KOH MAK PRANG ENVIRONEMENTAL ASSESSMENT

REPORT BY :

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IN PARTNERSHIP WITH THE FISHERIES ADMINISTRATION

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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 Mak Prang, Koh Angkrong 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 ecosystem that lies adjacent to Koh Mak Prang. 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. However, monitoring methods during 2015 differed from those in 2017. Total hard coral cover was found to be relatively healthy but differed significantly between sites and sponges dominated some areas. Coral diversity appeared low and more than 10% of the corals were found to have bleached. Total fish abundance and fish species richness significantly increased between monitoring years. Herbivorous fish abundance did not change over time and remained relatively low between monitoring years. Herbivorous urchin abundance, however, significantly increased between years, despite a significant decline in total invertebrate abundance and species richness.

Following a reduction in illegal fishing pressures, the Koh Mak Prang 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 Mak Prang 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 Mak Prang, Koh Angkrong 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. Kuch Virak	Director of Kep Fisheries Cantonment
Mr. Paul Ferber	Managing Director and Project Founder, MCC

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1. Introduction

This report is the 2017 environmental assessment of the Koh Mak Prang 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 Mak Prang 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.

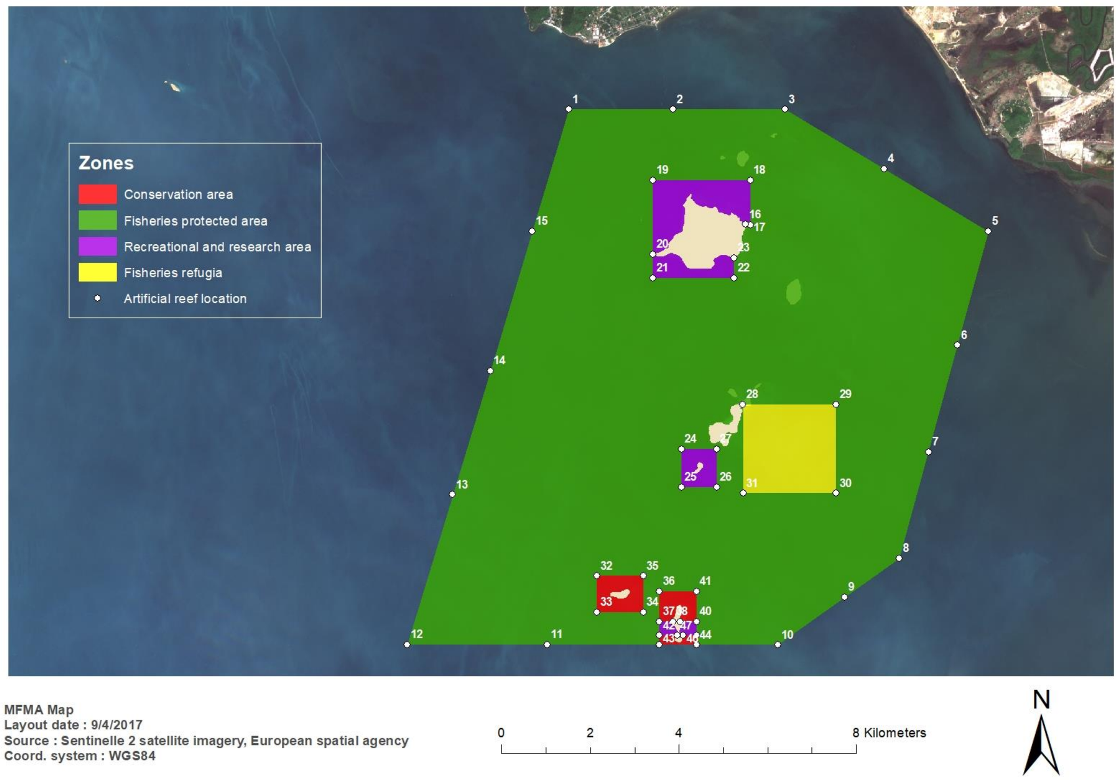


Figure 1: Location of the Marine Fisheries Management Area in the Kep Archipelago, relative to mainland Cambodia.

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 Mak Prang is located within Cambodia's Kep Archipelago, at, or about, GPS coordinates 10°23'20.9"N 104°19'27.6"E (Figure 2). Koh Mak Prang is positioned approximately 3km 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. Some tourism vessels also operate in the area.

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

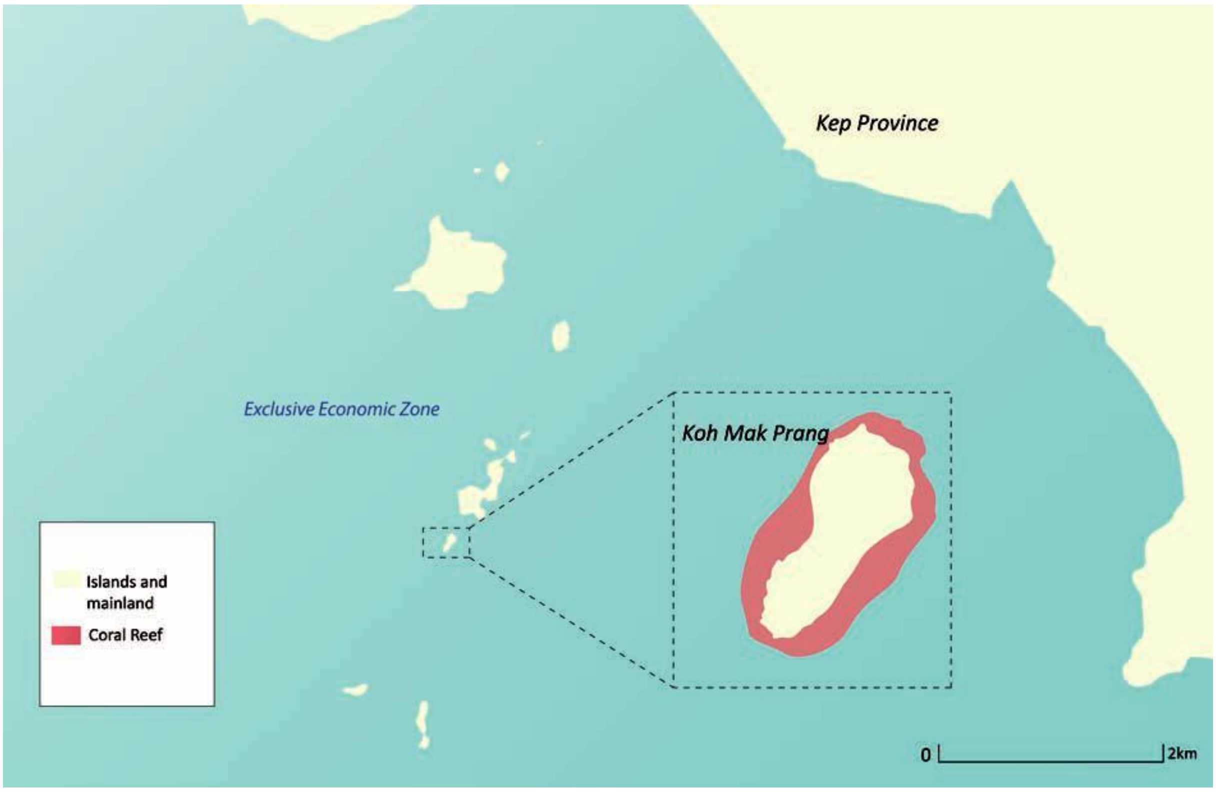


Figure 2: Location of Koh Mak Prang in the Kep Archipelago, relative to mainland Cambodia.

The 2017 coral reef assessment for Koh Mak Prang was conducted between April and August. 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 Mak Prang (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	Intermediate
Site 3	Relatively 'poor'

Each of the site conditions was 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 Mak Prang 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. Illegal divers have caused some destruction on the reef over the past two years, and some previously healthy sections of coral reef have deteriorated. However, the variance in conditions between sites are not often great 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.

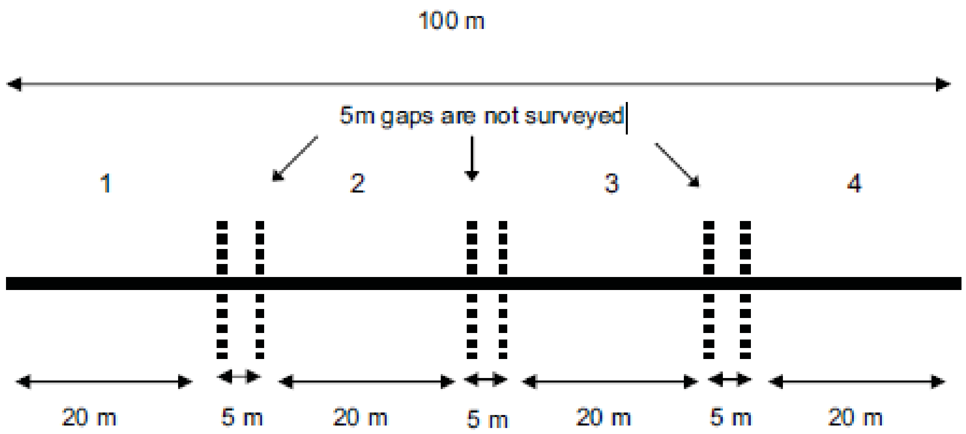
Figure 3: 2017 survey site locations.

2.2 Data Collection

Procedures for collecting field data followed a modified version of the 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 the 2017 year. 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.

Seven sites were selected during 2015 that were positioned around the entire fringing reef (Figure 5). Surveys were undertaken using the same transect line technique used during 2017, however, only one replicate was completed per site. The 2015 year included a total of 28 surveys, however, 36 surveys were conducted during 2017 for each of the monitored categories. A number of survey sites monitored during 2015 also 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.

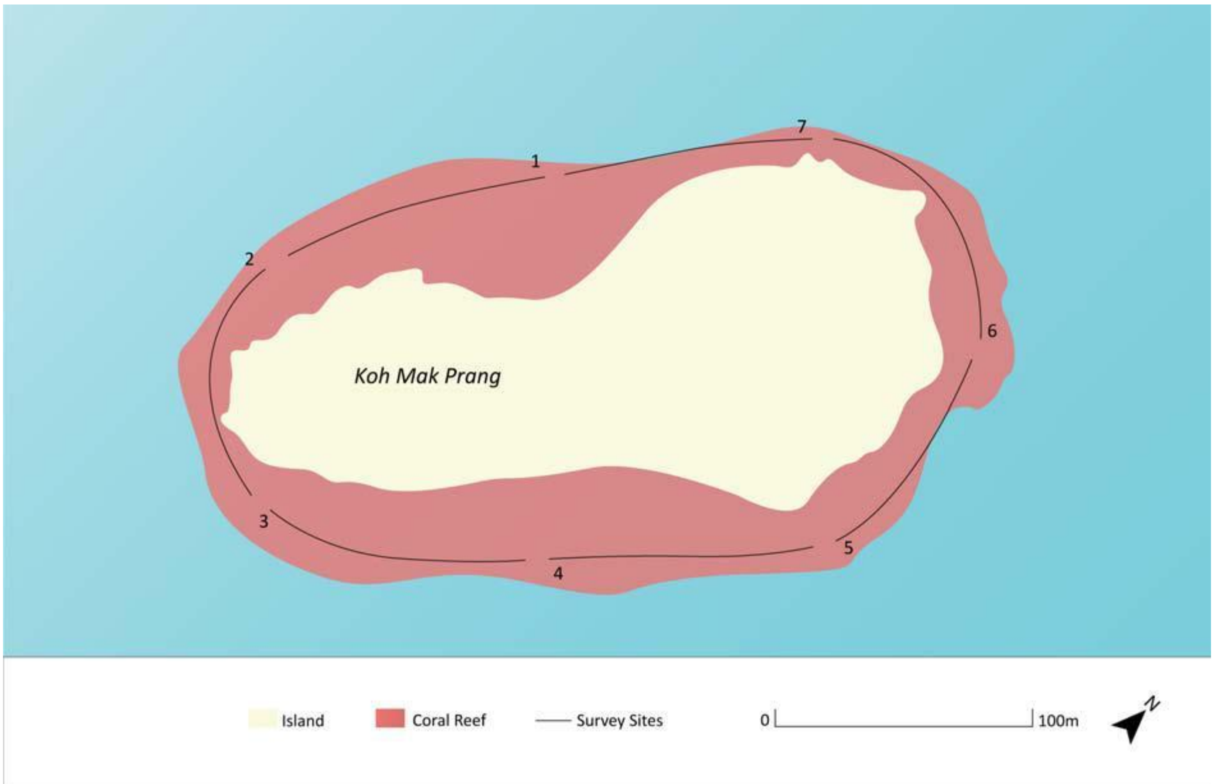


Figure 5: 2015 Survey site locations.

2.3 Species Monitoring List: Additions & 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 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 each species/group that are present have been displayed for each site and 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 were 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 considered not to be 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 total average species abundance and average herbivore abundance per $100m^2$ of transect (20m segment), between years. Total average fish and invertebrate abundance and total herbivorous fish and urchin abundance between years have been investigated using a two-sample t-test. Fish species/groups statistically analysed include: total butterflyfish, total rabbitfish, sergeant fish, total snapper, fusilier, total grouper, total wrasse, and cardinalfish. Invertebrate species/groups statistically analysed include: feather duster worms, christmas tree worms, true crab, and *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 angelfishes 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. Furthermore. Herbivorous urchins included the flower urchin, *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.

An ANOVA and two-sample t-tests were used to compare differences in species richness, per $100m^2$, between sites for 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 two-sample t-test was used to compare total richness for fish and invertebrates (both combined and separately) between 2015 and 2017.

Note that paired t-tests were unable to be utilised when assessing before and after data due to differences in sample sizes between years; and therefore two-sample t-test methods have been utilised as a best fit.

3. Results

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

3.1 Impact Assessment

Medium levels of ‘other’ coral damage were recorded at site 1 during 2017 (Figure 6, Table C1). Sites 1 and 3 exhibited some coral damage, considered low. There was no trash or coral predation recorded at any of the sites during 2017. Between years, the median level of coral was recorded as low (Figure 7, Table C2). Furthermore, there was no trash or coral predation recorded.

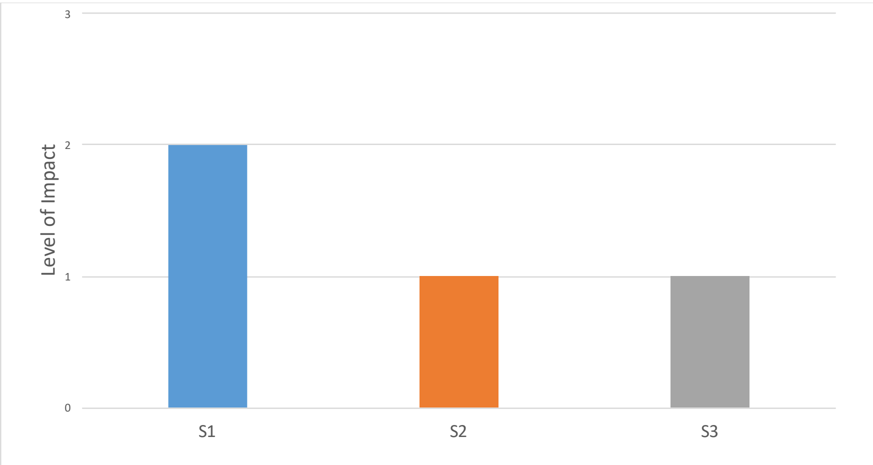


Figure 6: Median level of coral damage at each site during 2017. 0 = none, 1 = low, 2 = medium, and 3 = high.

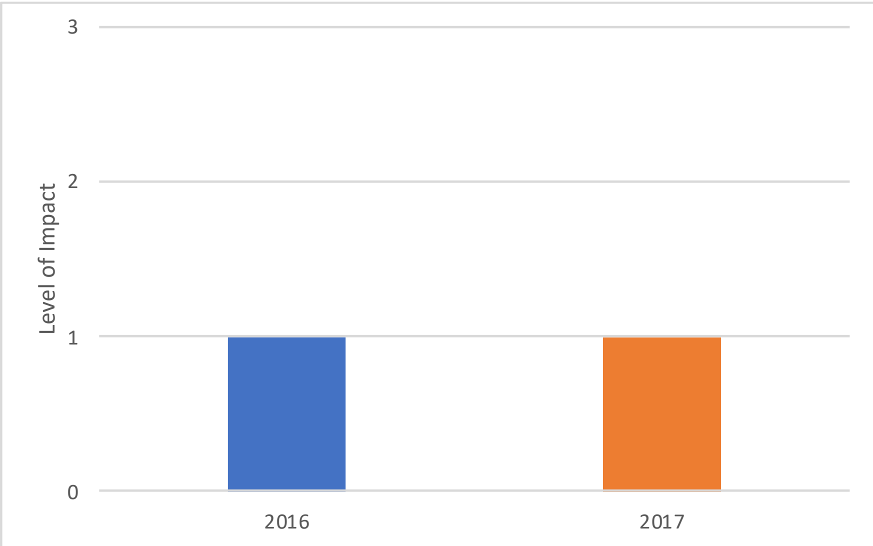


Figure 7: Median level of coral damage during 2015 and 2017. 0 = none, 1 = low, 2 = medium, and 3 = high.

An average of 30.9% of the coral population at site 1 exhibited bleaching (Figure 8, Table C3). This was significantly greater than average bleaching observed at both sites 2 (t_{22}=2.37, p=0.027) and 3 (t_{22}=2.53, p=0.0231), which displayed 1% and 0.8%, respectively (Table C4). There were no significant differences between sites 2 and 3 for average percent bleaching of the coral population (t_{22}=1.14, p=0.281) or between individual corals (t_{22}=1.31, p=0.205) (Table C5). Instances of coral disease were low and there were no significant differences between sites in 2017 ($f_{2,33}$=1.76, p=0.187) (Table C6, Table C7).

On average 10.67% of the total coral population had bleached at Koh Mak Prang in 2017 (Figure 9, Table C8). During 2015, only 0.75% of the population was recorded as being bleached. However, due to large variances in the data, there was no significant difference between monitoring years (t_{62}=-1.82, p=0.073). There was also no significant difference between the average presence of bleaching on an individual coral between years (t_{62}=-1.86, p=0.068) (Table C9). On average 3% of the population suffered from disease, with individually affected corals experiencing an average of 4.67% disease cover. No Black Band or White Band diseases were observed during 2015 surveys.

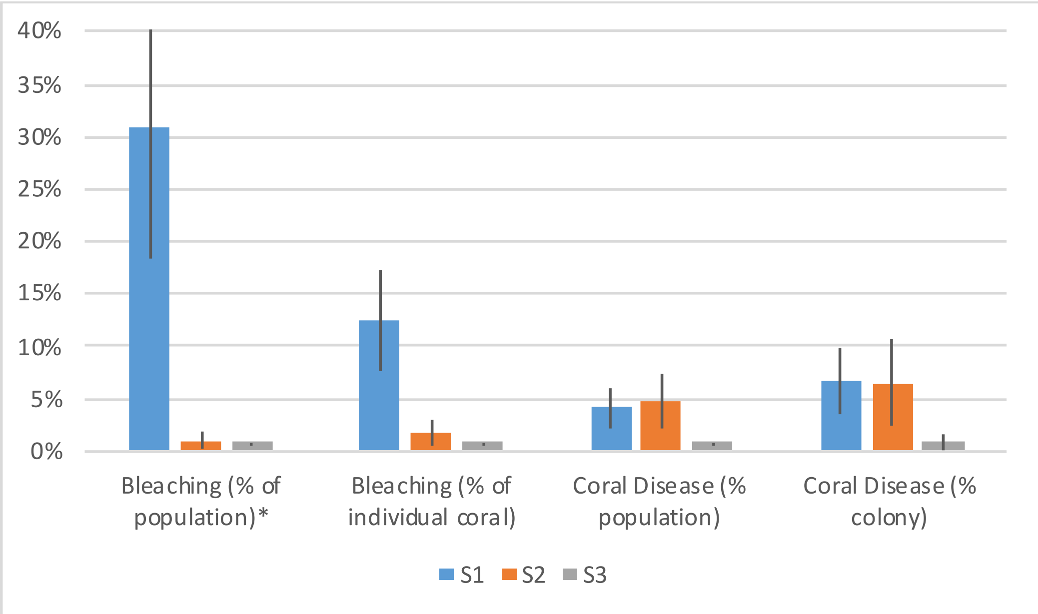


Figure 8: Mean (± SE) percent of bleached and diseased corals within the population and per individual coral cover, between sites.

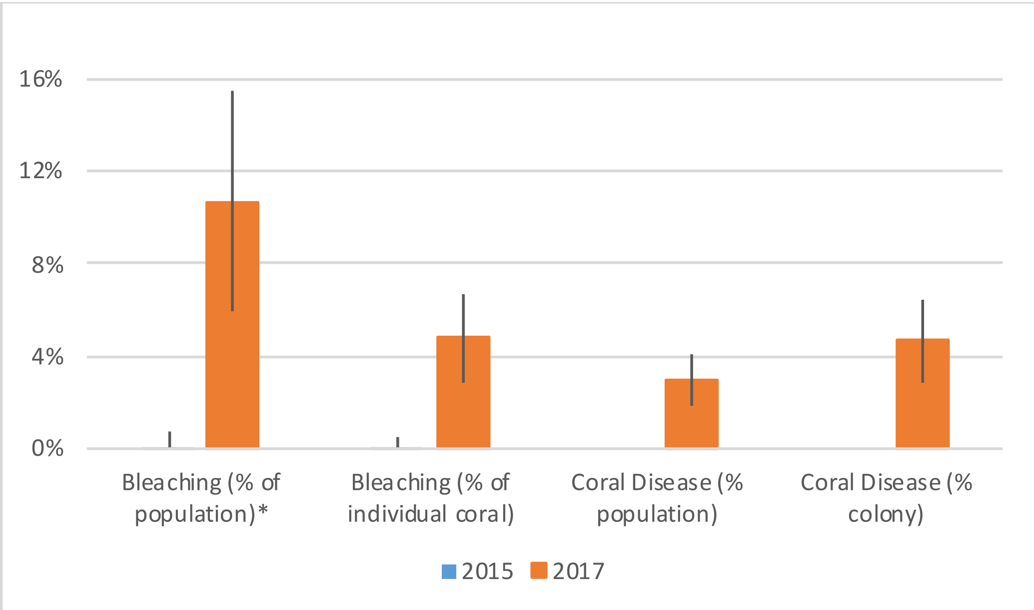


Figure 9: Mean (± SE) percent of bleached and diseased corals within the population and per individual coral cover, between years.

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 Mak Prang during 2017 (Figure 11). Refer to *APPENDIX B* (Table B3) for a complete list of substrates and their acronyms.

Hard Coral

Hard coral (HC) cover at site 3 was significantly lower than hard coral cover at site 1 (t_{22}=4.94, p=<0.001) and site 2 (t_{22}=3.74, p=0.001). Site 1 and site 2 displayed the greatest covers at averages of 39.3% and 44.2%, respectively. Hard coral at site 3 was characterized by a relatively low cover of hard coral, displaying an average cover of 17.5%. Refer to Table C11 and Table C12.

Soft Coral

All three sites experienced differing amounts of soft coral (SC) cover. Site 3 exhibited the greatest cover at an average of 15.8%. This was significantly greater than soft coral cover at site 1 (t_{22}=-3.67, p=0.001) and 2 (t_{22}=-5.39, p=<0.001), which exhibited covers of 4.5% and 0.8%, respectively. Soft coral cover at site 1 was also significantly greater than soft coral cover at site 2 (t_{22}=2.71, p=0.013). Refer to Table C13 and Table C14.

Sponge

Sponge (SP) cover differed across all sites. Site 3 displayed an average sponge cover of 32.9% and exceeded average hard coral cover. This was significantly greater than average sponge cover at site 1 (t_{22}=-2.43, p=0.023) and site 2 (t_{22}=-6.06, p=<0.001), which exhibited average covers of 23.5% and 11.4%, respectively. Average sponge cover at site 1 was also significantly greater than sponge cover at site 2 (t_{22}=3.63, p=0.001). Refer to Table C15 and Table C16.

Rock

Average percent of rock (RC) cover did not significantly differ between sites ($f_{2,33}$=1.02, p=0.372). Site 3 displayed the greatest average percent of rock cover at 10%. Site 1 displayed an average of 6.4% rock cover, and site 2 had an average of 8.9%. Refer to Table C17 and Table C18.

Coral Rubble

Coral rubble (RB) cover did not significantly differ between sites ($f_{2,33}$=0.2, p=0.82). Sites 2 and 3 both exhibited averages of 10.6% covers of coral rubble, while site 1 displayed an average cover of 8.6%. Refer to Table C19 and Table C20.

Sand

Sand (SD) cover did not significantly differ between sites ($f_{2,33}$=2.39, p=0.107). Site 2 exhibited the greatest with an average of 12.08% sand cover, while site 1 and 3 displayed 5.8% and 7.9% covers, respectively. Refer to Table C21 and Table C22.

Zoanthid

Zoanthid (ZO) cover did not significantly differ between sites ($f_{2,33}$=3.2, p=0.054). Sites 1 and 2 exhibited average zoanthid covers 2.7% and 3.3%, respectively, while site 3 displayed an average zoanthid cover of 0.65%. Refer to Table C23 and Table C24.

Other

"Other" (OT) substrate cover did not differ significantly between sites ($f_{2,33}$=3.12, p=0.057). Site 1 and site 2 both displayed an average cover of 7.9% "other" substrate, while site 3 had an average cover of 2.1%. Refer to Table C25 and Table C26.

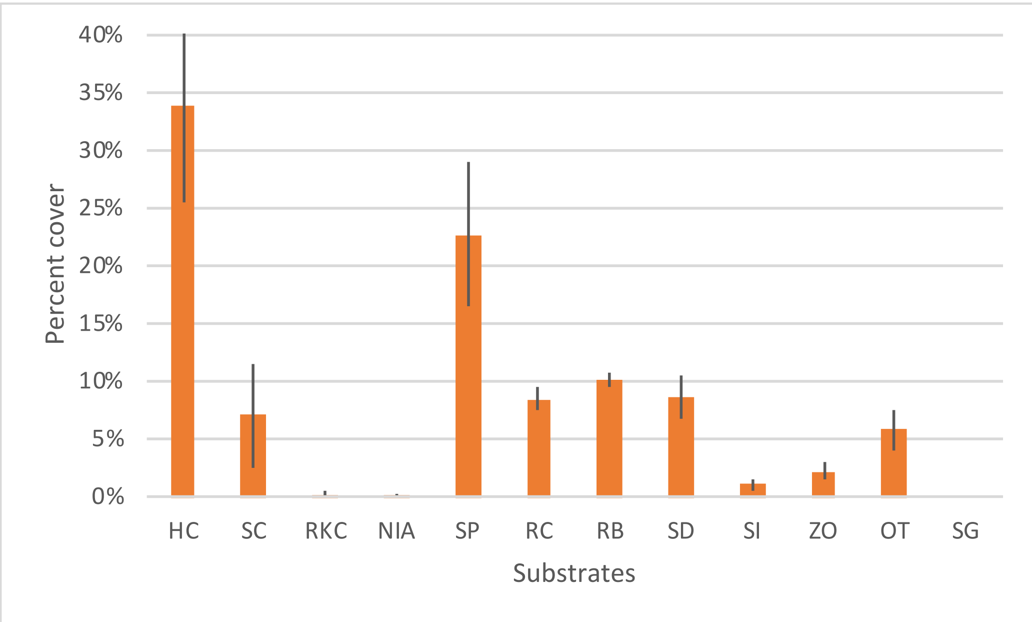


Figure 10: Total mean (± SE) percent cover of substrates during 2017.

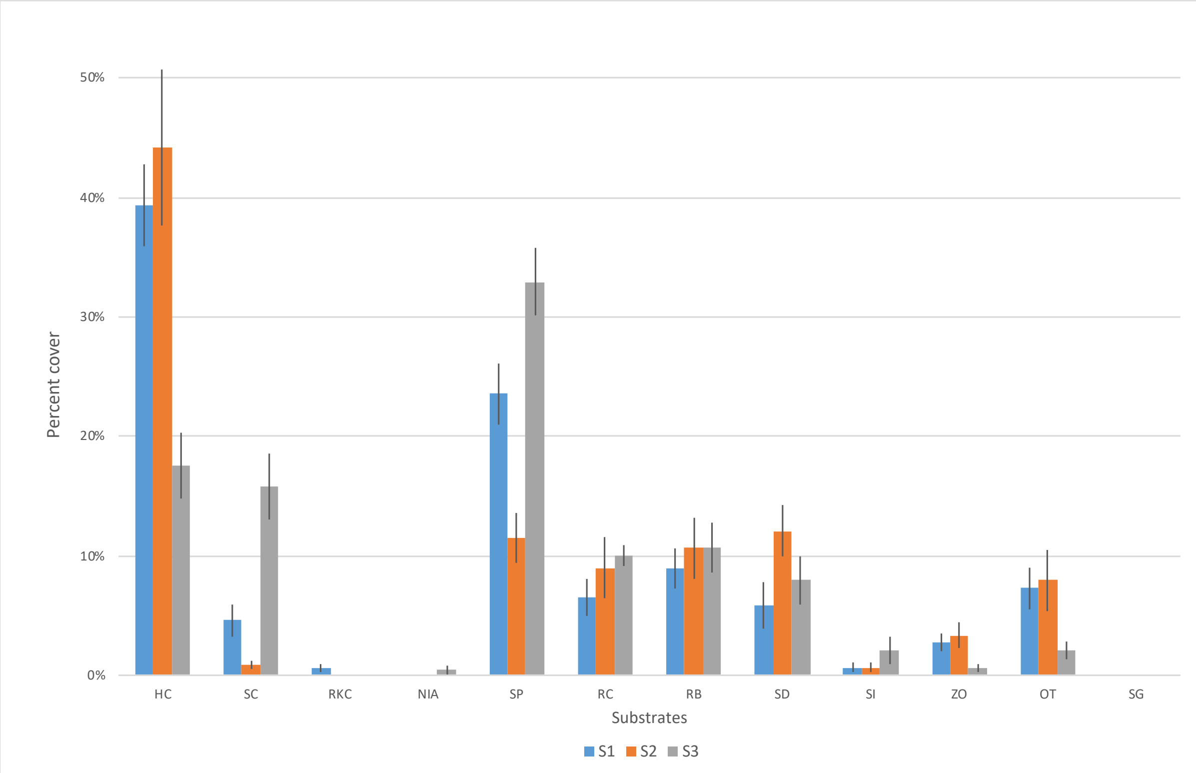


Figure 11 Mean (± SE) percent cover of substrate type for all sites (S1, S2, S3) during 2017.

3.3 Fish

Refer to Table B1 for the complete list of fish species monitored by MCC.

3.3.1 Totals Between Years

The Koh Mak Prang system exhibited a greater variety of fish species/groups during 2017, compared with 2015 (Figure 12, Figure 13, Table C27). A total of 38 fish species/groups from the MCC species monitoring list were recorded as being present during 2017. During the 2015 monitoring year 19 fish species/groups were identified from the monitoring list (refer to Table B4 for the complete list of fish species/groups that were observed during 2015 and 2017 monitoring years). In total, there were 24 new fish species/groups identified in 2017 which had not been observed during 2015 (Table 2).

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

Virgate Rabbitfish	Bridled Monocle Bream	Weedy Surge Wrasse
Dusky Rabbitfish	Whitecheek Monocle Bream	other Wrasse
Spanish Flag Snapper	Emperor	Catfish
Black-Spot Snapper	Jacks	Boxfish
Brown stripes Snapper	Mullet	Carpet Blenny Eel
One-Spot Snapper	Obtuse Barracuda	Scad
unknown Snapper	Orange-Spotted Grouper	Pipefish
Monogram Monocle Bream	Gold Spotted Sweetlips	

There were 6 fish species/groups recorded during 2015 that were not observed during 2017 (Table 3).

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

Checkered Snapper
Checkerboard Wrasse
Squirrelfish/Soldierfish
Goby
Blenny
Goatfish

Goby's, blenny's and goatfish were removed from MCC's species monitoring list following the 2015 monitoring year due to their high abundances.

Species/groups that were recorded during both monitoring years included total butterflyfish, total rabbitfish, total snapper, total grouper, total wrasse, sergeant fish, fusilier, cardinalfish and filefish. Only one filefish was observed in each of the years, and for that reason no statistical analysis has been performed on data. Total butterflyfish, total snapper, total grouper, total wrasse, sergeant fish and fusilier mean abundances all significantly increased between monitoring years (Table C28).

Butterflyfish significantly increased from an average of 3.82 individuals per 100m^2 in 2015 to 6.11 individuals per 100m^2 in 2017 (t_{62}=-2.09, p=0.04). Snapper significantly increased from an average 0.82 individuals per 100m^2 in 2015 to 14.56 individuals per 100m^2 in 2017 (t_{62}=-6.71, p=<0.001). Sergeant fish significantly increased from an average of 9.86 individuals per 100m^2 in 2015 to 14.25 individuals per 100m^2 in 2017 (t_{62}=-2.01, p=0.049). Fusilier significantly increased from an average of 2 individuals per 100m^2 during 2015 to 13.47 individuals per 100m^2 in 2017 (t_{62}=-2.68, p=0.009). Total grouper and total wrasse mean abundances remained relatively low, however, between years, total grouper significantly increased from an average of 0.07 to 0.56 individuals per 100m^2 (t_{62}=-3.04, p=0.003) and total wrasse from an average of 0.96 to 4.58 individuals per 100m^2 (t_{62}=-6.89, p=<0.001). The analysis revealed no significant increase in abundance of total rabbitfish (t_{62}=1.12, p=0.265) or cardinalfish (t_{62}=-0.63, p=0.532) over time, which were both present in relatively high abundances compared to other monitored groups.

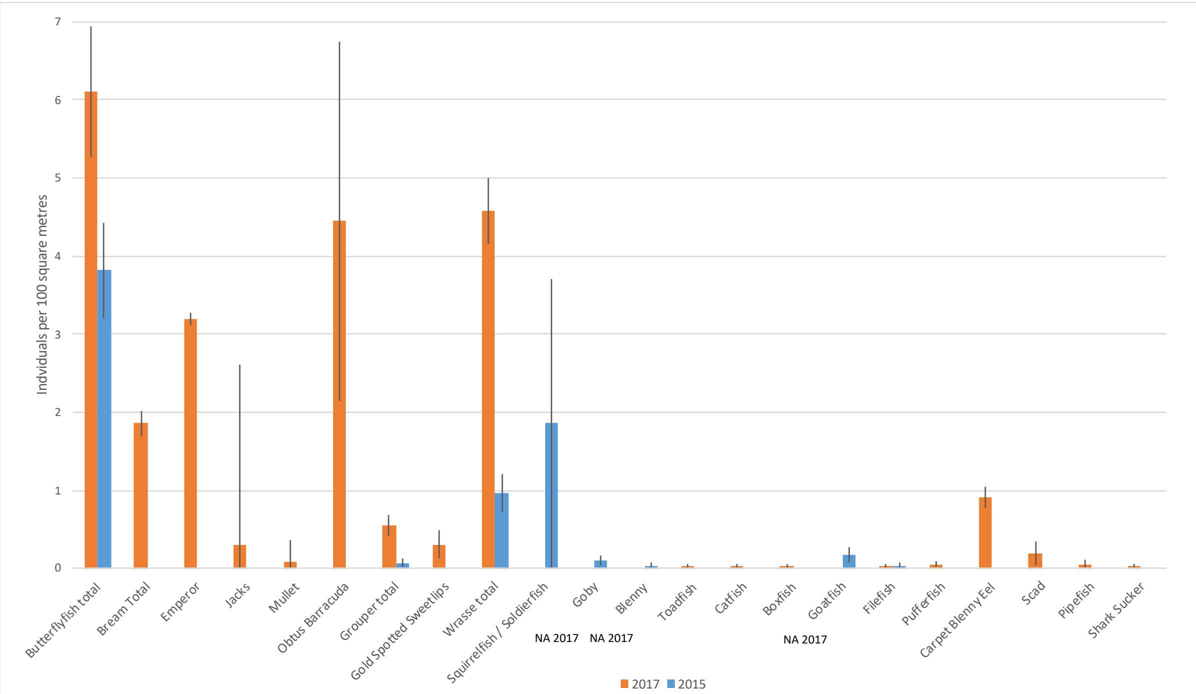


Figure 12: Total mean (± SE) fish species/group abundance per 100m^2 during 2015 and 2017.

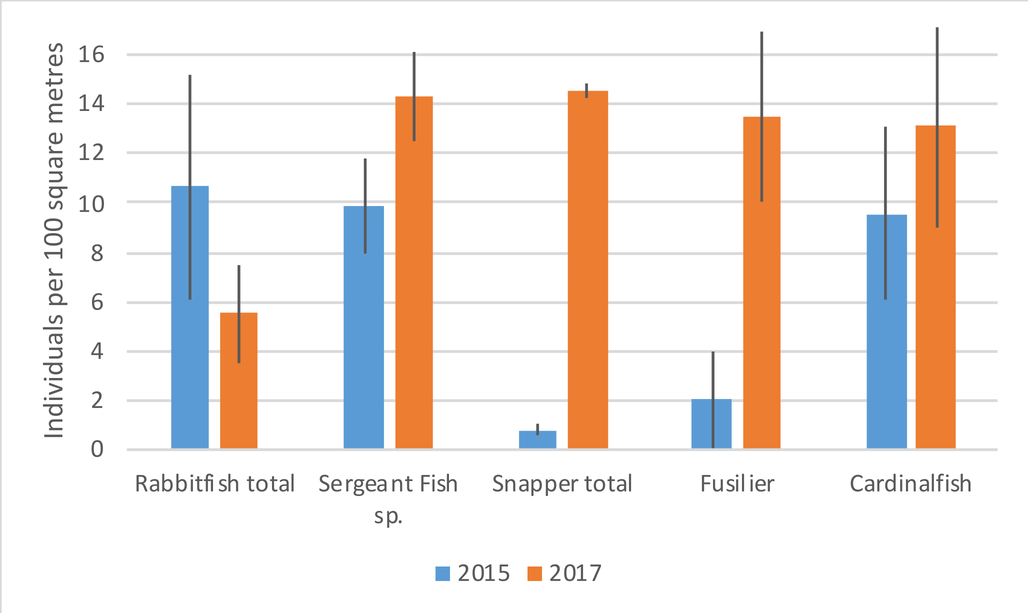


Figure 13: Total mean (± SE) abundances of total rabbitfish, sergeant fish, total snapper, fusilier, and cardinalfish per $100m^2$ during 2015 and 2017.

3.3.2 Combined Total Abundance

Combined total average fish abundance differed significantly between years (Figure 14, Table C29, Table C30). Total fish abundance significantly increased from an average of 40.1 individuals per $100m^2$ during 2015 to 84.2 individuals per $100m^2$ in 2017 (t_{62}=-3.71, p=<0.001).

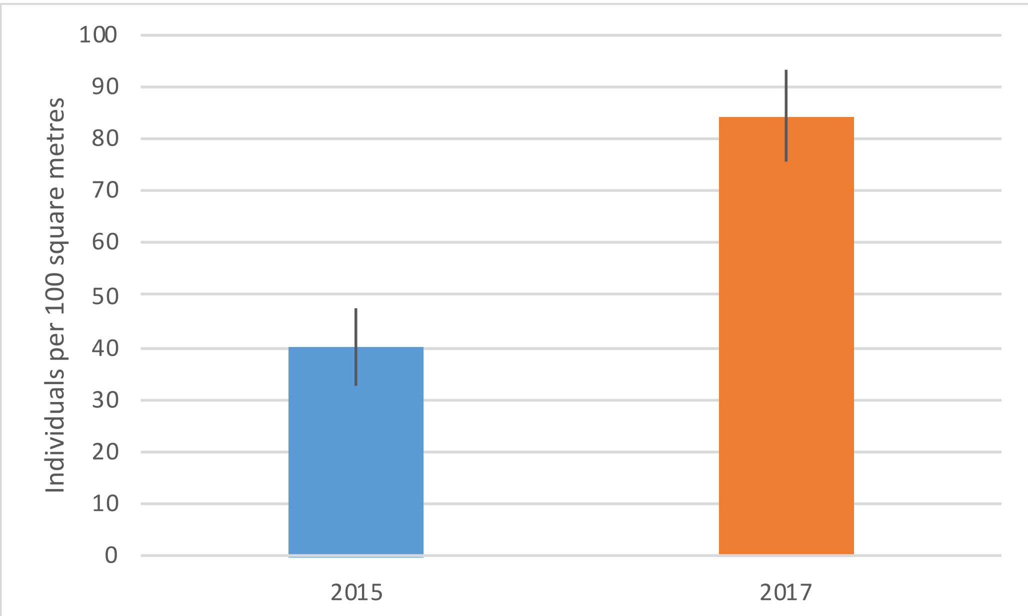


Figure 14: Combined total mean (± SE) number of individuals per $100m^2$, for fish, during 2015 and 2017 monitoring years.

There was no significant difference in the combined total average fish abundance between sites ($f_{2,33}$=3.12, p=0.058) (Figure 15, Table C31, Table C32). Sites 1, 2 and 3 exhibited an average of 113.42, 71.08 and 68.17 individuals per 100m^2 in 2017, respectively. There was a total of 1361 individuals recorded at site 1 during 2017, compared with 853 individuals recorded at site 2 and 818 individuals recorded at site 3.

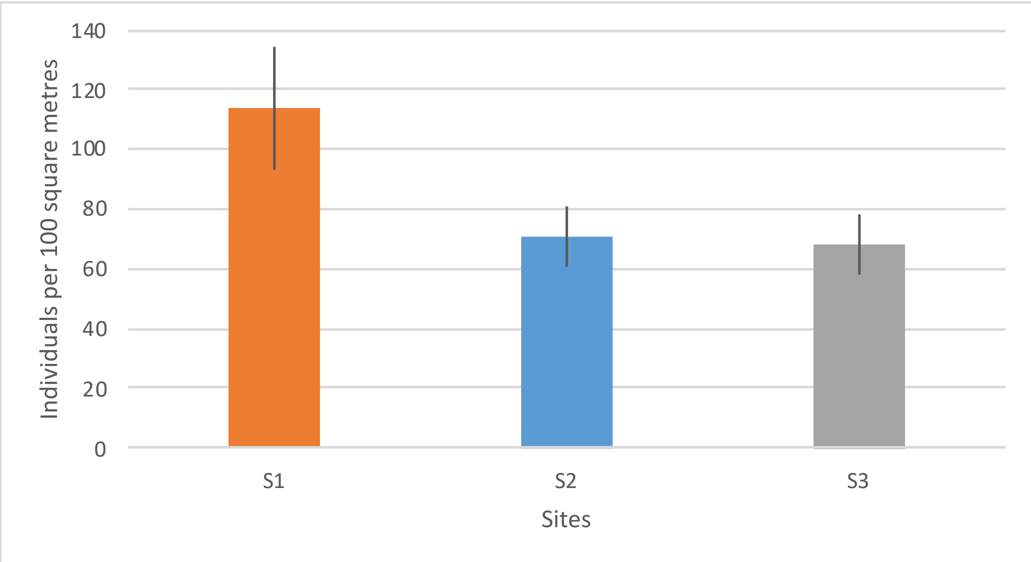


Figure 15: Combined total mean (± SE) number of individuals per 100m^2, for fish, at each site (S1, S2, S3) during 2017.

3.4 Invertebrates

Refer to 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 (Figure 16, Figure 17, Table C33). In 2017, a total of 11 invertebrate species/groups from the MCC species monitoring list were recorded as being present at Koh Mak Prang. During 2015, there was a total of 16 invertebrate species/groups recorded as being present (refer to Table B5 for the complete list of invertebrate species/groups observed during 2015 and 2017 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 Mak Prang during 2017.

Anemone Shrimp
Cowrie
Boring Bivalves
Collector Urchin

There were 9 invertebrate species/groups recorded during 2015 that were not observed during 2017 (Table 5).

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

Flatworm	Other gastropods	Synaptic Sea Cucumber
Murex	Chocolate Drop Starfish	
Drupella	Flower Urchin	
Nudibranchs	Pencil Urchin	

Synaptic sea cucumbers were removed from MCC's species monitoring list following 2015 due to their high abundance.

Species that were recorded during both monitoring years included: feather duster worms, christmas tree worms, true crabs, top shells, cuttlefish, cushion stars, and the *Diadema* sea urchin. Feather duster worms, true crabs, top shells, cuttlefish and cushion stars were all present in relatively low abundances. No statistical analysis was performed on data collected for top shells, cuttlefish or cushion stars due to their low numbers. True crab and feather duster worm mean abundances did not significantly differ between years (t_{62}=1.8, p=0.077; t_{62}=1.62, p=0.111) (Table C34). Christmas tree worm abundance increased significantly from an average of 1.64 individuals per 100m^2 in 2015 to 12.14 individuals per 100m^2 in 2017 (t_{62}=-3.3, p=0.002). The average abundance of *Diadema* sea urchin significantly increased from 46.07 individuals per 100m^2 in 2015 to 63.53 individuals per 100m^2 in 2017 (t_{62}=-2.08, p=0.041).

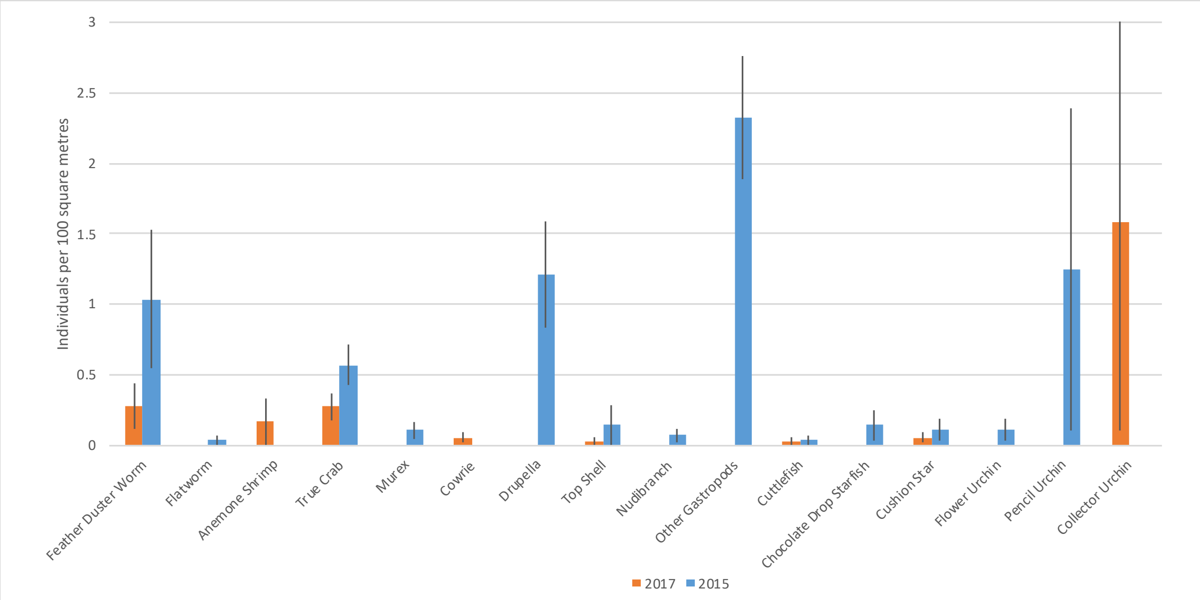


Figure 16: Total mean (± SE) invertebrate species/group abundance per 100m[2] during 2015 and 2017.

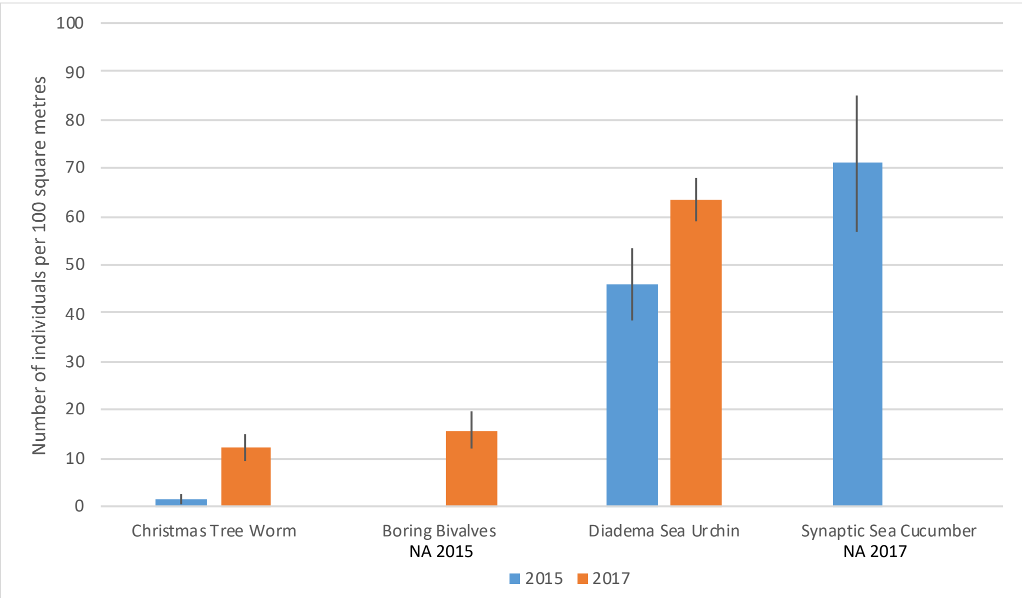


Figure 17: Total mean (± SE) christmas tree worm, boring bivalve, *Diadema* sea urchin and synaptic sea cucumber abundance per 100m[2] during 2015 and 2017.

3.4.2 Combined Total Abundance

The combined total average invertebrate abundance significantly decreased from an average of 126.14 individuals per 100m^2 during 2015 to 93.89 individuals per 100m^2 in 2017 (t_{62}=2.12, p=0.038) (Figure 18, Table C35, Table C36).

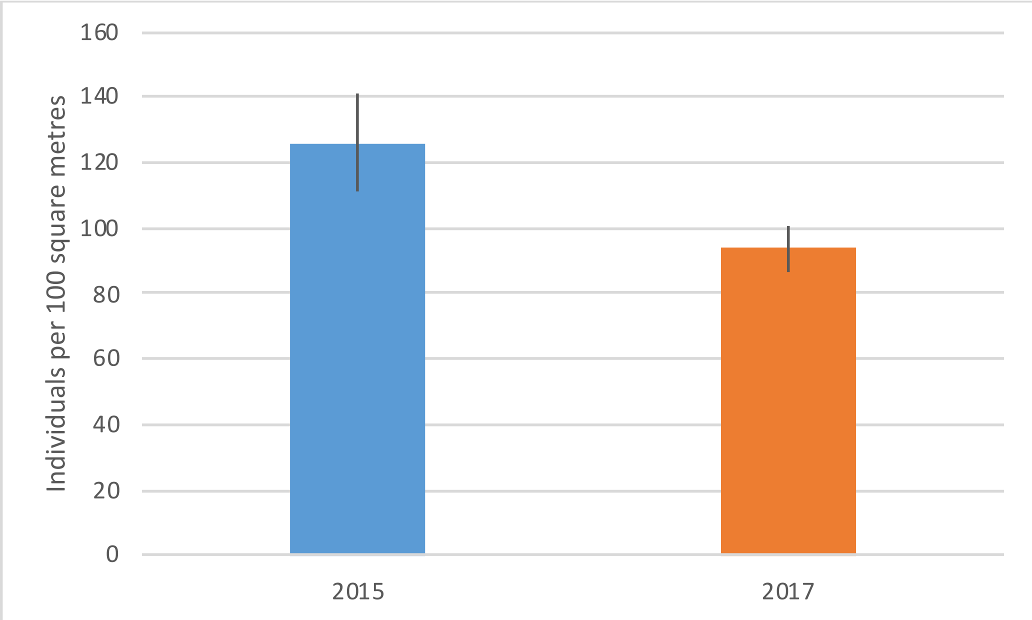


Figure 18: Combined total mean (± SE) number of individuals per 100m^2, for invertebrates, during 2015 and 2017 monitoring years.

Sites 2 and 3 experienced total invertebrate abundances that significantly differed from each other during 2017 (Figure 19, Table C37, Table C38). Site 2 exhibited an average of 116.58 individuals per 100m^2, compared to site 3, which was significantly less, having an average of 70.92 individuals (t_{22}=2.76, p=<0.011). Site 1 displayed an average of 94.17 individuals per 100m^2. There was no difference between average invertebrate abundances observed between sites 1 and 2 (t_{22}=-1.32, p=0.2) and sites 1 and 3 (t_{22}=1.67, p=<0.109). Sites 1, 2 and 3 displayed combined totals of 1130, 1399 and 851 individuals, respectively.

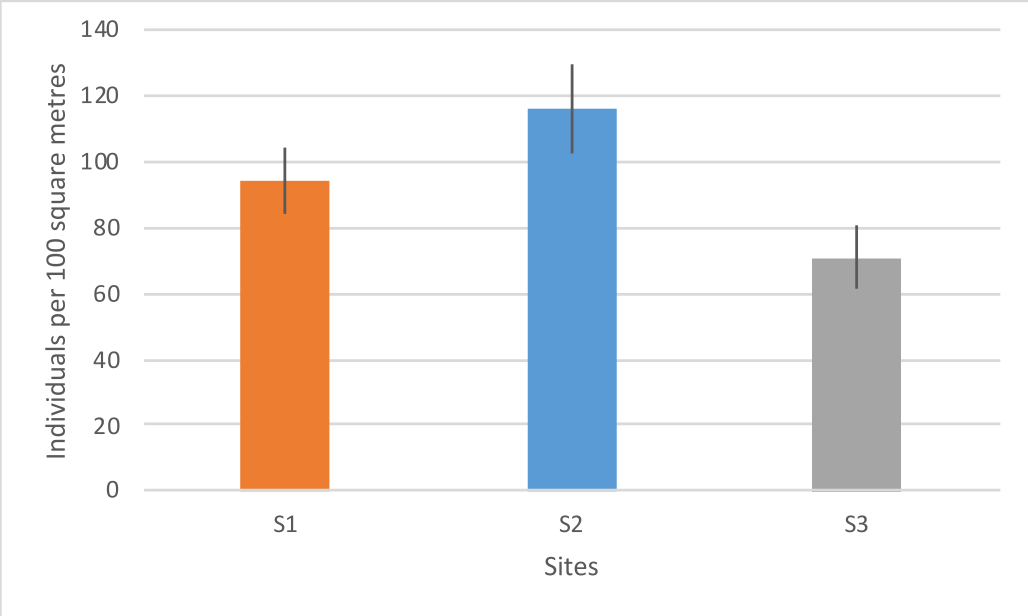


Figure 19: Combined total mean (± SE) number of individuals per 100m^2, for invertebrates, between sites (S1, S2, S3).

3.5 Herbivore Abundance

No significant differences were observed between 2015 and 2017 monitoring years for total average abundance of herbivorous fish (t_{62}=0.14, p=0.889) (Figure 20, Table C39, Table C40). Average herbivorous fish abundance was recorded at 20.5 individuals per 100m^2 during 2015, compared with 19.75 individuals per 100m^2 in 2017. No parrotfishes (and other important herbivorous fishes) were observed during monitoring. Total average urchin abundance was significantly greater than herbivorous fish during 2015 (t_{54}=-2.99, p=0.004) and 2017 (t_{70}=-8.42, p=<0.001). Furthermore, urchin abundance significantly increased from an average of 47.43 individuals per 100m^2 in 2015 to 65.11 individuals per 100m^2 in 2017 (t_{62}=2.09, p=0.041) (Figure 20, Table C39, Table C40).

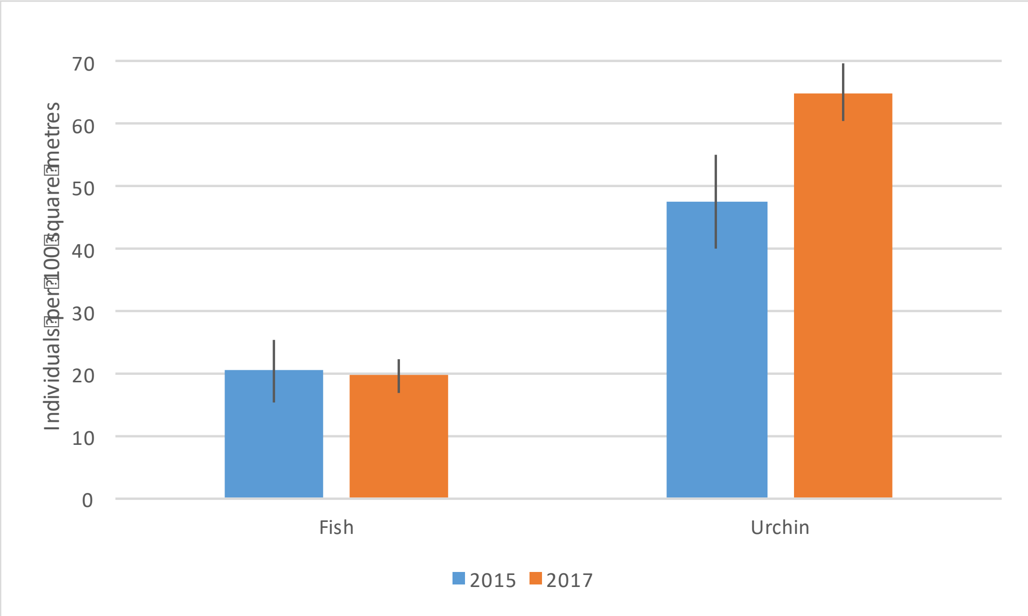


Figure 20: Mean (± SE) herbivore abundance per 100m^2, for fish and urchins, between 2015 and 2017.

Analysis of the data revealed no significant difference in average herbivorous fish abundance between sites ($f_{2,33}$=0.03, p=0.967) (Figure 21, Table C41, Table C42). Mean herbivorous fish abundance at site 1 was recorded at 18.75 individuals per 100m^2. At site 2 and 3 average herbivorous fish abundances were recorded at 20.5 and 20 individuals per 100m^2, respectively.

Average urchin abundance significantly differed between sites (Figure 21, Table C41, Table C43). Site 1 exhibited an average of 83.08 urchins per 100m^2, which was significantly greater than the mean urchin abundances exhibited at site 2 (t_{22}=2.65, p=<0.015) and site 3 (t_{22}=2.16, p=<0.042), which displayed averages of 52.35 and 59 individuals per 100m^2, respectively. There was no significant difference between site 2 and site 3 (t_{22}=-0.71, p=<0.486).

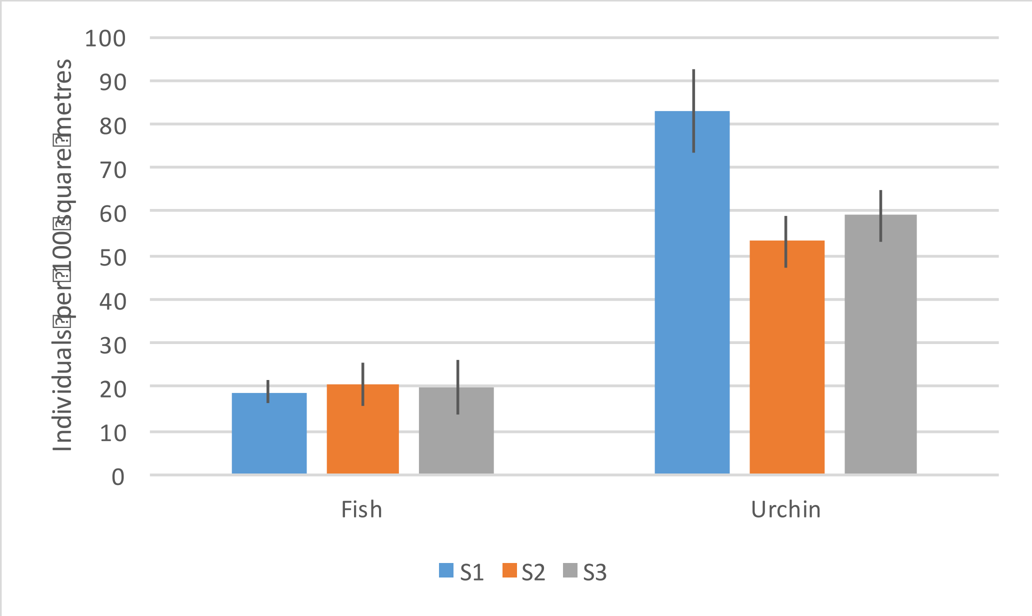


Figure 21: Mean (± SE) herbivore abundance for fish and urchins per 100m^2, between sites (S1, S2, S3), during 2017.

3.6 Species Richness

There was a significant increase in total (combined fish and invertebrates) average species richness between 2015 and 2017 monitoring years, despite invertebrate richness declining (Figure 22, Table C44, Table C45). The analysis revealed a significant increase from an average of 9.54 species (from the MCC species monitoring list) per 100m^2 during 2015 to 15.72 species per 100m^2 in 2017 (t_{62}=-8.27, p=<0.001). Fish species richness significantly increased from an average of 5.14 species per 100m^2 during 2015 to 12.92 species per 100m^2 in 2017 (t_{62}=-11,5, p=<0.001), while Invertebrate species richness significantly declined from an average of 4.39 species per 100m^2 during 2015 to 2.81 species per 100m^2 in 2017 (t_{62}=5.83, p=<0.001) (Figure 23, Table C46, Table C47).

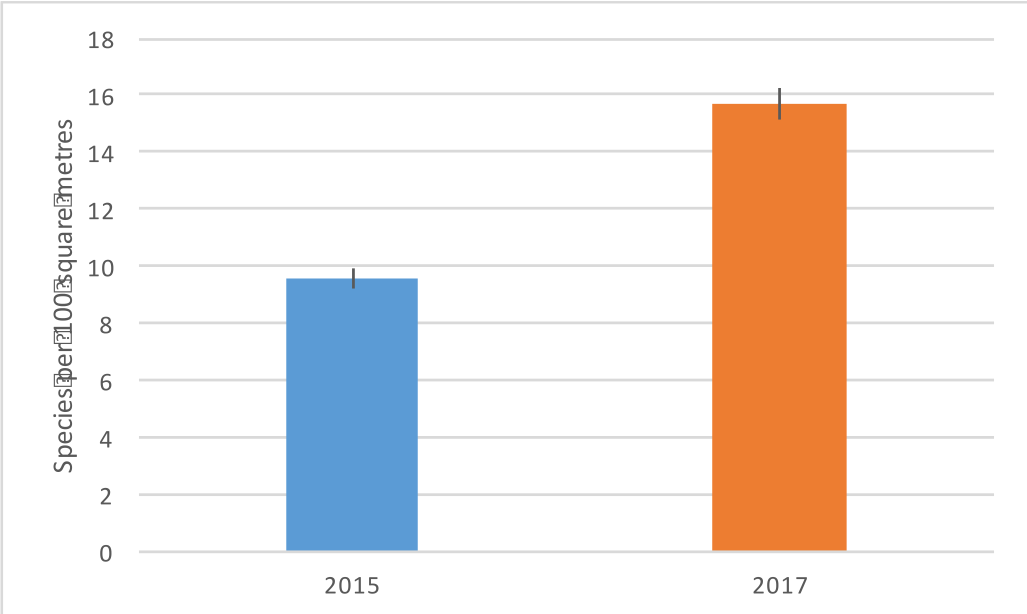


Figure 22: Total mean (± SE) species richness per $100m^2$, from 2015 to 2017.

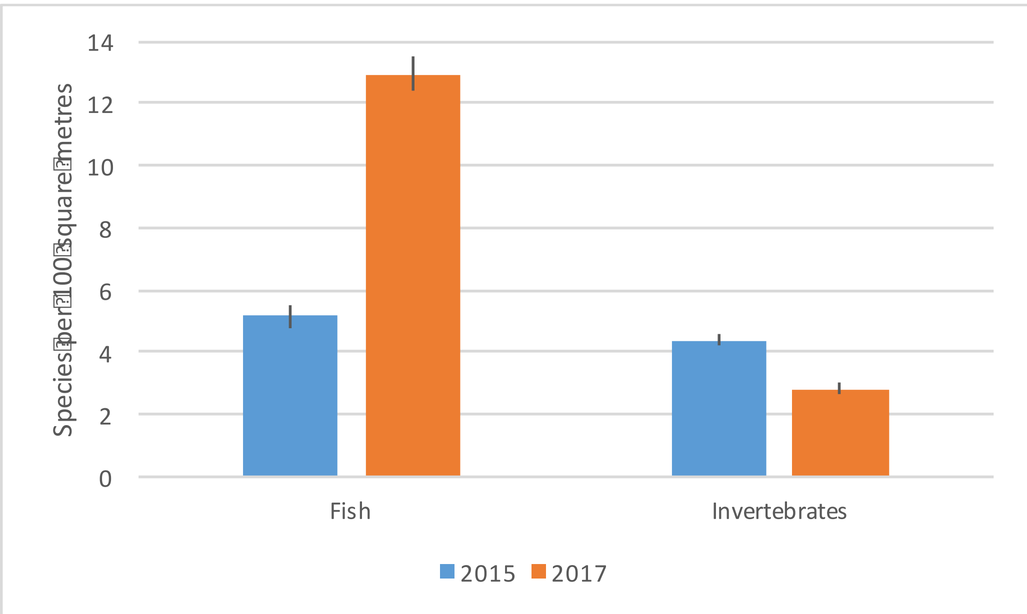


Figure 23: Mean (± SE) fish and invertebrate species richness per $100m^2$, from 2015 to 2017.

There was no significant difference in species richness (combined fish and invertebrates) between sites in 2017 ($f_{2,33}$=0.11, p=0.9) (Figure 24, Table C48, Table C49). Site 1 displayed an average of 6 species per $100m^2$, while site 2 and site 3 exhibited averages of 16.83 and 16.33 species per $100m^2$, respectively.

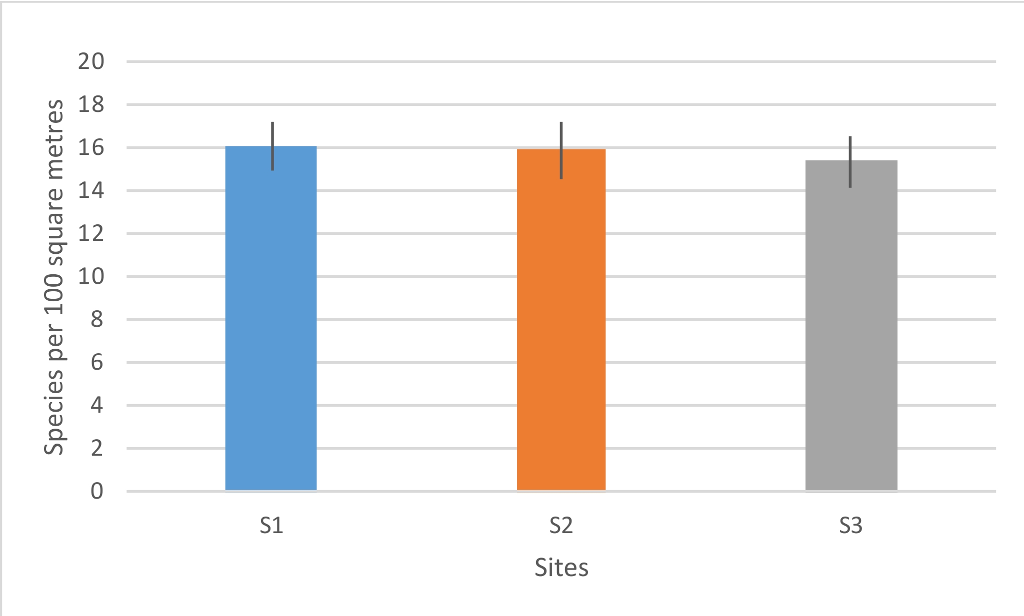


Figure 24: Mean (± SE) species richness per $100m^2$, between sites (S1, S2, S3), during 2017.

4. Discussion

The results suggest that the Koh Mak Prang 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 Make Prang 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 increased over time.

4.1 Environmental Conditions

The overall anthropogenic impact at Koh Mak Prang 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 largely been accredited 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 was observed across each of the monitored sites. Damage was primarily caused by divers harvesting reef species and damaging coral structures in the process. MCC staff were able to document instances where fishers had physically removed live corals from the reef and used them as cage weights for their fishing gear (Figure 25). This practice was also observed on other reefs.

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

Coral bleaching was relatively high at site 1, 30.9% of the population exhibited bleaching. The average surface area bleached covered an average of 12.78% of affected corals at the site. However, seasonal bleaching is often observed on coral reefs in the Kep Archipelago and may be a response to elevations in sea surface temperature or degraded water qualities (Vega *et al*., 2014; Brown and Dunne, 2016). The severity and scale of coral bleaching is only expected to increase in frequency and severity under climate change (Van Hooidonk *et al*., 2017). Disease presence was relatively low with 3% of the coral population showing disease symptoms. In the Caribbean, 80% of reefs display a disease prevalence that affects less than 10% of the population (Ruiz-Morenol *et al*., 2012). Coral disease can develop as a result of the eutrophication of water, which may increasingly become more of an issue over time in the Kep Archipelago (Vega *et al*., 2014).

4.2 Substrate

The overall substrate compositions at Koh Mak Prang were favourable indicating that the system has been resilient to past disturbances. Hard, reef-building corals dominated the substrate in most areas, however, reef condition varied significantly between sites. Hard corals covered an average of 33.7% of the benthos on the reef suggesting that key ecosystem functions have largely been maintained despite ongoing water quality issues and threats from IUU fishers. Coral species diversity also appeared to be low across sites. Nutrient indicator algae prevalence was low, suggesting that ecosystem herbivory is being maintained, which is often considered a critical component of coral reef resilience (Pratchett *et. al*, 2014; Nash *et. al*, 2016).

Site 1 and site 2 both displayed higher amounts of hard coral cover at 39.4% and 44.2%, compared to site 3, which displayed an average cover of only 17.5%. In comparison, average coral cover on the Great Barrier Reef, which is an UNESCO – 'World Heritage Site', is estimated at only 13.8%, and in the past Cambodian reefs have been described as exhibiting average coral covers between 4.1% and 72.1% (Chou *et al*., 2002; De'ath *et al*., 2012). Regardless, it is important to consider that sponge cover at site 3 exceeded the average cover of hard coral cover, at 32.9%. Soft coral cover was also relatively high at 15.8%. This may suggest that site 3 has degraded or is experiencing perturbation, as sponges have been known to colonise areas of coral reef following a disturbance that results in loss of hard corals (Norström *et al*., 2009; Bell *et al*., 2013). Site 3 may transition further into a sponge dominated state unless resilience can be maintained at. Furthermore, connectivity between reefs will likely play an important role in the resilience, and buffering, of site 3 (Graham *et al*., 2011). Species abundances and diversity at site 3, however, do not reflect that of a system more degraded than sites 1 and 2 at this stage. And other substrates that were monitored during 2017 did not significantly differ between the sites.

4.3 Fish

Combined total fish abundance increased from an average of 40.07 individuals per 100m^2 in 2015 to 84.22 individuals per 100m^2 in 2017. 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 38 species recorded, including 24 identified as being new to the reef system, from a total of 86 listed on MCC's species monitoring list. Total butterflyfish, total snapper, total grouper, total wrasse and fusilier abundances increased between years. The larger snapper and grouper species 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. A study conducted on a reef in the Philippines noted that the butterflyfish population declined following an ecosystem disturbance that caused a decline in hard branching corals (Russ and Leahy, 2017). The observed increase in abundance of butterflyfish may be attributed to their food source, as hard coral cover remained relatively healthy around the Island. Further, wrasse and fusilier abundances likely increased due to the prevalence of hard corals and 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 Mak Prang reef during 2017.

4.4 Invertebrates

Total invertebrate abundance decreased between monitoring years. However, large populations of *Diadema* sea urchin, synaptic sea cucumbers and boring bivalves boosted invertebrate numbers during both years.

The combined total invertebrate abundance significantly decreased from a total of 126.14 individuals per 100m^2 in 2015 to 93.89 individuals per 100m^2 in 2017. Interestingly, invertebrate species compositions differed substantially between monitoring years too, with 9 out of the 16 species recorded in 2015, not observed during 2017 surveys. Furthermore, only 4 species out of the 11 recorded during 2017 had not been observed during 2015. 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 might also have the potential to affect invertebrate distributions. For example, Netchy *et al.* (2017) found that 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% encountered only once during sampling (Plaisance *et al*., 2011).

The *Diadema* sea urchin and christmas tree worm both significantly increased between years, while other species observed during both monitoring years remained unchanged or were present in numbers too low to perform any statistical analysis on. 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 positively correlated with sedimentation rates. The *Diadema* sea urchin likely experienced 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). Synaptic sea cucumbers were also present in large numbers and therefore not monitored in 2017. Despite increases in the abundance of the *Diadema* sea urchin and the addition of boring bivalves in 2017 surveys, differences in total invertebrate abundance may have been different with the exclusion of synaptic sea cucumbers during both years of monitoring.

4.5 Functional Groups

While the Koh Mak Prang reef exhibited increases in total fish abundance, herbivorous fish abundance remained unchanged between years while herbivorous urchin abundance increased. There was an average abundance of 20.5 herbivorous fish per 100m^2 during 2015 and 19.75 per 100m^2 in 2017. 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 functional group plays a particular role in the maintenance of substrate and control of algal growth on a reef system (Green & 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). Average urchin abundance was recorded at 47.43 urchins per 100m^2 during 2015 and 65.11 per 100m^2 in 2017. This was mainly due of an increase in the *Diadema* sea urchin. The lower number of herbivorous fish relative to urchins 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 & 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 Mak Prang 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. Urchins were recorded in greater abundances than herbivorous fish during both years. 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 (Nash *et al.*, 2016). All sites displayed high urchin abundances, with site 1 (considered the healthiest site) displaying the greatest abundance. Going forward, urchins may play an important role in determining whether or not site 3 recovers to a state that is once again dominated by hard corals. Spongivores will likely also play an important role at site 3. The unregulated harvesting of the *Diadema* sea urchin, of which there has been a recent increase 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 9.54 fish and invertebrate species per 100m^2 in 2015 to 15.72 species per 100m^2 in 2017. Increases in total species richness were due to an increase of fish species to the Koh Mak Prang reef, as invertebrate species richness actually declined over time. Fish species richness significantly increased from an average of 5.14 species per 100m^2 during 2015 to 12.92 per 100m^2 in 2017, while invertebrate species richness significantly declined from an average of 4.39 species per 100m^2 to 2.81 per 100m^2. Invertebrate harvesting may have contributed to losses of invertebrate diversity. Total species diversity (fish and invertebrates) between sites was similar during 2017, despite differing amounts of hard coral cover between them. 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). Additionally, climatic variables that control primary productivity, and the geomorphic context of a reef environment have also been found as important determinants of diversity on coral reefs (Yeager *et al*., 2017). Favourable benthic assemblages and the structural complexity of habitat have likely played an important role in increasing fish diversity, 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. Because sampling methodologies differed between years, sample sizes differed, which affected the type of statistical analysis that could be used to analyse the data. While the paired t-test was the tool most suited for analysing data collected between years, two-sample t-tests were used in their place, as these tests (in the Microsoft Excel package) allowed for the comparison of two different data sets that varied in size.

Other implications caused by differing methodologies between years also existed. While fish monitoring was likely to be relatively unaffected by these, substrate and invertebrate surveys may have unintentionally incorporated some sampling bias. This is because, during 2015, substrate surveys were undertaken around the entire perimeter of Koh Mak Prang and included some areas that were not coral reef. This may help to explain the presence of flower and pencil urchins and chocolate drop starfish during 2015, which are often found in areas covered in seagrass. Furthermore, invertebrate abundances and species richness may have been underestimated during both years 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 included the synaptic sea cucumber, which was recorded in higher numbers than any other invertebrate species/group. The species was removed from 2017 surveys, which likely effected the total invertebrate abundance between years, despite the inclusion of Boring Bivalves. Furthermore, during 2015 surveys, some invertebrate taxa, outside of the reef boundaries may have been included. Going forward, the focus will be on coral reef habitat only and the survey 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 Mak Prang system and in some places the reef is now beginning to show signs of recovery, following protection from illegal fishing. It is important that functional groups and ecosystem processes are provided with increased protection. Site 3 should be closely monitored in order to understand if the area will recover from sponge dominance. With low numbers of herbivorous fish recorded 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 the management of the Kep Archipelago provides the necessary foundations for the Koh Mak Prang system to recover. 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 Mak Prang, Koh Angkrong 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: Substrate types monitored

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

2015	**2017**
Eight Banded Butterflyfish	Eight Banded Butterflyfish
Long-Beaked Coral Fish	Long-Beaked Coral Fish
Other Butterflyfish (i.e. Ocellated Butterflyfish)	Ocellated Butterflyfish
Golden Rabbitfish	Golden Rabbitfish
Java Rabbitfish	Virgate Rabitfish
Sergeant Fish sp.	Java Rabbitfish
Checkered Snapper	Dusky Rabbitfish
Other Snapper	Sergeant Fish sp.
Fusilier	Spanish Flag Snapper
Blue-Lined Grouper	Black-Spot Snapper
Honeycomb Grouper	Brown stripes Snapper
Checkerboard Wrasse	One-Spot Snapper
Squirrelfish / Soldierfish	Other Snapper
Cardinalfish	Unknown Snapper
	Monogram Monocle
Goby	Bream
Blenny	Bridled Monocle Bream
	Whitecheek Monocle
Goatfish	Bream
Filefish	Emperor
Moray eel	Jacks
	Mullet
	Obtuse Barracuda
	Fusilier
	Orange-Spotted Grouper
	Blue-Lined Grouper
	Honeycomb Grouper
	Gold Spotted Sweetlips
	Weedy Surge Wrasse
	Other Wrasse
	Cardinalfish
	Toadfish
	Catfish
	Boxfish

	Filefish
	Pufferfish
	Carpet Blenny Eel
	Scad
	Pipefish
	Shark Sucker

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

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

2015	**2017**
Feather Duster Worm	Feather Duster Worm
Christmas Tree Worm	Christmas Tree Worm
Flatworm	Anemone Shrimp
True Crab	True Crab
Murex	Cowrie
Drupella	Top Shell
Top Shell	Boring Bivalves
Nudibranch	Cuttlefish
Other Gastropods	Cushion Star
Cuttlefish	*Diadema* Sea Urchin
Chocolate Drop Starfish	Collector Urchin
Cushion Star	
Flower Urchin	
Diadema Sea Urchin	
Pencil Urchin	
Synaptic Sea Cucumber	

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
Ocellated Butterflyfish	Lizardfish / Sandperch
Unknown Butterflyfish	Goby
Dusky Rabbitfish	Blenny
Unknown Rabbitfish	Goatfish
Scatfish	Moray eel
Spanish Flag Snapper	
Black-Spot Snapper	
Brown stripes Snapper	
One-Spot Snapper	
Unknown Snapper	
Monogram Monocle Bream	
Whitecheek Monocle Bream	
Other Bream	

Unknown Bream	
Bream Total	
Golden Trevally	
Big Eye Trevally	
Other Trevally	
Jacks	
Mullet	
Obtuse Barracuda	
Orange-Spotted Grouper	
Unknown Grouper	
Gold Spotted Sweetlips	
Cleaner Wrasse	
Weedy Surge Wrasse	
Other Wrasse	
Unknown Wrasse	
Toadfish	
Scorpionfish	
Catfish	
Needlefish	
Boxfish	
Seahorse	
Carpet Blenny Eel	
Scad	
Whiptail	
Gurnard	
Pipefish	
Shark Sucker	
Razorfish	

Table B7: Invertebrate species/groups added and removed for the 2017 monitoring year include:

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

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	Site 1	Site 2	Site 3
Coral damage: boat/anchor	0	0	0
Coral damage: dynamite	0	0	0
Coral damage: other	2	1	1
Coral predation	0	0	0
Trash: fish nets	0	0	0
Trash: general	0	0	0

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	0	0
Coral damage: dynamite	0	0
Coral damage: other	1	1
Coral predation	NA 2015	0
Trash: fish nets	0	0
Trash: general	0	0

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	0.31	0.44	0.13
		2	0.01	0.03	0.01
		3	0.00	0.00	0.00
	Disease	1	0.04	0.07	0.02
		2	0.05	0.09	0.03
		3	0.00	0.00	0.00
Mean % of individual	Bleaching	1	0.13	0.17	0.05
		2	0.02	0.04	0.01
		3	0.00	0.00	0.00
	Disease	1	0.07	0.11	0.03
		2	0.07	0.15	0.04
		3	0.01	0.03	0.01

Table C4: Two-sample t-test outputs for average percent of bleached corals 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	0.30916667	0.01	Mean	0.30916667	0.00083333	Mean	0.01	0.00083333
Variance	0.19119015	0.00081818	Variance	0.19119015	8.3333E-06	Variance	0.00081818	8.3333E-06
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	2.36506884		t Stat	2.44269294		t Stat	1.1045278	
P(T<=t) two-tail	0.02726342		P(T<=t) two-tail	0.02307002		P(T<=t) two-tail	0.28129857	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Table C5: Two-sample t-test outputs for average percent of bleaching per affected individual corals 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	0.125	0.0175	Mean	0.125	0.00083333	Mean	0.0175	0.00083333
Variance	0.02886364	0.00194773	Variance	0.02886364	8.3333E-06	Variance	0.00194773	8.3333E-06
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	2.12150289		t Stat	2.53138055		t Stat	1.30541386	
P(T<=t) two-tail	0.04538301		P(T<=t) two-tail	0.01901511		P(T<=t) two-tail	0.20523989	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

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

Anova: Single Factor						
Disease % population						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0.5	0.04166667	0.0044697		
S2	12	0.57	0.0475	0.00871136		
S3	12	0.01	0.00083333	8.3333E-06		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01551667	2	0.00775833	1.76467547	0.18701986	3.28491765
Within Groups	0.14508333	33	0.00439646			
Total	0.1606	35				

Anova: Single Factor						
Disease % individual						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0.8	0.06666667	0.01151515		
S2	12	0.78	0.065	0.02115455		
S3	12	0.1	0.00833333	0.00083333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02646667	2	0.01323333	1.18496744	0.31843054	3.28491765
Within Groups	0.36853333	33	0.01116768			
Total	0.395	35				

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

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

Scope	Impact	Year	Mean	SD	SE
Mean % of population	Bleaching	2015	0.00	0.04	0.01
		2017	0.11	0.29	0.05
	Disease	2015	0.00	NA 2015	
		2017	0.03	0.07	0.01
Mean % of individual	Bleaching	2015	0.00	0.03	0.00
		2017	0.05	0.11	0.02
	Disease	2015	0.00	NA 2015	
		2017	0.05	0.11	0.02

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: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
% population			**% individual**		
	2015	*2017*		*2015*	*2017*
Mean	0.0075	0.10666667	Mean	0.00714286	0.04777778
Variance	0.00142685	0.08145143	Variance	0.00068783	0.01280063
Observations	28	36	Observations	28	36
df	62		df	62	
t Stat	-1.8230712		t Stat	-1.8589432	
P(T<=t) two-tail	0.0731145		P(T<=t) two-tail	0.0677827	
t Critical two-tail	1.99897152		t Critical two-tail	1.99897152	

Substrate

2017 Total

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

Substrate	2017		
	Mean	SD	SE
HC	0.34	0.14	0.08
SC	0.07	0.08	0.05
RKC	0.00	0.00	0.00
NIA	0.00	0.00	0.00
SP	0.23	0.11	0.06
RC	0.08	0.02	0.01
RB	0.10	0.01	0.01
SD	0.09	0.03	0.02
SI	0.01	0.01	0.00
ZO	0.02	0.01	0.01
OT	0.06	0.03	0.02
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	0.39	0.12	0.03
2	0.44	0.23	0.07
3	0.18	0.10	0.03

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	0.39375	0.44166667	Mean	0.39375	0.175	Mean	0.44166667	0.175
Variance	0.01433239	0.05185606	Variance	0.01433239	0.00920455	Variance	0.05185606	0.00920455
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	-0.6451878		t Stat	4.93928129		t Stat	3.73834002	
P(T<=t) two-tail	0.52547755		P(T<=t) two-tail	6.1035E-05		P(T<=t) two-tail	0.00113928	
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	0.05	0.05	0.01
2	0.01	0.01	0.00
3	0.16	0.10	0.03

Table C14: Two-sample t-test outputs for average percent soft 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	0.04583333	0.00833333	Mean	0.04583333	0.15833333	Mean	0.00833333	0.15833333
Variance	0.00214015	0.00015152	Variance	0.00214015	0.00912879	Variance	0.00015152	0.00912879
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	2.7136021		t Stat	-3.6711457		t Stat	-5.3938741	
P(T<=t) two-tail	0.0126851		P(T<=t) two-tail	0.0013404		P(T<=t) two-tail	2.0411E-05	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

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

Site	Mean	SD	SE
1	0.24	0.09	0.03
2	0.11	0.07	0.02
3	0.23	0.11	0.06

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*		*S1*	*S3*		*S2*	*S3*
Mean	0.23541667	0.11458333	Mean	0.23541667	0.32916667	Mean	0.11458333	0.32916667
Variance	0.00789299	0.00539299	Variance	0.00789299	0.00964015	Variance	0.00539299	0.00964015
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	3.63145363		t Stat	-2.4526298		t Stat	-6.0626389	
P(T<=t) two-tail	0.00147523		P(T<=t) two-tail	0.02257866		P(T<=t) two-tail	4.212E-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	0.06	0.05	0.02
2	0.09	0.09	0.03
3	0.10	0.03	0.01

Table C18: ANOVA t-test output for average percent rock coral cover between sites, 2017.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0.775	0.06458333	0.002892992		
S2	12	1.075	0.08958333	0.007892992		
S3	12	1.2	0.1	0.000909091		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00795139	2	0.00397569	1.019838057	0.37173944	3.28491765
Within Groups	0.12864583	33	0.00389836			
Total	0.13659722	35				

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

Site	Mean	SD	SE
1	0.09	0.06	0.02
2	0.11	0.09	0.03
3	0.11	0.07	0.02

Table C20: ANOVA output for average percent coral rubble cover between sites, 2017.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	1.075	0.08958333	0.00346117		
S2	12	1.275	0.10625	0.00808239		
S3	12	1.275	0.10625	0.00512784		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00222222	2	0.00111111	0.1999432	0.8197618	3.284917651
Within Groups	0.18338542	33	0.00555713			
Total	0.18560764	35				

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

Site	Mean	SD	SE
1	0.06	0.07	0.02
2	0.12	0.08	0.02
3	0.08	0.07	0.02

Table C22: ANOVA output for average percent sand cover between sites, 2017.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0.7	0.05833333	0.00481061		
S2	12	1.45	0.12083333	0.00577652		
S3	12	0.95	0.07916667	0.00464015		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02430556	2	0.01215278	2.39427861	0.106914075	3.28491765
Within Groups	0.1675	33	0.00507576			
Total	0.19180556	35				

Table C23: Average percent zoanthid cover between sites, during 2017.

Site	Mean	SD	SE
1	0.03	0.02	0.01
2	0.03	0.04	0.01
3	0.01	0.01	0.00

Table C24: ANOVA output for average percent zoanthid cover between sites, 2017.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0.325	0.02708333	0.00062027		
S2	12	0.4	0.03333333	0.00151515		
S3	12	0.075	0.00625	0.00012784		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00482639	2	0.00241319	3.19874477	0.05373397	3.284917651
Within Groups	0.02489583	33	0.00075442			
Total	0.02972222	35				

Table C25: Average percent "other" cover between sites, during 2017.

Site	Mean	SD	SE
1	0.07	0.06	0.02
2	0.08	0.09	0.02
3	0.02	0.03	0.01

Table C26: ANOVA output for average percent "other" cover between sites, 2017.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	0.875	0.07291667	0.00368845		
S2	12	0.95	0.07916667	0.00748106		
S3	12	0.25	0.02083333	0.00066288		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02461806	2	0.01230903	3.12084834	0.0573643	3.28491765
Within Groups	0.13015625	33	0.00394413			
Total	0.15477431	35				

Fish

Species Totals

Table C27: Total mean fish species/group abundances per 100m^2 during 2015 and 2017.

Fish	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Butterflyfish total	3.82	3.24	0.61	6.11	5.02	0.84
Rabbitfish total	10.64	24.06	4.55	5.50	11.73	1.95
Sergeant Fish sp.	9.86	10.11	1.91	14.25	7.40	1.80
Snapper total	0.82	1.06	0.20	14.56	10.78	0.30
Bream total	NA 2015			1.86	1.79	0.16
Emperor	0.00	0.00	0.00	3.19	5.00	0.08
Jacks	NA 2015			0.31	0.98	2.30
Mullet	NA 2015			0.08	0.50	0.29
Obtus Barracuda	NA 2015			4.44	13.81	2.30
Fusilier	2.00	10.58	2.00	13.47	20.61	3.43
Grouper total	0.07	0.26	0.05	0.56	0.81	0.13
Gold Spotted Sweetlips	0.00	0.00	0.00	0.31	1.06	0.18
Wrasse total	0.96	1.32	0.25	4.58	2.52	0.42
Squirrelfish / Soldierfish	1.86	9.83	1.86	0.00	0.00	0.00
Cardinalfish	9.57	18.76	3.55	13.08	24.52	4.09
Goby	0.11	0.31	0.06	NA 2017		
Blenny	0.04	0.19	0.04	NA 2017		
Toadfish	NA 2015			0.03	0.17	0.03
Catfish	NA 2015			0.03	0.17	0.03
Boxfish	NA 2015			0.03	0.17	0.03
Goatfish	0.18	0.55	0.10	NA 2017		
Filefish	0.04	0.19	0.04	0.03	0.17	0.03
Pufferfish	0.00	0.00	0.00	0.06	0.23	0.04
Moray Eel	0.00	0.00	0.00	NA 2017		
Carpet Blenny Eel	NA 2015			0.92	0.81	0.13
Scad	NA 2015			0.19	0.89	0.15
Pipefish	NA 2015			0.06	0.33	0.06
Shark Sucker	NA 2015			0.03	0.17	0.03

Table C28: Two-sample t-test outputs for total average abundances of fish species/groups between 2015 and 2017 monitoring years.

t-Test: Two-Sample Assuming Equal Variances		
Butterflyfish		
	2015	*2017*
Mean	3.82142857	6.11111111
Variance	10.5224868	25.2444444
Observations	28	36
df	62	
t Stat	-2.0938844	
P(T<=t) two-tail	0.0403658	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Rabbitfish		
	2015	*2017*
Mean	10.6428571	5.5
Variance	578.904762	137.571429
Observations	28	36
df	62	
t Stat	1.12393831	
P(T<=t) two-tail	0.26537214	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Sergeant fish		
	2015	2017
Mean	9.85714286	14.25
Variance	102.126984	54.7071429
Observations	28	36
df	62	
t Stat	-2.0082764	
P(T<=t) two-tail	0.04897529	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Snapper		
	2015	*2017*
Mean	0.82142857	14.5555556
Variance	1.11507937	116.196825
Observations	28	36
df	62	
t Stat	-6.7050869	
P(T<=t) two-tail	6.9468E-09	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Fuisiler		
	2015	*2017*
Mean	2	13.4722222
Variance	112	424.656349
Observations	28	36
df	62	
t Stat	-2.6804966	
P(T<=t) two-tail	0.00940511	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Grouper		
	2015	*2017*
Mean	0.07142857	0.55555556
Variance	0.06878307	0.65396825
Observations	28	36
df	62	
t Stat	-3.0411835	
P(T<=t) two-tail	0.00345092	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Wrasse		
	2015	*2017*
Mean	0.96428571	4.58333333
Variance	1.73941799	6.36428571
Observations	28	36
df	62	
t Stat	-6.8861812	
P(T<=t) two-tail	3.383E-09	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Cardinalfish		
	2015	*2017*
Mean	9.57142857	13.0833333
Variance	351.883598	601.164286
Observations	28	36
df	62	
t Stat	-0.6279613	
P(T<=t) two-tail	0.53233556	
t Critical two-tail	1.99897152	

Combined Total Abundance

Table C29: Total mean fish abundance per 100m^2 between 2015 and 2017.

Group	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Fish	40.07	39	7.37	84.22	54.68	8.78

Table C30: Two-sample t-test output for total mean fish abundance between 2015 and 2017.

t-Test: Two-Sample Assuming Equal Variances		
Fish		
	2015	*2017*
Mean	40.0714286	84.2222222
Variance	1520.73545	2775.43492
Observations	28	36
df	62	
t Stat	-3.7112524	
P(T<=t) two-tail	0.00044341	
t Critical two-tail	1.99897152	

Table C31: Total mean fish abundance per 100m^2 between sites, 2017.

Site	Fish		
	Mean	SD	SE
S1	113.42	70.8	20.4
S2	71.08	34.43	9.94
S3	68.17	35.07	10.12

Table C32: ANOVA output for total mean fish abundance between sites, 2017.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	1361	113.416667	5016.26515		
S2	12	853	71.0833333	1185.17424		
S3	12	818	68.1666667	1230.15152		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15392.7222	2	7696.36111	3.10688298	0.0580422	3.28491765
Within Groups	81747.5	33	2477.19697			
Total	97140.2222	35				

Invertebrates

Species Totals

Table C33: 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	1.04	2.59	0.49	0.28	0.97	0.16
Christmas Tree Worm	1.64	5.27	1.00	12.14	16.15	2.69
Flatworm	0.04	0.19	0.04	0.00	0.00	0.00
Anemone Shrimp	0.00	0.00	0.00	0.17	1.00	0.17
True Crab	0.57	0.74	0.14	0.28	0.57	0.09
Murex	0.11	0.31	0.06	NA 2017		
Cowrie	0.00	0.00	0.00	0.06	0.23	0.04
Drupella	1.21	1.99	0.38	0.00	0.00	0.00
Top Shell	0.14	0.76	0.14	0.03	0.17	0.03
Nudibranch	0.07	0.26	0.05	0.00	0.00	0.00
Volute Snail	NA 2015			0.00	0.00	0.00
Other Gastropods	2.32	2.29	0.43	0.00	0.00	0.00
Boring Bivalves	NA 2015			15.75	23.12	3.85
Cuttlefish	0.04	0.19	0.04	0.03	0.17	0.03
Chocolate Drop Starfish	0.14	0.59	0.11	0.00	0.00	0.00
Cushion Star	0.11	0.42	0.08	0.06	0.23	0.04
Flower Urchin	0.11	0.42	0.08	0.00	0.00	0.00
Diadema Sea Urchin	46.07	39.42	7.45	63.53	27.59	4.60
Pencil Urchin	1.25	6.04	1.14	0.00	0.00	0.00
Collector Urchin	0.00	0.00	0.00	1.58	8.83	1.47
Synaptic Se Cucumber	71.07	74.96	14.17	NA 2017		

Table C34: Paired t-test outputs for total average abundances of invertebrate species/groups that were present during the 2015 and 2017 monitoring years.

t-Test: Two-Sample Assuming Equal Variances		
FeatherDuster Worm		
	2015	*2017*
Mean	1.03571429	0.27777778
Variance	6.70238095	0.94920635
Observations	28	36
df	62	
t Stat	1.61835165	
P(T<=t) two-tail	0.11066341	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
Christmas Tree Worm		
	2015	*2017*
Mean	1.64285714	12.1388889
Variance	27.7936508	260.80873
Observations	28	36
df	62	
t Stat	-3.2999747	
P(T<=t) two-tail	0.00160585	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
True Crab		
	2015	*2017*
Mean	0.57142857	0.27777778
Variance	0.55026455	0.32063492
Observations	28	36
df	62	
t Stat	1.79687885	
P(T<=t) two-tail	0.07722591	
t Critical two-tail	1.99897152	

t-Test: Two-Sample Assuming Equal Variances		
***Diadema* Sea Urchin**		
	2015	*2017*
Mean	46.0714286	63.5277778
Variance	1553.62434	761.342063
Observations	28	36
df	62	
t Stat	-2.0827822	
P(T<=t) two-tail	0.04140251	
t Critical two-tail	1.99897152	

Combined Total Abundance

Table C35: Total mean invertebrate abundance per 100m^2 between 2015 and 2017.

Group	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Invertebrates	126	77.98	14.74	93.89	42.21	7.03

Table C36: Two-sample t-test output for total mean invertebrate abundance between 2015 and 2017.

t-Test: Two-Sample Assuming Equal Variances		
Invertebrates		
	2015	*2017*
Mean	126.142857	93.8888889
Variance	6080.71958	1781.53016
Observations	28	36
df	62	
t Stat	2.11764694	
P(T<=t) two-tail	0.0382224	
t Critical two-tail	1.99897152	

Table C37: Total mean invertebrate abundance per 100m^2 between sites, 2017.

Site	Invertebrates		
	Mean	SD	SE
S1	94.16	35.25	10.18
S2	116.58	47	13.57
S3	70.92	32.84	9.48

Table C38: 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	94.1666667	116.583333	Mean	94.1666667	70.9166667	Mean	116.583333	70.9166667
Variance	1242.69697	2209.17424	Variance	1242.69697	1078.99242	Variance	2209.17424	1078.99242
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	-1.3217045		t Stat	1.67151979		t Stat	2.75875431	
P(T<=t) two-tail	0.1998467		P(T<=t) two-tail	0.10878431		P(T<=t) two-tail	0.01145765	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Herbivore Abundance

Totals Between Years

Table C39: Average herbivorous fish and urchin abundances per 100m[2], between 2015 and 2017.

Herbivore Group	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Fish	20.5	25.99	4.91	19.75	16.52	2.75
Urchin	47.43	39.86	7.53	65.11	27.76	4.63

Table C40: Two-sample t-test outputs for total average herbivorous fish and urchin abundances between 2015 and 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
Herbivorous fish			**Urchins**		
	2015	*2017*		*2015*	*2017*
Mean	20.5	19.75	Mean	47.4285714	65.1111111
Variance	675.37037	272.935714	Variance	1588.84656	770.673016
Observations	28	36	Observations	28	36
df	62		df	62	
t Stat	0.14059527		t Stat	-2.0903928	
P(T<=t) two-tail	0.88864548		P(T<=t) two-tail	0.04068939	
t Critical two-tail	1.99897152		t Critical two-tail	1.99897152	

Table C41: Average herbivorous fish and urchin abundances per 100m[2], between sites, in 2017.

Site	Fish			Urchin		
	Mean	SD	SE	Mean	SD	SE
S1	18.75	9.06	2.61	83.08	33.39	9.64
S2	20.50	17.67	5.10	53.25	20.20	5.83
S3	20.00	21.74	6.28	59.00	19.56	5.65

Table C42: ANOVA output for average herbivorous fish abundances between sites, 2017.

Anova: Single Factor						
Herbivorous Fish						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	225	18.75	82.0227273		
S2	12	246	20.5	312.090909		
S3	12	240	20	472.545455		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.5	2	9.75	0.0337503	0.96684622	3.28491765
Within Groups	9533.25	33	288.886364			
Total	9552.75	35				

Table C43: 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		
S1 S2			**S1 S3**			**S2 S3**		
	S1	*S2*		*S1*	*S3*		*S2*	*S3*
Mean	83.0833333	20.5	Mean	83.0833333	59	Mean	53.25	59
Variance	1114.81061	312.090909	Variance	1114.81061	382.545455	Variance	408.204545	382.545455
Observations	12	12	Observations	12	12	Observations	12	12
df	22		df	22		df	22	
t Stat	5.73921262		t Stat	2.15597975		t Stat	-0.7083353	
P(T<=t) two-tail	8.9842E-06		P(T<=t) two-tail	0.04228444		P(T<=t) two-tail	0.48617519	
t Critical two-tail	2.07387307		t Critical two-tail	2.07387307		t Critical two-tail	2.07387307	

Species Richness

Total Between Years

Table C44: Total average species richness per 100m^2, between 2015 and 2017.

Year	Mean	SD	SE
2015	9.54	2.05	0.37
2017	15.72	3.52	0.57

Table C45: Two-sample t-test output for species richness between 2015 and 2017.

t-Test: Two-Sample Assuming Equal Variances		
	2015	*2017*
Mean	9.53571429	15.7222222
Variance	4.18386243	12.3777778
Observations	28	36
df	62	
t Stat	-8.2720131	
P(T<=t) two-tail	1.3364E-11	
t Critical two-tail	1.99897152	

Fish and Invertebrates Between Years

Table C46: Average species richness per 100m^2, for fish and invertebrates, during 2015 and 2017.

Group	2015			2017		
	Mean	SD	SE	Mean	SD	SE
Fish	5.14	1.94	0.37	12.92	3.14	0.53
Invertebrates	4.39	1.03	0.19	2.81	1.12	0.19

Table C47: Two-sample t-test outputs for average fish and invertebrate species richness per 100m^2, between 2015 and 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
Fish			**Invertebrates**		
	2015	*2017*		*2015*	*2017*
Mean	5.14285714	12.9166667	Mean	4.39285714	2.80555556
Variance	3.75661376	9.85	Variance	1.06216931	1.2468254
Observations	28	36	Observations	28	36
df	62		df	62	
t Stat	-11.500472		t Stat	5.83275845	
P(T<=t) two-tail	5.1114E-17		P(T<=t) two-tail	2.1304E-07	
t Critical two-tail	1.99897152		t Critical two-tail	1.99897152	

Total Between Sites

Table C48: Total average species richness per 100m^2, between sites, 2017.

Site	Total		
	Mean	SD	SE
S1	16.00	3.64	1.05
S2	15.83	3.64	1.05
S3	15.33	3.55	1.02

Table C49: ANOVA output for total average species richness per 100m^2, between sites, 20

Anova: Single Factor						
Total Species						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S1	12	192	16	13.2727273		
S2	12	190	15.8333333	13.2424242		
S3	12	184	15.3333333	12.6060606		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.88888889	2	1.44444444	0.11076685	0.89547882	3.28491765
Within Groups	430.333333	33	13.040404			
Total	433.222222	35				