KOH ANGKRONG ENVIRONEMENTAL ASSESSMENT

REPORT BY :
- ALEX REID, TEAM SCIENTIST
- AMICK HAISSOUNE, PROJECT COORDINATOR
- PAUL FERBER, MANAGING DIRECTOR

IN PARTNERSHIP WITH THE FISHERIES ADMINISTRATION

2017

Executive Summary

Important tropical ecosystems in the Kep Archipelago are highly threatened by illegal fishing pressures, which destroy significant habitat and overexploit marine species. In early 2014, the Kep Provincial Government commissioned Marine Conservation Cambodia (MCC) for the development and undertaking of a coral reef monitoring programme. The research and monitoring would occur within a geographical triangle encompassing the islands of Koh Angkrong, Koh Mak Prang and Koh Seh. The purpose of the monitoring programme is to obtain information on the distribution and ecology of coral reefs in the Archipelago over time. Following initial MCC reports on the state of coral reef ecosystems in the Kep Archipelago, a conservation strategy was developed and is currently being implemented. The strategy involves the creation a of 11,354ha Marine Fisheries Management Area (MFMA), in combination with the deployment of artificial reef structures, the use of community management techniques and the enforcement of fisheries regulations. The aim of the initiative is to abolish illegal fishing activities, and to protect, promote and enhance marine life and the livelihoods of local Khmer fishermen and their communities.

This environmental assessment report forms the second in a series of ongoing investigations of a fringing coral reef that lies adjacent to Koh Angkrong. Three sites were monitored during 2017, whereby four surveys were each conducted for fish, invertebrates and substrate over a distance of 20m. This was replicated three times at each site. Monitoring methods during 2015 differed from those in 2017. Total hard coral cover was found to be relatively healthy but differed significantly between sites. Coral diversity also appeared low. The prevalence of coral disease was found to be relatively high on a global scale. Total fish abundance and fish species richness significantly increased between monitoring years. Herbivorous fish abundance, however, did not increase and remained relatively low between monitoring years. Herbivorous urchin abundance remained relatively high while also significantly decreasing between years. Total invertebrate abundance significantly increased while invertebrate species richness remained unchanged during monitoring years.

Following a reduction in illegal fishing pressures, the Koh Angkrong reef appears to be displaying some signs of recovery. The overall condition of the benthic community suggests that coral reef functionality has been maintained to some degree. In the absence of some major herbivore functional groups, ecosystem herbivory has been largely attributed to urchin grazing, particularly by the *Diadema* sea urchin. A paucity of herbivores fish has resulted in the *Diadema* sea urchin becoming highly abundant on the Koh Angkrong reef.

The establishment of the MFMA in combination with other conservation tools is expected to create the foundations so desperately needed for the recovery of marine ecosystems in the Kep Archipelago. The conservation strategy provides mitigation against a multitude of threats and should be effective at reducing trawling activities and other major anthropogenic stressors. The proposed conservation strategy has been designed to protect entire ecosystems and their services by including ecosystem-based management techniques that will provide wider environmental, social and economic benefits to the region. Ongoing monitoring and research will be conducted by MCC for Koh Angkrong, Koh Mak Prang and Koh Seh reefs, in order to assess the effectiveness of conservation efforts over time.

Acknowledgements

Marine Conservation Cambodia would like to acknowledge those that have been involved with, and participated in, conserving Cambodia's marine environment and protecting the livelihoods of the people that are dependent on marine resources. Marine Conservation Cambodia's partnerships with the Fisheries Administration (FiA) of the Royal Government of Cambodia (RGC), local governments and authorities, other government bodies (national and provincial), international institutions, notably the International Conservation Fund of Canada (ICFC), and other stakeholder groups have been pivotal to MCC's success. Many thanks to the following people:

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Mr. Paul Ferber	Managing Director and Project Founder, MCC

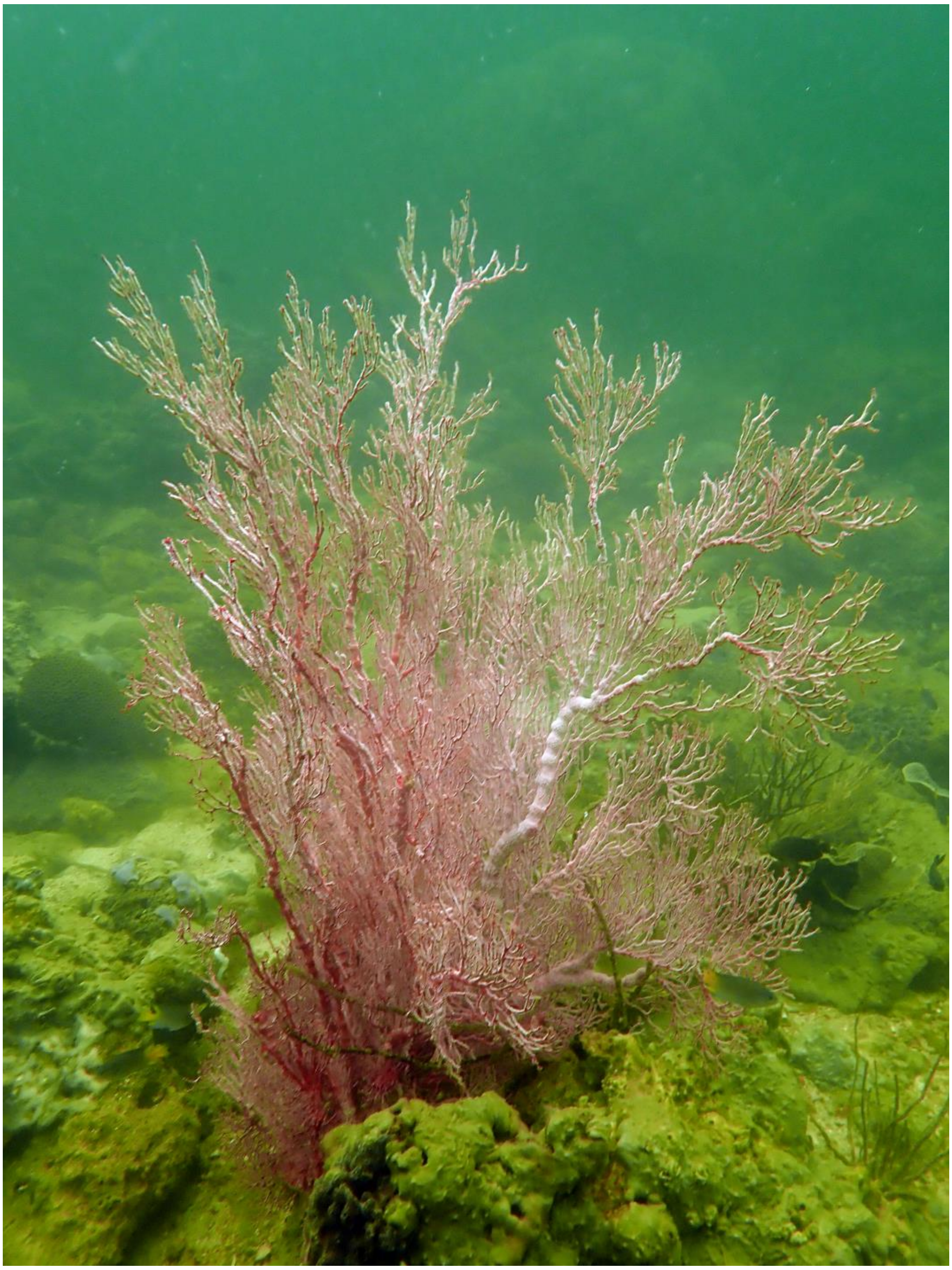
Research Team

Survey Data Collection Team:

Amick Haïssoune, Carney Miller, Tom Collombat, Tanguy Freneat, Delphine Duplain.

Contributors to the Report:

Maps by: Tom Collombat & Delphine Duplain



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1. Introduction

This report is the 2017 environmental assessment of the Koh Angkrong coral reef ecosystem, located in Cambodia. This research, completed by Marine Conservation Cambodia (MCC) analyses and presents survey data collected as part of an ongoing research and monitoring programme between The Royal Government of Cambodia and MCC. Environmental assessments have been completed for three fringing coral reef systems within the Kep Archipelago, which have been selected to act as indicators for the marine environment. The monitored reefs are adjacent to the islands of Koh Seh, Koh Mak Prang and Koh Angkrong. Monitoring data collected by MCC has been compared to baseline data over time in order to track ecosystem changes and to assess the effectiveness of conservation efforts in combatting illegal fishing practices in the region. This research is critical for Cambodia's marine environment, which has experienced prolonged unsustainable and destructive fishing. Outside of MCC's initiative, no other long-term environmental science or monitoring programmes are being conducted in the region. This document aims to provide context on environments, fisheries and important issues within the Kep Archipelago. The report then reviews and discusses anthropogenic impacts, changes to species abundance and richness, herbivore abundance and substrate cover for the Koh Angkrong coral reef ecosystem. Finally, the document will discuss the conservation strategy currently being implemented in relation to the future of coral reefs (and adjacent ecosystems) in the Kep Archipelago.

1.1 The Marine Environment

The Kep Archipelago boasts a spectacular array of important marine ecosystems. They help to support the local economy, have high social values, and many livelihoods depend upon the goods and services produced by these ecosystems. Key marine ecosystems within the Kep Archipelago include:

- coral reefs;
- seagrass meadows;
- bivalve beds;

- mangrove forests.

Coral reefs cover less than 0.2% of the seas surface, and yet, are among the most diverse and productive ecosystems in the known world (Knowlton *et al*., 2010; Hoegh-Guldberg, 2011). They provide important services to approximately 500 million people, globally, as well as to surrounding seagrass, bivalve and mangrove ecosystems, to which they share trophic linkages (Hoegh-Guldberg, 2011; Davis *et al*., 2014; Mumby & Hastings, 2008; Olds *et al*., 2013). Coral species are considered highly diverse in the South China Sea, and in the Kep Archipelago fringing coral reefs have formed around each of the islands while extensive seagrass meadows and bivalve beds occupy much of the shallow seafloor (Huang *et al*., 2015). Seagrasses play important roles in the nutrient cycling of carbon, phosphorus and nitrogen, and support fish productivity and biodiversity of coral reef ecosystems (Unsworth & Cullen, 2010; Sigman & Hain, 2012; Nordlund *et al*., 2017). They also play an important role in nutrient retention and recycling, and help to regulate water quality (Unsworth *et al*., 2008; Nordlund *et al*., 2017). Bivalve beds also perform major roles in regulating water quality as the shellfish filter nutrients, sediment and phytoplankton from the water column (Coen *et al*., 2007; Ostroumov, 2005; Grabowski and Peterson, 2007). Water quality control is thought to be most effective when bivalve biomass is high and water depth is shallow, such as the water depth in the Kep Archipelago (Grabowski and Peterson, 2007).

Mangrove forests provide some similar services to seagrasses and act as important fish nurseries for coral reef and seagrass species (Lee *et al*., 2014). Mangrove forests help to increase fish abundance and diversity on coral reefs and seagrass meadows, and are known to improve the likelihood of coral reef recovery following a disturbance (Unsworth *et al*., 2008; Olds *et al*., 2013). In the Kep Archipelago, coral reefs, seagrass meadows, bivalve beds and mangrove forests provide habitat, food, shelter and breeding sites for a multitude of commercial and non-commercial marine species.

1.2 Fisheries and the Economy

Marine and inland fisheries are important economic contributors to the domestic market in Cambodia, and provide approximately 80% of animal protein to the population. The industry is particularly crucial for the food security and income of the country's poorest people (MAFF, 2011). It has been reported that marine fisheries land an average of 120,500 tonnes of commercial catch per annum, accounting for 20% of total fisheries production (PIC, 2017). However, this is likely underestimated as it is difficult to account for all small scale fishers (which make up a large proportion of fisheries) and large foreign vessels operating illegally in Cambodian waters. In Kep, marine fisheries provide livelihoods for many of the population, where, in the sea, their vessels are largely targeting seagrass associated species, such as shrimp, fish and the world-renowned blue swimmer crab (PIC, 2017). Fishing and collecting valuable marine life on coral reefs is also commonly practiced. Furthermore, coral reefs contribute to the economy through tourism, although, in Kep, this industry has not yet been fully developed.

1.3 The Illegal Fishing Threat

Important drivers behind changing tropical ecosystems, excluding climate change, have been attributed, globally, to human activities related to agricultural land-use, coastal development and overfishing (Mora, 2008; Wear, 2016). In Cambodia, destructive fishing, overfishing, sedimentation, pollution (nutrient enrichment and contamination) and physical damage (anchors, boats, etc.) continue to destroy coral reefs, causing rapid losses of biodiversity (van-Bochove *et al.,* 2011). Overfishing, including the use of destructive methods, can have profound effects upon an ecosystem, especially when the harvesting of functional groups is not reported within unregulated fisheries. (McClanahan *et al*., 2011; Edwards *et al*., 2014; Pratchett *et al*., 2014). Illegal, unregulated, unreported (IUU) fishing is one of the most immediate threats to coral reefs (as well as seagrass meadows and bivalve beds) in Cambodia's coastal provinces (Teh *et al*., 2017). In the Kep Archipelago, unsustainable, destructive fishing methods, such as bottom trawling (includes trawling, electric trawling and pair trawling), seine netting and air-tube diving are occurring on a daily basis (particularly during the night), despite fisheries laws that have been introduced to prohibit such practices. Trawling threatens the sustainability of the legal, commercial fishing industry and the livelihoods of subsistence fishers. For instance, the economically important blue swimmer crab has been continuing to reduce in size and abundance as they are caught and their habitat destroyed by trawling vessels (Cane & Muong, 2015).

The destruction of seagrass meadows, bivalve beds and other ecosystems indirectly effects coral reefs (Davis *et al*, 2014). Trawling vessels, which are often foreign, frequently drag their nets along the seabed at depths of less than 20 metres, which is illegal under Cambodian law. The entire Kep Archipelago is less than 10m deep in most places. Trawling techniques indiscriminately remove all marine life in their path. These methods are destructive and completely unsustainable, removing not only entire living communities, but also essential habitat that marine species use for shelter, feeding and breeding. Trawling through seagrass meadows and bivalve beds also threatens water quality in the Archipelago, which is already relatively poor and another major issue requiring serious focus.

The greatest direct threats to coral reefs in the Kep Archipelago are illegal diving and the collecting of marine life on reefs. For example, fish and invertebrates are often collected by divers (or by set net), whereby the fishers may remove anything they perceive as being of instrumental value. This includes species of fish for consumption or the aquarium trade; beautiful corals and shells to be sold and used as ornaments; and organisms believed to have medicinal value, such as seahorses.

According to a threat index used by Rizvi & Singer (2011), 90% of coral reefs in Cambodia are classified as being at high risk from destructive and overfishing, while the remaining 10% are classified as being at very high risk. The degradation of coral reefs, seagrass meadows, bivalve beds and mangrove forests threatens ecosystem functionality and the productiveness of the entire Kep Archipelago. If regulations are not properly enforced and these critical ecosystems are not conserved, then future ecological and economic consequences could be immense.

1.4 Conservation

While the appropriate legislation has been introduced to provide environmental protection and to promote sustainable marine resources (refer to *APPENDIX A*), enforcement of the law, on the other hand, has not been successful since the implementation of new legislation in 2006. The Kep Provincial Government has, however, recognised the increasing pressure that is being placed on marine resources in the Archipelago and are acting to restrict illegal and unsustainable fishing. By working alongside MCC, the provincial government has implemented the first Marine Fisheries Management Area (MFMA) in the Kep Province (Figure 1). The area will cover 11,354ha, encompass 12 islands and include highly protected ‘no-take’ zones around coral reefs, seagrass meadows, bivalve beds and mangroves. In combination with this conservation tool, MCC will design and deploy a minimum of 47 artificial reefs (AR) throughout the MFMA. The AR’s will attract marine life, be seeded with oyster spat to enhance water filtration and, in the future, be sustainably harvested by local fishing communities. They also act as anti-trawling devices and have been designed to inflict irreparable damage to any trawling net coming into contact with them.

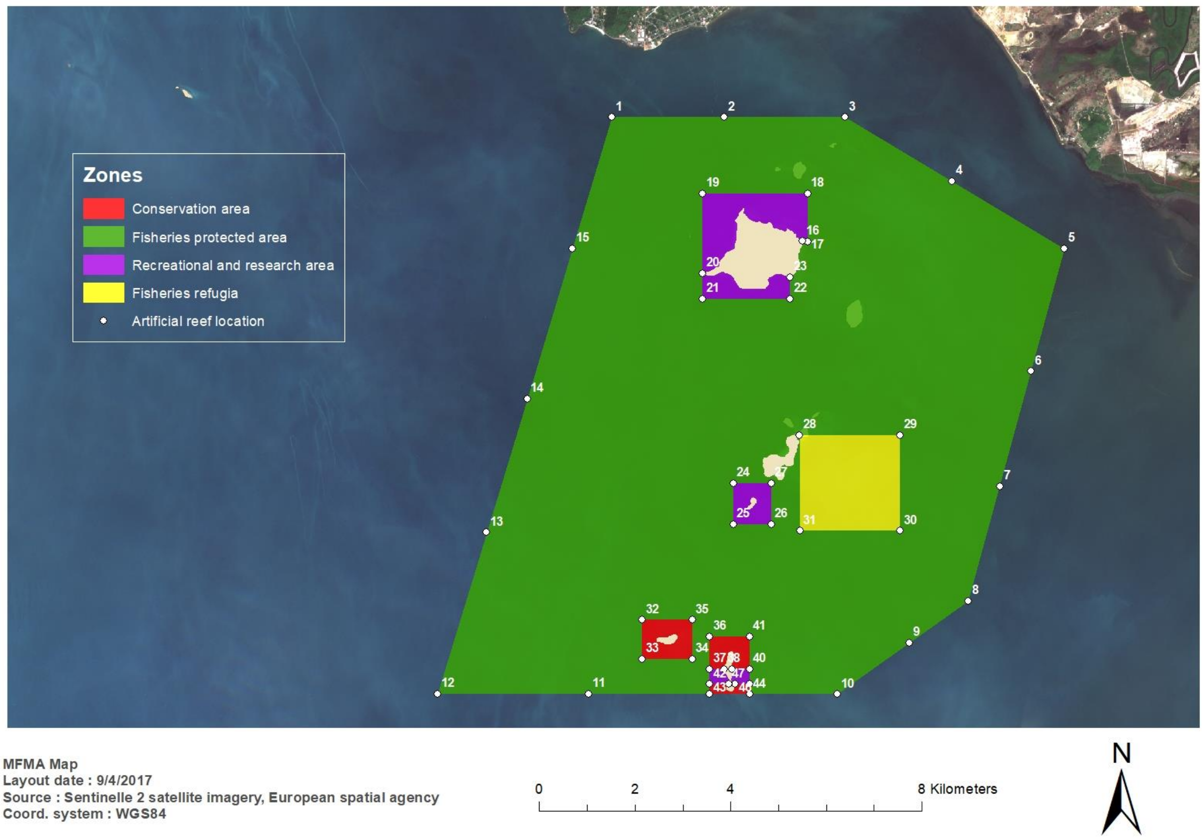


Figure 1: Location of the Marine Fisheries Management Area in the Kep Archipelago, relative to mainland Cambodia.

The idea is that the MFMA will safeguard entire ecosystems and their functions, including critical habitats and the species that live there. It is expected that this conservation strategy will help support the restoration of fish populations and fisheries, and over time we will begin to observe increases in size and abundances of target species, which has been an outcome in other geographical areas where similar strategies have been applied (Brown *et al*., 2014). The MFMA will be largely managed by local fishers (with help from MCC and local authorities) and regulations enforced by marine police and the Fisheries Administration (FiA). The effectiveness of this conservation strategy will be monitored over time in order to determine its success.

2. Methods

2.1 Site Selection

Koh Angkrong is located within Cambodia's Kep Archipelago, at, or about, GPS coordinates 10°21'29.4"N 104°19'11.8"E (Figure 2). Koh Angkrong is positioned approximately 1.1km from Koh Seh, location of MCC's headquarters. The Island is largely uninhabited, however, local fishers have established make-shift homes that they frequent while fishing the area. A fringing coral reef surrounds the island, which is fished by commercial and subsistence fishers. The methods used are set net, line, cage and air tube fishing/diving. Set nets, line fishing, and cages are all legal fishing methods, so long as protected or endangered species are not caught and no damage to coral reef incurs. Air tube diving, on the other hand, is illegal. It is a method primarily utilised in order to target rare, aesthetically pleasing natural structures and animals found among coral reefs.

Since the introduction of regulatory patrols in 2015, MCC have reduced illegal fishing on coral reefs by an estimated 50-70%. However, illegal fishers continue to fish adjacent seagrass meadows intensely, particularly during the night to more easily evade authorities. The eastern side of Koh Angkrong is visible from Koh Seh and MCC's presence there has provided higher protection for that section of the Koh Angkrong reef. There are also some tourism vessels that operate in the area.

Monitoring data has been collected for the Koh Angkrong coral reef system on two occasions, over three years, during the years of 2015 and 2017.

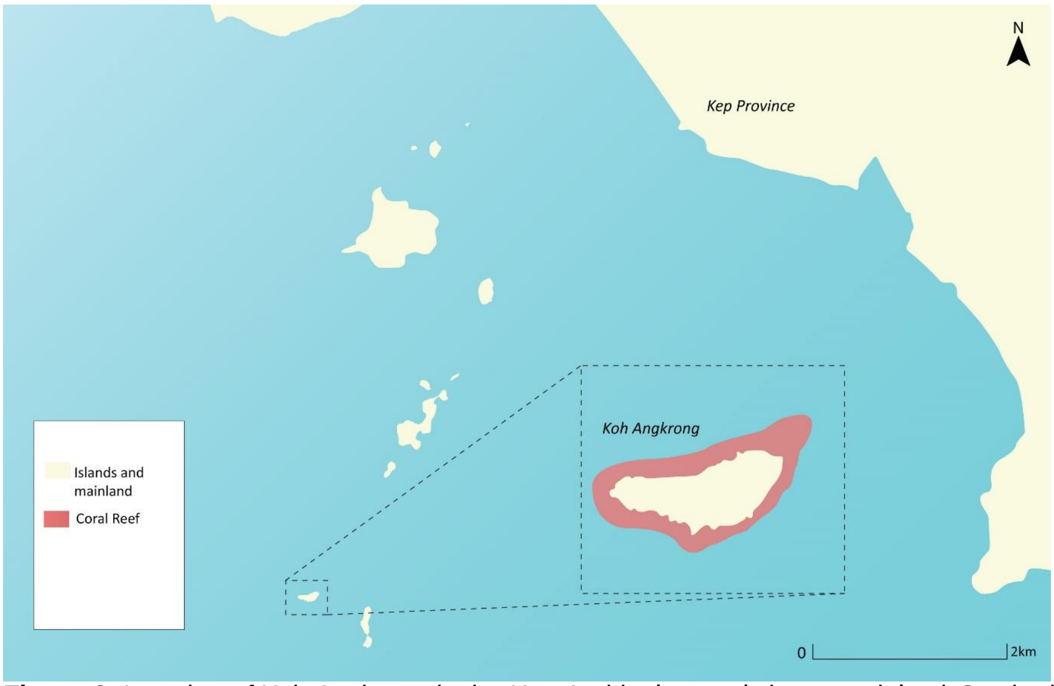


Figure 2: Location of Koh Angkrong in the Kep Archipelago, relative to mainland Cambodia.

The 2017 coral reef assessment for Koh Angkrong was conducted between February and April. Preliminary dive investigations were undertaken in order to determine the suitability of potential survey sites. Three sites were selected that were perceived to be representative of the existing state of coral reef surrounding Koh Angkrong (Figure 3). Areas of coral reef were selected for based on varying levels of anthropogenic impact and environmental variation. Relative to each other, the sites ranged from 'relatively good' to 'relatively poor' with an 'intermediate' site also included (Table 1).

Table 1: Site conditions.

Site Name	Condition
Site 1	'Relatively good'
Site 2	'Relatively poor'
Site 3	'Intermediate'

Each of the site conditions were based on their perceived condition at the time of surveying. It is important to note that all sites had experienced some degree of degradation, as fishing pressures in the past are thought to have pushed the Koh Angkrong system to near collapse. The site labelled 'relatively good' was, at the time, in the best condition compared to the other sites, but not existing in, by any means, a pristine or exceptionally healthy state on its own. Initially, site 3 had been documented as being in the poorest condition, however, in the last two years site 2 transcended in the poorest of the sites. This was due to illegal diving that caused the destruction of many corals. However, the variance in conditions between sites are not often huge and each of the sites share also many similarities. The GPS locations of all three sites were recorded during 2017 and will continue to be used for future surveys.

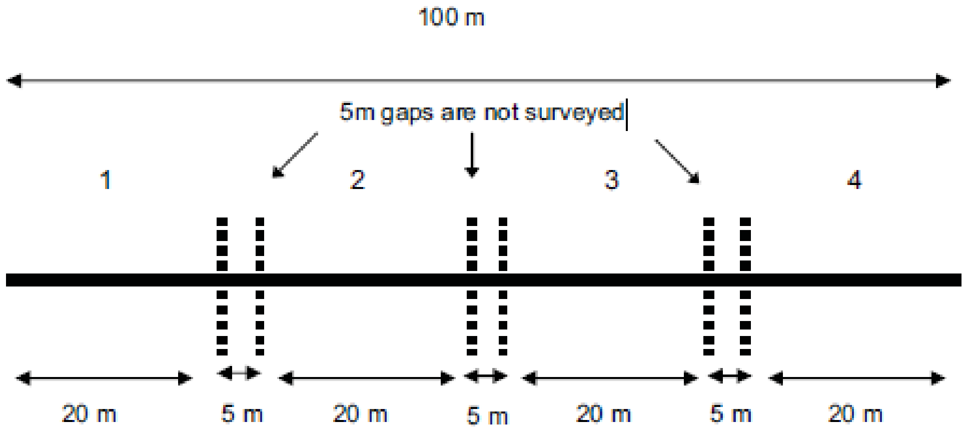
Figure 3: 2017 survey site locations.

2.2 Data Collection

Procedures for collecting field data followed a modified version of Reef Check's international guidelines for coral reef monitoring, detailed by Hodgson *et al.* (2006).

2.2.1 Coral Reef Surveys

Three sites were selected during 2017. At each of the sites, a 100m transect line was placed along sections of coral reef. Along the transect line, four surveys, each conducted over a distance of 20m, were undertaken with 5m breaks in between each survey length where no data was collected (refer to Figure 4). This was replicated three times for each of the three sites.



Hodgson *et al* (2006)

Figure 4: Reef Check's coral reef survey transect method for collecting species' data.

Separate surveys for fish, invertebrates, substrate and anthropogenic impacts were conducted by trained divers. For fish and invertebrate surveys, species data was collected from the seabed to 5m above the seafloor (but at no point was there ever 5m of water between the seafloor and surface at sites) and 2.5m either side of the transect line. Therefore, each 20m survey had the potential to examine 500m^3 of coral reef environment. However, in this report, for fish and invertebrate data, we measure each of the 20m survey segments as 100m^2 of area examined. During substrate surveys data was collected by logging the substrate every 0.5m, parallel with the transect line. This was performed by lowering a plumb line until it was about to make contact with (if the particular substrate was considered to be sensitive) a substrate. The diver then recorded the substrate which the plumb had been lowered to. The side of the transect line in which data was collected differed with recorder but remained consistent throughout each survey.

The Reef Check methodology suggests a particular focus on the monitoring of coral reef indicator species. Indicator species are living organisms whose presence and abundance is able to indicate the state or condition of an environment where they are found (Siddig *et al.*, 2016). Coral reef indicator species that are monitored by MCC in the Kep Archipelago have been selected on the basis of their economic and ecological value to the area, as well as for their sensitivity to human impacts. Species have also been added to the monitoring list when they have (re)appeared in the Archipelago. These include a wide variety of fish and invertebrates, at varying taxonomic levels, and substrates that act as both regional and global indicators of coral reef health. Please note that anthozoans, poriferans, ascidians, and hydrozoans have been considered amongst the substrates for this report, as they are sessile invertebrates that can cover large areas of the seafloor and make up a large proportion of the benthos. Only species/groups that have been included on the MCC species monitoring list were recorded during surveys (refer to *APPENDIX B*).

2.2.2 Impact Assessment

Impact assessment surveys were undertaken and completed by trained divers. During each survey dive, the level of coral damage (‘boat/anchor’, ‘dynamite’, ‘other’), trash (‘fishing trash’, ‘general’), and predation was recorded using the following scale:

0 = none, 1 = low (1 piece), 2 = medium (2-4 pieces) and 3 = high (5+ pieces)

Bleached and diseased corals were also recorded during surveys. The average percent of the coral population that were bleached and diseased was recorded between sites and years. The survey team also recorded the average percent cover of disease/bleaching for individually affected corals. Please note that comparative analyses for diseased corals could not be completed between years. This is due to the specific surveying of only black band and white band coral diseases during 2015, which was then amended to a general disease presence/absence investigation for 2017.

2.2.3 Data Collection 2015: Methods and Limitations

The methods utilised for surveying the reef during the 2015 environmental assessment differed from the most recent methods that MCC have adopted going forward. Please note that differences observed in the data between years may be attributed, in some degree, to modifications made to the methodology between sampling years. Improvements, including the addition of proper scientific replication, were made to the

2017 sampling methodology, and caution is advised when comparing that with data from 2015 in some instances.

Nine sites were selected during 2015 that were positioned around the entire fringing reef, bordering Koh Angkrong (Figure 5). Surveys were undertaken using the same transect line technique used during 2017, however, only one replicate was completed per site. Both years included totals of 36 surveys for each of the monitored categories. Nevertheless, a few of the 2015 survey sites included areas that were not coral reef, which effected the comparability of the data between years. For this reason, substrate comparisons between years have not been presented in this report.

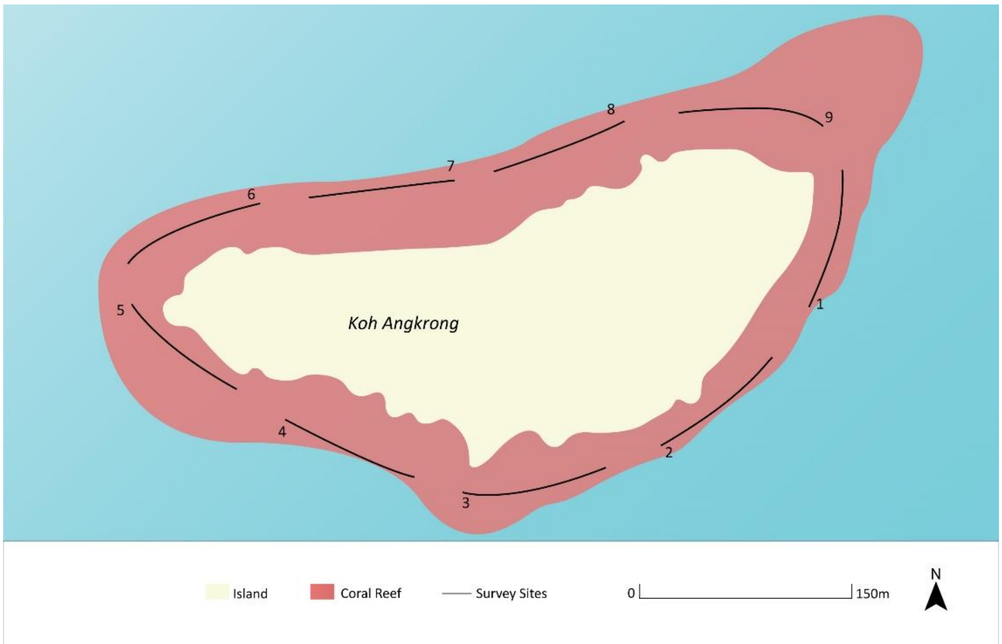


Figure 5: 2015 Survey site locations.

2.3 Species Monitoring List: Additions and Removals

In order to improve the information MCC collect from coral reefs in the Kep Archipelago, additional species/groups have been added to the monitoring list from previous years for both fish and invertebrates, as well as the addition of two substrate types. This is largely due to the apparition of new species that have been observed by trained divers. There is a total of 86 fish and 40 invertebrate species/groups (including ‘other’ and unknown’; excluding ‘total’ and size classes) on the 2017 MCC species monitoring list. A number of species have also been removed from both fish and invertebrate groups, where the monitoring of these species was found to add no substantial value to the environmental assessments undertaken by MCC. Please refer to *APPENDIX B* for the substrate groups, and the fish (Table B6) and invertebrate (Table B7) species/groups that have been added and removed for the 2017 monitoring year. Furthermore, refer to Table B8 for the complete list of scientific names/classifications for fish and invertebrate species/groups that were monitored.

2.4 Data Analysis

Total mean abundances of fish and invertebrate species/groups have been calculated per survey segment. Each survey segment is equal to 100m^2. Substrate cover was also calculated by averaging all 36 survey segments (12 for each site). This provided a total mean percent cover for each substrate type. All species on MCC’s monitoring list that were identified as being present have been displayed on each of the figures. Note that some closely related species with similar functional roles have been grouped together and presented as a total value within their respective group. These included species within the butterflyfish, rabbitfish, snapper, bream, grouper, parrotfish, and wrasse groups. Species not listed on the species monitoring list have not been recorded during monitoring. Species/groups that were present during both monitoring years, but only recorded during one of those years have been accounted for by displaying “NA” (not applicable) by the species name on respective figures. The same applies to substrate groups. Abundances of species/groups that are present have been displayed for each site and as a total between years.

Microsoft Excel’s ‘Data Analysis’ package has been used to statistically investigate relationships within the data. For the impact assessment analysis, paired t-tests have been used to compare data between years, while Two-sample t-tests were used to compare data between sites.

Percent cover of hard coral, soft coral, sponge, rock, coral rubble, sand, zoanthid and 'other' were examined between sites for 2017 using two-sample t-tests. The additional substrate categories were not well represented within the data and no statistical comparisons were therefore investigated. The 2015 data included sections of marine habitat that were not coral reef, so as a consequence of this known data bias total substrate cover has not been compared between years.

Analysis of variance (ANOVA) and two-sample t-tests were used to examine both total average species abundance and average herbivore abundance per $100m^2$ of transect, between years. Total average fish and invertebrate abundance and total herbivorous fish and urchin abundance between years have been investigated using two-sample t-tests. Fish species/groups statistically analysed include: butterflyfish, rabbitfish, sergeant fishes, snapper, cardinalfish, and fusilier. Invertebrate species/groups statistically analysed include: feather duster worm, christmas tree worm, true crab, cowrie, *Drupella,* top shell, nudibranch, other gastropods, cuttlefish, and the *Diadema* sea urchin. Herbivorous fish groups included rabbitfish and sergeant fish as these were considered the only important herbivore groups present during monitoring. Other important herbivorous fish groups, such as parrotfishes, surgeons and rudderfish were not observed and have been considered locally extinct. Batfish are known to the Archipelago's reef systems, however, none were observed during the time of monitoring. Damselfish are highly abundant on the reef system, however, most species are territorial algal-farmers, with the exception of sergeant fish, and were not monitored by MCC. Herbivorous urchins included the flower urchin, the *Diadema* sea urchin, the pencil urchin and the collector urchin. Please note that the flower and collector urchins are often associated more with seagrass habitat.

ANOVAs and two-sample t-tests were used to compare differences in species richness per $100m^2$, between sites in 2017. Average species richness was measured by investigating the number of species identified from MCC's species monitoring list. It is important to note that higher taxonomic groups, in some cases, were considered as a single species (e.g. other gastropods). Groups labelled with 'total' were excluded from the species richness count, which, included only individual species/groups. Size class categories were also excluded. A paired t-test was used to compare total species richness for fish and invertebrates (both combined and separately) between 2015 and 2017.

3. Results

Refer to *APPENDIX C* for the corresponding tables and statistical outputs.

3.1 Impact Assessment

High levels of coral damage (excluding damage caused by boat, anchor or dynamite fishing) were recorded at site 2 during 2017 (Figure 6, Table C1). Sites 1 and 3 exhibited some coral damage, recorded as being low. Between years, a medium level of coral damage caused by boat/anchor was recorded during 2015, as well as a low level of ‘other’ coral damage. A medium level of ‘other’ coral damage was recorded during 2017 (Figure 7, Table C2).

There was a medium level of general trash observed during 2015, which dropped to low by 2017, at each of the sites (Figure 6, Figure 7, Table C1, Table C2). Fishing net trash was also low during 2017, except at site 2 which brought the 2017 total up to a medium level. Fish net trash during 2015 was documented as being low. Site 3 displayed high levels of coral predation compared with sites 1 and 2, which both displayed medium levels (Figure 6, Table C1). In total, coral predation was considered to be at a medium level for the Koh Angkrong system during 2017 (Figure 7, Table C2).

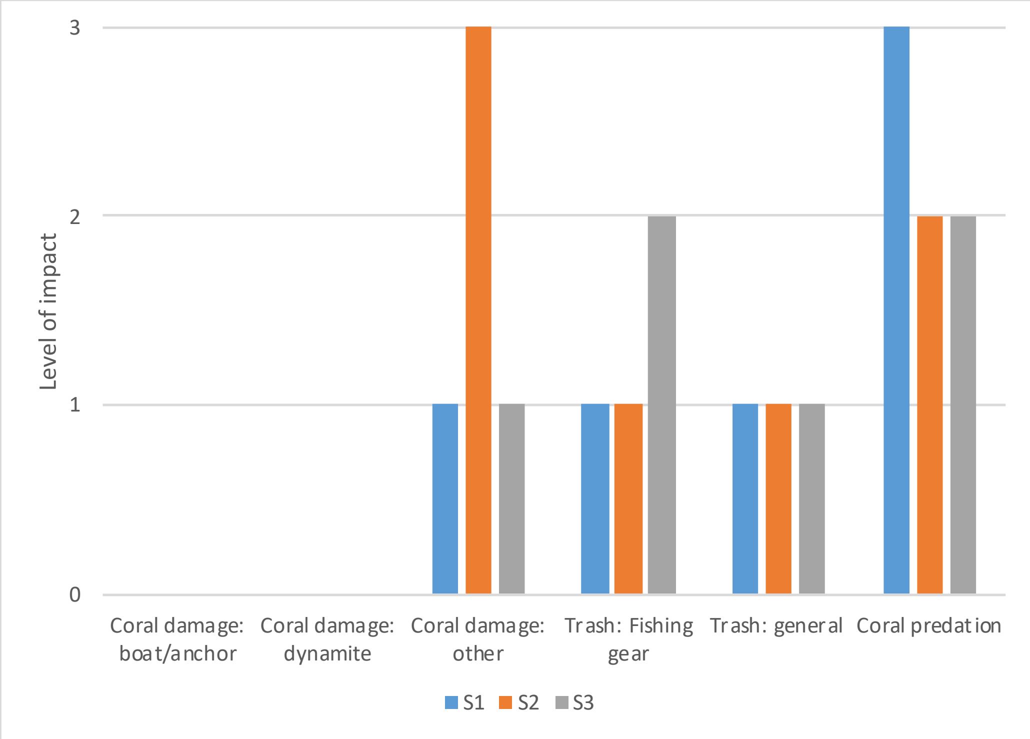


Figure 6: Median level of coral damage, trash and predation at each site (S1, S2, S3) during 2017. 0 = none, 1 = low (1 piece), 2 = medium (2-4 pieces) and 3 = high (5+ pieces).

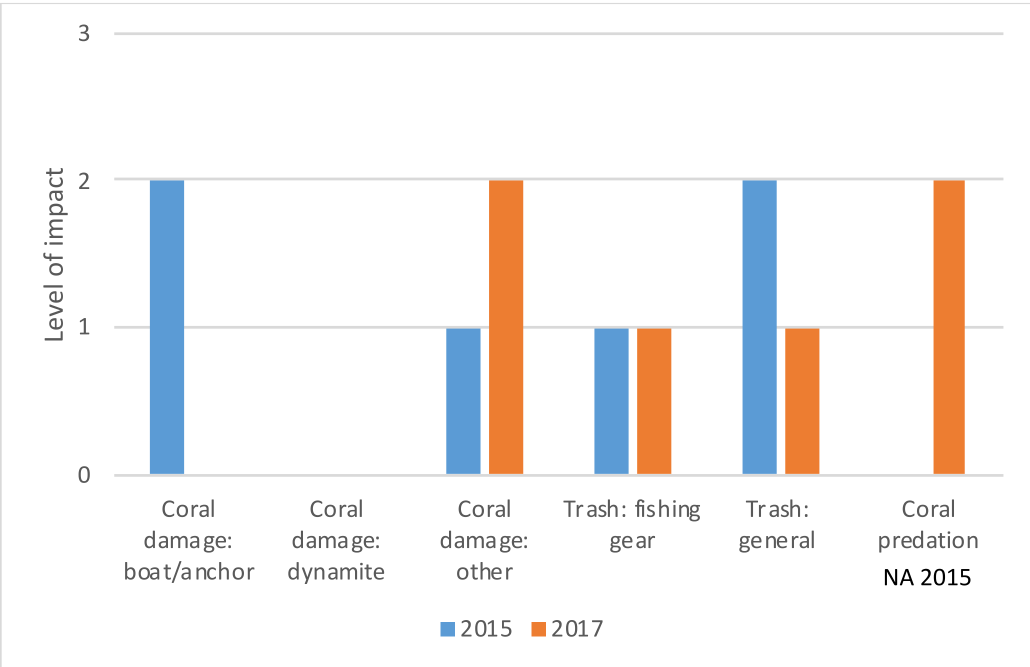


Figure 7: Total median level of coral damage, trash and predation at Koh Angkrong during 2015 and 2017. 0 = none, 1 = low (1 piece), 2 = medium (2-4 pieces) and 3 = high (5+ pieces).

Less than 10% of the coral population, on average, was recorded as bleached during both years. Instances of coral disease among the population were recorded at a greater presence and averaged at 16.47% of the population. No Black Band or White Band diseases were recorded during 2015 surveys (Figure 9, Table C8).

The average percent of bleached corals in the population did not significantly differ between site or year (t_{35}=-1.97, p=0.056; $f_{2,33}$=1.07, p=0.352) (Figure 8, Figure 9, Table C3, Table C8). There was also no significant difference between the average percent of bleaching on an individual coral between site and year (t_{35}=1.45, p=0.16; $f_{2,33}$=1.12, p=0.337) (Table C4, Table C5, Table C9).

No significant differences was revealed for the average percent of diseased corals between sites ($f_{2,33}$=1.19, p=0.318). Furthermore, there was no significant difference between the average percent of disease cover on an individual coral between sites ($f_{2,33}$=0.93, p=0.404) (Table C6, Table C7, Table C9).

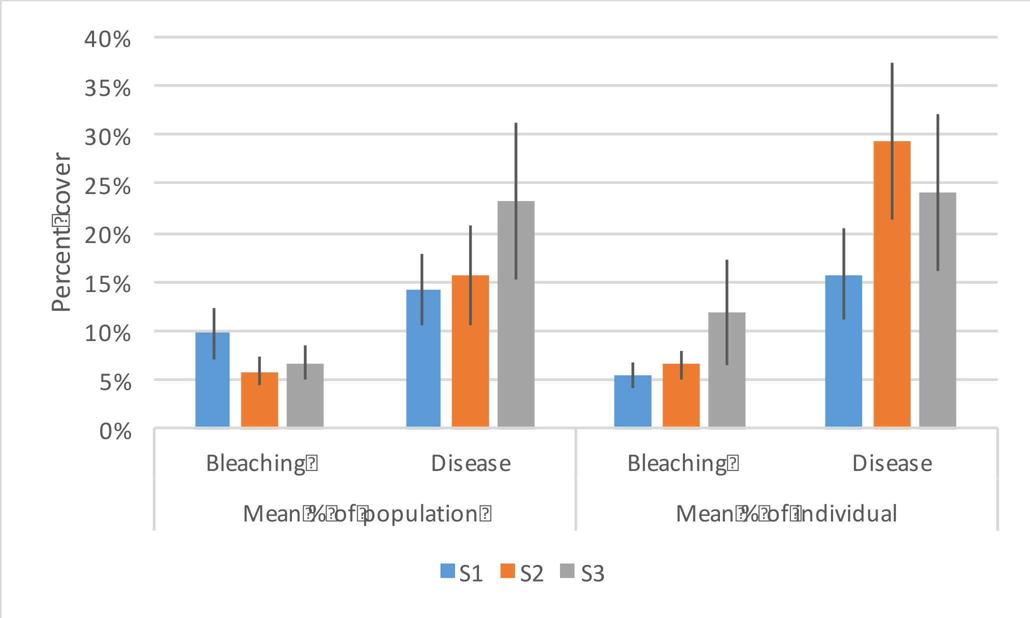


Figure 8: Mean (± SE) percent of bleached and diseased corals within the population and per individual coral cover, between sites (S1, S2, S3) during 2017.

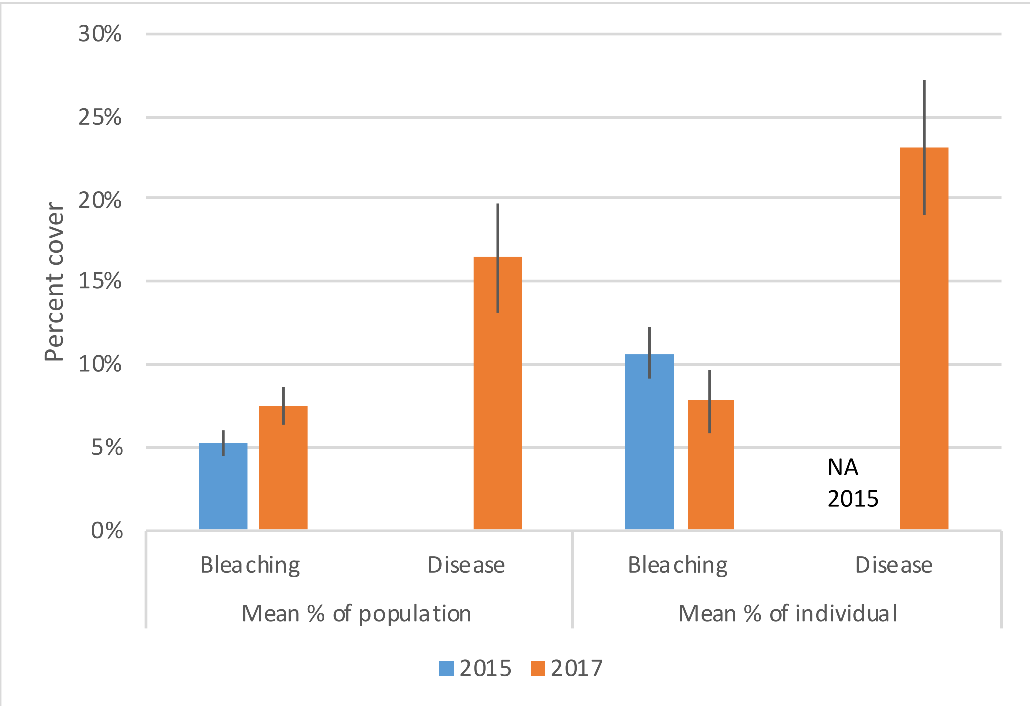


Figure 9: Mean (± SE) percent of bleached and diseased corals within the population and per individual coral cover, between years.

3.2 Substrate Cover

Total substrate cover during 2017 has been presented below, and excludes a comparison between years (Figure 10, Table C10). Substrate cover varied significantly between sites at Koh Angkrong during 2017 (Figure 11). Refer to *APPENDIX B* (Table B3) for a complete list of substrates and their acronyms.

Hard Coral

All three sites exhibited varying amounts of hard coral (HC) cover. Site 1 displayed the greatest average cover, at 76%. This significantly differed from site 2, which displayed the lowest average cover between groups, at 27% (t_{22}=11.6, p=<0.001). Hard coral at site 3 was characterized by an intermediate level of cover, displaying an average cover of 54%. The analysis revealed that site 3 was significantly different from both sites 1 (t_{22}=4.44, p=<0.001) and 2 (t_{22}=-5.62, p=<0.001). Refer to Table C11 and Table C12.

Soft Coral

Average soft coral (SC) cover at sites 2 and 3 was relatively low. No soft coral was recorded for site 1. Analysis revealed no significant difference in soft coral cover between sites ($f_{2,33}$=2.39, p=0.107). Refer to Table C13 and Table C14.

Sponge

Site 2 displayed an average sponge (SP) cover of 28%, the greatest cover between groups. This significantly differed from sponge cover at sites 1 (t_{22}=-7.55, p=<0.001) and 3 (t_{22}=6.24, p=<0.001), which displayed 6% and 8% covers, respectively. There was no significant difference observed in sponge cover between sites 1 and 3 (t_{22}=-1.07, p=0.297). Refer to Table C15 and Table C16.

Rock

The average percent of rock (RC) cover did not differ between sites ($f_{2,33}$=2.01, p=0.151). Site 2 displayed the greatest average percent of rock cover, at 17%. Site 1 displayed an average of 12% rock cover, and site 3 had an average of 8%. Refer to Table C17 and Table C18.

Coral Rubble

Coral rubble (RB) appeared most prevalent at site 2, with an average cover of 14%. Coral rubble cover at site 2 was significantly greater than the cover exhibited at both sites 1 (t_{22}=-6.91, p=<0.001) and 3 (t_{22}=2.47, p=0.022). Site 3 displayed an average cover of 1% and was significantly greater than site 1 where no coral rubble was recorded (t_{22}=-1.84, p=0.079). Refer to Table C19 and Table C20.

Zoanthid

Sites 1 and 2 exhibited relatively low zoanthid (ZO) cover, at 1%, and did not significantly differ from each other (t_{22}=0.84, p=0.409). Average zoanthid cover at Site 3 was higher at 15%. Site 3 displayed significantly greater zoanthid cover than what was observed at both sites 1 (t_{22}=-2.69, p=0.013) and 2 (t_{22}=-2.9, p=0.008). Refer to Table C21 and Table C22.

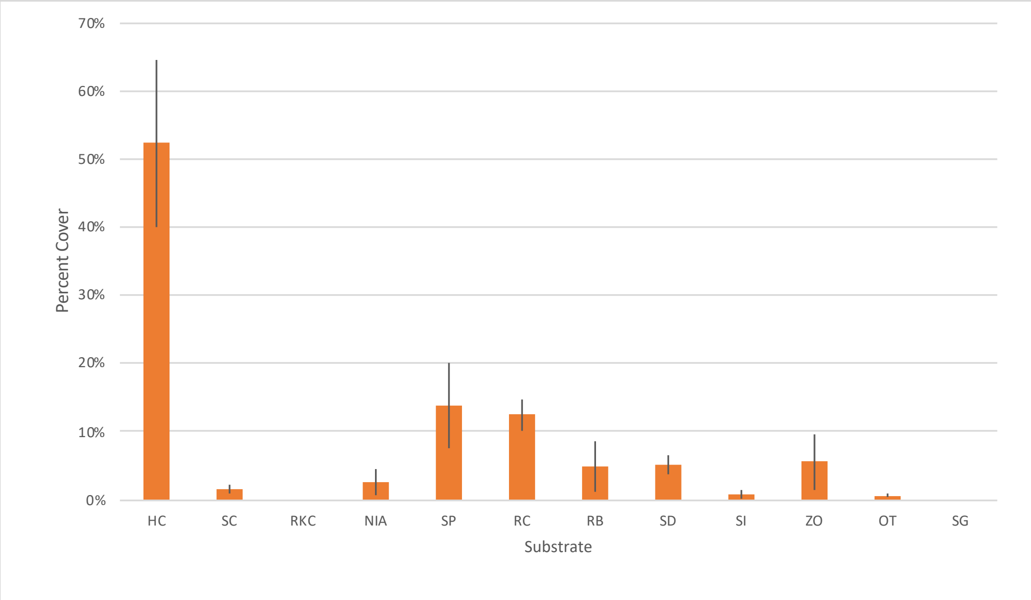


Figure 10: Total mean (± SE) percent cover of substrates during 2017.

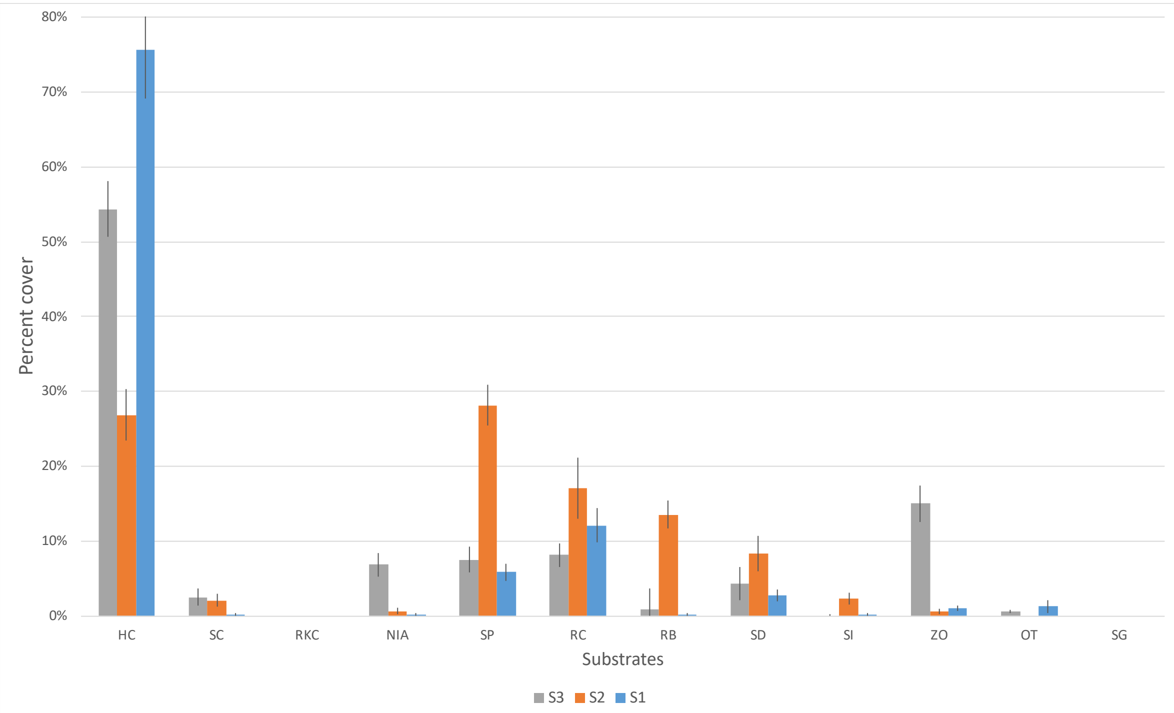


Figure 11: Mean (± SE) percent cover of substrates between sites (S1, S2, S3) during 2017.

3.3 Fish

Refer to *APPENDIX B* (Table B1) for the complete list of fish species monitored by MCC.

3.3.1 Totals Between Years

The Koh Angkrong reef system exhibited greater variety and abundances of fish species/groups during 2017, compared to 2015 (Figure 12, Figure 13, Table C23). A total of 30 fish species/groups from the MCC species monitoring list were recorded as being present during 2017. During the 2015 monitoring year only 9 fish species/groups were identified from the monitoring list (refer to Table B4 for the complete list of fish species/groups observed during both monitoring years). In total, there were 22 new fish species/groups identified in 2017 which had not been observed during 2015 (Table 2).

Table 2: New fish species observed at Koh Angkrong during 2017.

Golden Rabbitfish	White Streak Monocle Bream	Weedy Surge Wrasse
Other Rabbitfish	Emperor	other wrasse
Spanish Flag Snapper	Jacks	Pufferfish
Black-Spot Snapper	Yellowtail Barracuda	Carpet Blenny Eel
Red Snapper	Blue-Lined Grouper	Whiptail
Brown Stripe Snapper	Chocolate Grouper	Shark Sucker
Monogram Monocle Bream	Doublebanded Soapfish	
White Cheek Monocle Bream	Gold Spotted Sweetlips	

Species recorded during the 2015 monitoring year that were not observed during 2017 include (Table 3).

Table 3: Fish species observed during 2015 at Koh Angkrong that were not observed during 2017.

Longfin Bannerfish
Trevally

Total butterflyfish, fusilier and total snapper mean abundances all significantly increased between monitoring years (Table C24). Butterflyfish significantly increased from an average of 0.8 individuals per 100m^2 in 2015 to 2.58 individuals per 100m^2 in 2017 (t_{35}=-3.085, p=0.004). Fusilier significantly increased from an average of 0.03 individuals per 100m^2 during 2015 to 6.94 individuals per 100m^2 in 2017 (t_{35}=-2.72, p=0.01). And snapper significantly increased from 0.36 individuals per $100m^2$ in 2015 to 5.13 individuals per $100m^2$ in 2017 (t_{35}=-8.43, p=<0.001). The analysis revealed no significant increase in abundance over time for total rabbitfish (t_{35}=-0.5, p=0.62), sergeant fish (t_{35}=-1.05, p=0.089) or cardinalfish (t_{35}=-1.08, p=0.077) species/groups.

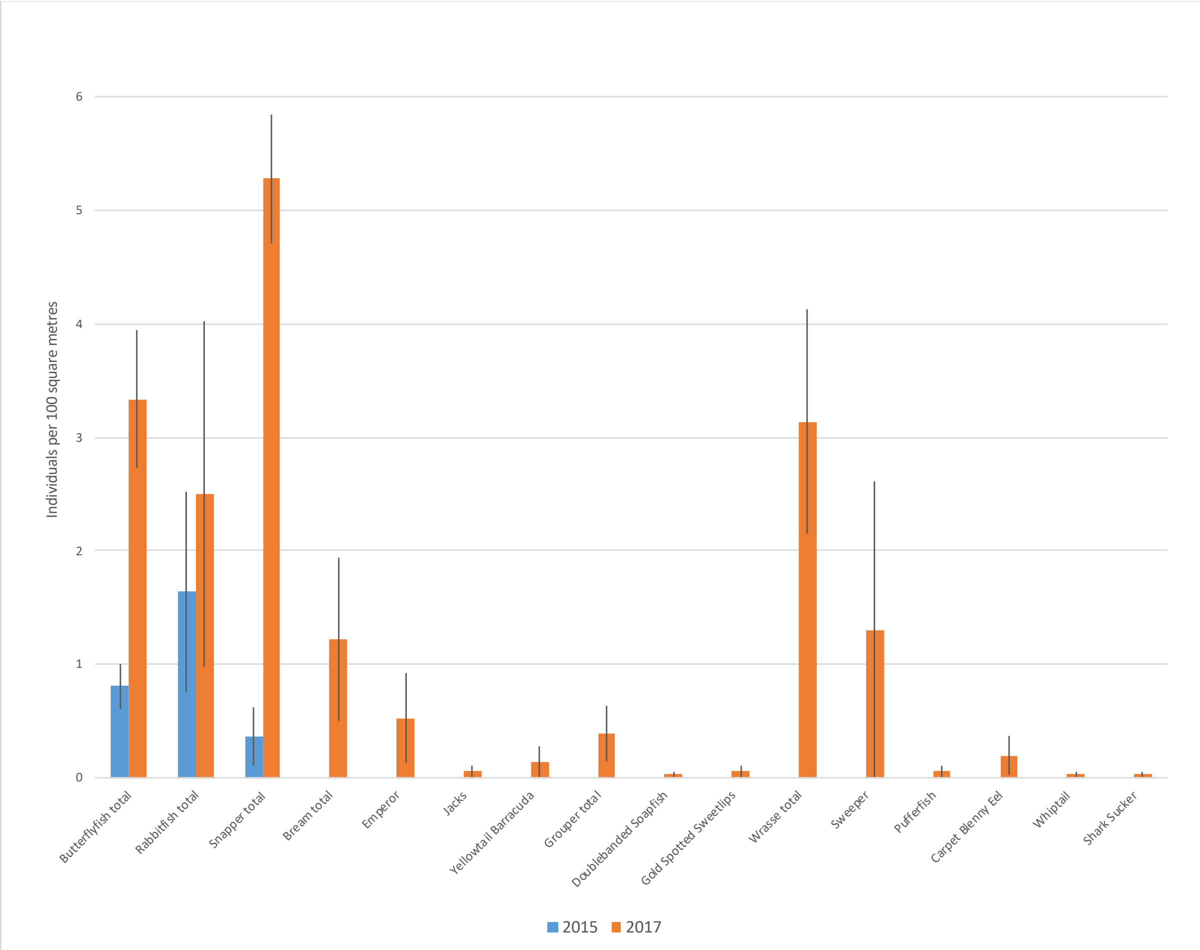


Figure 12: Total mean (± SE) fish species/group abundance per 100m² during 2015 and 2017.

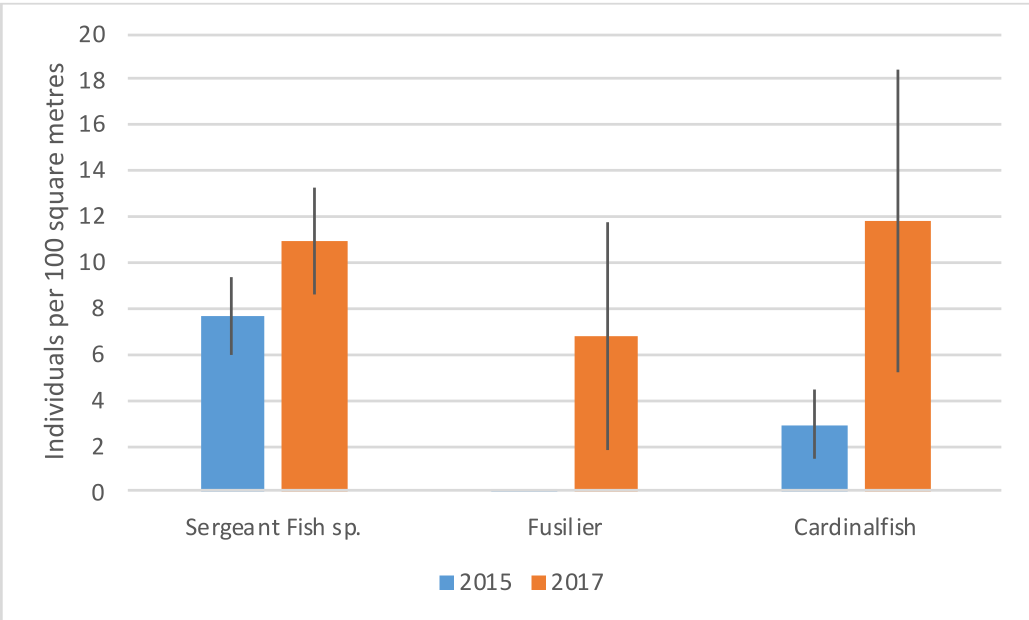


Figure 13: Total mean (± SE) abundance of sergeant fish, fusilier and cardinalfish per 100m² during 2015 and 2017.

3.3.2 Combined Total Abundance

Combined total average fish abundance differed significantly between years (t_{35}=-6.06, p=<0.001), exhibiting more than a three-fold increase over time (Figure 14, Table C25, Table C26). Average total fish abundance increased from 13.61 individuals per 100m^2 during 2015 to 54.22 individuals per 100m^2 in 2017. A combined total of 490 fish were recorded during 2015 surveys, compared to 2017 when 1952 fish were recorded.

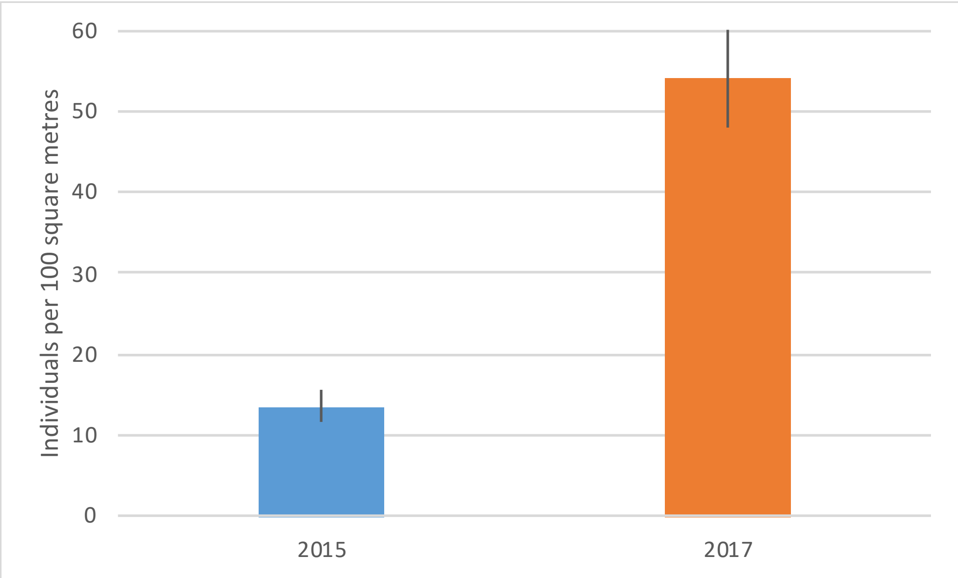


Figure 14: Combined total mean (± SE) number of individuals per 100m^2, for fish, during 2015 and 2017 monitoring years.

There was no significant difference in the combined total average abundance of fish between sites ($f_{2,33}$=1.07, p=0.353) (Figure 15, Table C27, Table C28). Sites 1, 2 and 3 exhibited an average of 47.25, 47.92 and 67.5 individuals per 100m^2 in 2017, respectively. There was a total of 567 individuals recorded at site 1 during 2017, compared with 575 individuals recorded at site 2 and 810 individuals recorded at site 3.

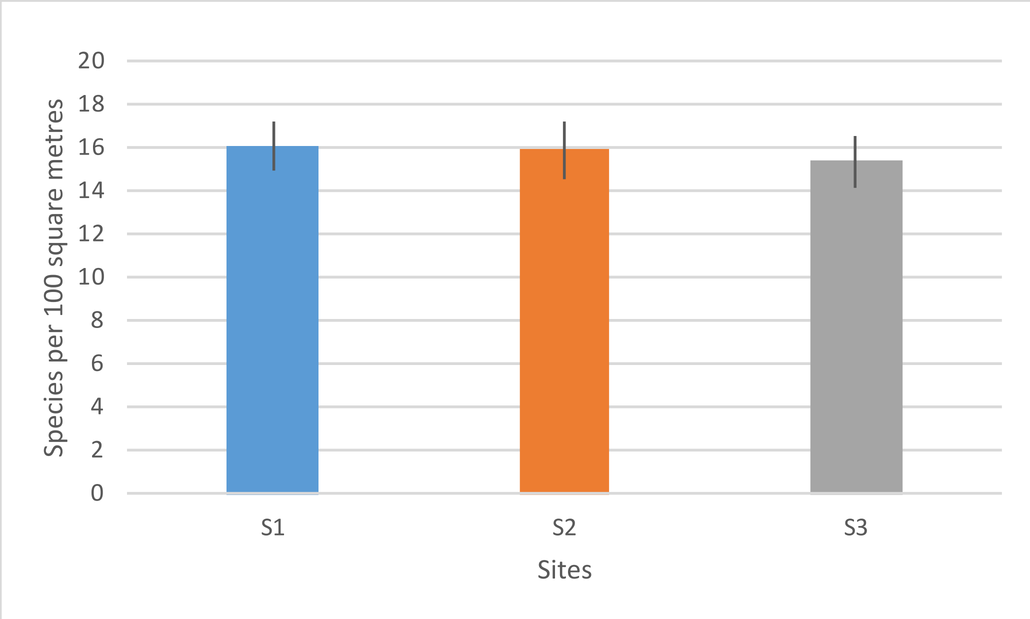


Figure 15: Combined total mean (± SE) number of individuals per 100m^2, for fish, at each site (S1, S2, S3) during 2017.

3.4 Invertebrates

Refer to *APPENIX B* (Table B2) for the complete list of invertebrate species monitored by MCC.

3.4.1 Totals Between Years

Invertebrate species/group compositions and total mean abundances differed between monitoring years at Koh Angkrong (Figure 16, Figure 17, Table C29). In 2017, a total of 15 invertebrate species from the MCC species monitoring list were recorded as being present at the Koh Angkrong system. During 2015, there was a total of 14 invertebrate species/groups recorded as being present (refer to Table B5 for a complete list of invertebrate species/groups observed during monitoring years). A total of 4 invertebrate species/groups that were recorded in 2017 had not been observed during the 2015 monitoring year (Table 4).

Table 4: New invertebrate species observed at Koh Angkrong during 2017.

Volute Snail
Boring Bivalves

Brittle Star
Collector Urchin

There were 4 invertebrate species/groups observed during 2015 that were absent from 2017 surveys (Table 5).

Table 5: Invertebrate species observed during 2016 at Koh Angkrong that were not observed during 2017.

Flatworms
Murex
Flower Urchin
Synaptic Sea Cucumbers (NA 2017)

Synaptic sea cucumbers were removed from MCC's species monitoring list following 2015 because of large populations present across all monitored reefs in the Archipelago.

Christmas tree worms and top shells significantly increased between monitoring years, while true crab, *Drupella*, 'other' gastropods, and *Diadema* sea urchins all significantly decreased (Table C30). Christmas tree worms significantly increased from an average of 0.22 individuals per $100m^2$ in 2015 to 15.33 individuals per $100m^2$ in 2017 (t_{35}=-4.23, p=<0.001). Top shells significantly increased from average of 0.22 individuals per $100m^2$ in 2015 to 1.47 individuals per $100m^2$ in 2017 (t_{35}=-3.06, p=0.004). Average abundance of true crab significantly decreased from 1.17 individuals per $100m^2$ in 2015 to 0.086 individuals per $100m^2$ in 2017 (t=3.84, p=<0.001). *Drupella* significantly decreased from an average of 1.16717 individuals per $100m^2$ in 2015 to 0.167 individuals per $100m^2$ in 2017 (t_{35}=3.69, p=<0.001). 'Other' gastropods significantly decreased from an average of 4.056 individuals per $100m^2$ in 2015 to 1.28 individuals per $100m^2$ in 2017 (t_{35}=4.09, p=<0.001). The *Diadema* sea urchin significantly decreased from an average of 69.25 individuals per $100m^2$ in 2015 to 48.56 individuals per $100m^2$ in 2017 (t_{35}=2.79, p=0.009). Invertebrate species that did not significantly change in average abundance between years include the feather duster worm (t_{35}=-

1.68, p=0.1), cowries (t_{35}=0, p=1), nudibranchs (t_{35}=1.39, p=0.173), and cuttlefish (t_{35}=-0.81, p=0.422).

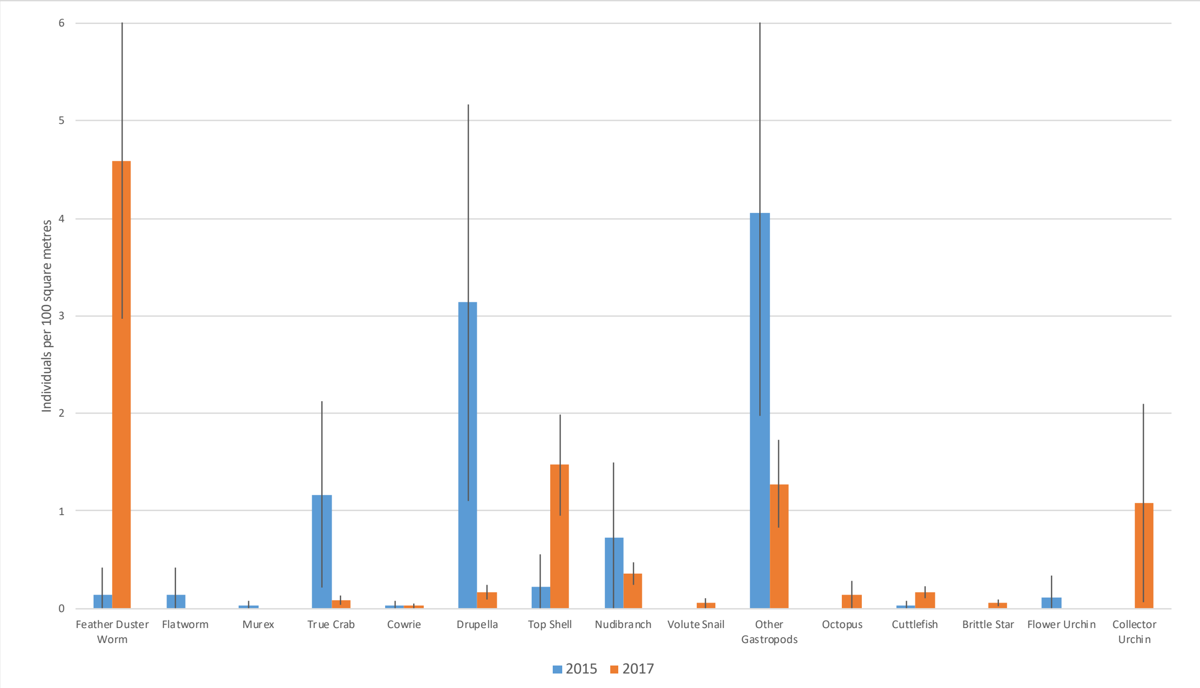


Figure 16: Total mean (± SE) invertebrate species/group abundance per 100m^2 during 2015 and 2017.

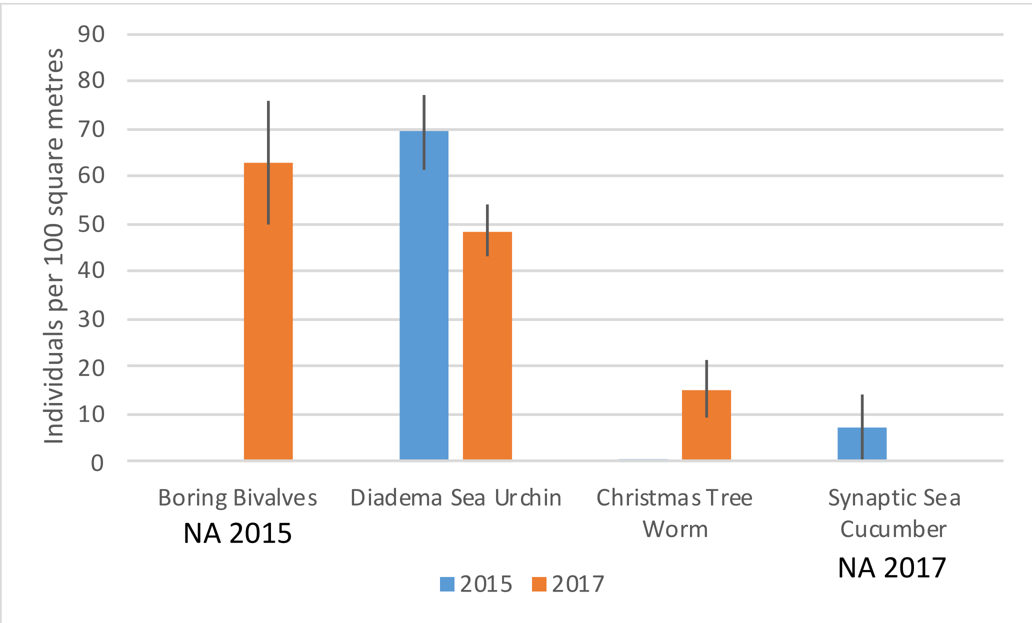


Figure 17: Total mean (± SE) boring bivalve, *Diadema* sea urchin, christmas tree worm, and synaptic sea cucumber abundances per 100m^2 during 2015 and 2017.

3.4.2 Combined Total Abundance

The combined total average abundance of invertebrates significantly increased between years (Figure 18, Table C31, Table C32). Invertebrate abundance significantly increased from 86.56 individuals per 100m^2 during 2015 to 136.02 individuals per 100m^2 in 2017 (t_{35}=-2.55, p=0.015). There was a combined total of 3116 individuals recorded during 2015 surveys, compared to 4897 individuals recorded in 2017.

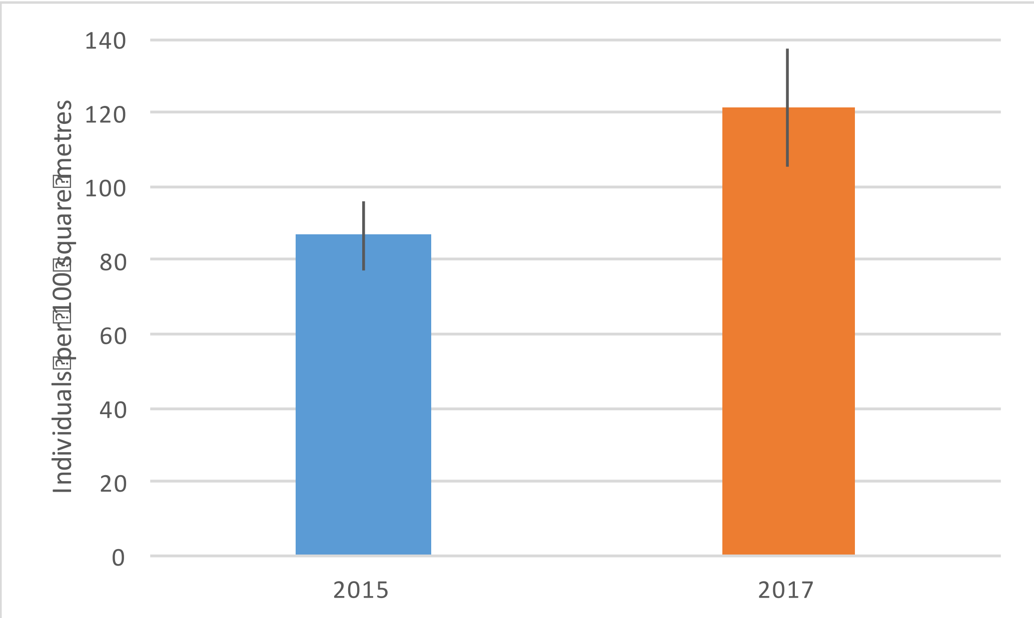


Figure 18: Combined total mean (± SE) number of individuals per 100m^2, for invertebrates, during 2015 and 2017 monitoring years.

Sites 1 and 3 and sites 2 and 3 experienced significantly different invertebrate abundances from each other during 2017 (Figure 19, Table C33, Table C34). Site 1 exhibited an average of 101.08 individuals per 100m^2 compared to site 3 which was significantly greater, having an average of 232.67 individuals per 100m^2 (t_{22}=7.256, p=<0.001). Site 2 displayed an average of 74.33 individuals per 100m^2, which was significantly less than site 3 (t_{22}=-6.25, p=<0.001). There was no difference between average invertebrate abundances observed between sites 1 and 2 (t_{22}=1.6, p=<0.123). Sites 1, 2 and 3 displayed combined totals of 1213, 892 and 2792 individuals, respectively.

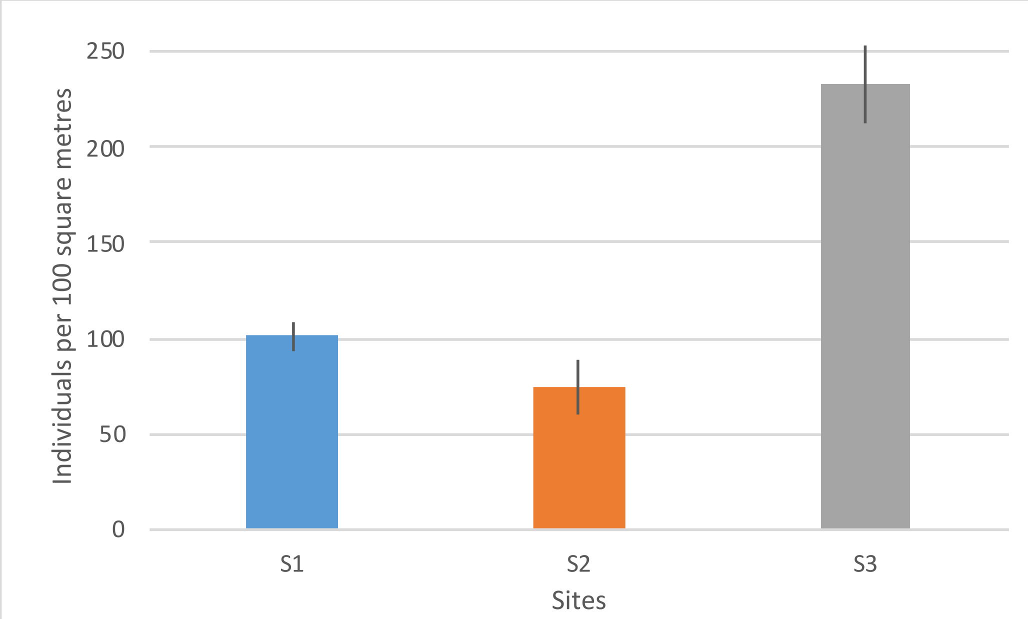


Figure 19: Combined total mean (± SE) number of individuals per 100m^2, for invertebrates, at each site (S1, S2, S3), during 2017.

3.5 Herbivore Abundance

No significant differences were observed between 2015 and 2017 monitoring years for total average abundance of herbivorous fish (t_{35}=-0.97, p=0.356) (Figure 20, Table C35, Table C36). Average herbivorous fish abundance was recorded at 37.22 individuals per 100m^2 during 2015, compared with 53.89 individuals per 100m^2 in 2017. No species of parrotfish or surgeon were observed during monitoring. Total average urchin abundance was significantly greater than herbivorous fish abundance during 2015 (t_{35}=-7.33, p=<0.001) and 2017 (t_{35}=-5.45, p=<0.001), even though the average urchin abundance changed significantly over time (Table C37). Urchin abundance significantly decreased from 69.36 urchins per 100m^2 in 2015 to an average of 49.64 urchins per 100m^2 in 2017 (t_{35}=2.1, p=0.043) (Figure 20, Table C35, Table C36).

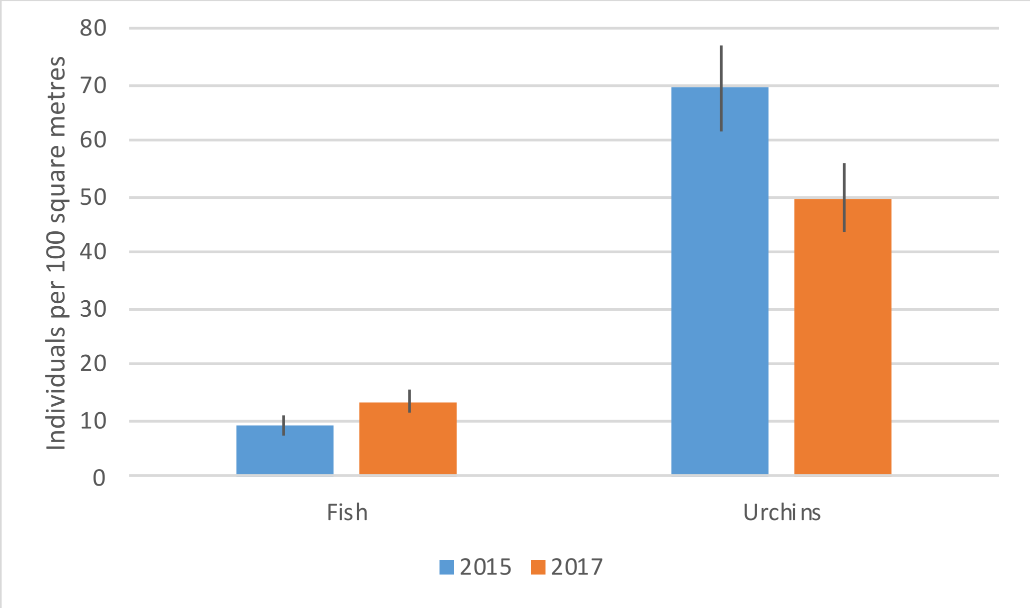


Figure 20: Mean (± SE) herbivore abundance per 100m^2, for fish and urchins, between 2015 and 2017.

Analysis of the data revealed no significant difference between sites for average herbivorous fish abundance ($f_{2,33}$=0.45, p=0.642) (Figure 21, Table C38, Table C39). Mean herbivore abundance a site 1 was recorded at 15.75 individuals per 100 m^2. At site 2 and site 3 average herbivore abundance per 100m^2 was recorded at 10.92 and 12.42 individuals per 100 m^2, respectively.

Average urchin abundance was significantly different between each site (Figure 21, Table C38, Table C40). Site 1 exhibited an average abundance of 20 urchins per 100m^2, which was significantly less than the mean urchin abundances exhibited at site 2 (t_{22}=-3.29, p=0.003) and site 3 (t_{22}=-6.69, p=<0.001). Site 2 had an average of 41.33 individuals per 100m^2, which was significantly less than the 87.58 individuals per 100m^2 observed at site 3 (t_{22}=-4.12, p=<0.001).

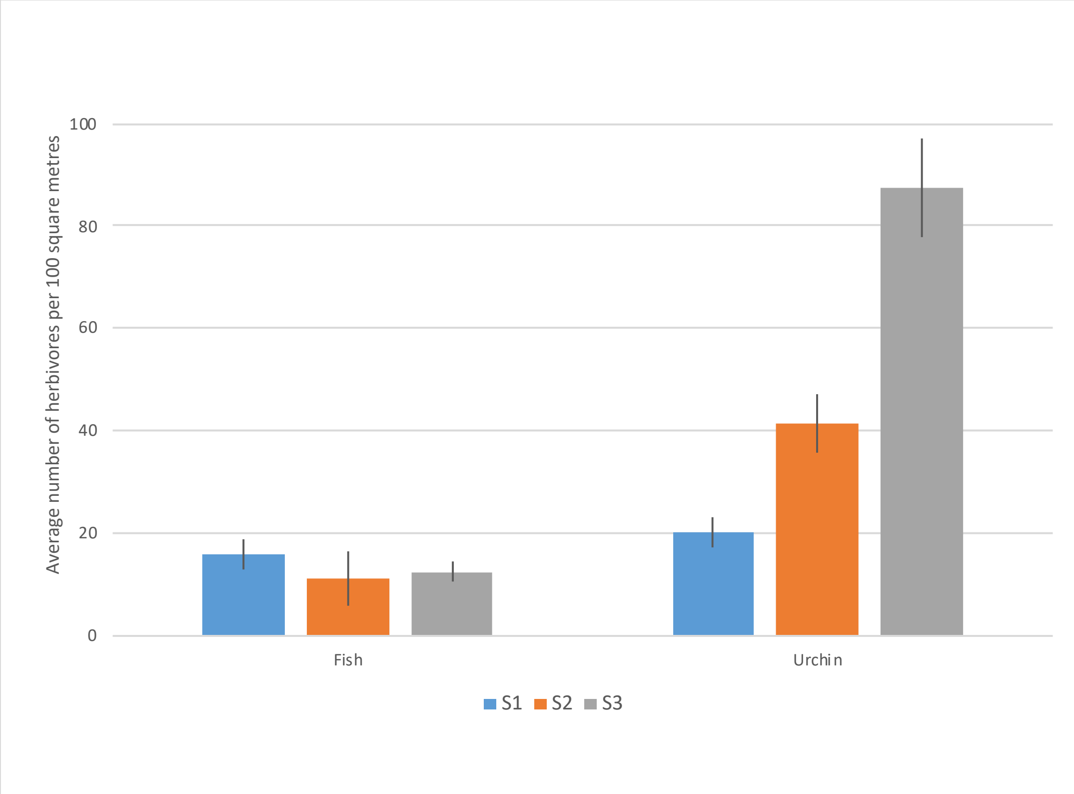


Figure 21: Mean (± SE) herbivore abundance per 100m^2, for fish and urchins, between sites (S1, S2, S3) during 2017.

3.6 Species Richness

There was a significant difference in total (combined fish and invertebrates) average species richness between 2015 and 2017 monitoring years (Figure 22, Table C41, Table C42). The analysis revealed a significant increase from an average of 6.69 species (from the MCC species monitoring list) per 100m^2 in 2015 to 13.72 per 100m^2 species in 2017 (t_{35}=-11.42, p=<0.001). Fish species richness also significantly increased between years, while the number of invertebrate species per 100m^2 remained similar (Figure 23, Table C43, Table C44). Fish species richness significantly increased from an average of 2.47 species per 100m^2 during 2015 to 8.97 species per 100m^2 in 2017 (t_{35}=-16.27, p=<0.001). There was no significant difference between average invertebrate species per 100m^2 (t_{35}=-1.3, p=0.203). An average of 4.22 invertebrate species were observed per 100m^2 during 2015, while, during 2017, an average of 4.75 species per 100m^2 was observed.

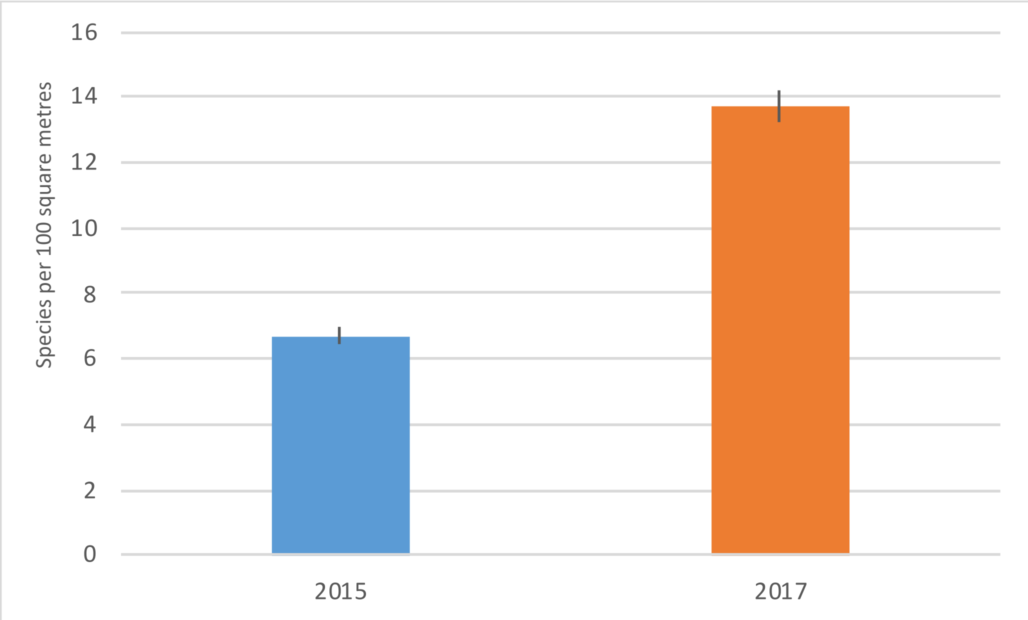


Figure 22: Total mean (± SE) species richness per 100m^2, between 2015 and 2017.

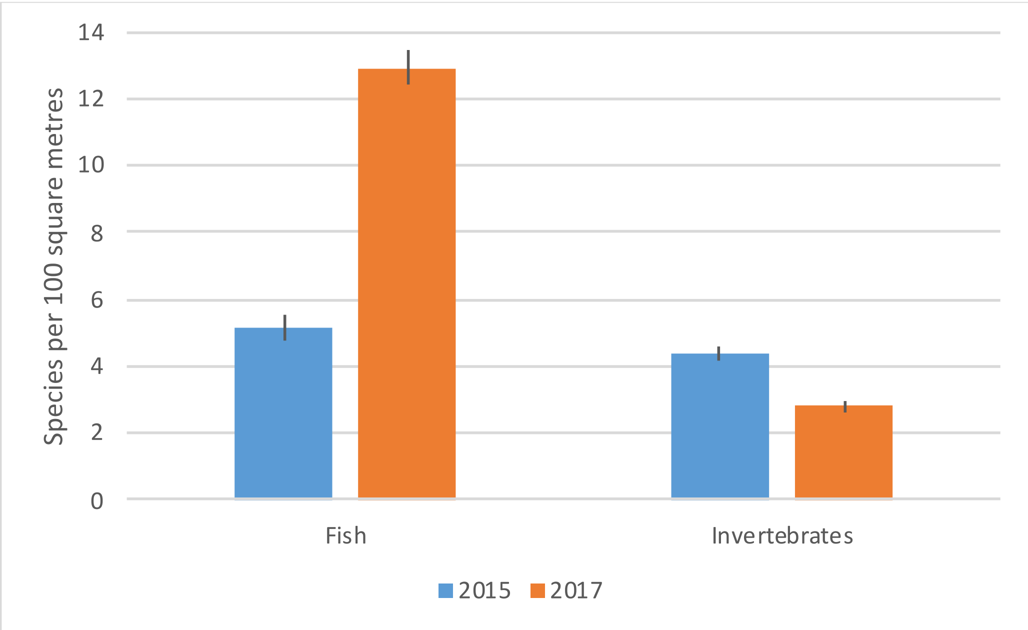


Figure 23: Mean (± SE) species richness per 100m^2, for fish and invertebrates, between 2015 and 2017.

Site 1 displayed an average of 13.83 species per 100m^2 and did not significantly differ from site 2 (t_{22}=1.47, p=0.155) or site 3 (t_{22}=-1.25, p=0.225), which exhibited averages of 12.08 and 15.25 species per 100m^2, respectively (Figure 24, Table C45, Table

C46). There was, however, a significant difference in average species richness between sites 2 and 3 (t_{22}=-2.8, p=0.011).

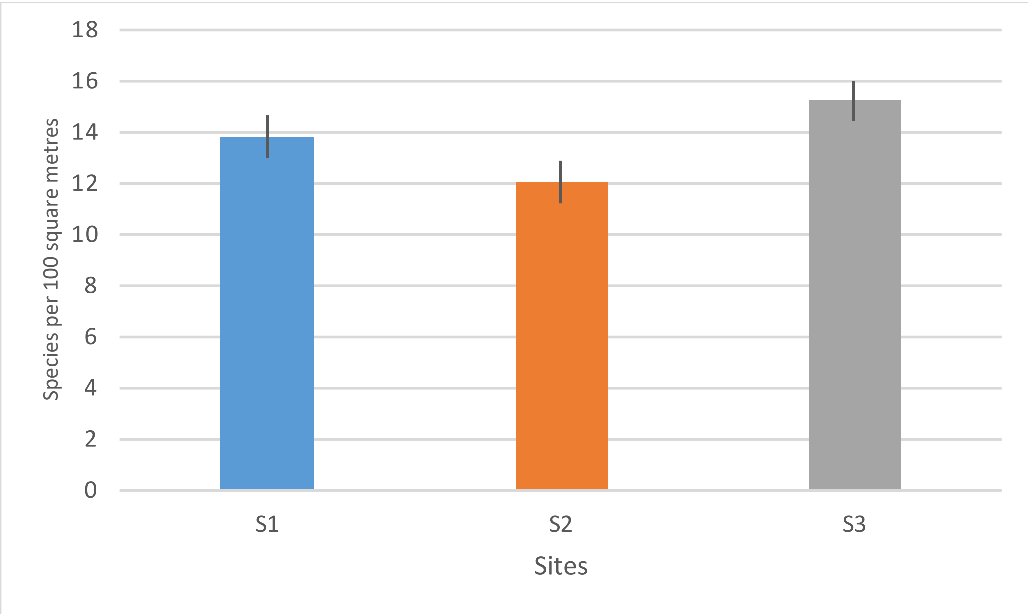


Figure 24: Total mean (± SE) species richness per 100m^2 between sites (S1, S2, S3) during 2017.

4. Discussion

The results suggest that the Koh Angkrong reef, while subjected to ongoing stressors, may be beginning to show some signs of recovery, following a reduction of illegal fishing pressures. Monitored sites around Koh Angkrong varied in condition, however, increases in fish abundance and diversity were evident between monitoring years, and hard coral cover appeared relatively healthy. Herbivorous fish abundance remained low between years while large populations of the *Diadema* sea urchin declined over time.

4.1 Environmental Conditions

The overall anthropogenic impact at Koh Angkrong was considered relatively high. Trawling activities have continued to overexploit marine resources, destroy critical habitat and degrade water quality. Water quality, now a major issue, has been largely attributed to increases in suspended sediment, generated by trawling activities disturbing the seafloor. Furthermore, high rates of tropical forest clearing in Cambodia, including the deforestation of mangroves, contributes to this problem (Hansen, 2008). Elevated sediment levels smother/clog corals (and other suspension feeders), reduce light availability to corals and seagrasses (and other photosynthetic organisms), and inhibit the settlement of coral larvae (and other planula larvae) (Hodgson, 1990; Rodgers, 1990; McCulloch *et al*., 2003; Fabricius *et al*., 2013; Bartley *et al*., 2014).

Coral damage at site 2 was recorded as being ‘high’ during 2017, with low to medium levels of underwater trash across sites. Site 2, previously hosting some of the healthiest benthic assemblages had, in the recent past, been subjected to severe damage from anthropogenic stressors. Damage was primarily caused by divers harvesting reef species and damaging coral structures in the process. MCC staff were able to document an instance where fishers had physically removed live corals at site 2 and used them as cage weights for their gear (Figure 25). This practice was also observed on other reefs. There was also some visible damage at sites 1 and 3 as a result of illegal diving activities.

Figure 25: Fish cages weighted with live corals that have been physically removed from the Koh Angkrong reef.

Prevalence of coral disease was relatively high on a global scale, with 16.47% of the population displaying signs of a disease. Poor water quality has been recognised as a major threat to coral reefs throughout Cambodia and may be associated with increased disease prevalence, particularly when nutrient levels are elevated. (Harvell *et al*., 2001; van-Bochove *et al.* 2011; Vega *et al*., 2014). Ruiz-Morenol *et al.* (2012) found that 20% of Caribbean reefs and only 2.7% of Pacific reefs exceeded a disease prevalence of more than 10%. This suggests that healthier coral reefs experience lower a disease prevalence than what has been observed on the Koh Angkrong system. Furthermore, at the time of sampling an average of 7.5% of corals were bleached, to some degree. The severity and scale of coral bleaching is only expected to increase in frequency and severity under climate change (Van Hooidonk *et al*., 2017).

4.2 Substrate

The observed compositions of substrate suggested that the Koh Angkrong reef has been resilient to ongoing stressors. Hard, reef-building, corals dominated the benthic community in most areas, however, substrate compositions significantly differed between sites. Hard corals covered an average of 52.2% of the substrate indicating that the key ecosystem functions have largely been maintained despite ongoing water quality issues and threats from IUU fishers. In comparison, average coral cover on the Great Barrier Reef, which is an UNESCO – 'World Heritage Site', is estimated to be only 13.8% (De'ath *et al*., 2012). Approximately 15 years ago hard coral cover on the Great Barrier Reef was estimated at 22.9%, and for Indo-Pacific reefs average cover was estimated at 22.1%. During that time coral reefs in Cambodia were described as having hard coral covers ranging between 4.1% and 72.1% (Chou *et al*., 2002; Bruno and Selig, 2007; De'ath *et al*., 2012). It is important to consider, however, that species compositions and coral assemblages differ considerably between geographical regions (Birkeland, 2015).

Nutrient indicator algal cover was low, suggesting that ecosystem herbivory is being maintained at sufficient rates on the reef. Herbivory is often considered a critical component of coral reef resilience (Pratchett *et al.*, 2014; Nash *et al.*, 2016). Algal cover did, however, differ between sites, with site 3 exhibiting the greatest cover. Zoanthid cover was also higher at site 3. In the past, fast colonising zoanthids spread following disturbance events that resulted in coral destruction. Site 2, now recently having a higher degree of damage than sites 1 and 3 expectedly displayed greater amounts of coral rubble and appeared to have a higher sponge presence. Sponges are not unknown to colonise areas of coral reef following disturbances (Norström *et al*., 2009; Bell *et al*., 2013).

4.3 Fish

Combined total fish abundance increased between 2015 and 2017 from an average of 13.61 individuals per 100m^2 to 48.25 individuals per 100m^2. This has been largely accredited to MCC's patrolling presence, limiting the destructive fishing practices that were once more common around the Island.

There were 33 species recorded, including 22 identified as being new to the reef system, from a total of 86 listed on MCC's species monitoring list. Total butterflyfish, fusilier, and total snapper abundances increased between years. Large species of snapper are highly mobile and can travel up to hundreds of kilometres, making them efficient at recruiting to new reefs that host suitable refuge (Green *et al*., 2015). On the contrary, butterflyfish have smaller spatial ranges and are corallivorous. The observed increase in abundance of butterflyfish may be attributed to their food source, as hard coral cover remained relatively healthy around the Island. For example, a study conducted on a reef in the Philippines noted that the butterflyfish population declined following a disturbance that caused a decline in hard branching corals (Russ and Leahy, 2017). Further, the population of fusilier likely increased while cardinalfish, rabbitfish, and sergeant fish populations were maintained, due to the structural complexity of reef habitat that remained (Russ *et al*., 2017). This may also help to explain the number of new fish species observed on the Koh Angkrong reef during 2017.

4.4 Invertebrates

Total invertebrate abundance was greater than total fish abundance during both monitoring years. However, most of the invertebrate species that were monitored were present in lower abundances than fish, and numbers were boosted by large populations of the *Diadema* sea urchin and boring bivalves. Interestingly, invertebrate species compositions differed substantially between monitoring years with 4 out of the 15 observed species recorded for the first time. The monitoring list included a total of 40 invertebrate species that were surveyed for during 2017. Some species recorded in 2015 were not observed again during 2017 surveys. The observed changes in species compositions and abundances may be attributed to complex ecological interactions, increased protection, environmental and anthropogenic stressors (e.g. invertebrate harvesting), and because many invertebrate species are cryptic and often more difficult to observe than fish (Jackson and Hughes, 1985; Pinnegar *et al*., 2000;

Dulvy *et al*., 2004). Differing community structures and small spatial ranges amongst invertebrate groups could also have the potential to affect invertebrate distributions. For example, Netchy *et al.* (2017) found that even mobile invertebrate species formed distinct communities with unique, but overlapping, habitat requirements. Another study, investigating crustacean species diversity in three major oceans, found that there was a high prevalence of rare species on coral reefs, with 38% of invertebrate species encountered only once during sampling (Plaisance *et al*., 2011).

The combined total invertebrate abundance significantly increased from a total of 86.56 individuals per 100m^2 during 2015 to 121.25 individuals per 100m^2 during 2017. Species that were present during both monitoring years differed in abundance. Christmas tree worms and top shells increased between years. An increase in christmas tree worm abundance may indicate increasing nutrient enrichment (Birkeland, 1977), and a study by Harty (2011) also found that christmas tree worm density is positively correlated with sedimentation rates. On the contrary, true crab, *Drupella*, *Diadema* sea urchin, and 'other' gastropod groups all decreased. *Diadema* sea urchins were, however, present in far higher abundances than other groups (excluding boring bivalves), but decreased from an average of 69.25 individuals per 100m^2 in 2015 to 48.56 individuals per 100m^2 in 2017. It is unknown why the *Diadema* sea urchin population declined, however, there has been a recent increase in the harvesting of *Diadema* sea urchins by local fishers. There was most likely an initial population explosion due to a combination of there being few large macrophagous predators and low numbers of herbivorous fish present on the reef (both due to overharvesting) (Alvarado *et al*., 2016; Nash *et al.*, 2016; Kuempel and Altieri, 2017).

4.5 Functional Groups

While the Koh Angkrong reef exhibited increases in total fish abundance, herbivorous fish abundance remained unchanged between years. There was an average abundance of 9.3 herbivorous fish per 100m^2 during 2015 and 13.47 per 100m^2 in 2017, which was low relative to herbivorous urchin abundance. Herbivorous fish counts included only two groups, rabbitfishes and sergeant fish, of which species are predominantly grazers. Other important herbivorous functional groups, such as browsers, scrapers and excavators were either represented poorly or completely absent. Each herbivore functional group plays a particular role in the maintenance of substrate and control of algal growth on a reef system (Green and Bellwood, 2009). Parrotfish, which are some of the most important algal eating fishes (with species belonging to scraper, excavator and browser functional groups), are thought to have been completely fished out of the Kep Archipelago (Hughes *et al*, 2010; Plass-Johnson *et al.*, 2015). The low number of herbivorous fishes observed at Koh Angkrong has been attributed to fishing pressures, which are known to affect herbivore community structures and coral reefs globally (Edwards *et al.*, 2014). Herbivores are considered important for maintaining coral reef resilience by controlling algal growth, which helps to prevent coral-algal phase-shifts (Mumby *et al.*, 2006; Green and Bellwood, 2009; Edwards *et al*., 2014; Pratchett *et al.*, 2014). Unfortunately, herbivorous fish groups, especially large bodied fish, are often the most susceptible to fishing (Edwards *et al*., 2014). Further, the removal of important herbivore functional groups can cause an increase of algal farming damselfish (Edwards *et al.*, 2014). Low numbers, or an absence, of important herbivore groups may help to explain the large number of damselfish present on the Koh Angkrong system. Damselfish (excluding sergeant fish) have not been monitored by MCC due to their high abundances compared to other reef fish species.

Despite a paucity of herbivorous fish algal growth remained low between years. The control of algal growth during this time has been largely attributed to urchin grazing. There was an average abundance of 69.36 sea urchins per $100m^2$ during 2015 and 49.64 per $100m^2$ in 2017. Urchins were recorded in greater abundances than herbivorous fish during both years despite displaying a significant decline (due to a decline of *Diadema* sea urchin). It is speculated that urchin populations originally exploded as competing herbivorous fish groups diminished, and, in some cases, may now have been made functionally redundant by the urchins (Nash *et al.*, 2016). For instance, site 3 exhibited the greatest amount of algal cover as well as the highest urchin abundance, while herbivorous fish abundance remained low and did not significantly change between any of the sites. The unregulated harvesting of the *Diadema* sea urchin in the Kep Archipelago may further threaten coral reefs, as urchins, in the absence of important functional groups, now play a fundamental role in prevention of coral-algal phase-shifts.

4.6 Diversity

Total species richness increased between years, from an average of 6.69 fish and invertebrate species per 100m^2 in 2015 to 13.72 species per 100m^2 in 2017. Increases in total species richness are largely due to an increase of fish species around the Koh Angkrong system. Fish species richness significantly increased from an average of 2.47 species per 100m^2 during 2015 to 8.97 species per 100m^2 in 2017. Invertebrate species richness, however, did not significantly change between years despite changes in species compositions and fluctuating abundances. There was an average of 4.75 invertebrate species per 100m^2 during 2017. Structural complexity of reef habitat is important for determining species richness, as well as the functional diversity of reef fishes (Darling *et al*., 2017; Richardson *et al*., 2017). For example, Site 2, characterised by a higher level of coral damage, displayed a significantly lower species richness (combined fish and invertebrates) than site 3. In addition, climatic variables that control primary productivity, and the geomorphic context of a reef environment have also been found to be important determinants of diversity on coral reefs (Yeager *et al*., 2017). Favourable benthic assemblages and the structural complexity of habitat on the fringing reef around Koh Angkrong have likely played an important role in increasing biodiversity, especially following a reduction in destructive fishing practices. However, it was noted that coral species diversity appeared low and was largely characterised by varieties of massive (i.e. ball or boulder shaped) corals.

4.7 Research Limitations

High sediment loads that effect turbidity and water clarity have been identified as an ongoing problem in the Kep Archipelago. Elevated sediment in the water has been attributed to trawling activities that disturb the seafloor. Because of this, MCC divers were often faced with conditions not suitable for scientific surveys. The minimum recommendation for an accurate reef survey requires a visibility of 3m.

An important consideration remains to be the comparability of the data between both monitoring years. While fish monitoring was likely to be relatively unaffected by the differences in sampling regimes, substrate and perhaps, to a lesser extent, invertebrate monitoring, may have some sampling bias incorporated into the data. This is because, during 2015, monitoring was undertaken around the entire perimeter of Koh Angkrong and included sections of environment that were not coral reef. For this reason, a substrate comparison between years has not been displayed.

It is believed that invertebrate abundance and invertebrate species richness may have been underestimated during both years of sampling, as many taxa are small, cryptic and well hid, which can make them difficult to find. It is likely that some invertebrates were missed or went unnoticed at times. Invertebrate surveys during 2015 also included the synaptic sea cucumber, which was recorded in high numbers. The species was removed from 2017 surveys, which effected the total invertebrate abundance between years, despite the inclusion of Boring Bivalves. Further, some invertebrate taxa living outside of reef boundaries may have been included in this study. Going forward, the focus will be on coral reef habitat only and survey site locations used during 2017 will continue to be used into the future.

It is important to note that actual species richness is likely to be substantially greater than what has been presented in this report, which is a proxy measure of ecosystem biodiversity. When investigating species richness, only species that were listed on MCC's species monitoring list were considered in the analysis. This measure provides a credible diversity estimate for the ecosystem by monitoring species richness within a selected sample group (the species monitoring list). The species included on MCC's species monitoring list are recognised as keystone species, or as being important to the Archipelago and coral reefs globally.

4.8 Conservation and the Future

Following a reduction in illegal and destructive fishing pressures, fish abundance and diversity has increased. In order to maximise the potential for this ecosystem to recover, the value of coral reefs in the Kep Archipelago need to be realised by governing bodies and other stakeholders, and greater, more stringent protection needs to be imposed. The value in protecting coral reef habitat has greater economic value, in terms of coastal protection and tourism, than what the unsustainable exploitation of coral reef fisheries can offer (Soede *et al*., 1999; Cesar *et al*., 2003; Brander *et al*., 2007; Madani *et al*., 2012; Sarkis *et al*., 2013; Spalding *et al*., 2017). However, conservation initiatives within the Kep Archipelago need to reflect all user's needs and provide protection for local fisheries, protection of food security, protection for other developing industries (e.g. tourism), and protection for the marine environment. Success should be considered in terms of environmental conservation and socio-economic improvements, and whether or not these reflect the aims of the legislative reform (refer to *APPENDIX A*) (Hargreaves-Allen *et al*., 2011). This should involve addressing the need for a resource in accordance with maintaining ecosystem function (Pratchett *et al*., 2014). Coral reef functionality is critical for the production of ecosystem goods and services utilised by fishing communities, the developing tourism industry, and adjacent mangrove and seagrass ecosystems that act as nurseries for many coral reef fish (Unsworth *et al*., 2008). Protecting connectedness between coral reefs and other ecosystems is an important underlying component of ecosystem resilience (Mumby and Hastings, 2008; Nystrom *et al*., 2008; Olds *et al*., 2013). By adopting an ecosystem based management (EBM) approach to the design of the MFMA, it will not only effectively protect coral reefs, but also important trophic linkages shared with other marine ecosystems that help to support coral reef functionality, biodiversity and spatial heterogeneity (McClanahan *et al*., 2011; Aswani *et al*., 2012; Menzel *et al*., 2013; Samhouri *et al*., 2013). This level of protection can provide an insurance effect against future uncertainty in a highly dynamic coral reef environment (Nystrom *et al*., 2008).

The conservation strategy developed by MCC and the FiA will combine the use of the MFMA with artificial reef (and anti-trawling) structures, community management techniques, and the enforcement of fisheries legislation. It is important that the management of the MFMA be adaptive and that it enhances coral reef resilience against future disturbances. Adaptive management helps to provide protection against uncertainty, and will more effectively continue to consider the wants and needs of important stakeholder groups going forward. Further, managing coral reefs with maximum resilience into the future will provide the most advantageous foundations for dealing with climate change associated stressors, and how these may interact with direct local stressors under future conditions (Ateweberhan *et al*., 2013).

5. Conclusion

The results suggest that key ecosystem functions have been maintained on the Koh Angkrong system and the reef is now beginning to show some signs of recovery, following protection from illegal fishing. It is important that functional groups and ecosystem processes are provided with increased protection. With low numbers of herbivorous fish recorded on the reef and an absence of some major functional groups, it is important that herbivore diversity be promoted and ecosystem herbivory maintained beneath critical levels to prevent a system phase-shift. Moreover, the unsustainable harvest of the *Diadema* sea urchin could have serious consequences for reefs in the Archipelago. It is of utmost importance that management provides the necessary foundations for recovery. The establishment of the MFMA should ensure a more effective management, concurrent with strategies that confront the major issues surrounding the region. These include both, fishing stressors exerted upon the Kep Archipelago and any existing disparities between stakeholder groups. Unenforced regulations and policies are expected to be addressed with the implementation of the MFMA, and management is to be constructed as to engage and allow the participation of the local communities in protecting the sustainability of their marine resources. This is critical as to avoid further social-ecological traps where the practicing of damaging activities can become increasingly difficult to remedy. Koh Angkrong, Koh Mak Prang and Koh Seh coral reefs will continue to be monitored over time in order to assess the effectiveness of this conservation in maintaining and improving ecosystem health.

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APPENDIX A – Key Policy and Legislation

Fisheries reform in Cambodia was undertaken during the 2000's. It aimed to promote the livelihoods of people in local communities for both socio-economic and environmental benefit. This includes the sustainability of natural resources, the conservation of biodiversity and cultural heritages.

Key policy and legislation for fisheries in Cambodia include the following:

Policy Statement

Management, conservation, and development of sustainable fisheries resources to contribute to people's food security and socio-economic development in order to enhance people's livelihood and the nation's prosperity. (Royal Govt of Cambodia, 2014)

Rules:

Article 49:

Trawling in the *inshore fishing areas shall be forbidden, except for the permission from the Minister of Agriculture, Forestry and Fisheries at the request of the Fisheries Administration to conduct scientific and technical research.

Article 52:

Shall be prohibited:

1. Fishing or any form of exploitation, which damages or disturbs the growth of seagrass or coral reef.
2. Collecting, buying, selling, transporting or stocking of corals.
3. Making port calls and anchoring in a coral reef area.
4. Destroying seagrass or coral by other activities.

All of the above activities mentioned in points 1, 2 and 3, may be undertaken only when permission is given from the Minister of Agriculture, Forestry and Fisheries. (FiA, 2007)

*The Fisheries Administration (FiA) define inshore fishing areas (or inshore coastal areas) as being the area, "which extends from the coastline at higher high tide to the 20 metre deep line."

APPENDIX B – Species Monitoring List

Table B1: Fish species/groups monitored.

Eight Banded Butterflyfish	Black-Spot Snapper	Mullet	Doublebanded Soapfish	Squirrelfish / Soldierfish	Blue-Spotted Ribbontail Ray
Longfin Bannerfish	Brown stripes Snapper	Great Barracuda	Gold Spotted Sweetlips	Cardinalfish	Razorfish
Long-Beaked Coral Fish	One spot Snapper	Yellowtail Barracuda	Bumphead parrotfish	Toadfish	
Ocellated Butterflyfish	Checkered Snapper	Obtus Barracuda	Other Parrotfish	Scorpionfish	
Unknown Butterflyfish	Red Snapper	Fusilier	Parrotfish 0-10cm	Catfish	
Other Butterflyfish	Blacktail Snapper	Barramundi Cod	Parrotfish 10-20cm	Needlefish	
Butterflyfish total	Other Snapper	Orange-Spotted Grouper	Parrotfish 20-30cm	Boxfish	
Angelfish	Unknown Snapper	Blue-Lined Grouper	Parrotfish 30-40 cm	Triggerfish	
Spadefish	Snapper total	Chocolate Grouper	Parrotfish 40-50 cm	Filefish	
Golden Rabbitfish	Monogram Monocle Bream	Peacock Grouper	Parrotfish >50 cm	Pufferfish	
Coral Rabbitfish	Bridled Monocle Bream	Honeycomb Grouper	Parrotfish total	Porcupinefish	
Virgate Rabitfish	Whitecheek Monocle Bream	Square-Tail Grouper	Cleaner Wrasse	Seahorse	
Java Rabbitfish	Whitestreak Monocle Bream	Other Grouper	Humphead wrasse	Carpet Blenny Eel	
Vermiculated Rabbitfish	Other Bream	Unknown Grouper	Red-Breasted Wrasse	Herring Scad	
Dusky Rabbitfish	Unknown Bream	Grouper 0-10cm	Crescent Wrasse	Other Scad	
Unknown Rabbitfish	Bream total	Grouper 10-20cm	Tripletail Wrasse	Scad total	
Rabbitfish total	Emperor	Grouper 20-30cm	Weedy Surge Wrasse	Whiptail	
Scatfish	Golden Trevally	Grouper 30-40 cm	Other Wrasse	Gurnard	
Sergeant Fish sp.	Big Eye Trevally	Grouper 40-50 cm	Unknown Wrasse	Pipefish	
Anemone Fish sp.	Other Trevally	Grouper >50 cm	Wrasse total	Shark Sucker	
Spanish Flag Snapper	Jacks	Grouper total	Sweeper	Bamboo Shark	

Table B2: Invertebrate species/groups monitored.

Feather Duster Worm	Giant Clam 30-40 cm
Christmas Tree Worm	Giant Clam 40-50 cm
Flatworm	Giant Clam >50 cm
Banded Coral Shrimp	Giant Clam total
Mantis Shrimp	Boring Bivalves
Anemone Shrimp	Octopus
Lobster	Cuttlefish
True Crab	Squid
Blue Swimmer Crab	Crown of Thorns
Cruxifix Crab	Chocolate Drop Starfish
Conch	Cushion Star
Cowrie	Brittle Star
Triton	Feather Star
Cone Shell	Basket Star
Drupella	Flower Urchin
Top Shell	Diadema Sea Urchin
Turbo	Pencil Urchin
Nudibranch	Collector Urchin
Volute Snail	Prickly Redfish
Other Gastropods	Greenfish
Giant Clam 0-10cm	Pinkfish
Giant Clam 10-20cm	Sea Pen
Giant Clam 20-30cm	Sea Hare

Table B3: Monitored substrates.

HC	Hard Coral
SC	Soft Coral
RKC	Recently Killed Coral
NIA	Nutrient Indicator Algae
SP	Sponge
RC	Rock
RB	Rubble
SD	Sand
SI	Silt
ZO	Zoanthid
SG	Sea Grass
OT	Other

Table B4: Total fish species/groups observed during 2015 and 2017 monitoring years.

2015	2017
Cardinalfish	Black-Spot Snapper
Eight Banded Butterflyfish	Blue-Lined Grouper
Fusilier	Brown stripe Snapper
Java Rabbitfish	Cardinalfish
Long-Beaked Coral Fish	Carpet Blenny Eel
Longfin Bannerfish	Chocolate Grouper
Other Butterflyfish	Doublebanded Soapfish
Other Snapper	Eight Banded Butterflyfish
Sergeant Fish sp.	Emperor
	Fusilier
	Gold Spotted Sweetlips
	Golden Rabbitfish
	Jacks
	Java Rabbitfish
	Long-Beaked Coral Fish
	Monogram Monocle Bream
	Other Butterflyfish
	Other Rabbitfish
	Other Wrasse
	Pufferfish
	Red Snapper
	Sergeant Fish sp.
	Shark Sucker
	Spanish Flag Snapper
	Sweeper
	Weedy Surge Wrasse
	Whiptail
	Whitecheek Monocle Bream
	Whitestreak Monocle Bream
	Yellowtail Barracuda

Table B5: Total invertebrate species/groups observed during 2015 and 2017 monitoring years.

2015	2017
Christmas Tree Worm	Collector Urchin
Cowrie	Feather Duster Worm
Cuttlefish	Christmas Tree Worm
Diadema Sea Urchin	True Crab
Drupella	Cowrie
Feather Duster Worm	*Drupella*
Flatworm	Top Shell
Flower Urchin	Nudibranch
Murex	Volute Snail
Nudibranch	Other Gastropods
Other Gastropods	Boring Bivalves
Synaptic Sea Cucumber	Octopus
Top Shell	Cuttlefish
True Crab	Brittle Star
	Diadema Sea Urchin

Fish and invertebrate species added to, and removed from, the species monitoring list are detailed below.

Table B6: Fish species/groups added and removed for the 2017 monitoring year.

Additions	**Removals**
Big Eye Travelly	Blenny
Black-Spot Snapper	Checkboard Wrasse
Carpet Blenny Eel	Goby
Catfish	Lizard Fish/ Sandperch
Dusky Rabbitfish	
Golden Travelly	
Gurnard	
Jacks	
Mullet	
Needlefish	
Ocellated Butterflyfish	
Other Wrasse	

Pipefish	
Razorfish	
Scad	
Scatfish	
Seahorse	
Shark Sucker	
Spanish Flag Snapper	
Toadfish	
Weedy Serge Wrasse	
Whiptail	

Table B7: Invertebrate spe moved for the 2017 monitoring year.

Additions	**Removals**
Blue Swimmer Crab	Murex
Boring Bivalves	Synaptic Sea Cucumber
Cruxifix Crab	
Volute Snail	

The two additional substrate types included for the 2017 monitoring year are zoanthids (ZO) and seagrass (SG).

Below are a list of common and scientific names/classifications for all monitored fish and invertebrate species.

Table B8: Common names for monitored species and their scientific name/classification.

COMMON NAME	SCIENTIFIC NAME
Big Eye Trevally	*Caranx sexfasciatus* (species)
Black-Spot Snapper	*Lutjanus ehrenbergii* (species)
Blue Swimmer Crab	*Portunus pelagicus* (species)
Blue-Lined Grouper	*Cephalopholis formosa* (species)
Boring Bivalves	*Bivalvia* (class)
Boxfish	*Ostrasiidae* (family)
Bream Total	*Nemipteridae* (family)

Butterflyfish total	*Chaetodontidae* (family)
Cardinalfish	*Apogonidae* (family)
Carpet Blenny Eel	*Congrogadus subducens* (species)
Catfish	*Plotosidae* (family)
Chocolate Grouper	*Cephalopholis boenak* (species)
Christmas Tree Worm	*Spirobranchus* (genus)
Cleaner Wrasse	*Labroides* (genus)
Collector Urchin	*Tripneustes* (genus)
Conch	*Strombidae* (family)
Cowrie	*Cypraeidae* (family)
***Diadema* Sea Urchin**	*Diadema* (genus)
Drupella	*Drupella* (genus)
Dusky Rabbitfish	*Siganus fuscescens* (species)
Duskytail Grouper	*Epinephelus bleekeri* (species)
Eight Banded Butterflyfish	*Chaetodon octofassiatus* (species)
Emperor	*Lethrinus* (genus)
Feather Duster Worm	*Sabellastarte* (genus)
Feather Star	*Crinoidea* (order)
Filefish	*Monacanthidae* (family)
Flatworm	*Platyhelminthes* (phylum)
Fusilier	*Caesionidae* (family)
Giant Clams	*Cardiidae* (family)
Gold Spotted Sweetlips	*Plectorhinchus flavomaculatus* (species)
Golden Rabbitfish	*Siganus guttatus* (species)
Golden Trevally	*Gnathanodon spesiosus* (species)
Grouper total	*Serranidae* (family)
Gurnard	*Triglidae* (family)
Jacks	*Carangidae* (family)
Java Rabbitfish	*Siganus javus* (species)

Long-Beaked Coral Fish	*Chelmon rostartus* (species)
Longfin Grouper	*Epinephelus quoyanus* (species)
Monogram Monocle Bream	*Scolopsis monogramma* (species)
Mullet	*Mugilidae* (family)
Needlefish	*Belonidae* (family)
Nudibranch	*Nudibranchia* (order)
Ocellated Butterflyfish	*Parachaetodon ocellatus* (species)
Orange-Spotted Grouper	*Epinephelus coioides* (species)
Other Bream	*Nemipteridae* (family)
Other Butterflyfish	*Chaetodontidae* (family)
Other Gastropods	mostly *Turbo* (genus)
Other Grouper	*Serranidae* (family)
Other Rabbitfish	*Siganidae* (family)
Other Snapper	*Lutjanidae* (family)
Other Trevally	*Carangidae* (family)
Other Wrasse	*Labridae* (family)
Paradise Whiptail	*Pentapodus paradiseus* (species)
Pencil Urchin	*Heterocentrotus mammilatus* (species)
Pipefish	*Syngnathinae* (sub family)
Rabbitfish total	*Siganidae* (family)
Scad	*Carangidae* (family)
Scatfish	*Scatophagus argus* (species)
Seahorse	*Hippocampus* (genus)
Sergeant Fish spp.	*Abudefduf* (genus)
Shark Sucker	*Echeneidae* (family)
Snapper total	*Lutjanidae* (family)
Spadefish	*Ephippidae* (family)
Spanish Flag Snapper	*Lutjanus carponotatus* (species)
Sweeper	*Pempheris* (genus)

Synaptic Sea Cucumber	*Synaptidae* (family)
Toadfish	*Batrachoididae* (genus)
Toadfish	*Batrachoididae* (family)
Top Shell	*Trochus* (genus)
Unknown Bream	*Nemipteridae* (family)
Unknown Butterflyfish	*Chaetodontidae* (family)
Unknown Snapper	*Lutjanidae* (family)
Unknown Wrasse	*Labridae* (family)
Virgate Rabitfish	*Siganus virgatus* (species)
Volute Snails	*Volutidae* (genus)
Weedy Surge Wrasse	*Halichoeres margaritaceus* (species)
Whiptail	*Pentapodus paradiseus* (species)
White-spotted Rabbitfish	*Siganus canaliculatus* (species)
Whitecheek Monocle Bream	*Scolopsis torquate* (species)
Wrasse total	*Labridae* (family)
Xanthid Crab	*Xanthidae* (family)

APPENDIX C – Tables and Values

Impact Assessment

Damage, Trash and Predation

Table C1: Median level of coral damage, trash and predation at each site during 2017. 0 = none, 1 = low (1 piece), 2 = medium (2-4 pieces) and 3 = high (5+ pieces).

Impact Type	S1	S2	S3
Coral damage: boat/anchor	0	0	0
Coral damage: dynamite	0	0	0
Coral damage: other	1	3	1
Trash: fish nets	1	1	2
Trash: general	1	1	1
Coral predation	3	2	2

Table C2: Median level of coral damage, trash and predation between 2015 and 2017. 0 = none, 1 = low (1 piece), 2 = medium (2-4 pieces) and 3 = high (5+ pieces).

Impact Type	2015	2017
Coral damage: boat/anchor	2	0
Coral damage: dynamite	0	0
Coral damage: other	1	2
Trash: fish nets	1	1
Trash: general	2	1
Coral predation	NA 2015	2

Bleaching and Disease

Table C3: Average percent of bleached and diseased corals within the population and per individual corals, between sites, 2017.

Scope	Impact	Site	Mean	SD	SE
Mean % of population	Bleaching	1	0.10	9.16	0.03
		2	0.06	4.62	0.01
		3	0.07	6.06	0.02
	Disease	1	0.14	4.61	0.01
		2	0.16	4.98	0.01
		3	0.23	18.50	0.05
Mean % of individual	Bleaching	1	0.06	13.05	0.04
		2	0.07	17.45	0.05
		3	0.12	28.04	0.08
	Disease	1	0.16	15.94	0.05
		2	0.29	27.69	0.08
		3	0.24	27.87	0.08

Table C4: ANOVA output for average percent of bleached corals between sites, 2017.

Anova: Single Factor						
Bleaching % Population						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	118	9.83333333	83.969697		
S2	12	71	5.91666667	21.3560606		
S3	12	81	6.75	36.75		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	102.166667	2	51.0833333	1.07864989	0.35174186	3.28491765
Within Groups	1562.83333	33	47.3585859			
Total	1665	35				

Table C5: ANOVA output for average percent of bleaching per affected individual corals between sites, 2017.

Anova: Single Factor						
Individual % Individual						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	63	5.25	21.2954545		
S2	12	79	6.58333333	24.8106061		
S3	12	142	11.8333333	342.151515		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	290.722222	2	145.361111	1.12318049	0.33736056	3.28491765
Within Groups	4270.83333	33	129.419192			
Total	4561.55556	35				

Table C6: ANOVA output for average percent of diseased corals between sites, 2017.

Anova: Single Factor						
Disease % Population						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	125	10.4166667	170.265152		
S2	12	189	15.75	304.386364		
S3	12	279	23.25	786.022727		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	997.555556	2	498.777778	1.186931	0.31784775	3.28491765
Within Groups	13867.4167	33	420.224747			
Total	14864.9722	35				

Table C7: ANOVA output for average percent of disease per affected individual corals between sites, 2017.

Anova: Single Factor						
Disease % Individual						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	189	15.75	254.022727		
S2	12	351	29.25	766.75		
S3	12	290	24.1666667	776.515152		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1115.72222	2	557.861111	0.93117155	0.40420023	3.28491765
Within Groups	19770.1667	33	599.09596			
Total	20885.8889	35				

Table C8: Average percent of bleached and diseased corals within the population and per individual corals, between sites, 2017.

Scope	Impact	Year	Mean	SD	SE
Mean % of population	Bleaching	2015	0.05	0.05	0.01
		2017	0.08	6.90	1.15
	Disease	2015	0.00	NA 2015	
		2017	0.16	20.61	3.43
Mean % of individual	Bleaching	2015	0.11	0.09	0.02
		2017	0.08	11.42	1.90
	Disease	2015	0.00	NA 2015	
		2017	0.23	24.43	4.07

Table C9: Two-sample t-test outputs for average percent of bleached corals per population and bleaching per individually affected corals between 2015 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
% Population			**% Individual**		
	2015	*2017*		*2015*	*2017*
Mean	0.0525	0.075	Mean	0.10666667	0.07888889
Variance	0.002150714	0.00475714	Variance	0.00864571	0.01303302
Observations	36	36	Observations	36	36
df	35		df	35	
t Stat	-1.976550635		t Stat	1.43607707	
P(T<=t) two-tail	0.056014328		P(T<=t) two-tail	0.15985877	
t Critical two-tail	2.030107928		t Critical two-tail	2.03010793	

Substrate

2017 Total

Table C10: Total average percent cover of substrates during 2017.

Substrate	2017		
	Mean	SD	SE
HC	0.52	0.24	0.12
SC	0.02	0.01	0.01
RKC	0.00	0.00	0.00
NIA	0.03	0.04	0.02
SP	0.14	0.12	0.06
RC	0.12	0.04	0.02
RB	0.05	0.08	0.04
SD	0.05	0.03	0.01
SI	0.01	0.01	0.01
ZO	0.06	0.08	0.04
OT	0.01	0.01	0.00
SG	0.00	0.00	0.00

Between Sites

Table C11: Average percent hard coral cover between sites, during 2017.

Site	Mean	SD	SE
1	0.76	0.08	0.04
2	0.27	0.11	0.11
3	0.54	0.14	0.07

Table C12: Two-sample t-test outputs for average percent hard coral cover between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
S1 S2			**S1 S3**			**S2 S3**		
	S1	*S2*		*S1*	*S3*		*S2*	*S3*
Mean	0.75833333	0.27125	Mean	0.75833333	0.56	Mean	0.27125	0.56
Variance	0.00674242	0.01441875	Variance	0.00674242	0.01721818	Variance	0.01441875	0.01721818
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	11.5990925		t Stat	4.43851237		t Stat	-5.6236131	
P(T<=t) two-tail	7.6133E-11		P(T<=t) two-tail	0.0002067		P(T<=t) two-tail	1.1809E-05	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Table C13: Average percent soft coral cover between sites, during 2017.

Site	Mean	SD	SE
1	0.00	0.00	0.00
2	0.02	0.03	0.03
3	0.03	0.04	0.02

Table C14: ANOVA output for average percent soft coral cover between sites, 2017.

Anova: Single Factor						
Soft Coral						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0	0	0		
S2	12	0.25	0.02083333	0.00089015		
S3	12	0.275	0.02291667	0.00152936		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00385417	2	0.00192708	2.38943249	0.10736755	3.28491765
Within Groups	0.02661458	33	0.0008065			
Total	0.03046875	35				

Table C15: Average percent sponge cover between sites, during 2017.

Site	Mean	SD	SE
1	0.06	0.04	0.02
2	0.28	0.09	0.09
3	0.08	0.06	0.03

Table C16: Two-sample t-test outputs for average percent sponge cover between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
S1 S2			**S1 S3**			**S2 S3**		
	S1	*S2*		*Variable 1*	*Variable 2*		*S2*	*S3*
Mean	0.06041667	0.28291667	Mean	0.06041667	0.08291667	Mean	0.28291667	0.08291667
Variance	0.00171117	0.00870208	Variance	0.00171117	0.00361117	Variance	0.00870208	0.00361117
Observations	12	12	Observations	12	12	Observations	12	12
Pooled Variance	0.00520663		Pooled Variance	0.00266117		Pooled Variance	0.00615663	
df	22		df	22		df	22	
t Stat	-7.5531365		t Stat	-1.0683695		t Stat	6.24358655	
P(T<=t) two-tail	1.5122E-07		P(T<=t) two-tail	0.29693715		P(T<=t) two-tail	2.7711E-06	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Table C17: Average percent rock cover between sites, during 2017.

Site	Mean	SD	SE
1	0.12	0.07	0.03
2	0.17	0.12	0.12
3	0.08	0.04	0.02

Table C18: ANOVA output for average percent rock cover between sites, 2017.

Anova: Single Factor						
Sponge						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	1.465	0.12208333	0.00581572		
S2	12	2.09	0.17416667	0.01979015		
S3	12	1.15	0.09583333	0.00293561		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.03815139	2	0.01907569	2.0050498	0.15072865	3.28491765
Within Groups	0.31395625	33	0.00951383			
Total	0.35210764	35				

Table C19: Average percent rubble cover between sites, during 2017.

Site	Mean	SD	SE
1	0.00	0.00	0.00
2	0.14	0.05	0.05
3	0.01	0.06	0.03

Table C20: Two-sample t-test outputs for average percent coral rubble cover between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
S1 S2			**S1 S3**			**S2 S3**		
	S1	*S2*		*S1*	*S3*		*S2*	*S3*
Mean	0.0025	0.1375	Mean	0.0025	0.05375	Mean	0.1375	0.05375
Variance	0.000075	0.00451136	Variance	0.000075	0.00923239	Variance	0.00451136	0.00923239
Observations	12	12	Observations	12	12	Observations	12	12
Pooled Variance	0.00229318		Pooled Variance	0.00465369		Pooled Variance	0.00687188	
df	22		df	22		df	22	
t Stat	-6.9054208		t Stat	-1.8402237		t Stat	2.47470146	
P(T<=t) two-tail	6.1986E-07		P(T<=t) two-tail	0.0792662		P(T<=t) two-tail	0.02152182	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Table C21: Average percent zoanthid cover between sites, during 2017.

Site	Mean	SD	SE
1	0.01	0.01	0.01
2	0.01	0.01	0.01
3	0.15	0.06	0.03

Table C22: Two-sample t-test outputs for average percent zoanthid cover between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
S1 S3			**S1 S2**			**S2 S3**		
	S1	*S3*		*S1*	*S2*		*S2*	*S3*
Mean	0.0125	0.07958333	Mean	0.0125	0.0075	Mean	0.0075	0.07958333
Variance	0.00023864	0.00722936	Variance	0.00023864	0.00018409	Variance	0.00018409	0.00722936
Observations	12	12	Observations	12	12	Observations	12	12
Pooled Variance	0.003734		Pooled Variance	0.00021136		Pooled Variance	0.00370672	
df	22		df	22		df	22	
t Stat	-2.6890775		t Stat	0.84242354		t Stat	-2.9001162	
P(T<=t) two-tail	0.0134029		P(T<=t) two-tail	0.40861621		P(T<=t) two-tail	0.00830318	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Fish

Species Totals

Table C23: Total mean fish species/group abundances per 100m^2 during 2015 and 2017.

Fish	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Butterflyfish total	0.81	0.94	0.19	3.33	2.69	0.61
Rabbitfish total	1.64	2.71	0.88	2.50	4.37	1.53
Sergeant Fish sp.	7.67	3.51	1.75	10.97	4.71	2.35
Snapper total	0.36	0.52	0.26	5.28	2.37	0.56
Bream Total	0.00	0.00	0.00	1.22	1.44	0.72
Emperor	0.00	0.00	0.00	0.53	0.78	0.39
Jacks	0.00	0.00	0.00	0.06	0.11	0.06
Yellowtail Barracuda	0.00	0.00	0.00	0.14	0.28	0.14
Fusilier	0.03	0.03	0.01	6.81	9.90	4.95
Grouper total	0.00	0.00	0.00	0.39	0.49	0.24
Doublebanded Soapfish	0.00	0.00	0.00	0.03	0.06	0.03
Gold Spotted Sweetlips	0.00	0.00	0.00	0.06	0.11	0.06
Wrasse total	0.00	0.00	0.00	3.14	1.97	0.98
Sweeper	0.00	0.00	0.00	1.31	2.61	1.31
Cardinalfish	2.92	3.02	1.51	11.81	13.28	6.64
Pufferfish	0.00	0.00	0.00	0.06	0.11	0.06
Carpet Blenny Eel	0.00	0.00	0.00	0.19	0.34	0.17
Whiptail	0.00	0.00	0.00	0.03	0.06	0.03
Shark Sucker	0.00	0.00	0.00	0.03	0.06	0.03

Table C24: Paired t-test outputs for total average abundances of fish species/groups that were present during 2015 and 2017 monitoring years.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
Butterflyfish			**Rabbitfish**			**Sergeant fish**		
	2015	*2017*		*2015*	*2017*		*2015*	*2017*
Mean	0.80555556	3.33383333	Mean	1.63888889	2.52777778	Mean	7.66666667	10.7777778
Variance	1.36111111	13.3357143	Variance	28.1801587	83.9134921	Variance	79.9428571	40.7492063
Observations	36	36	Observations	36	36	Observations	36	36
df	35		df	35		df	35	
t Stat	-3.085739		t Stat	-0.4982928		t Stat	-1.7475151	
P(T<=t) two-tail	0.00395353		P(T<=t) two-tail	0.62139463		P(T<=t) two-tail	0.08931774	
t Critical two-tail	2.03010793		t Critical two-tail	2.03010793		t Critical two-tail	2.03010793	
t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
Snapper			**Cardinalfish**			**Fusilier**		
	2015	*2017*		*2015*	*2017*		*2015*	*2017*
Mean	0.36111111	5.27773889	Mean	2.91666667	11.8111111	Mean	0.02777778	6.84444444
Variance	0.3515873	11.3801587	Variance	54.4785714	274.473016	Variance	0.02777778	232.511111
Observations	36	36	Observations	36	36	Observations	36	36
df	35		df	35		df	35	
t Stat	-8.4353115		t Stat	-1.8217077		t Stat	-2.7191305	
P(T<=t) two-tail	5.9613E-10		P(T<=t) two-tail	0.07705491		P(T<=t) two-tail	0.01011697	
t Critical two-tail	2.03010793		t Critical two-tail	2.03010793		t Critical two-tail	2.03010793	

Combined Total Abundance

Table C25: Total mean fish abundance per 100m^2 between 2015 and 2017.

Individuals	Fish	
	2015	2017
Total	490	1952
Average	13.61	54.22
SD	11.89	38.54
SE	1.98	6.42

Table C26: Two-sample t-test output for total mean fish abundance between 2015 and 2017.

t-Test: Paired Two Sample for Means		
Fish		
	2015	*2017*
Mean	13.6111111	54.2222222
Variance	141.387302	1485.66349
Observations	36	36
df	35	
t Stat	-6.0609765	
P(T<=t) two-tail	6.4181E-07	
t Critical two-tail	2.03010793	

Table C27: Total mean fish abundance per 100m^2 between sites, 2017.

Individuals	Fish		
	S1	S2	S3
Total	567	575	810
Average	47.25	47.92	67.50
SD	35.13	35.75	43.89
SE	10.14	10.32	12.67

Table C28: ANOVA output for total mean fish abundance between sites, 2017.

Anova: Single Factor						
Fish						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	567	47.25	1234.38636		
S2	12	575	47.9166667	1277.7197		
S3	12	810	67.5	1926.27273		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3176.05556	2	1588.02778	1.07338367	0.35348511	3.28491765
Within Groups	48822.1667	33	1479.4596			
Total	51998.2222	35				

Invertebrates

Species Totals

Table C29: Total mean invertebrate species/group abundance per 100m^2 during 2015 and 2017.

Invertebrates	2015			2017		
	Mean	**SD**	**SE**	**Mean**	**SD**	**SE**
Feather Duster Worm	0.14	0.28	0.11	4.58	7.01	1.61
Christmas Tree Worm	0.22	0.38	0.10	15.33	11.58	3.29
Flatworm	0.14	0.28	0.14	0.00	0.00	0.00
Murex	0.03	0.06	0.03	Merged with 'Other Gastropods'		
True Crab	1.17	0.95	0.28	0.08	0.17	0.05
Cowrie	0.03	0.06	0.03	0.03	0.06	0.03
Drupella	3.14	2.03	0.92	0.17	0.33	0.07
Top Shell	0.22	0.33	0.08	1.47	2.10	0.52
Nudibranch	0.72	0.78	0.23	0.36	0.50	0.11
Volute Snail	0.00	0.00	0.00	0.06	0.11	0.06
Other Gastropods	4.06	2.08	0.68	1.28	1.87	0.45
Boring Bivalves	NA 2015			62.67	26.30	13.15
Octopus	0.00	0.00	0.00	0.14	0.28	0.14
Cuttlefish	0.03	0.06	0.03	0.17	0.21	0.06
Brittle Star	0.00	0.00	0.00	0.06	0.06	0.03
Flower Urchin	0.11	0.22	0.11	0.00	0.00	0.00
Diadema Sea Urchin	69.25	36.76	7.69	48.56	19.00	5.33
Collector Urchin	0.00	0.00	0.00	1.08	2.03	1.01
Synaptic Sea Cucumber	7.28	14.28	7.14	NA 2017		

Table C30: Paired t-test outputs for total average abundances of invertebrate species/groups that were present during the 2015 and 2017 monitoring years.

t-Test: Paired Two Sample for Means		
Feather Duster Worm		
	2015	*2017*
Mean	0.13888889	2.77777777
Variance	0.46587302	93.6087302
Observations	36	36
df	35	
t Stat	-1.6767174	
P(T<=t) two-tail	0.10250883	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Christmas Tree Worm		
	2015	*2017*
Mean	0.22222222	15.33
Variance	0.34920635	391.221429
Observations	36	36
df	35	
t Stat	-4.2336641	
P(T<=t) two-tail	0.00015798	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
True Crab		
	2015	*2017*
Mean	1.16666667	0.08555556
Variance	2.88571429	0.05396825
Observations	36	36
df	35	
t Stat	3.83885948	
P(T<=t) two-tail	0.00049627	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Cowrie		
	2015	*2017*
Mean	0.02777778	0.02777778
Variance	0.02777778	0.02777778
Observations	36	36
df	35	
t Stat	0	
P(T<=t) two-tail	1	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Drupella		
	2015	*2017*
Mean	1.16666667	0.16673333
Variance	2.88571429	0.07857143
Observations	36	36
df	35	
t Stat	3.68750609	
P(T<=t) two-tail	0.00076284	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Top Shell		
	2015	*2017*
Mean	0.22222222	1.47221111
Variance	0.23492063	9.60873016
Observations	36	36
df	35	
t Stat	-3.0563092	
P(T<=t) two-tail	0.00427163	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Nudibranch		
	2015	*2017*
Mean	0.72222222	0.36133333
Variance	1.92063492	0.45714286
Observations	36	36
df	35	
t Stat	1.39049763	
P(T<=t) two-tail	0.17315697	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Other Gastropods		
	2015	*2017*
Mean	4.05555556	1.27755556
Variance	16.7968254	7.13253968
Observations	36	36
df	35	
t Stat	4.08596843	
P(T<=t) two-tail	0.00024328	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
Cuttlefish		
	2015	*2017*
Mean	0.02777778	0.16633333
Variance	0.02777778	0.13571429
Observations	36	36
df	35	
t Stat	-0.8126361	
P(T<=t) two-tail	0.4219201	
t Critical two-tail	2.03010793	

t-Test: Paired Two Sample for Means		
***Diadema* Sea Urchin**		
	2015	*2017*
Mean	69.25	48.5555222
Variance	2127.27857	1024.32063
Observations	36	36
df	35	
t Stat	2.78801429	
P(T<=t) two-tail	0.00851557	
t Critical two-tail	2.03010793	

Combined Total Abundance

Table C31: Total mean invertebrate abundance per 100m^2 between 2015 and 2017.

Individuals	Invertebrates	
	2015	**2017**
Total	3116	4897
Average	86.56	136.03
SD	57.51	87.08
SE	9.59	14.51

Table C32: Two-sample t-test output for total mean invertebrate abundance between 2015 and 2017.

t-Test: Paired Two Sample for Means		
Invertebrates		
	2015	*2017*
Mean	86.5555556	136.027778
Variance	3307.56825	7582.82778
Observations	36	36
df	35	
t Stat	-2.5512517	
P(T<=t) two-tail	0.01526061	
t Critical two-tail	2.03010793	

Table C33: Total mean invertebrate abundance per 100m^2 between sites, 2017.

Individuals	Invertebrates		
	S1	**S2**	**S3**
Total	1213	892	2792
Average	101.08	74.33	232.67
SD	27.48	50.82	71.53
SE	7.93	14.67	20.65

Table C34: Two-sample t-test outputs for total mean invertebrate abundance between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
S1 S2			**S1 S3**			**S2 S3**		
	S1	*S2*		*S1*	*S3*		*S2*	*S3*
Mean	101.083333	74.3333333	Mean	101.083333	232.666667	Mean	74.3333333	232.666667
Variance	755.356061	2582.60606	Variance	755.356061	5116.78788	Variance	2582.60606	5116.78788
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	1.60388678		t Stat	-5.9483041		t Stat	-6.2507871	
P(T<=t) two-tail	0.12300006		P(T<=t) two-tail	5.4983E-06		P(T<=t) two-tail	2.7255E-06	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Herbivore Abundance

Totals Between Years

Table C35: Average herbivorous fish and urchin abundances per 100m^2, between 2015 and 2017.

Herbivore Group	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Fish	10.28	11.14	1.86	13.03	12.59	1.4
Urchin	69.36	46.07	7.68	49.64	36.46	6.08

Table C36: Paired t-test outputs for total average herbivorous fish and urchin abundances between 2015 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
Herbivorous Fish			**Urchins**		
	2015	*2017*		*2015*	*2017*
Mean	10.2777778	13.0277778	Mean	69.3611111	49.6388889
Variance	124.034921	158.599206	Variance	2122.06587	1329.26587
Observations	36	36	Observations	36	36
df	35		df	35	
t Stat	-0.8821512		t Stat	2.14725809	
P(T<=t) two-tail	0.38371366		P(T<=t) two-tail	0.03877911	
t Critical two-tail	2.03010793		t Critical two-tail	2.03010793	

Table C37: Paired t-test outputs for total average herbivorous fish against urchin abundances between 2015 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
2015			**2017**		
	Urchin	*Fish*		*Urchin*	*Fish*
Mean	69.3611111	10.2777778	Mean	49.6388889	11.1111111
Variance	2122.06587	124.034921	Variance	1329.26587	70.1587302
Observations	36	36	Observations	36	36
df	35		df	35	
t Stat	7.2243957		t Stat	6.17686732	
P(T<=t) two-tail	1.9658E-08		P(T<=t) two-tail	4.5187E-07	
t Critical two-tail	2.03010793		t Critical two-tail	2.03010793	

Table C38: Average herbivorous fish and urchin abundances per 100m^2, between sites, in 2017.

Site	Fish			Urchin		
	Mean	SD	SE	Mean	SD	SE
1	15.75	10.11	2.91	20	10.17	2.94
2	10.92	18.48	5.33	41.33	20.02	5.78
3	12.42	6.89	2	87.58	33.48	9.66

Table C39: ANOVA output for average herbivorous fish abundances between sites, 2017.

Anova: Single Factor						
Herbivorous Fish						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	189	15.75	102.204545		
S2	12	131	10.9166667	341.537879		
S3	12	149	12.4166667	47.5378788		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	146.888889	2	73.4444444	0.44848803	0.64242765	3.28491765
Within Groups	5404.08333	33	163.760101			
Total	5550.97222	35				

Table C40: Two-sample t-test outputs for average urchin abundances between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
Urchin			**Urchin**			**Urchin**		
	S1	*S2*		*S1*	*S3*		*S2*	*S3*
Mean	20	41.3333333	Mean	20	87.5833333	Mean	41.3333333	87.5833333
Variance	103.454545	400.969697	Variance	103.454545	1120.81061	Variance	400.969697	1120.81061
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	13		df	18	
t Stat	-3.2904202		t Stat	-6.6910225		t Stat	-4.1070159	
P(T<=t) two-tail	0.00333703		P(T<=t) two-tail	1.491E-05		P(T<=t) two-tail	0.00066181	
t Critical two-tail	2.07387307		t Critical two-tail	2.16036866		t Critical two-tail	2.10092204	

Species Richness

Total Between Years

Table C41: Total average species richness per $100m^2$, between 2015 and 2017.

Year	Species Richness		
	Mean	SD	SE
2015	6.69	1.58	0.26
2017	13.72	3.04	0.51

Table C42: Paired t-test output for species richness, 2017.

t-Test: Paired Two Sample for Means		
Total		
	2015	*2017*
Mean	6.69444444	13.7222222
Variance	2.50396825	9.23492063
Observations	36	36
df	35	
t Stat	-11.422384	
P(T<=t) two-tail	2.3382E-13	
t Critical two-tail	2.03010793	

Fish and Invertebrates Between Years

Table C43: Average species richness per $100m^2$, for fish and invertebrates, between 2015 and 2017.

Year	Fish			Invertebrates		
	Mean	SD	SE	Mean	SD	SE
2015	2.47	1.16	0.19	4.22	1.15	0.19
2017	8.97	2.04	0.34	4.75	1.99	0.33

Table C44: Paired t-test outputs for average fish and invertebrate species richness, between 2015 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
Fish			**Invertebrates**		
	2015	*2017*		*2015*	*2017*
Mean	2.47222222	8.97222222	Mean	4.22222222	4.75
Variance	1.34206349	4.14206349	Variance	1.32063492	3.96428571
Observations	36	36	Observations	36	36
df	35		df	35	
t Stat	-16.274236		t Stat	-1.2959615	
P(T<=t) two-tail	6.7231E-18		P(T<=t) two-tail	0.20347009	
t Critical two-tail	2.03010793		t Critical two-tail	2.03010793	

Total Between Sites

Table C45: Average species richness per 100m^2, between sites, 2017.

Site	Species		
	Mean	SD	SE
1	13.83	2.92	0.84
2	12.08	2.91	0.84
3	15.25	2.63	0.76

Table C46: Two-sample t-test outputs for total average species richness, between sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
Total			**Total**			**Total**		
	S1	*S2*		*S1*	*S3*		*S2*	*S3*
Mean	13.8333333	12.0833333	Mean	13.8333333	15.25	Mean	12.0833333	15.25
Variance	8.51515152	8.4469697	Variance	8.51515152	6.93181818	Variance	8.4469697	6.93181818
Observations	12	12	Observations	12	12	Observations	12	12
Pooled Variance	8.48106061		Pooled Variance	7.72348485		Pooled Variance	7.68939394	
df	22		df	22		df	22	
t Stat	1.47193486		t Stat	-1.2486383		t Stat	-2.7972541	
P(T<=t) two-tail	0.15520025		P(T<=t) two-tail	0.22492188		P(T<=t) two-tail	0.01050083	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	