October–November 2018. We determined the extent of seagrass habitat and collected data on the seagrass species present. Remote sensing was not employed because water clarity was generally poor. Instead, the three main areas of seagrass within the archipelago were mapped by ground truthing. Preliminary dives were made in each instance to determine the general boundaries of each meadow. We then produced a series of grid maps overlaying each seagrass area and distributed survey sites among the grids. Surveyors at each site swam in predetermined directions (north-south or east-west) for 15 minutes and used 50x50 cm quadrats to record seagrass data every two minutes or when a noticeable change in the benthos was observed (e.g., the edge of a meadow or a change in species). Quadrat data were only recorded over seagrass habitat and the GPS location of each quadrat was recorded. Over the course of the survey, data were obtained from 270 quadrats within the Koh Seh seagrass meadow, 277 quadrats within the Koh Tonsay meadow and 367 quadrats within the Koh Pou meadow.

Data analysis

Fish density and diversity were compared over time for each of the monitored reefs. Separate analyses were also undertaken for Reef Check indicator organisms (fish and invertebrates: Hodgson *et al*., 2006) and selected herbivorous fish families (Green & Bellwood, 2009). Data was analysed using PAST 3.2 statistical software (Hammer *et al*. 2001). Box and whisker plots and tables were created in Microsoft Excel version 16.16.8, whereas maps were created in ArcGIS version 10.5.1. Diversity analyses were performed across aggregated taxonomic levels (family – species) following Obura (2014). Alpha (α) diversities were characterised using the Shannon Weiner Index (H) and beta (β) diversities using Whittaker's (1960) method. Because Shapiro-Wilk tests revealed that datasets (excluding substrates) were not normally distributed, we applied two-tailed (Wilcoxon) Mann-Whitney U tests to compare the density (individuals/100 m^2 and individuals/400 m^2) and diversity (H/100 m^2) of taxa between years. One-sample sign tests were undertaken in Excel when a taxon was only observed in one monitoring year. We also used a one-way ANOVA (analysis of variance) with a *post hoc* Tuckey's pairwise test to compare live hard coral cover between the reef sites in 2017. The critical threshold for significance was set at $p<0.05$ in all tests.

Results

Substrate

The composition of substrates varied between each of the monitored reefs (Table 2). Live hard coral varied significantly between reefs but was also the dominant substrate in all cases (ANOVA: $F_{2,117}=7.15$, $p=0.001$). Our Tuckey's pairwise test revealed significant differences in cover between the Koh Angkrong and Koh Mak Prang reefs ($p=<0.001$). Hard coral cover on the Koh Seh reef did not differ significantly from the Koh Angkrong reef ($p=0.078$) or the Koh Mak Prang reef ($p=0.159$). Sponges, zoanthids and rock were the next most prevalent groups, respectively. Nutrient indicator algal cover did not exceed 3% on any of the reefs. The Koh Mak Prang reef exhibited the highest mean cover of coral rubble and sponges as well as the lowest mean cover of hard corals, whereas the Koh Seh reef exhibited a relatively high mean zoanthid cover compared to other substrates.

Table 2 Mean substrate cover of coral reefs studied in the Kep Arichipelago in 2017.

Substrate (%)	Koh Seh (*n*=60)	Koh Mak Prang (*n*=36)	Koh Angkrong (*n*=36)	Total (*n*=132)
Live hard coral	42.4 (±3.1)	33.7 (±8.2)	52.3 (±12.2)	42.9 (±2.1)
Recently killed coral	0.2 (±0.1)	0.2 (±0.2)	0	0.1 (±0.1)
Coral rubble	3.2 (±0.5)	10.1 (±0.6)	4.9 (±3.8)	6.3 (±0.7)
Soft coral	0	7.1 (±4.5)	1.6 (±0.6)	2.6 (±0.5)
Nutrient indicator algae	1.5 (±0.4)	0.1 (±0.1)	2.6 (±1.9)	1 (±0.3)
Sponge	9.2 (±0.8)	22.6 (±6.2)	13.8 (±6.2)	14.7 (±1)
Zoanthid	24.2 (±1.9)	2.2 (±0.8)	5.6 (±4.1)	11.3 (±1.3)
Rock	11.7 (±0.9)	8.5 (±1.1)	12.4 (±2.2)	11.1 (±0.7)
Sand	7.17 (±1)	8.6 (±1.8)	5.1 (±1.4)	7.4 (±0.6)
Silt/clay	0.1 (±0.1)	1.1 (±0.5)	0.8 (±0.6)	0.6 (±0.2)
Other	0.3 (±0.2)	5.8 (±1.8)	0.9 (±0.3)	2 (±0.4)

Impact assessment

Levels of coral damage and trash were low across all reefs (Table 3). No coral damage caused by dynamite was observed. Damage caused by boat/anchor decreased on the Koh Seh and Koh Angkrong reefs over time, and the first instances of coral damage on the Koh Mak Prang reef were observed in 2017. Both trash types (fishing gear and other) were observed on each of the reefs, with yearly totals remaining similar over time.

Indicators of over-exploitation

Four of the eighteen indicators of over-exploitation (excluding *Diadema* sp. and *Acanthaster planci*) monitored were recorded on reefs during the 2014/15 surveys (Table 4). This increased to seven in 2017 with the appearance of sweetlips (Haemulidae), jacks (Carangidae), and the giant clam *Charonia tritonis*. Butterflyfish (Chaetodontidae), grouper (Serranidae), snapper (Lutjanidae), sweetlips and jacks displayed significant increases in density over time. The greatest increases were exhibited by snapper (1,050%) and butterflyfish (157%). High densities of the long-spinned black sea urchin *Diadema* sp. were recorded each monitoring year (>165 individuals/400 m^2). Changes in density over time trended downwards but were not significant, although their populations were less variable between reefs in 2017. Only the pencil urchin *Heterocentrotus mammillatus* exhibited a significant decline over time.

Herbivorous fish

Some major herbivorous fish families and their associated functional groups were entirely absent from the reefs (Table 5). Siganidae was the only family observed on reefs in 2014/15 and was represented by three species. Fish belonging to Siganidae and Ephippidae were observed in 2017 and were represented by six siganid species (including the same species previously recorded) and one ephippid species. Siganids belong to the grazer functional group, whereas ephippids (*Platax* spp.) are browsers. Browsers were represented by only two observations of the batfish *Platax tiera*, whereas other functional groups were not found at all. The total density of ephippids did not change significantly over time, whereas the total density of siganids did (1,700%).

The total density of herbivorous fish (which largely reflects the density of siganids) changed significantly on two of the reefs monitored (Fig. 2). These increased significantly over time on the Koh Seh reef from a median of 0 to 8.5 individuals/100 m^2 (2014 mean rank=25.9, 2017 mean rank=44.6, U=390, p=<0.001), whereas they declined significantly on the Koh Mak Prang reef from a median of 5.5 to 0 individuals/100 m^2 (2015 mean rank=17.3, 2017 mean rank=15.3, U=310, p=0.007). Herbivore density on the Koh Angkrong reef remained at a median of 0 individuals/100 m^2 (2015 mean rank=17.3, 2017 mean rank=19.2, U=581.5, p=0.374). The combined total herbivorous fish density increased significantly over time from a median of 0 to 2 individuals/100 m^2 (2014/15 mean rank=59.4, 2017 mean rank=79.1, U=5966, p=<0.001; Fig 2).

Fish density and diversity

The density of fish increased significantly over time on each of the reefs. Specifically, median values increased from 14 to 76.5 individuals/100 m^2 on the Koh Seh reef (2014 mean rank=27.5, 2017 mean rank=43.2, U=589, p=<0.001), from 26 to 72 individuals/100 m^2 on the Koh Mak Prang reef (2015 mean rank=9.4, 2017 mean rank=23.1, U=195.5, p=<0.001), and from 10 to 39 individuals/100 m^2 on the Koh Angkrong reef (2015 mean rank=10.5, 2017 mean rank=26, U=88.5, p=<0.001; Fig. 3).

Table 3 Mean values for coral damage and trash at reefs monitored in the Kep Arichipelago in 2014/15 and 2017.

Impact Type	2014/15			2017			Total	
	Koh Seh	Koh Mak Prang	Koh Angkrong	Koh Seh	Koh Mak Prang	Koh Angkrong	2015	2017
Coral damage: boat/anchor	0.1	0	0.6	0	0	0	0.2	0
Coral damage: dynamite	0	0	0	0	0	0	0	0
Coral damage: other	0.1	0	0.2	0	0.7	0.3	0.1	0.4
Trash: fishing gear	0.4	0.3	0.4	0.1	0.3	0.8	0.4	0.4
Trash: other	0.1	0.3	0.6	0.1	0.5	0.2	0.3	0.3

Key: 0=none, 1= low (1 piece), 2=medium (2–4 pieces) and 3=high (5+ pieces).

Table 4 Relative occurrence of indicators of over-exploitation on reefs in the Kep Arcipelago in 2014/15 (n=36) and 2017 (n=33).

Species / Group	2014/15		2017			Test values (U, p)
	Median Abundance (per 400 m²)	Interquartile Range (Mean Rank)	Median Abundance (per 400 m²)	Interquartile Range (Mean Rank)	Positive Sign *	
Fish						
Barrimundi cod (*Cromileptes altivelis*) [1,2,3]	Absent		Absent			
Bumphead parrotfish (*Bolbometopon muricatum*) [1]	Absent		Absent			
Butterflyfish (Chaetodontidae) [1,4]	7	3–11 (13)	18	10–25.5 (22)		233, <0.001
Grouper (Serranidae) [1,4]	0	0–0 (11.7)	2	1–3.5 (23.3)		144, <0.001
Grunts/sweetlips (Haemulidae) [1]	Absent		0	0–1	9	-, <0.002
Humphead wrasse (*Cheilinus undulates*) [1,2]	Absent		Absent			
Jacks (Carangidae) [1]	Absent		1	0–5	20	-, <0.001
Moray eel (Muraenidae) [1]	Absent		Absent			
Other parrotfish (Scaridae) [1]	Absent		Absent			
Snapper (Lutjanidae) [1]	2	1–14 (11.1)	23	13–59 (23.9)		98.5, <0.001
Invertebrates						
Banded coral shrimp (*Stenopus hispidus*) [4]	Absent		Absent			
Collector urchin (*Tripneustes* sp.) [1]	Absent		Absent			
Crown-of-thorns starfish (*Acanthaster planci*) [5]	Absent		Absent			
Long-spinned black sea urchin (*Diadema* sp.) [6]	237.5	43.3–342.5 (19.5)	167	103.8–232.8 (14)		457, 0.294
Edible sea cucumbers (*Holothuria edulis*, *Stichopus chloronotus*, *Thelenota ananas*) [7]	Absent		Absent			
Giant clam (*Charonia tritonis*) [1]	Absent		0	0–1	1	-, 0.5
Lobster (Decapoda) [1,4]	Absent		Absent			
Pencil urchin (*Heterocentrotus mammillatus*) [8]	0	0–6.5 (20.9)	0	0 (12.6)		369, 0.006
Triton (*Charonia tritonis*) [8]	Absent		Absent			

Key: *= One sample sign test. Indicators of 1=Over-fishing, 2=Live fish trade, 3=Spear-fishing, 4=Aquarium trade, 5=Crown-of-thorns outbreaks, 6=In high numbers, over-fishing of urchin predators, 7=Beche-de-mer fishing, 8=Curio trade.

These values correspond to increases of 446%, 177% and 290%, respectively. The total combined density of fish increased significantly over time from a median of 16 to 60 individuals/100 m^2 (2014/15 mean rank=46.9, 2017 mean rank=91.6, U=2517.5, p=<0.001).

Alpha (α) diversity index values also increased significantly on each of the monitored reefs (Fig. 4). The median values increased over time from 0.88 to 1.57 H/100 m^2 on the Koh Seh reef (2014 mean rank=28.8, 2017 mean rank=41.7, U=794.5, p=<0.001), from 1.67 to 2.03 H/100 m^2 on the Koh Mak rang reef (2015 mean rank=10, 2017 mean rank=22.5, U=235.5, p=<0.001), and from 0.58 to 1.63 H/100 m^2 on the Koh Angkrong reef (2015 mean rank=9.3, 2017 mean rank=27.2, U=6, p=<0.001). Total

Table 5 Relative occurrence of herbivorous fish families and associated functional groups on reefs in the Kep Arcipelago in 2014/15 (*n*=36) and 2017 (*n*=33).

Herbivorous Fish Families	2014/15		2017			Test Values (U, p)	Functional Group Present
	Median Abundance (per 400 m²)	Interquartile Range (Mean Rank)	Median Abundance (per 400 m²)	Interquartile Range (Mean Rank)	Positive Sign *		
Acanthuridae (surgeonfish, unicornfish) [1,2]	Absent		Absent				
Ephippidae (batfish) [1]	Absent		0	0–1	2	-, 0.25	Browsers
Kyphosidae (rudderfish) [1]	Absent		Absent				
Pomacanthidae (angel-fish) [2]	Absent		Absent				
Scaridae (parrotfish) [1,3,4]	Absent		Absent				
Siganidae (rabbitfish) [1,2]	1	0–15.8 (13.2)	18	4–65 (21.8)		244, <0.001	Grazers

Key: *= One sample sign test. Functional group: 1=Browsers, 2=Grazers/detritivores, 3=Large excavators/bioeroders, 4=Scrapers/small excavators.

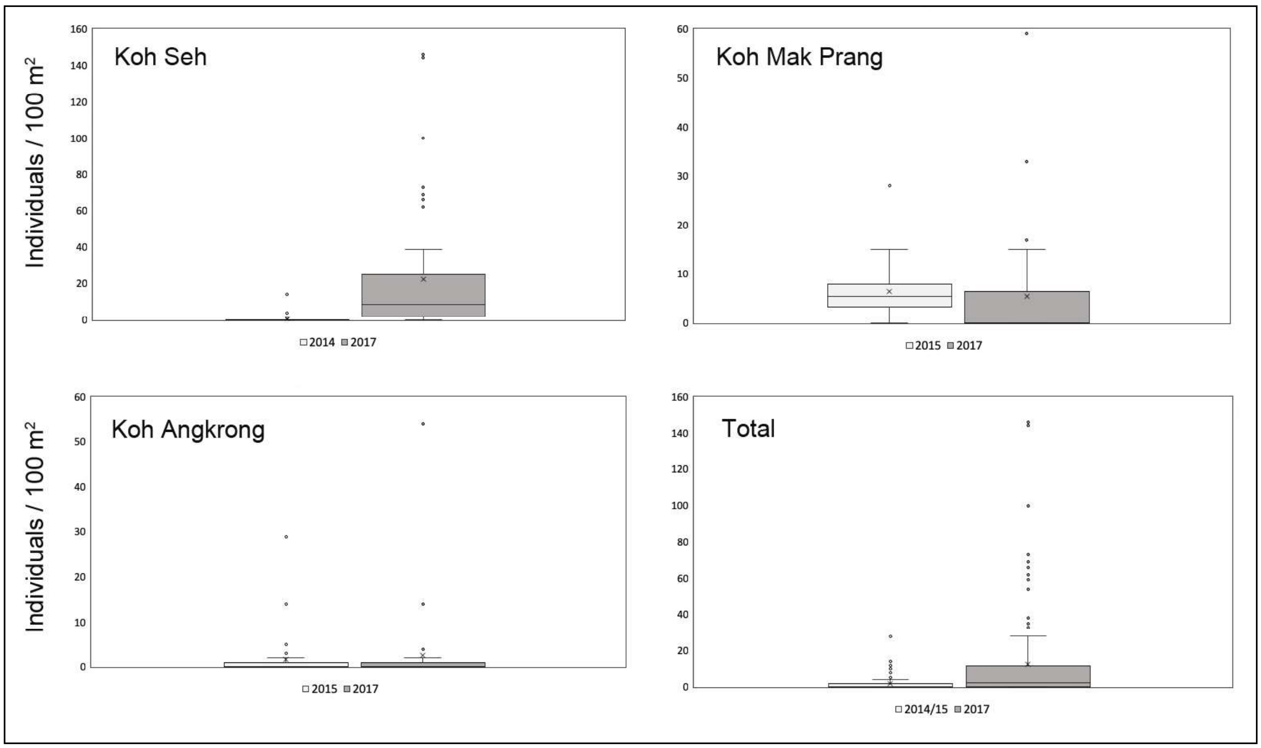

Fig. 2 Variation in herbivorous fish density between years on the Koh Seh, Koh Mak Prang and Koh Angkrong islands. Centre lines within boxes represent medians, whereas boxes indicate the 25th and 75th percentile values and 'x' represents means.

α-diversity increased significantly over time from 0.95 to 1.76 H/100 m² (2014/15 mean rank=47.9, 2017 mean rank=90.6, U=2788.5, p=<0.001).

Beta (β) diversity values indicated substantial differences in the composition of species between years, with the greatest change occurring on the Koh Angkrong reef

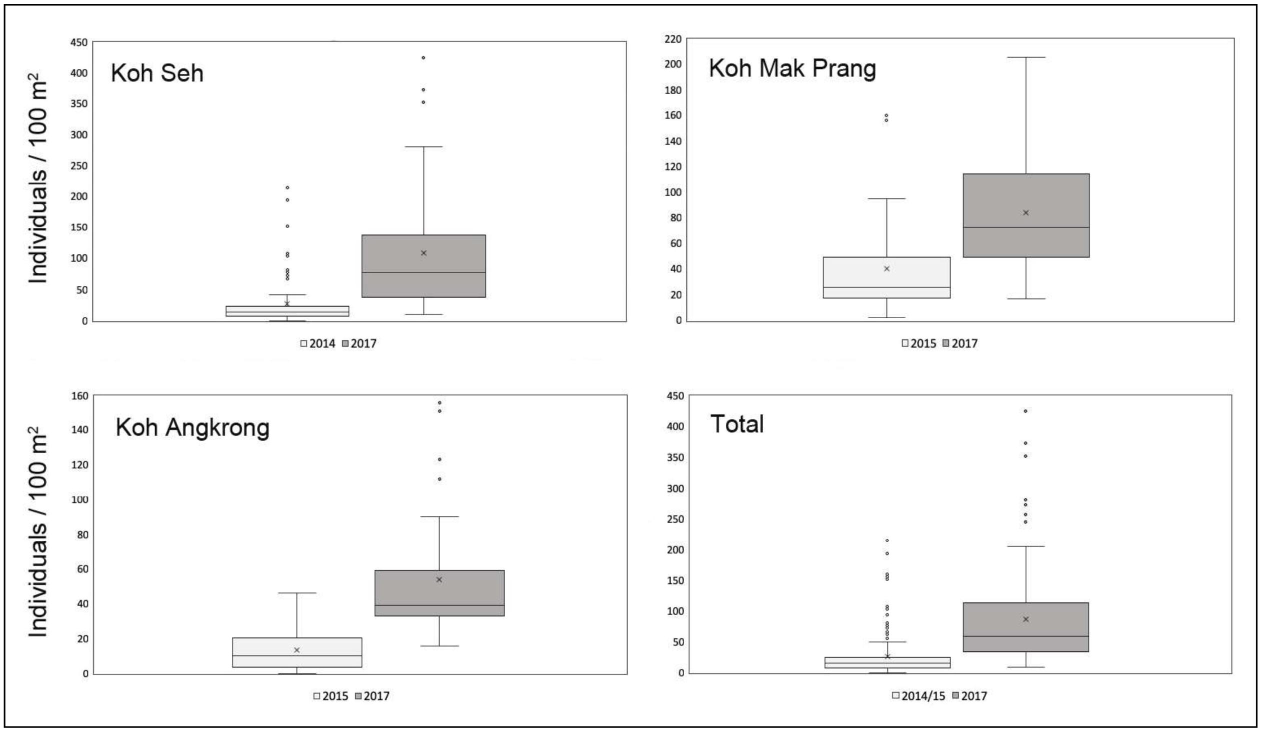

Fig. 3 Variation in fish density between years on the Koh Seh, Koh Mak Prang and Koh Angkrong islands. Centre lines within boxes represent medians, whereas boxes indicate the 25th and 75th percentile values and 'x' represents means.

Table 6 Beta (β) diversity index values between study sites in the Kep Archipelago in 2014/2015 and 2017.

Reef	2014/15			2017			β-Diversity between years
	Koh Seh	Koh Mak Prang	Koh Angkrong	Koh Seh	Koh Mak Prang	Koh Angkrong	
Koh Seh	/	0.21	0.36	/	0.29	0.39	0.58
Koh Mak Prang	0.21	/	0.42	0.29	/	0.35	0.51
Koh Angkrong	0.36	0.42	/	0.39	0.35	/	0.69

(Table 6). Species compositions differed less between reefs in comparison. The greatest differences between reefs were observed between Koh Angkrong and Koh Mak Prang in 2015 and between Koh Angkrong and Koh Seh in 2017 (Table 6).

Seagrass

The three main seagrass meadows in the Kep Archipelago were estimated to cover a combined area of 7.5 km^2 (Fig. 5). Nine species of seagrass were identified in total, with the most common overall being *Thalassia hemprichii,* which was present in 76% of quadrats (Table 7).

The Kou Pou seagrass meadow was the largest of the three meadows, covering an area of 4.56 km^2 and exhibiting a mean seagrass cover of 22.1%. This was dominated by *T. hemprichii*, which was present in 87.8% of quadrats. *Halophila ovalis* was the next most common species, present in 18% of quadrats, whereas *Enhalus acoroides* occurred in 11.5%. Other seagrass species observed in the meadow included *Halodule uninervis* (7.6% of quadrats), *Syringodium isoetifolium* (2.8%), *Cymodocea serrulata* (2%) and *H. decipiens* (0.4%).

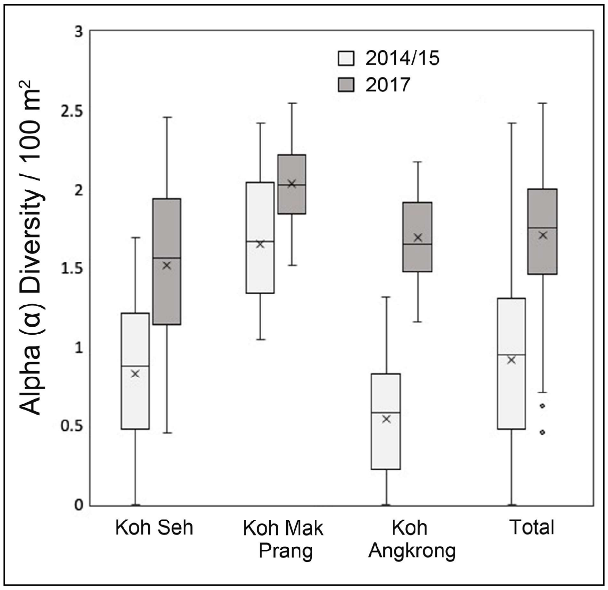

Fig. 4 Variation in alpha (α) diversity between years on the Koh Seh, Koh Mak Prang and Koh Angkrong islands. Centre lines within boxes represent medians, whereas boxes indicate the 25th and 75th percentile values and 'x' represents means.

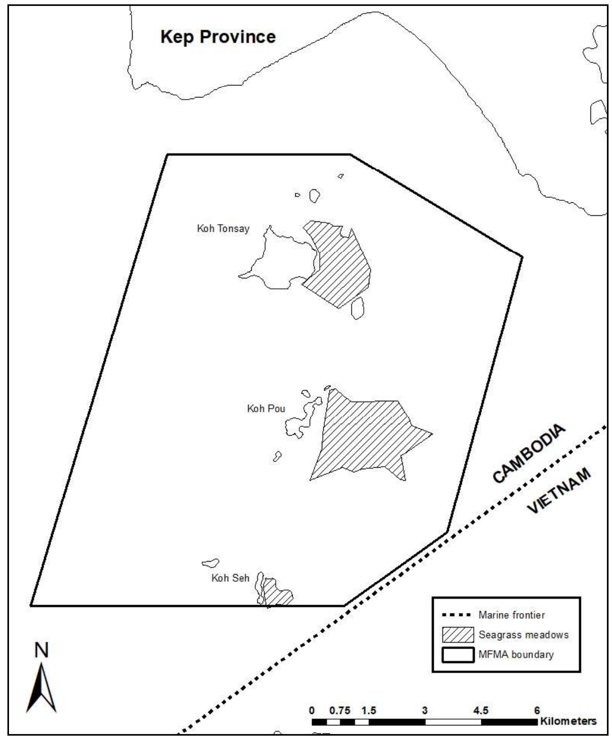

Fig. 5 Seagrass meadows surveyed in the Kep Archipelago in 2018.

The Koh Tonsay meadow covered 2.61 km^2 with a mean seagrass cover of 24.6%. This mostly comprised *E. acoroides* and *T. hemprichii*, which occurred in 62.7% and 62.3% of quadrats respectively. The next most prevalent species were *H. ovalis* and *C. serrulata*, which occurred in 13.6% and 12.3% of quadrats respectively. Other species observed included *H. uninervis* (8% of quadrats), *C. rotundata* and *H. pinifolia* (both 2.5%).

The Koh Seh meadow was the smallest of the three meadows, covering an area of 0.38 km^2 with a mean seagrass cover of 21.2%. This was dominated by *T. hemprichii*, which was present in 76% of quadrats. The next most common species was *H. ovalis* which was present in 36% of quadrats. Other species observed included *H. uninervis* (5.6% of quadrats), C. *serrulata* (2.8%), *E. acoroides*, *H. decipiens* and *H. pinifolia* (all 0.9%).

Table 6 Relative presence of seagrass species in the Kep Archipelago in 2018.

Species	Percentage of Samples
Thalassia hemprichii	76
Enhalus acoroides	29
Halophila ovalis	20
Halophila universalis	7
Cymodocea serrulata	6
Cymodocea rotundata	1
Halodule pinifolia	1
Syringodium isoetifolium	1
Halophila decipiens	0.3

Discussion

The absence of indicator taxa combined with the high number of *Diadema* sp. suggest that reefs in the Kep Archipelago have been heavily over-exploited (Hodgson *et al*., 2006). Moreover, the absence of certain indicator fish and invertebrates suggest over-harvesting across trophic levels. Our surveys in 2014/2015 revealed a paucity of fish life, including high-value fishery targets and important functional groups of herbivores. Similar results were found on reefs in the Kou Pou island group of the Kep Archipelago in 2003 (UNEP, 2007a). At this time, Reef Check indicator organisms were absent from all reefs, including parrotfishes which were undetected during our study, along with a number of other major groups of herbivorous fish. Herbivorous fish are often the most susceptible to fishing pressure on coral reefs and over-fishing of key groups can have profound adverse effects on an ecosystem including loss of functionality and lowered resilience (Hughes *et al*., 2007; Nyström *et al*., 2008; Edwards *et al*., 2014; Pratchett *et al*., 2014; Heenan *et al*., 2016).

Rabbitfishes in the grazer functional group were the most important herbivorous fish in our study and increased significantly over time. The other families of herbivorous fish that we targeted were largely absent and showed no signs of recovery between 2014 and 2017, which means that browser, scraper and excavator functional groups remained either poorly represented or absent from the reefs studied. Representation of each herbivore functional group is important for substrate maintenance and controlling algal growth (Green & Bellwood, 2009). In the absence of certain groups of fish herbivores, the control of algal growth might be attributed to urchin grazing, particularly by *Diadema* sp. If rabbitfish in the archipelago continue to increase in abundance and competition for food resources becomes greater, population sizes of *Diadema* sp. could trend further downward. However, our data indicates that the recovery of rabbitfish was limited to the Koh Seh reef only.

With the exception of jacks and sweetlips, the indicator taxa (Reef Check indicators) and selected herbivores that were lacking in 2014/15 either remained absent or did not show any sign of significant recovery. However, certain taxa that were present in 2014/15 displayed significant increases in density over time. In particular, the increases in high-value snapper, grouper, jacks and sweetlips are promising as these fish are important in domestic and export markets (UNEP, 2007b). Snapper were the most common of these in 2017 when large schools of blackspot snapper *Lutjanus ehrenbergii* (>300 individuals/400 m^2) were observed on the Koh Seh reef. Another ecouraging finding was the increase in butterflyfish on reefs. Butterflyfishes play important ecological roles, possessing a wide range of feeding behaviours that include plankton feeding, cleaning activity, invertivory and corallivory (Cole *et al*., 2008; Green & Bellwood, 2009; Konow & Ferry-Graham, 2013). The eight-banded butterflyfish *Chaetodon octofasciatus*, which was present on reefs in Kep, is an obligate hard coral feeder most often associated with the coral genus *Acropora* (Mazlan *et al*., 2006). This could potentially make the species an important bioindicator of coral health and over-fishing (Madduppa *et al*., 2014).

The condition of benthic assemblages at our study sites in 2017 did not entirely reflect the state of reef fish. Hard coral cover ranged from moderate to high by Cambodian standards and appeared to be dominated by massive growth forms (Chou *et al*., 2002; van-Bochove *et al*., 2011; Thorne *et al*., 2015). Our total mean cover differed by only 1.9% from the group mean (41%) recorded at Koh Pou island approximately 14 years before (UNEP, 2007a). While this might suggest that coral cover on reefs has not changed substantially over this period, hard coral cover differed significantly between our studied reefs and we noted that some reefs at Koh Pou were among the most degraded in the archipelago. Similar to findings in 2003 (UNEP, 2007a), we also found coral damage was low. However, we found no evidence of damage from dynamite fishing which was previously identified as a major threat (UNEP, 2007a), although instances where hard corals had been broken and used to weight fishing cages were observed on each of the reefs studied (Fig. 6). Bleached and diseased corals were also observed regularly and sediment appeared to be a major issue affecting water quality.

Sponges and zoanthids were the most prevalent substrates after hard coral on the Koh Mak Prang and Koh Seh reefs respectively and some patches of degraded reef appeared to be dominated by these two groups. In comparison, macroalgae cover was low (total mean=1%) and seemed to have been controlled reasonably successfully by *Diadema* sp. Because a macroalgae cover of >10% was previously recorded on the reefs of Kou Pou (UNEP, 2007a), our data could reflect the apparent reduction in seaweed farming in Cambodia after 2006 (with no production having been reported since this time: FAO, 2011). The population density of *Diadema* sp. also appears to have changed, having shifted from an average of 4.3 individuals/100 m^2 in 2003 (estimated from 167 individuals/ 400m^2: UNEP, 2007a) to 41.6 individuals/100 m^2 in 2017, which is equivalent to an increase of 867%.

We identified nine seagrass species in the Kep Archipelago in 2018, all of which were found by Supkong & Bourne (2014) in seagrass meadows in the neighbouring Kampot Province in 2013. Our community structure appears to differ with *T. hemprichii* being the dominant species in the Kep Archipelago, whereas *H. uninervis* and *E. acoroides* were found to be dominant in Kampot, albeit in different studies (Vibol *et al*., 2010; Supkong & Bourne, 2014). We observed trawl lines through much of the seagrass meadows in Kep and large areas appeared to be in a state of recovery. They also supported populations of the collector urchin *Tripneustes* sp. (which was not found on reefs: Table 4), which appeared to be relatively common.

A joint patrol system was introduced to alleviate fishing pressure in the Kep Archipelago in 2014. The patrols were undertaken by MCC, marine police and FiA within the boundary of the MFMA, albeit before its establishment. During this time, Cambodian and Vietnamese benthic trawlers (including pair trawlers) appeared to be the most abundant vessels engaged in illegal fishing and most of these appeared to target shrimp using electric nets. Air-tube fishing vessels were also often seen operating around coral reefs. Seagrass habitats were the most challenging to protect as these extend over relatively large areas and were often illegally fished by trawlers at night. However, over time we found that patrols discouraged illegal fishing activities and our study demonstrates that total reef fish density and diversity increased significantly within four years of the patrols commencing. We believe these increases are attributable to the protection provided by the patrols, but acknowledge that this conclusion is speculative due to factors such as pseudoreplication, seasonal variation and surveyor changes.

First, pseudoreplication is a valid concern for the surveys we undertook in 2014/15, because these only included one replicate per site (four surveys). However, there was a greater number of monitoring sites on reefs at that time and because of this each reef received a similar number of surveys in 2014/15 and 2017 (Table 1). Further, the surveys in 2014/15 were subject to greater temporal variation as they were conducted over approximately four weeks. We assume that the survey effort in 2014/15 was sufficient to capture the basic conditions on each reef for these reasons.

Second, seasonal variation, particularly in reef fish recruitment, tends to be greater during summer months although it is rarely consistent between years (Sale & Dybdahl, 1975; Talbot *et al*., 1978; Williams, 1983). Our species surveys were largely conducted during the dry season (winter months), although some of the surveys around Koh Seh and Koh Mak Prang in 2017 were conducted at other times. While the data from these sites could therefore include seasonal variation, we believe this is unlikely to have affected our overall findings. This is supported by the fact that the data from these sites are consistent with data from the Koh Angkrong reef where surveys were undertaken in the same season throughout the study.

Third, the use of volunteers with varying abilities and changes in surveyors can affect the ability of a monitoring programme to detect ecological changes (Savage *et al*., 2017). This can be particularly true with respect to identification of fish and seagrass species, which can be challenging. In our study however, our surveyors only changed between 2014 and 2015 (as the same fish surveyor was involved from 2015 onwards) and the findings in both years were relatively consistent. In addition, the seagrass species identified by MCC staff and trained volunteers were consistent with the findings of Vibol *et al*. (2010) and Supkong & Bourne (2014) from the neighbouring Kampot Province.

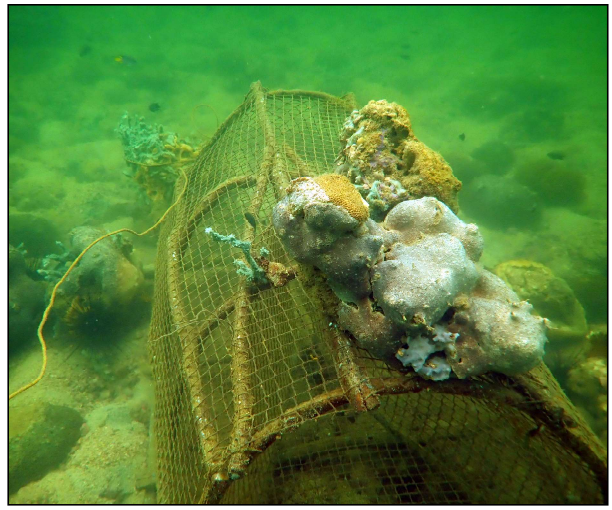

Fig. 6 Example of a fish cage illegally weighted with live coral, Koh Mak Prang, 2017 (© Amick Haissoune).

A conservation strategy was launched in early 2018 to promote the recovery of marine ecosystems in the Kep Archipelago. This aims to protect, promote and enhance marine life and the livelihoods of local fishers and their communities. The strategy included the establishment of the Kep MFMA, which encompasses coral reefs, seagrass beds and mangroves and includes no-take zones. Anti-trawling reefs (ATR) have been deployed within the boundaries of the MFMA to attract marine life and deter benthic trawlers. These have been used to conserve seagrass beds in the Mediterranean and can be important for conserving coral reefs, particularly where habitat complexity has been lost (Giakoumi *et al*., 2015; Rogers *et al*., 2015). We anticipate that the ATRs deployed in the Kep MFMA will help to disperse fish biomass, making exploitation more difficult (Smith *et al*., 2015). Small-scale subsistence fishers and recreational line fishers operating outside of no-take zones in the MFMA are not expected to substantially compromise fish assemblages at low intensities (Martin *et al*., 2017). In addition, bivalves are being deposited alongside the ATR's to facilitate the formation of bivalve beds, which also occur naturally and provide important water filtration services (Grabowski & Peterson, 2007; Walles *et al*., 2016). It is envisaged that local fishers will be able to harvest bivalves from some of the sites over time. It is also anticipated that community stakeholders will progressively adopt the various management activities of the MFMA with continued support.

Law enforcement patrols are integral to protecting and enabling the recovery of degraded ecosystems in the Kep Archipelago. The establishment of Kep MFMA and conservation activities there should contribute to mitigating a multitude of threats, protect ecosystem processes and promote the recovery of coral reefs and seagrass meadows. MCC will continue to monitor these ecosystems to assess the effectiveness of ongoing conservation efforts. Our study highlights the importance of baseline studies and ecosystem monitoring to ensure that the limited resources available for conservation are allocated appropriately. Looking forward, we recommend continuation of impact assessments and fish and invertebrate surveys in the Koh Seh, Koh Pou and Koh Tonsay seagrass meadows. We also recommend documentation of patrol effort and monitoring of illegal fishing activities to assess the effectiveness of law enforcement in reducing related pressures in the Kep Archipelago.

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References

Bobenrieth, M.E, Sun K., Kong K.S. & Mather, R. (2012) *Vulnerability and Capacity Assessment of Koh Kong and Kampot Provinces, Cambodia*. IUCN, Gland, Switzerland.

Chou L.M., Tuan V.S., Reefs, P., Yeemin, Y., Cabanban A. & Suharsono, K.I. (2002) Status of Southeast Asia coral reefs. In *Status of Coral Reefs of the World: 2002* (ed. C. Wilkinson), pp. 123–152. Australian Institute of Marine Science, Townsville, Darwin and Perth, Australia.

Cole, A.J., Pratchett, M.S. & Jones, G.P. (2008) Diversity and functional importance of coral-feeding fishes on tropical coral reefs. *Fish and Fisheries*, **9**, 286–307.

Davis, J.P., Pitt, K.A., Fry, B., Olds, A.D. & Connolly, R.M. (2014) Seascape-scale trophic links for fish on inshore coral reefs. *Coral Reefs*, **33**, 897–907.

Edwards, C.B., Friedlander, A.M., Green, A.G., Hardt, M.J., Sala, E., Sweatman, H.P., Williams, I.D., Zgliczynski, S.A., Sandin S.A. & Smith, J.E. (2014) Global assessment of the status of coral reef herbivorous fishes: evidence for fishing effects. *Proceedings of the Royal Society of London B: Biological Sciences*, **281**, 20131835.

FAO—Food and Agriculture Organization of the United Nations (2011) *Fishery and Aquaculture Country Profiles: The Kingdom of Cambodia*. Http://www.fao.org/fishery/facp/KHM/en [Accessed 11 November 2018].

Giakoumi, S., Brown, C.J., Katsanevakis, S., Saunders, M.I. & Possingham, H.P. (2015) Using threat maps for cost-effective prioritization of actions to conserve coastal habitats. *Marine Policy*, **61**, 95–102.

Gillett, R. (2004) *The Marine Fisheries of Cambodia*. FAO FishCode Review, No. 4. Food and Agriculture Organization of the United Nations, Rome, Italy.

Gillett, R. (2008) *Global Study of Shrimp Fisheries*. FAO Fisheries Technical Paper 475. Food and Agriculture Organization of the United Nations, Rome, Italy.

Grabowski, J.H. & Peterson, C.H. (2007) Restoring oyster reefs to recover ecosystem services. In *Ecosystem Engineers: Plants to Protists* (eds K. Cuddington, J.E. Byers, W.G. Wilson & A. Hastings), pp. 281–298. Academic Press, Elsevier.

Green, A.L. & Bellwood, D.R. (2009) *Monitoring Functional Groups of Herbivorous Reef Fishes as Indicators of Coral Reef Resilience: A Practical Guide for Coral Reef Managers in the Asia Pacific Region*. IUCN, Gland, Switzerland.

Hammer, O., Harper, D.A.T. & Ryan, P.D. (2001) PAST: paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, **4**, 1–9.

Heenan, A., Hoey, A.S., Williams, G.J. & Williams, I.D. (2016) Natural bounds on herbivorous coral reef fishes. *Proceedings of the Royal Society of London B: Biological Sciences*, **283**, 20161716.

Hodgson, G., Hill, J., Kiene, W., Maun, L., Mihaly, J., Liebeler, J., Shuman, C. & Torres, R. (2006) *Reef Check Instruction Manual: A Guide to Reef Check Coral Reef Monitoring*. Reef Check Foundation, Pacific Palisades, California, USA.

Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., Moltschaniwskyj, N., Practhett, M.S., Steneck, R.S. & Willis, B. (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology*, **17**, 360–365.

Konow, N. & Ferry-Graham, L. (2013) Functional morphology of butterflyfishes. In *The Biology of Butterflyfishes* (eds M.S. Prachett, M.L. Berumen & B.G. Kapoor), pp. 19–47. CRC Press, Taylor & Francis Group.

Leng P. (2013) Assessment of fishing practices in marine fisheries management areas around Koh Rong and Koh. *Cambodian Journal of Natural History*, **2013**, 113.

Madduppa, H.H., Zamani, N.P., Subhan, B., Aktani, U. & Ferse, S.C.A (2014) Feeding behavior and diet of the eight-banded butterflyfish *Chaetodon octofasciatus* in the Thousand Islands, Indonesia. *Environmental Biology of Fishes*, **97**, 1353–1365.

Martin, T.S.H., Connolly, R.M., Olds, A.D., Ceccarelli, D.M., Fenner, D.E., Schlacher, T.A. & Beger, M. (2017) Subsistence harvesting by a small community does not substantially compromise coral reef fish assemblages. *ICES Journal of Marine Science*, **74**, 2191–2200.

Mazlan, A.G., Mei Yee, N., Alfian, K., Adziz, A. & Aziz, A. (2006) Linking the feeding regime of Chaetodon octofasciatus to the coral health in Redang Island, Malaysia. *Coastal Marine*

Science, **20**, 276–282.

Nyström, M., Graham, N.A.J., Lokrantz, J. & Norström, A.V. (2008) Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs*, **27**, 795–809.

Obura, D. (2014) *Coral Reef Monitoring Manual South-West Indian Ocean Islands*. Http://commissionoceanindien.org/fileadmin/resources/ISLANDSpdf/Coral_Reef_Monitoring_Manual.pdf [Accessed 19 January 2019].

Paul, M.C. & Keothyda, M.K. (2017) *Situation of Marine Fisheries and the Establishment of Fishing Communities*. Parliamentary Institute of Cambodia, Briefing Note, Senate Comission 1. Https://www.pic.org.kh/images/2017Research/20171227_Situation%20of%20Marine%20Fisheries%20and%20the%20Establishment%20of%20Fishing%20Communities_En.pdf [Accessed 20 July 2018].

Pratchett, M.S., Hoey, A.S. & Wilson, S.K. (2014) Reef degradation and the loss of critical ecosystem goods and services provided by coral reef fishes. *Current Opinion in Environmental Sustainability*, **7**, 37–43.

Razak Latun, A., Ali, M., Ahmad, A., Tamimi, M. & Katoh, M. (2016) Boosting national mechanisms to combat IUU fishing: Dynamism of the Southeast Asian fisheries sector. *Fish for the People*, **14**, 36–43.

Rizvi, A.R. & Singer, U. (2011) *Cambodia Coastal Situation Analysis*. IUCN, Gland, Switzerland.

Rogers, A., Blanchard, J.L. & Mumby, P.J. (2018) Fisheries productivity under progressive coral reef degradation. *Journal of Applied Ecology*, **55**, 1041–1049.

Rogers, A., Harborne, A.R., Brown, C.J., Bozec, Y.M., Castro, C., Chollett, I., Hock, K., Knowland, C.A., Marshell, A., Ortiz, J.C., Razak, T., Roff, G. Samper-Villarreal, J. Saunders, M.I., Wolff, N.H. & Mumby, P.J. (2015) Anticipative management for coral reef ecosystem services in the 21st century. *Global Change Biology*, **21**, 504–514.

Savage, J.M., Osborne, P.E. & Hudson, M.D. (2017) Effectiveness of community and volunteer based coral reef monitoring in Cambodia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **27**, 340–352.

Sale, P.F. & Dybdahl, R. (1975) Determinants of community structure for coral reef fishes in an experimental habitat. *Ecology*, **56**, 1343–1355.

Sherman, J., Leak K., Theavy C. & Somony P. (2007) *Experiences from Three Marine Community Fisheries: Chikhor Krom and Chroy Svay communes, Koh Kong Province and Stung Hav district, Kompong Som Province*. American Friends service Committee & Fisheries Action Coalition Team, Cambodia. Https://www.afsc.org/sites/default/files/documents/Three%20Marine%20Community%20Fisheries.pdf [Accessed 23 November 2018].

Smith, J.A., Lowry, M.B. & Suthers, I.M. (2015) Fish attraction to artificial reefs not always harmful: a simulation study. *Ecology and Evolution*, **5**, 4590–4602.

Sopanha C., Kiman M. & Chansothea T. (2012) *Crab Fisheries in Cambodia and the Development of Crab Banks*. The Learning Institute and the WorldFish Center, Phnom Penh, Cambodia.

Supkong, P. & Bourne, L. (2014) *A Survey of Seagrass Beds in Kampot, Cambodia*. IUCN, Bangkok, Thailand.

Talbot, F.H., Russell, B.C. & Anderson, G.R. (1978) Coral reef fish communities: unstable, high-diversity systems? *Ecological Monographs*, **48**, 425–440.

Teh L., Shon, D., Zylich, K. & Zeller, D. (2014) *Reconstructing Cambodia's Marine Fisheries Catch, 1950–2010*. Fisheries Centre, Vancouver, Canada.

Teh L.S., Witter, A., Cheung W.W., Sumaila, U.R. & Yin X. (2017) What is at stake? Status and threats to South China Sea marine fisheries. *Ambio*, **46**, 57–72.

Thorne, B.V., Mulligan, B., Mag Aoidh, R. & Longhurst, K. (2015) Current status of coral reef health around the Koh Rong Archipelago, Cambodia. *Cambodian Journal of Natural History*, **2015**, 98–113.

UNEP— United Nations Environment Programme (2007a) *National Reports on Coral Reefs in the Coastal Waters of the South China Sea*. UNEP/GEF/SCS Technical Publication No. 11. United Nations Environment Programme, Bangkok, Thailand.

UNEP—United Nations Environment Programme (2007b) *National Reports on the Fish Stocks and Habitats of Regional, Global, and Transboundary Significance in the South China Sea*. UNEP/GEF/SCS Technical Publication No. 15. United Nations Environment Programme, Bangkok, Thailand.

UNEP—United Nations Environment Programme (2008a) *National Reports on Mangroves in the South China Sea*. UNEP/GEF/SCS Technical Publication No. 14. United Nations Environment Programme, Bangkok, Thailand.

UNEP—United Nations Environment Programme (2008b) *National Reports on Seagrass in the South China Sea*. UNEP/GEF/SCS Technical Publication No. 12. United Nations Environment Programme, Bangkok, Thailand.

van-Bochove, J.W., Ioannou, N., McVee, M. & Raines, P. (2011) Evaluating the status of Cambodia's coral reefs through baseline surveys and scientific monitoring. *Cambodian Journal of Natural History*, **2011**, 114–121.

Vibol O., Nam S., Puy L. & Wath, P.S. (2010) Seagrass diversity and distribution in coastal area of Kampot Province, Cambodia. *International Journal of Environmental and Rural Development*, **1**, 112–117.

Vo S.T., Pernetta, J.C. & Paterson, C.J. (2013) Status and trends in coastal habitats of the South China Sea. *Ocean & Coastal Management*, **85**, 153–163.

Walles, B., Troost, K., van den Ende, D., Nieuwhof, S., Smaal, A.C. & Ysebaert, T. (2016) From artificial structures to self-sustaining oyster reefs. *Journal of Sea Research*, **108**, 1–9.

Whittaker, R.H. (1960) Vegetation of the Siskiyou mountains, Oregon and California. *Ecological monographs*, **30**, 279–338.

Williams, D.M. (1983) Daily, monthly and yearly variability in recruitment of a guild of coral reef fishes. Marine ecology progress series. *Oldendorf*, **10**, 231–237.

Appendix 1 Fish species monitored in the Kep Archipelago in 2014/15 and 2017

Survey Taxa		Observed
Common Name	**Family / Species**	
Angelfish	Pomacanthidae	
Bamboo shark	*Chiloscyllium* spp.	
Barramundi cod	*Cromileptes altivelis*	
Barracuda	Sphyraenidae	Yes
Great	*Sphyraena barracuda*	
Obtuse	*Sphyraena obtusata*	
Yellowtail	*Sphyraena flavicauda*	
Boxfish	Ostrasiidae	Yes (1–2 species)
Bream/whiptail bream	Nemipteridae	Yes
Bridled monocle	*Scolopsis affinis*	
Monogram monocle	*Scolopsis monogramma*	
Paradise whiptail	*Pentapodus paradiseus*	
White-cheek monocle	*Scolopsis vosmeri*	
White-streak monocle	*Scolopsis ciliata*	
Other		2–3 species
Butterflyfish	Chaetodontidae	Yes
Eight-banded	*Chaetodon octofasciatus*	
Long-beaked coralfish	*Chelmon rostartus*	
Longfin bannerfish	*Heniochus acuminatus*	
Ocellated	*Parachaetodon ocellatus*	
Cardinalfish	Apogonidae	Yes (1–4 species)
Carpet eel blenny	*Congrogadus subducens*	Yes
Catfish	*Plotosus lineatus*	Yes
Double-banded soapfish	*Diplioprion bifasciatum*	Yes
Emperor	Lethrinidae	Yes
Emperor	*Lethrinus* spp	(2–3 species)
Filefish	Monacanthidae	Yes (5–8 species)
Fusilier	Caesionidae	Yes (3–5 species)
Grouper	Serranidae	Yes
Blue-lined	*Cephalopholis formosa*	
Chocolate	*Cephalopholis boenak*	
Honeycomb	*Epinephelus merra*	
Orange-spotted	*Epinephelus coioides*	
Peacock	*Cephalopholis argus*	
Squaretail	*Plectropomus areolatus*	
Other		6 species
Grunts/sweetlips	Haemulidae	Yes
Gold-spotted sweetlips	*Plectorhinchus flavomaculatus*	
Gurnard	Triglidae	
Jacks/scads	Carangidae	Yes
Jacks		3–5 species
Scad		2–3 species

Appendix 1 Cont'd

Survey Taxa		Observed
Common Name	Family / Species	
Moray eel	Muraenidae	
Mullet	Mugilidae	Yes (1–3 species)
Needlefish	Belonidae	Yes (2–3 species)
Parrotfish	Scaridae	
Pipefish	Syngnathinae	Yes (5–6 species)
Porcupinefish	Diodontidae	Yes (1 species)
Pufferfish	Tetraodontidae	Yes (1–2 species)
Rabbtfish	Siganidae	Yes
Dusky	*Siganus fuscescens*	
Golden	*Siganus guttatus*	
Java	*Siganus javus*	
Virgate	*Siganus virgatus*	
White-spotted	*Signanus canaliculatus*	
Rudderfish	Kyphosidae	
Scatfish	Scatophagidae	Yes
Spotted	*Scatophagus argus*	
Scorpionfish	Scorpaenidae	
Seahorse	*Hippocampus* spp.	Yes (4 species)
Sergeantfish	*Abudefduf* spp.	Yes (3–5 species)
Shark sucker	Echeneidae	Yes (1–2 species)
Snapper	Lutjanidae	Yes
Black-spot	*Lutjanus ehrenbergii*	
Brown-stripe	*Lutjanus vitta*	
Checkered	*Lutjanus decussatus*	
One-spot	*Lutjanus monostigma*	
Red	*Lutjanus campechanus*	
Spanish flag	*Lutjanus carponotatus*	
Other		1–4 species
Soldierfish/squirrelfish	Holocentridae	Yes (1–2 species)
Spadefish	Ephippidae	Yes
Batfish	*Platax teira*	
Surgeonfish/tangs/unicornfish	Acanthuridae	
Sweeper	*Pempheris* spp.	Yes
Toadfish	*Batrachoididae* spp.	
Triggerfish	Balistidae	
Wrasse	Labridae	Yes
Cleaner	*Labroides* spp.	
Weedy surge	*Halichoeres margaritaceus*	
Other		1–3 species