KOH SEH ENVIRONEMENTAL ASSESSMENT

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

IN PARTNERSHIP WITH THE FISHERIES ADMINISTRATION

2017

Executive Summary

Important tropical ecosystems in the Kep Archipelago are highly threatened by illegal fishing pressures, which destroy significant habitat and overexploit marine species. In early 2014, the Kep Provincial Government commissioned Marine Conservation Cambodia (MCC) for the development and undertaking of a coral reef monitoring programme. The research and monitoring would occur within a geographical triangle encompassing the islands of Koh Seh, Koh Mak Prang and Koh Angkrong. 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 Seh. Five 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. Two sites on the East of the Island were compared to two sites on the West. Total comparisons between years included an additional site on the East side of the Island, known as the pier, where many fish would congregate. Monitoring methods for the pier during 2016 differed from those in 2017 resulting in fewer samples overall.

Hard coral cover differed significantly between the East and West sides of Koh Seh. The West exhibited a relatively healthy coral cover compared to the East, which displayed was dominated by zoanthids in large areas. Overall, coral diversity appeared low. More than 25% of the corals were found to have bleached during 2016 and disease prevalence was elevated under the environmental conditions at this time. There were no significant differences in fish abundance and diversity between years.

However, fish abundance and diversity were significantly greater on the East side of the Island compared to the West. Between years, herbivorous fish abundance significantly increased while at the same time herbivorous urchin abundance significantly decreased. Herbivorous fish appeared in significantly greater numbers on the East side of the Island where urchins were few. Contrarily, urchin abundance was significantly greater in the West, where herbivorous fish abundance remained low over time. Invertebrate abundance/observations significantly declined between years, as did invertebrate diversity. There were no significant differences in invertebrate abundances and diversity between the East and West sides of the Island.

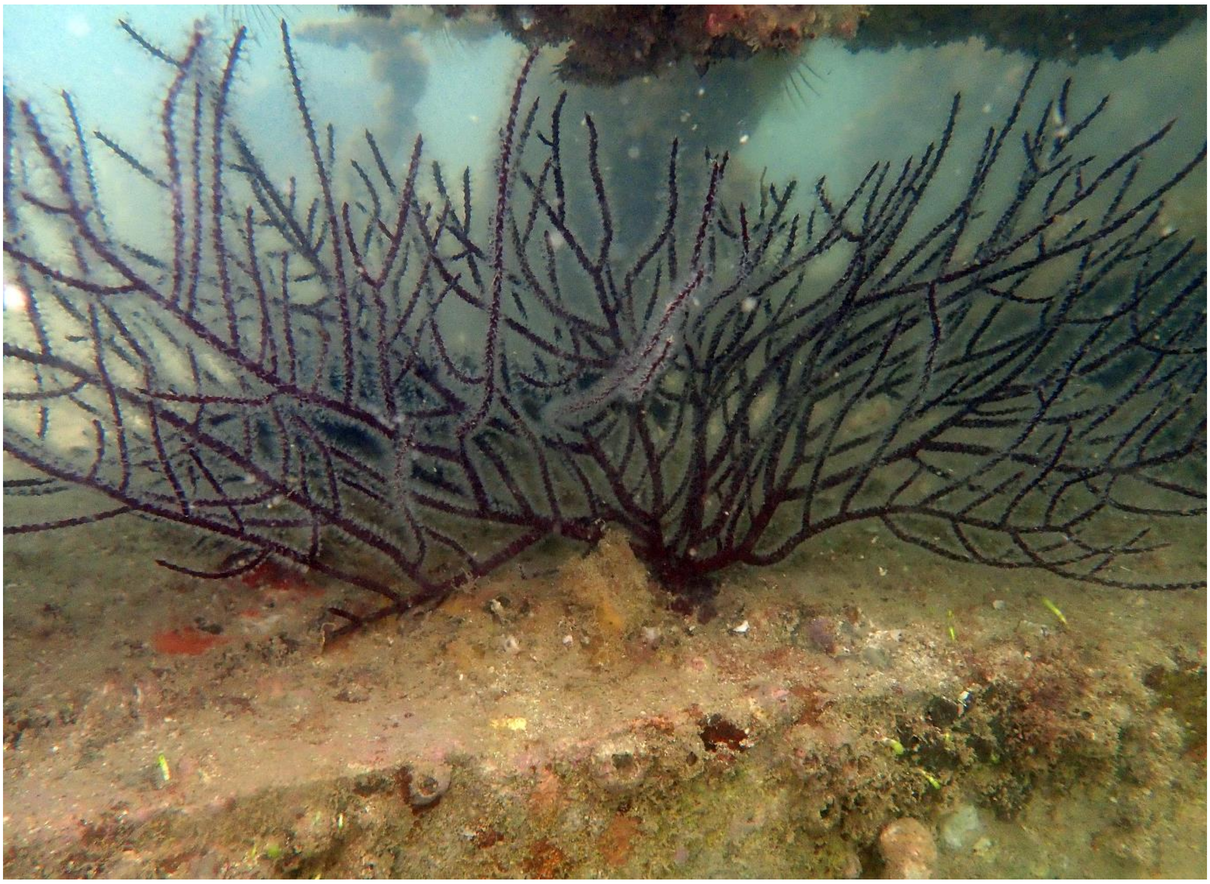
Following a reduction in illegal fishing pressures, the Koh Seh reef appears to be displaying some signs of fish recovery, despite poor habitat quality on the East side of the Island. In the absence of some major herbivore functional groups, ecosystem herbivory had been largely attributed to urchin grazing, particularly by the *Diadema* sea urchin. A paucity of herbivores fish has resulted in the *Diadema* sea urchin becoming highly abundant on reefs in the Kep Archipelago. However, if herbivorous fish populations are able to recover, the population sizes of the *Diadema* sea urchin may decrease, as has been observed on the east side of Koh Seh.

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 Seh, Koh Angkrong and Koh Mak Prang 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:

H.E. Ken Satha	Governor, Kep Province
H.E. Eng Cheasan	Director General of the Fisheries Administration
H.E Som Piseth	Deputy Governor, Kep Province
H.E Tep Yuthy	Deputy Governor, Kep Province
Mr. Ouk Vibol	Director of Fisheries Conservation Division
Mr. Sar Sorin	Director of Kampot Fisheries Cantonment
Mr. Kuch Virak	Director of Kep Fisheries Cantonment
Mr. Paul Ferber	Managing Director and Project Founder, MCC



Research Team

Survey Data Collection Team:

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

Contributors to the Report:

Maps by: Tom Collombat & Delphine Duplain

TABLE OF CONTENTS

1. Introduction

This report is the 2017 environmental assessment of the Koh Seh 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 Seh 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.

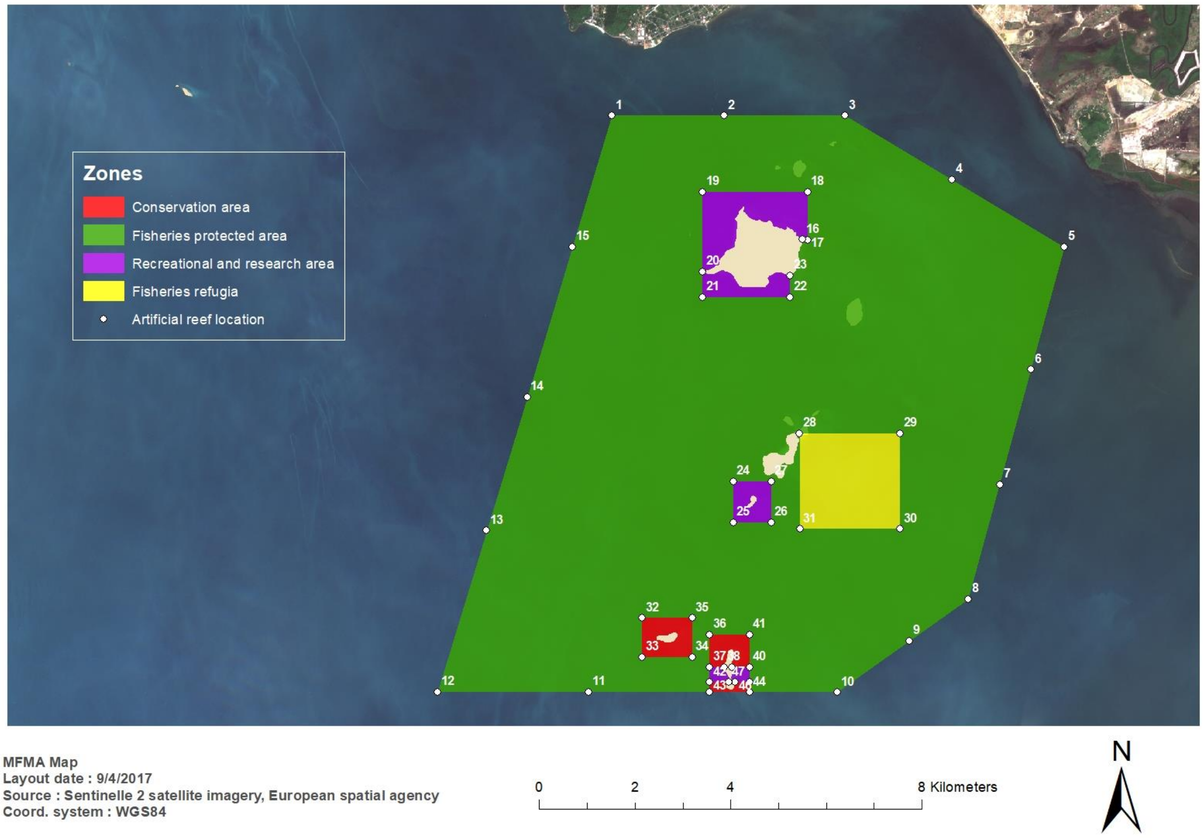


Figure 1: Location of the Marine Fisheries Management Area in the Kep Archipelago, relative to mainland Cambodia.

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 Seh is located within Cambodia's Kep Archipelago, at, or about, GPS coordinates 10°23'20.9"N 104°19'27.6"E. Koh Seh is home to the headquarters of MCC. Furthermore, there is a marine police outpost stationed at Koh Seh. Local fishers have also established make-shift homes that they frequent while fishing the area. A fringing coral reef surrounds the island, which is fished by commercial and subsistence fishers. The methods used are set net, line, cage and air tube fishing/diving. Set nets, line fishing, and cages are all legal fishing methods, so long as protected or endangered species are not caught and no damage to coral reef incurs. Air tube diving, on the other hand, is illegal. It is a method primarily utilised in order to target rare, aesthetically pleasing natural structures and animals found among coral reefs.

Since the introduction of regulatory patrols in 2015, MCC have reduced illegal fishing on coral reefs by an estimated 50-70%. However, illegal fishers continue to fish adjacent seagrass meadows intensely, particularly during the night to more easily evade authorities. The North-Eastern reef, which is immediately adjacent MCC's base, is controlled by MCC and no fishing on this section of reef has been allowed, and fisherman are asked to leave if fishing is attempted. Crab fishers do, however, lay their cages in areas beyond the eastern reef. At times, illegal trawlers have deliberately trawled through seagrass meadows and bivalve beds directly in front of MCC's base.

Monitoring data has been collected from the Koh Seh coral reef system on two occasions, over two years, during the years of 2016 and 2017.

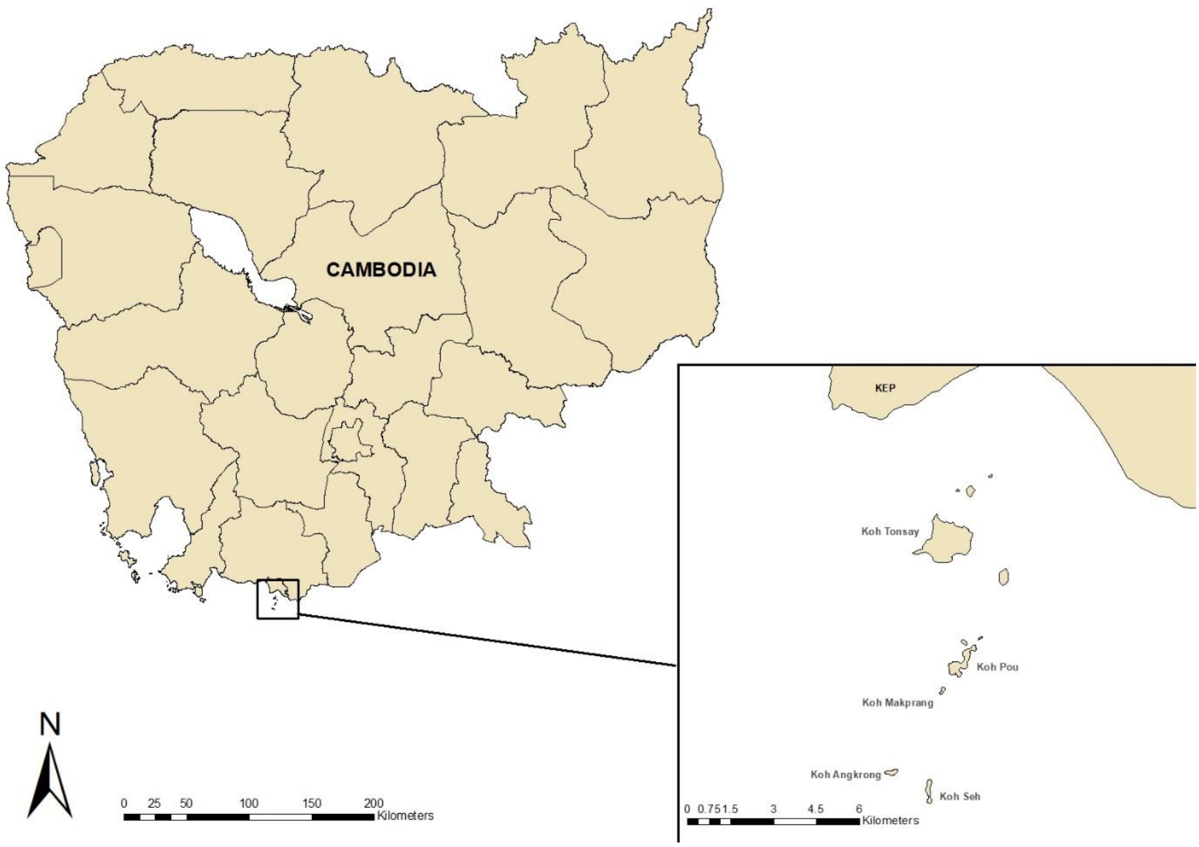


Figure 2: Location of Koh Seh in the Kep Archipelago, relative to mainland Cambodia.

The 2017 coral reef assessment for Koh Seh was conducted between April and December. However, all but two surveys had been completed by October. Preliminary dive investigations were undertaken during 2016 in order to determine the suitability of potential survey sites. Four sites were selected that were perceived to be representative of the state of coral reef surrounding Koh Seh (Figure 3). These were based on varying levels of anthropogenic impact, and environmental and topographical variation. Two sites were selected on the eastern side of the Island, which included a section of reef directly in front of the MCC base, and the other, a section of reef south of the pier, which extended a bay area where local fisherman moor their boats. MCC's boats are docked on the pier, which is located in between the two eastern sites. The other two sites are located on the western side of the Island. One site is on a north western section of reef while the other is on a the south western section. The western side of the Island has less boat activity crossing the reef, but is subject to more invertebrate fishing, diving/collecting, and a greater density of crab fishers, who's boats traverse the waters between Koh Seh and Koh Angkrong. A fifth site, running the length of the pier (East side) was also selected. Fish are fed from the pier each morning by MCC staff and congregate there in relatively large numbers. Only fish surveys (no substrate or invertebrate surveys) have been conducted at the pier site as there is no coral reef directly below the pier structure.

Table 1: Site conditions.

Side of Koh Seh	Site Name	Site Description
East	**North Eastern Reef (NER)**	In front of MCC base; coral cover is relatively poor in some areas; least amount of fishing pressure; some boating activity off reef edge; MCC boats pass by this section of reef most of the time when departing from the Island.
	South Eastern Reef (SER)	Extends south of pier towards Police Station and sandy bay area where fisherman's boats are moored; boating activity immediately south of the site is relatively high; coral cover is relatively poor in areas; some fishing activity, predominantly set net and line fishing.
	pier	Extends approximately 50m from the shore; MCC boats dock towards the seaward end; fish are fed food scraps each morning at the seaward end; substrate is largely silt; there is no fishing from the pier.
West	**North Western Reef (NWR)**	Opposite side of the Island to MCC's base; coral cover is relatively high; most boating activity from crab fisherman off the reef edge; Some fishing activity, predominantly, invertebrate collection, squid fishing, line fishing; some tourism.
	South Western Reef (SWR)	Opposite side of the Island to the South Eastern Reef site, however remaining in close proximity to where the local fisherman group and the Police Station; coral cover is relatively high; most boating activity from crab fisherman off the reef edge; fisherman more boats in bay immediately south of the reef site; some fishing activity, predominantly, invertebrate collection, squid fishing, line fishing, set net, and some illegal diving.

The sites were selected on each side of the Island for the purpose of comparative analysis between East and West reefs. 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 Seh system to near collapse. The western sections of reef were considered to be in better condition compared to the eastern sections. The GPS locations of all sites were recorded during 2016 and 2017 and will continue to be used for future surveys.

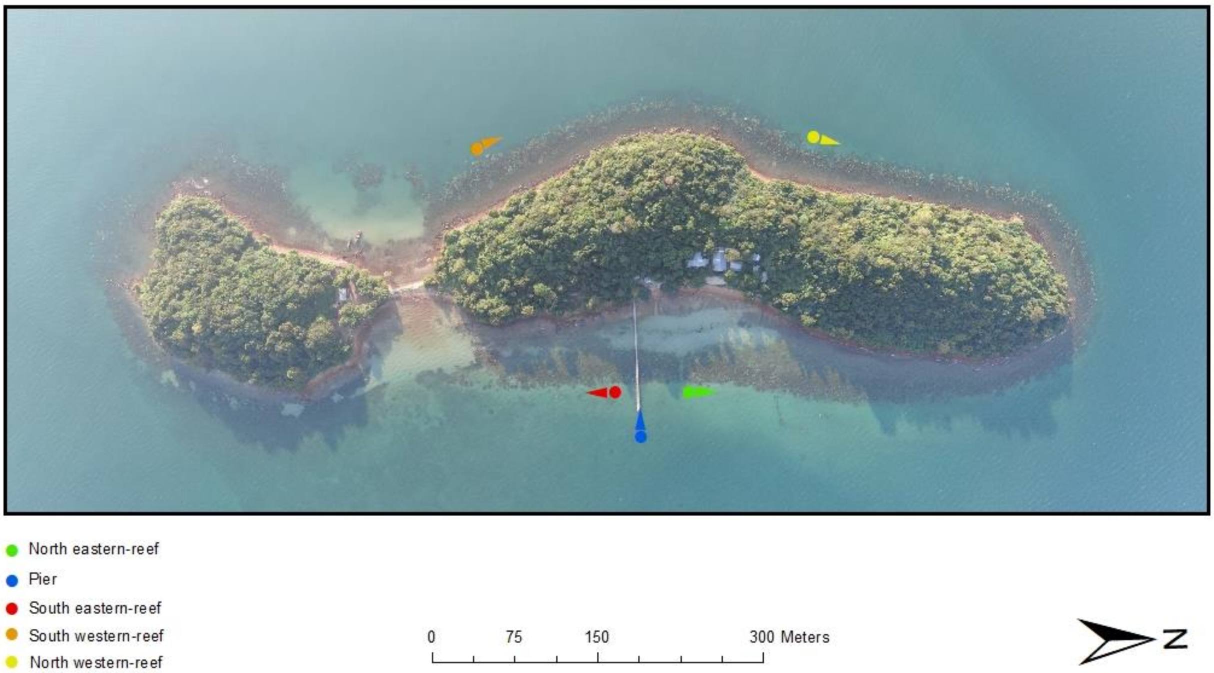


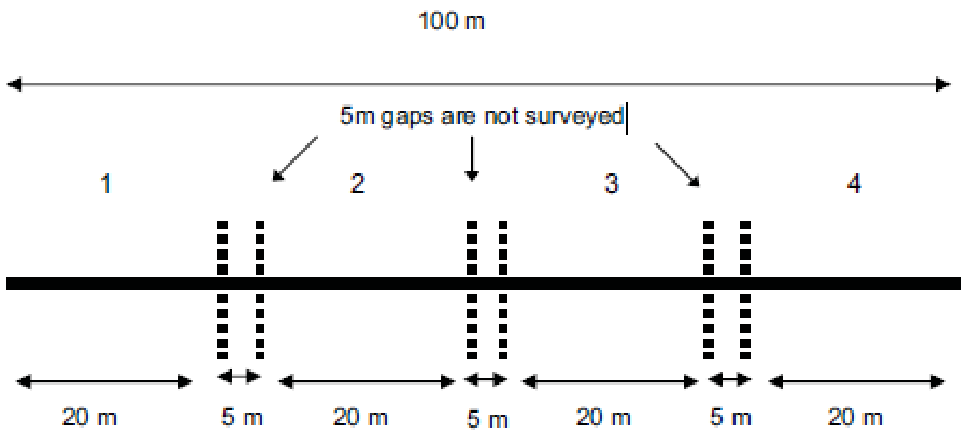
Figure 3: Survey site locations

2.2 Data Collection

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

2.2.1 Coral Reef Surveys

Five sites were established during the 2016 year. At each of the sites, except the pier, 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 four sites. The same method was used at the pair during 2017, where four surveys, over a distance of 20m were replicated three times along the length of the pair that crosses the reef. (Please refer to section 2.2.3 below for the 2016 pier data collection methodology).



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.

2.2.3 Pier Data Collection 2016: Methods and Limitations

The methods utilised for surveying the pier during 2016 surveys differed from the 2017 methods. Only three 20m surveys were completed under the length of the pier during 2016 (tides may have been a factor in this decision) and only one replicate was performed. Because of this, 2016 included a total of 52 fish surveys, whereas, the

2017 monitoring year included 60 fish surveys. Invertebrate, substrate and impact assessment monitoring included a total of 48 surveys during both years (as the pier was excluded for these categories).

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 one substrate type. 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 (fish = 60 survey segments; invertebrates = 48 survey segments). Each survey segment is equal to 100m^2. Substrate cover was also calculated by averaging 48 survey segments. This provided a total mean percent cover for each substrate type. All species on MCC's monitoring list that were identified as being present have been displayed on each of the figures. Note that some closely related species with similar functional roles have been grouped together and presented as a total value within their respective group. These included species within the butterflyfish, rabbitfish, snapper, bream, grouper, parrotfish, and wrasse groups. Species not listed on the species monitoring list have not been recorded during monitoring. Species/groups that were present during both monitoring years, but only recorded during one of those years have been accounted for by displaying “NA” (not applicable) by the species name on respective figures. The same applies to substrate groups. Abundances of each species/group that are present have been displayed for East and West sides of Koh Seh during 2017 and between 2016 and 2017. When comparing fish data between East and West sides of the Island, only the Four main sites were incorporated into the analysis (NER, SER, NWR, and SWR), with the pier being excluded. However, the pier was included for total comparisons between years.

Herbivorous fish groups included rabbitfish, sergeant fish and batfish as these were considered the only important herbivore groups present during monitoring. Other important herbivorous fish groups, such as parrotfishes, surgeonfish and rudderfish were not observed and have been considered locally extinct. Damselfish are highly abundant on the reef system, however, most species are territorial algal-farmers, with the exception of sergeant fish, and were not monitored by MCC. Herbivorous urchins included the flower urchin, the *Diadema* sea urchin, the pencil urchin and the collector urchin. Please note that the flower and collector urchins are often associated more with seagrass habitat.

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 East and West data.

Percent cover of hard coral, nutrient indicator algae, sponge, rock, coral rubble, sand, zoanthid and ‘other’ substrates were examined between 2016 and 2017 years using paired t-tests. These substrates were also examined between East and West sides of Koh Seh using two-sample t-tests. Other substrate categories were either not, or poorly, represented within the data and no statistical comparisons were therefore investigated for these.

Two-sample t-test methods were used to compare before and after data for fish abundance, combined total fish abundance, herbivorous fish abundance, and fish species richness per 100m^2 between years. Note that paired t-tests were unable to be used due to differences in sample sizes between 2016 and 2017. Fewer surveys were conducted under the pier during 2016 than what were conducted in 2017. Paired t-tests were used to compare differences in invertebrate abundances between years. Only fish and invertebrate species perceived as to be of particular interest (at the discretion of MCC) have been statistically analysed between years. These include important functional species and high value fisheries targets present in sufficient numbers.

Paired t-tests have been used to investigate average invertebrate abundance, combined total invertebrate abundance, urchin abundance and invertebrate species richness per $100m^2$ between years.

Two-sample t-tests were used to examine fish and invertebrate data between East and West sites. This included fish and invertebrate abundances, combined total fish and invertebrate abundances, herbivore abundances, and fish and invertebrate species richness per $100m^2$.

3. Results

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

3.1 Impact Assessment

Coral damage was observed to be low on each side of Koh Seh and between years (Figure 4, Figure 2, Table C1, Table C2). Coral predation was considered to be medium during both years and on the East and West sides of the Island. Trash, which included general trash and fishing gears was low during both years, however, all trash observed during 2017 was on the Western side of the Koh Seh. There was no damage caused by boat/anchor or dynamite recorded during both monitoring years.

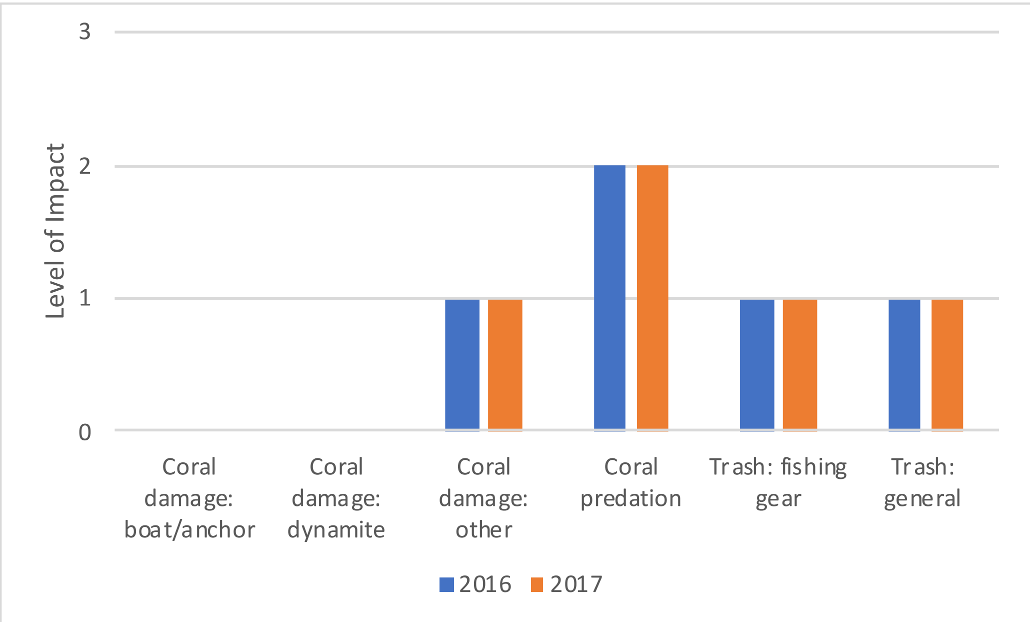


Figure 4: Median level of coral damage, coral predation, and trash during 2015 and 2017. 0 = none, 1 = low, 2 = medium, and 3 = high.

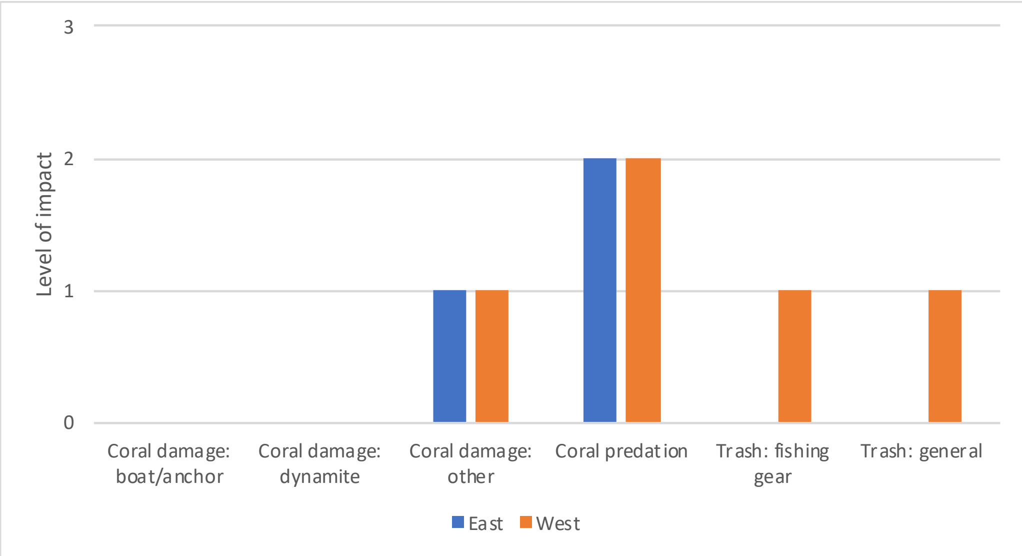


Figure 5: Median level of coral damage, coral predation, and trash at East and West sites during 2017. 0 = none, 1 = low, 2 = medium, and 3 = high.

An average of 28% of the coral population was recorded as having bleached during 2016 surveys. In 2017, an average of 0.6% of the population were found to have bleached (Figure 6, Table C3, Table C4). Furthermore the amount of bleaching on individually affected corals was averaged at 26% during 2016 compared to an average of 2.5% in 2017. There were significantly more bleached corals, as well as a significantly greater amount of bleaching on individually affected corals, during 2016 (t_{47}=6.11, p=<0.001; t_{47}=5.98, p=<0.001). There was also a higher prevalence of coral disease during 2016 (Table C3, Table C5). An average of 7.8% of the coral population was diseased, with individually affected corals exhibiting an average disease cover of 12.4%. Disease prevalence during 2017 was significantly less than in 2016 with an average of 2.5% of the coral population affected (t_{47}=2.74, p=0.009), exhibiting an average disease cover of 4.8% on individually affected corals (t_{47}=2.63, p=0.012).

Between East and West sides of Koh Seh during 2017 coral bleaching and disease prevalence was low (Figure 7, Table C6). There was no significant differences in bleaching between coral populations (t_{46}=-0.45, p=657) and individually affected corals (t_{46}=0.29, p=0.772) on the East and West of Koh Seh (Table C7, Table C8). There was also no significant difference in disease prevalence amongst coral populations (t_{46}=-1.52, p=0.135) and individually affected corals (t_{46}=-0.3, p=0.768) between sides of the Island.

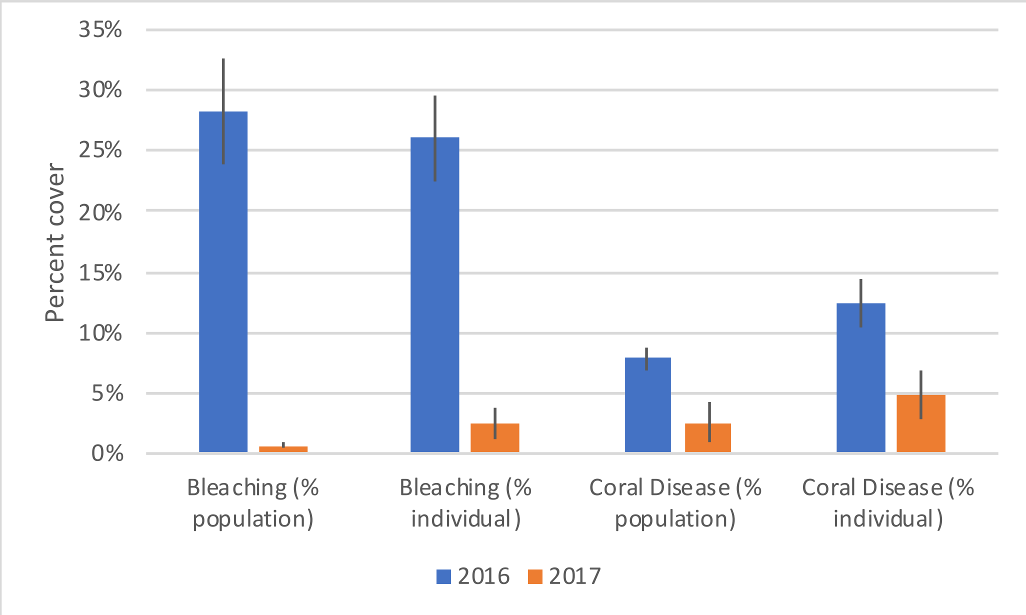


Figure 6: Mean (± SE) percent of bleached and diseased corals within the population and per individual coral cover, between years.

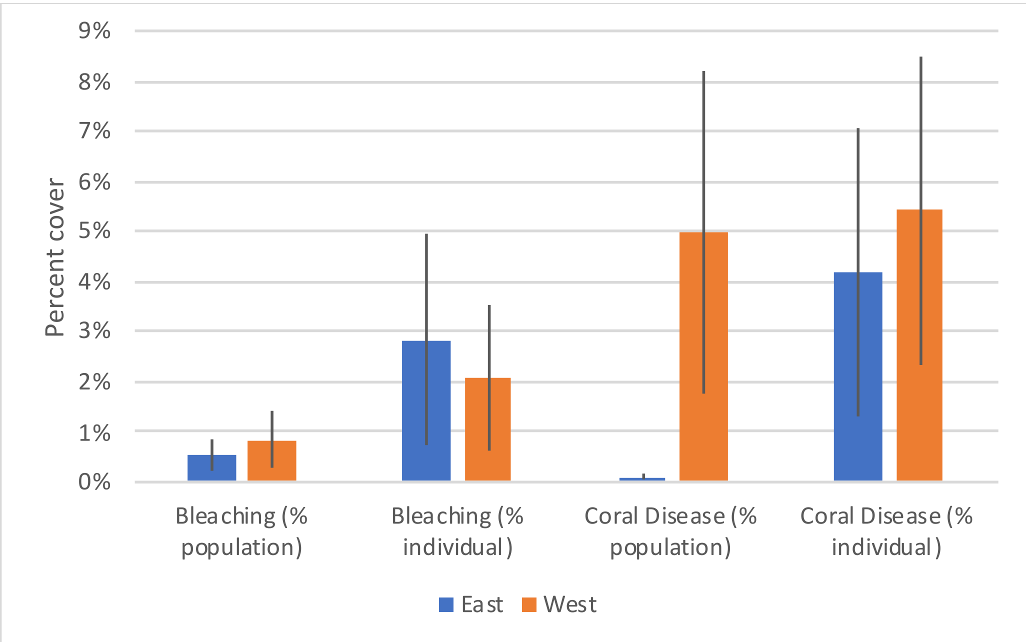


Figure 7: Mean (± SE) percent of bleached and diseased corals within the population and per individual coral cover, between East and West.

3.2 Substrate

Total substrate cover did not vary substantially between years, however, did significantly differ between East and West sides of the Island during 2017 (Figure 8, Figure 9, Table C9, Table C11). Statistical analysis has been performed for hard coral, nutrient indicator algae, sponges, rock, coral rubble, sand, zoanthids, and ‘other’ substrate types (Table C10, Table C12). Some ‘recently killed coral’ and silt substrate types were recorded, however, there was little of these substrates on the reef. Soft coral and seagrass substrates were not recorded during surveys (however seagrasses do not typically grow on coral reefs). Refer to *APPENDIX B* (Table B3) for a complete list of substrates and their acronyms.

Hard Coral

There was no significant difference in Hard coral (HC) cover between years (t_{47}=0.49, p=0.625), with total cover having an average of 42.4% in 2017. However, The East side of Koh Seh displayed relatively low hard coral cover compared to the West. There was an average hard coral cover of 25.1% on the East side of the Island, which was significantly less than coral cover on the West, which displayed an average cover of 59.7% (t_{46}=-9.46, p=>0.001).

Nutrient Indicator Algae

Nutrient indicator algae (NIA) significantly decreased between years. There was an average total cover of 6.4% during 2016 which significantly decreased to an average of 1.5% cover in 2017 (t_{47}=4.28, p=<0.001). There were no significant differences between the East and West sides of Koh Seh for nutrient identifying algae (t_{46}=0.59, p=0.118).

Sponge

Sponge (SP) cover significantly increased between monitoring years. There was an average total sponge cover of 6.7% during 2016, which significantly increased to an average of 9.2% in 2017 (t_{47}=-2.94, p=0.005). There were no significant differences between the East and West sides of Koh Seh for sponges (t_{46}=0.8, p=0.426).

Rock

There was no significant difference in average total rock (RC) cover between years (t_{47}=-0.11, p=0.916) or between the East and West sides of Koh Seh (t_{46}=1.8, p=0.078). Rock cover exhibited an average of 11.7% cover during 2017.

Coral Rubble

Coral rubble (RB) significantly increased between monitoring years and significantly differed between the East and West sides of Koh Seh during 2017. There was an average of 1.7% coral rubble cover during 2016, which significantly increased to an average 3.2% in 2017 (t_{47}=-2.72, p=0.009). Furthermore, the East side of Koh Seh exhibited an average rubble cover of 5.5%, which was significantly greater than the average cover of 0.94% on the West (t_{46}=-2.5.09, p=<0.001).

Sand

Sand (SD) significantly increased between monitoring years and significantly differed between the East and West sides of Koh Seh during 2017. There was an average total of 2.4% sand cover during 2016, which significantly increased to an average of 7.2% in 2017 (t_{47}=-5.11, p=<0.009). During 2017 the East side of Koh Seh exhibited an average cover of 9.8% sand, which was significantly greater than the West, which displayed an average of 4.6% (t_{46}=2.84, p=0.007).

Zoanthid

Total zoanthid (ZO) cover was relatively high during both monitoring years, but did not significantly differ (t_{47}=0.68, p=0.502). There was a total average zoanthid cover of 24% during 2017. Zoanthids were the most dominant substrate on the East, exceeding hard coral cover. The East displayed an average zoanthid cover of 34%, which was significantly greater than the West, which displayed an average zoanthid cover of 14.4% (t_{46}=7.4, p=<0.001).

Other

'Other' (OT) substrate cover significantly declined between years. There was a total average cover of 1.8% other cover during 2016, which significantly decreased to an average of 0.2% cover in 2017 (t_{47}=3.55, p=<0.001). There was no significant difference in other substrate covers between the East and West sides of Koh Seh (t_{46}=-1.55, p=0.128).

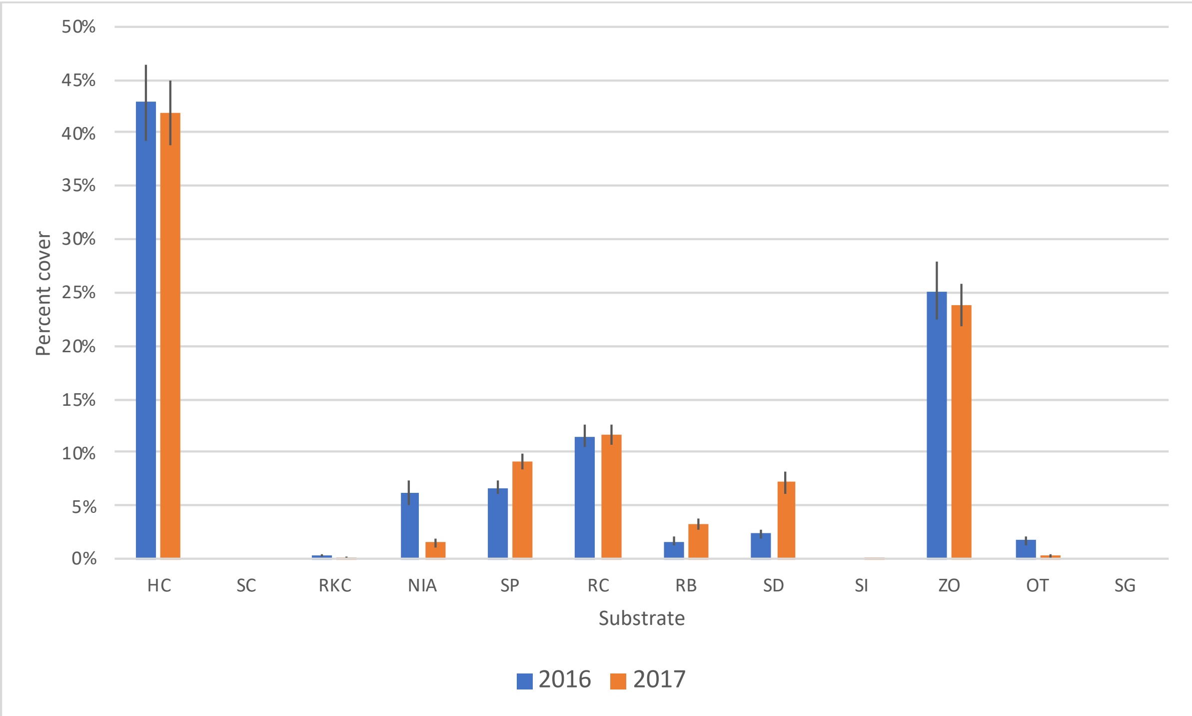


Figure 8: Total mean (± SE) percent cover of substrates during 2016 and 2017.

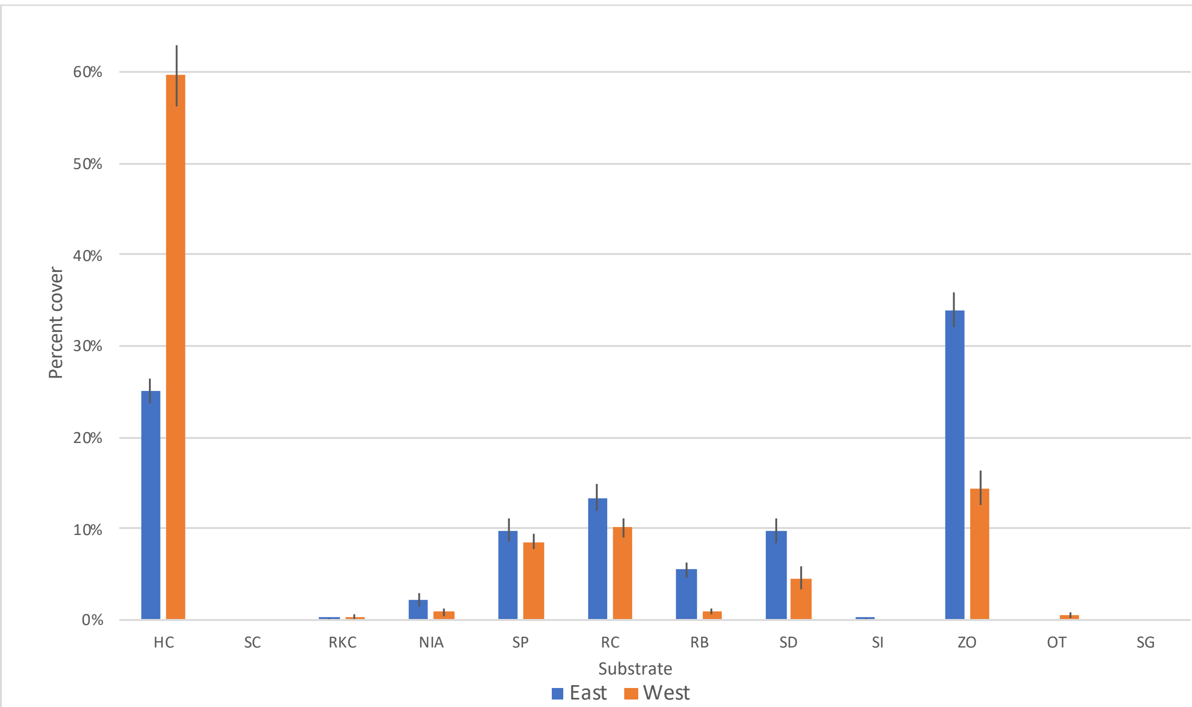


Figure 9: Mean (± SE) percent cover of substrate types between the East and West of Koh Seh, 2017.

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 Seh system exhibited a varying abundances of fish species/groups between monitoring years (Figure 10, Figure 11, Table C13). A total of 49 fish species/groups from the MCC species monitoring list were recorded as being present during 2017. During the 2016 monitoring year 41 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 2016 and 2017 monitoring years). In total, there were 13 fish species/groups that were identified in 2017 that had not been observed during 2016 (Table 2).

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

Longfin Bannerfish
Spadefish
Big Eye Trevally
Great Barracuda
Yellowtail Barracuda
Obtus Barracuda
Peacock Grouper
Square-Tail Grouper
Squirrelfish / Soldierfish
Porcupinefish
Herring Scad
other Scad
Whiptail

No scad species were observed during 2016 surveys, however, scad were observed in relatively larges abundances compared to some of the other species that first arrived at the pier during 2017. There were 7 fish species/groups recorded during 2016 that were not recorded during 2017 (Table 3).

Table 3: Fish species observed during 2016 at Koh Seh that were not observed during 2017.

Unknown Butterflyfish
Other Butterflyfish
Whitestreak Monocle Bream
Other Travelly
Doublebanded Soapfish
Catfish
Boxfish

Species/groups that were statistically compared between years include total butterflyfish, total rabbitfish, sergeant fish, sweeper, scatfish, total snapper, total bream, emperor, jacks, mullet, fusilier, total grouper, total wrasse, cardinalfish, needlefish, filefish, and carpet eel blenny (Table C14).

Sergeant fish, total snapper and emperor mean abundances significantly increased between 2016 and 2017 monitoring years, while sweeper, total wrasse, and carpet eel blenny declined. There were no significant differences in the mean abundances of total butterflyfish, total rabbitfish, scatfish, total bream, jacks, mullet, fusilier, total grouper, cardinalfish, needlefish or filefish.

Sergeant fish significantly increased from an average abundance of 18.59 individuals per $100m^2$ to 38.58 individuals per $100m^2$ (t_{109}=-2.83, p=0.006). Total snapper significantly increased from an average abundance of 7.55 individuals per $100m^2$ to 23.1 individuals per $100m^2$ (t_{109}=-1.99, p=0.049). Emperor significantly increased from an average abundance of 0.41 individuals per $100m^2$ to 1.32 individuals per $100m^2$ (t_{109}=-2.78, p=0.006).

Sweeper significantly decreased from an average abundance of 32.04 individuals per $100m^2$ to 3.97 individuals per $100m^2$ (t_{109}=2.98, p=0.004). Total wrasse significantly decreased from an average abundance of 6.63 individuals per $100m^2$ to 1.6 individuals per $100m^2$ (t_{109}=8.78, p=<0.001). The carpet eel blenny significantly decreased from an average abundance of 0.88 individuals per $100m^2$ to 0.37 individuals per $100m^2$ (t_{109}=3.67, p=<0.001).

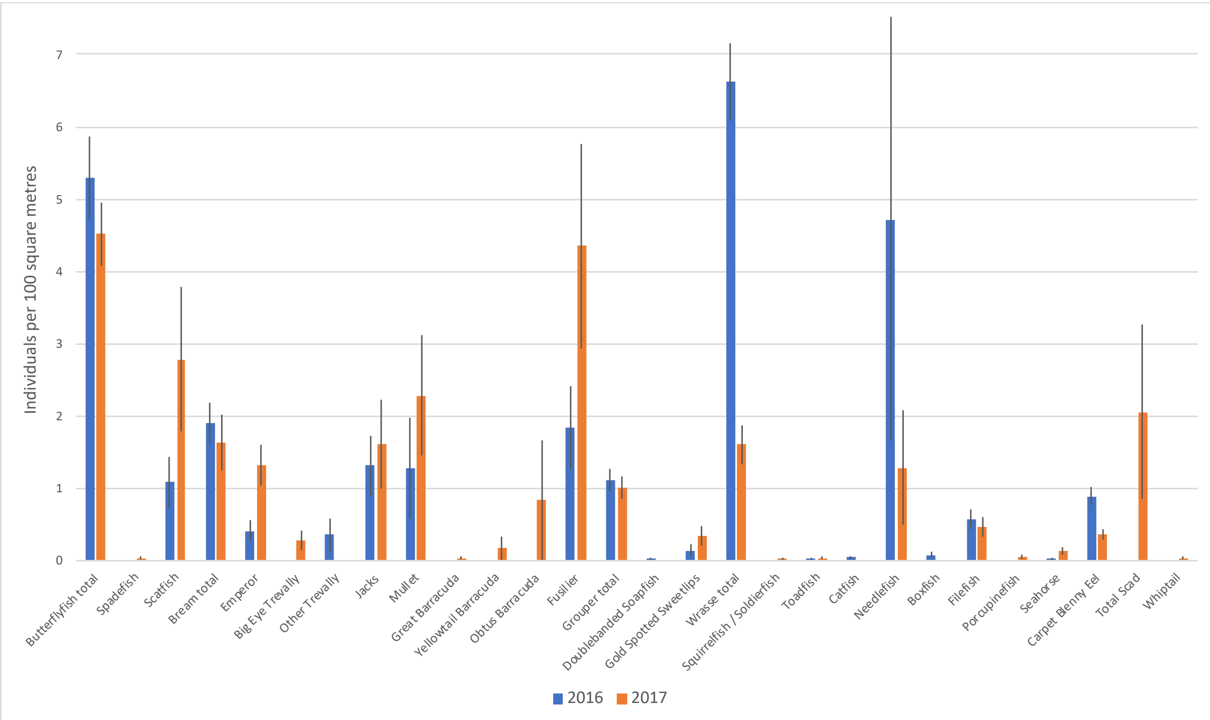


Figure 10: Total mean (± SE) fish species/group abundance per $100m^2$ during 2016 and 2017 (includes pier data).

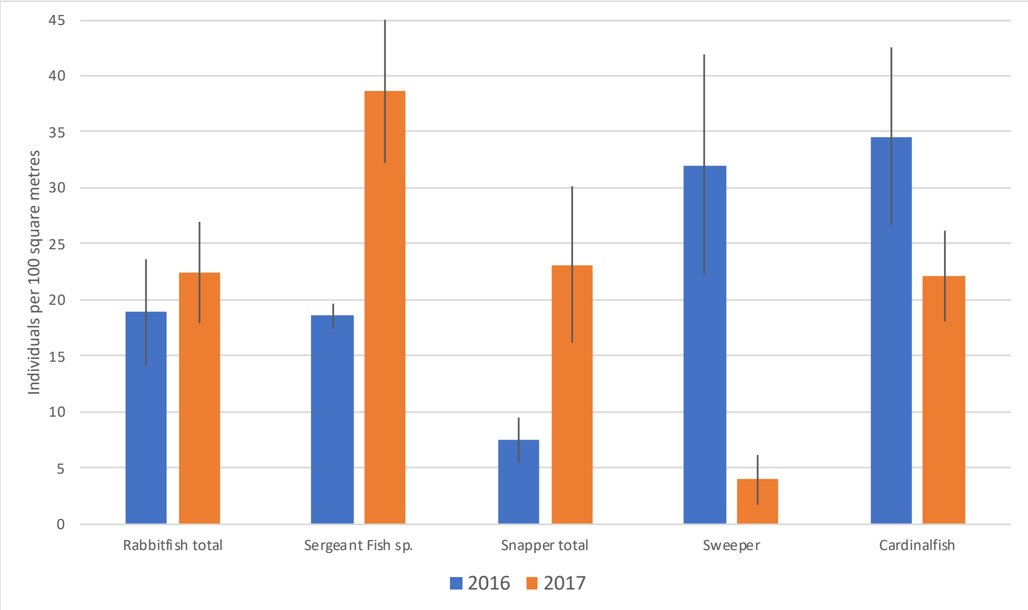


Figure 11: Total mean (±SE) abundances of total rabbitfish, sergeant fish, total snapper, sweeper, and cardinalfish per $100m^2$ during 2016 and 2017 (includes pier data).

3.3.2 Combined Total Abundance

Combined total fish abundance did not significantly differ between years (t_{109}=1.36, p=0.178) (Figure 12, Table C15, Table C16). During 2016 fish abundance was recorded at an average of 139.39 individuals per $100m^2$. In 2017 fish abundance was recorded at an average of 108.63 individuals per $100m^2$. A combined total of 7109 individuals (51 surveys) were recorded during 2016, compared to 6518 individuals (60 surveys) in 2017.

Note that with the exclusion if the pier data average fish abundances did not change considerably and there remained no significant difference in average abundance between the years (t_{47}=1.55, p=0.129) (Table C30).

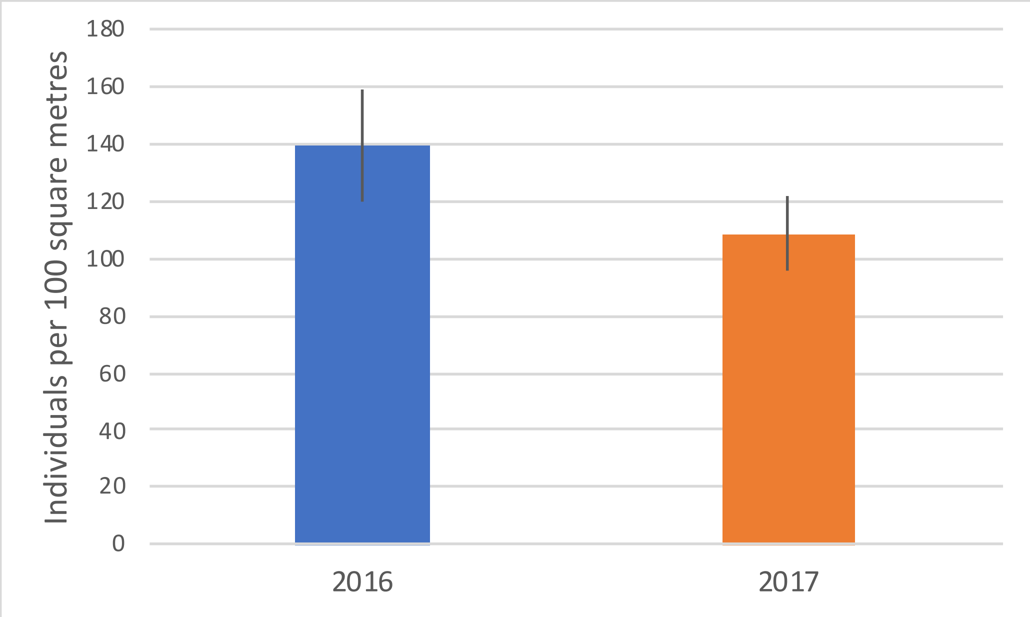


Figure 12: Combined total mean (± SE) number of individuals per 100m², for fish (includes pier data), during 2016 and 2017 monitoring years.

Combined total fish abundance significantly differed between the East and West sides of Koh Seh (Figure 13, Table C17, Table C18). The East exhibited an average fish abundance of 146.95 individuals per $100m^2$ in 2017 (excluding pier data). This was significantly greater than the average fish abundance recorded on the West, where there was an average of 45.75 individuals per $100m^2$ (t_{46}=5.11, p=<0.001). There was a total of 3527 individuals recorded at on the East, compared with 1098 individuals recorded on the West.

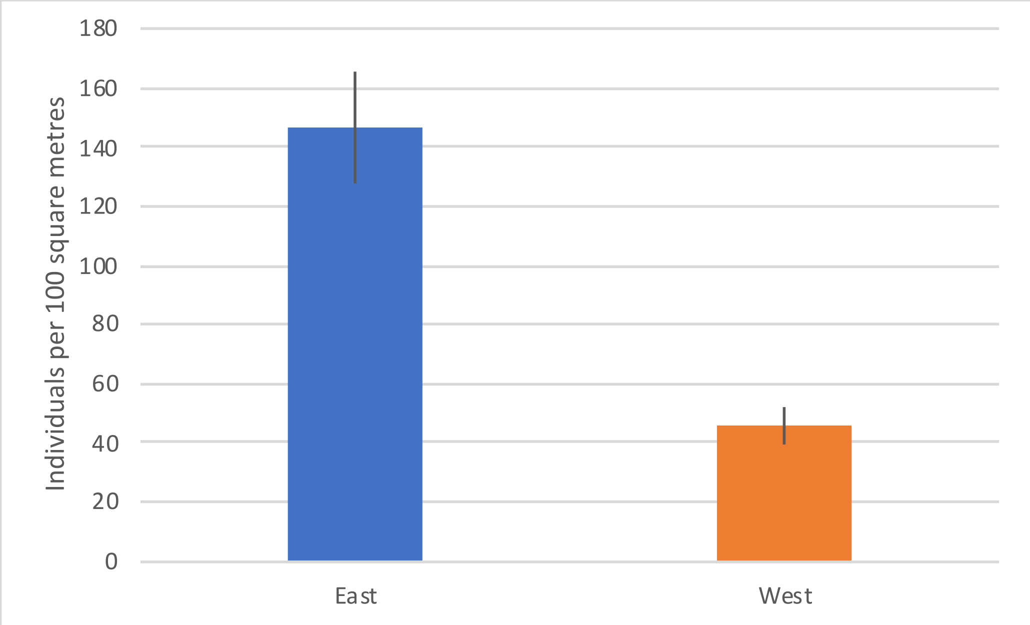


Figure 13: Combined total mean (±SE) number of individuals per 100m^2, between East and West sides of Koh Seh, during 2017.

3.4 Invertebrates

Refer to Table B2 for the complete list invertebrate species monitored by MCC

3.4.1 Totals Between Years

Some invertebrate species/group abundances varied between monitoring years (Figure 14, Figure 15, Table C19). In 2017, a total of 13 invertebrate species/groups from MCC's species monitoring list that had been observed at Koh Seh. In 2016, there was a total of 17 invertebrate species/groups that had been observed (refer to Table B5 for the complete list of invertebrate species/groups recorded during 2016 and 2017 monitoring years). There was 1 invertebrate species recorded in 2017 that was not recorded during the 2016 monitoring year (Table 4).

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

Giant Clam

There were 5 invertebrate species/groups recorded during 2016 that were not recorded during 2017 (Table 5).

Table 5: Invertebrate species observed at Koh Seh during 2016 that were not recorded in 2017.

Blue Swimmer Crab
Conch
Octopus
Feather Star
Collector Urchin

Species/groups that were statistically compared between years include the feather duster worm, christmas tree worm, flatworm, true crab, *Drupella*, top shells, turbo/other gastropods, nudibranchs, boring bivalves, *Diadema* sea urchin, and pencil urchin (Table C20).

There were significant decreases in abundances between 2016 and 2017 monitoring years for the feather duster worm, christmas tree worm, flatworm, *Drupella*, turbo/other gastropods, boring bivalves, and the *Diadema* sea urchin. The observed abundances of true crab, top shells, nudibranchs and pencil urchins did not significantly change between years.

Feather duster worm abundance significantly decreased from an average of 0.44 individuals per $100m^2$ to 0.1 individuals per $100m^2$ (t_{47}=2.18, p=0.034). Christmas tree worm abundance significantly decreased from an average of 31.31 individuals per $100m^2$ to 10.92 individuals per $100m^2$ (t_{47}=5.22, p=<0.001). Flatworm abundance significantly decreased from an average of 0.38 individuals per $100m^2$ to 0.06 individuals per $100m^2$ (t_{47}=2.34, p=<0.024). *Drupella* significantly decreased from an average 5.25 individuals per $100m^2$ to 0.19 individuals per $100m^2$ (t_{47}=4.12, p=<0.001). Turbo/other gastropods significantly decreased from an average 6.9 individuals per $100m^2$ to 3.13 individuals per $100m^2$ (t_{47}=7.01, p=<0.001). Boring bivalves significantly decreased from an average 53.96 individuals per $100m^2$ to 29.38 individuals per $100m^2$ (t_{47}=5.68, p=<0.001). The *Diadema* sea urchin significantly decreased from an average 67.08 individuals per 100m^2 to 27.44 individuals per 100m^2 (t_{47}=4.81, p=<0.001).

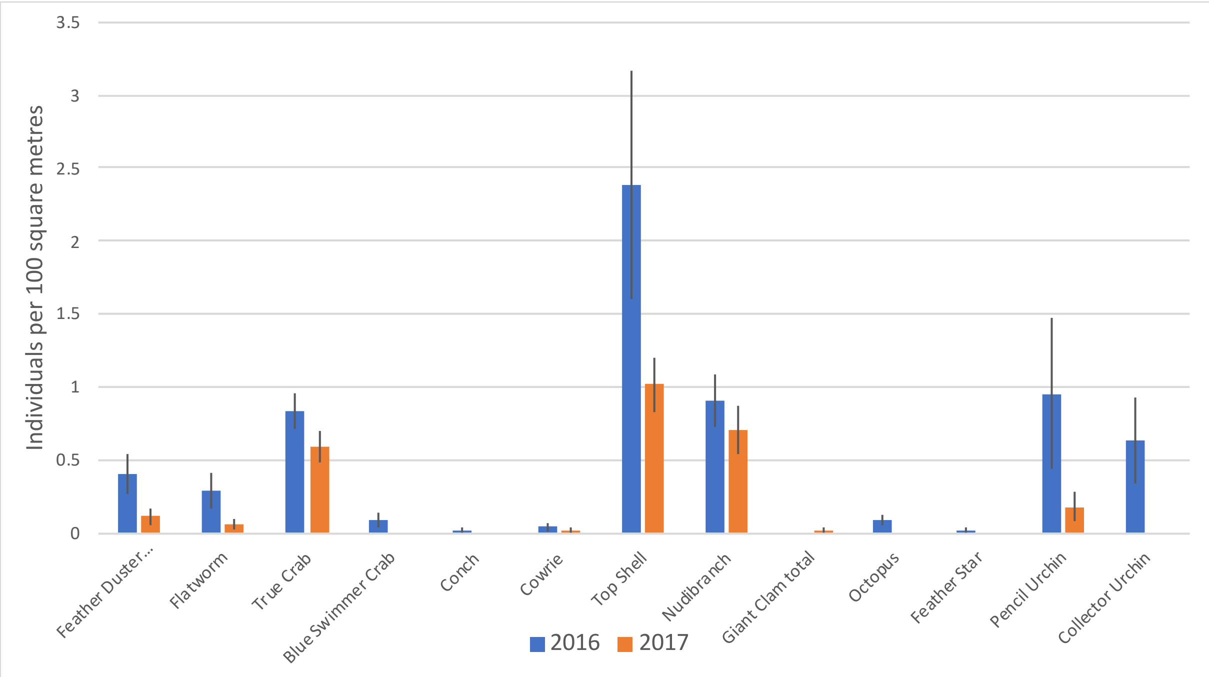


Figure 14: Total mean (± SE) invertebrate species/group abundance per 100m^2 during 2016 and 2017.

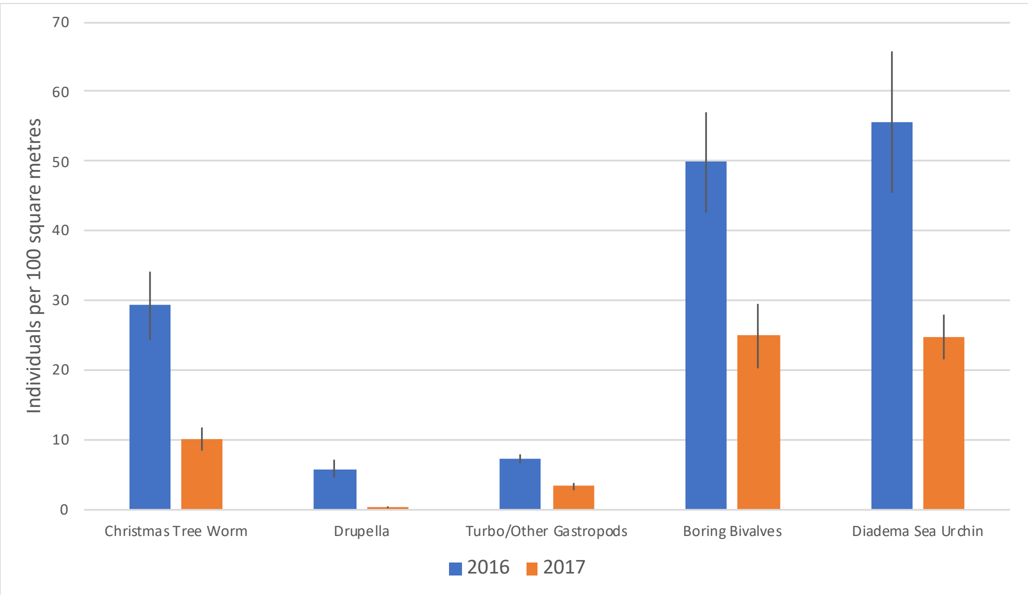


Figure 15: Total mean (± SE) christmas tree worm, *Drupella*, turbo/other gastropods, boring bivalves, and *Diadema* sea urchin abundance per 100m^2 during 2016 and 2017.

3.4.2 Combined Total Abundance

Combined total invertebrate abundance declined significantly between 2016 and 2017. There was an average of average of 170.81 individuals per 100m^2 during 2016, which significantly decreased to an average of 73.63 individuals per 100m^2 in 2017 (t_{47}=7.2, p=<0.001) (Figure 16, Table C21, Table C22). There was a combined total of 8199 individuals recorded during 2016 surveys, compared to 3534 individuals recorded in 2017.

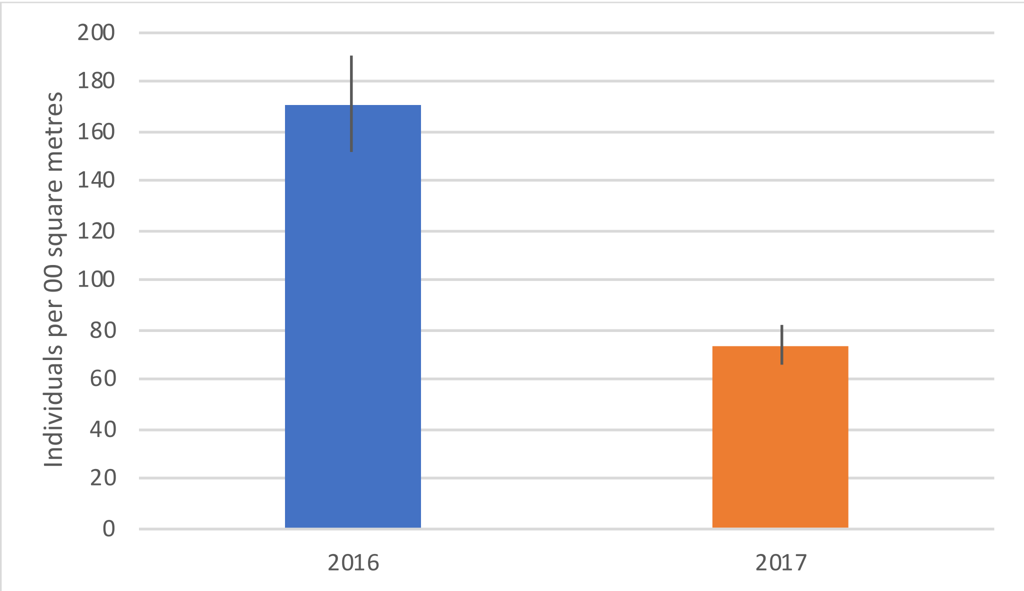


Figure 16: Combined total mean (± SE) number of individuals per 100m^2, for fish, during 2016 and 2017 monitoring years.

The East and West sides of Koh Seh experienced significantly different invertebrate abundances during 2017 (Figure 17, Table C23, Table C24). The West exhibited an average of 122.46 individuals per 100m^2. This was significantly greater than the East which displayed a relatively low average of 24.79 individuals per 100m^2 (t_{46}=-13.03, p=<0.001). There was a total of 2939 individuals recorded on the West, compared to 595 recorded on the East.

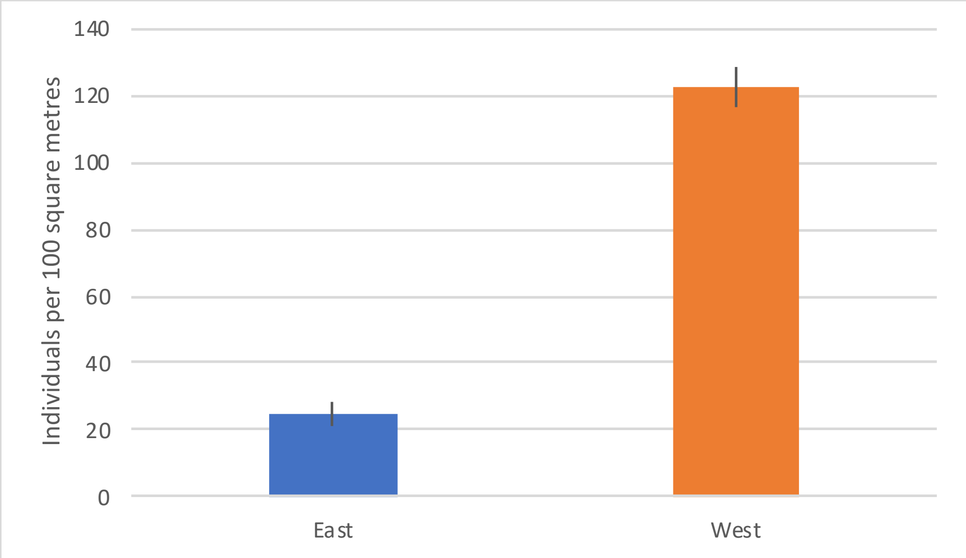


Figure 17: Combined total mean (± SE) number of individuals per 100m^2, for invertebrates, between East and West sides of Koh Seh, 2017.

3.5 Herbivore Abundance

Total average herbivorous fish abundance significantly increased between years while total average urchin abundance declined (Figure 18, Table C25, Table C26). Herbivorous fish abundance significantly increased from an average of 37.51 individuals per 100m^2 in 2016 to 61.03 individuals per 100m^2 in 2017(t_{109}=-2.06, p=0.041). Urchin abundance significantly decreased from an average 68.51 individuals per 100m^2 in 2016 to 27.63 individuals per 100m^2 in 2017(t_{47}=4.92, p=<0.001). During 2016, urchin abundance was significantly greater than herbivorous fish abundance (t_{97}=-2.75, p=0.007) (Table C27). This was then reversed in 2017 when herbivorous fish abundance became significantly greater urchin abundance (t_{106}=3.02, p=0.003).

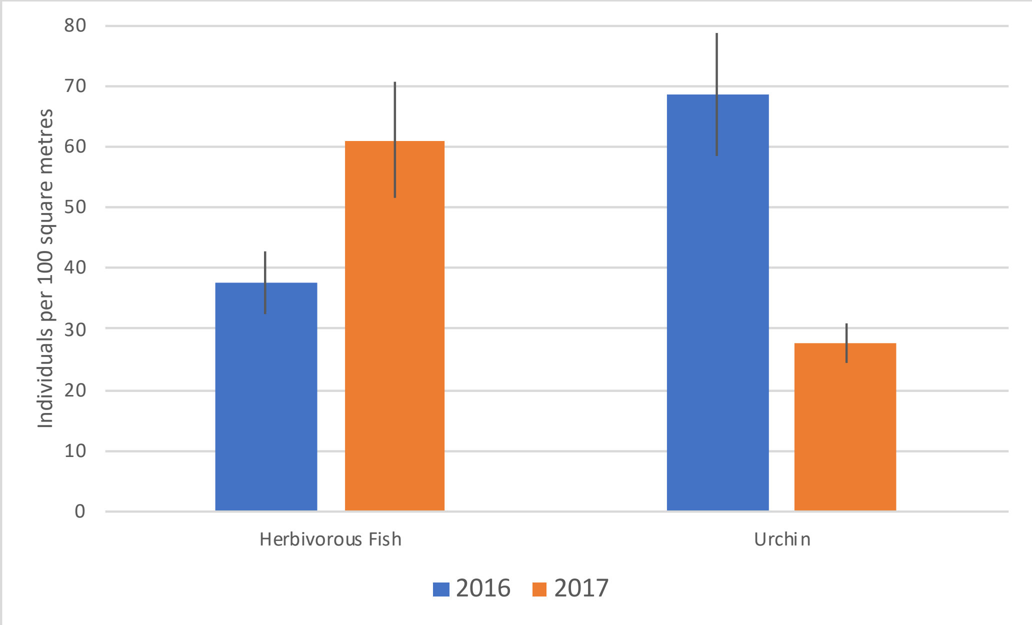


Figure 18: Mean (± SE) herbivore abundance per 100m^2, for fish (includes pier data) and urchins, between 2016 and 2017.

Analysis of the data revealed significant differences in the average abundaces of herbivorous fish and urchins between the East and West during 2017 (Figure 19, Table C28, Table C29). The East exhibited an average herbivorous fish abundance of 60.96 individuals per 100m^2, which was significantly greater than the West, which had an average of 23.83 individuals per 100m^2 (t_{46}=3.57, p=<0.001). For urchins in the East there was an average of 13 individuals per 100m^2, which was significantly less than the average of 42.25 urchins per 100m^2 in the West (t_{46}=-6.06, p=<0.001). Furthermore, herbivorous fish abundance was significantly greater than urchin abundance on the East (t_{46}=4.42, p=<0.001), whereas urchin abundance was significantly greater than herbivorous fish abundance on the West (t_{46}=-4.99, p=<0.001) (Table C30).

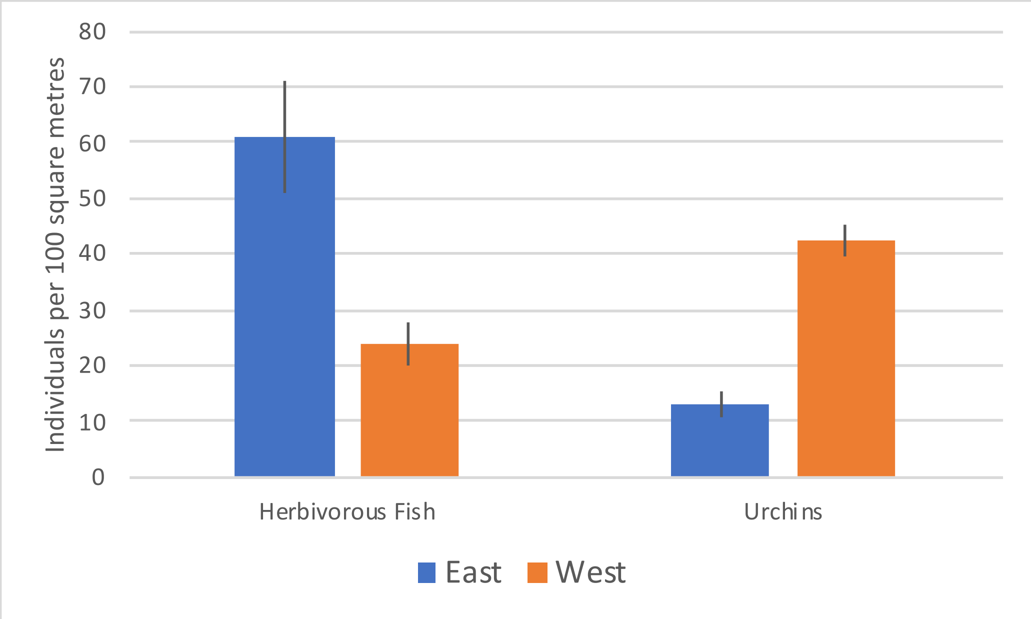


Figure 19: Mean (± SE) herbivore abundance for fish and urchins per 100m², between East and West sides of Koh Seh, 2017.

3.6 Species Richness

There was no significant difference in fish species total average richness between 2016 and 2017 monitoring years (t_{109}=1.5, p=0.136). There was an average of 11.55 fish species per 100m² in 2017 (Figure 20, Table C31, Table C32). Invertebrate species richness did, however, differ significantly between monitoring years. Invertebrate species richness significantly declined from an average of 6.75 species per 100m² during 2016 to 4.69 species per 100m² in 2017 (t_{47}=6.91, p=<0.001) (Figure 20, Table C31, Table C32).

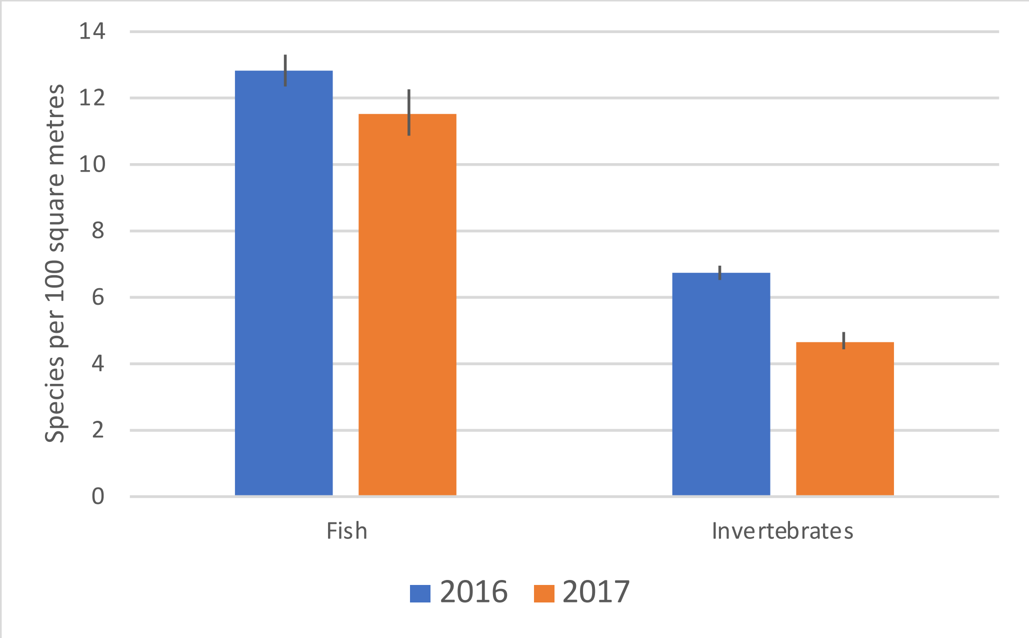


Figure 20: Mean (± SE) fish (includes pier data) and invertebrate species richness per 100m², from 2016 to 2017.

Fish species richness significantly differed between the East and West during 2017 (Figure 21, Table C33, Table C34). There was an average of 13.88 species per 100m² on the East, which was significantly greater than the West where there was an average of 8.21 species per 100m² (t_{46}=5.74, p=<0.001). There was no significant difference in invertebrate species richness between the East and the West side of the Island (t_{46}=1.01, p=0.318) (Figure 21, Table C33, Table C34).

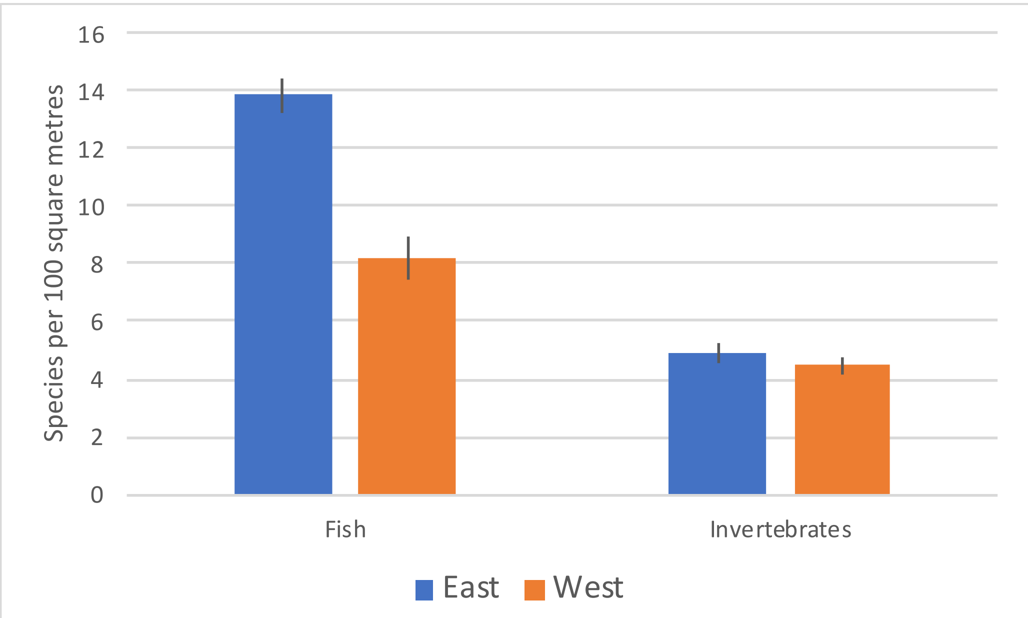


Figure 21: Mean (± SE) fish and invertebrate species richness per 100m², between East and West sides of Koh Seh, 2017.

4. Discussion

The results suggest that the Koh Seh reef, while subjected to ongoing stressors, may be beginning to show signs of recovery following a reduction in illegal fishing pressures. While 2014 and 2015 data was not used in this analysis (due to differing methodologies), the 2016 environmental assessment of Koh Seh suggests that fish species have been recovering relatively rapidly over recent years where protection has been imposed (refer to Koh Seh Marine Environmental Assessment, 2016). This has being strongly reinforced by MCC's observations, where staff have reported monumental transformations in some areas where there are now hundreds of fish, but until recently there was very few. Between 2016 and 2017, hard coral cover remained unchanged; total fish abundance and variety remained similar, while herbivorous fish abundance significantly increased. This coincided with a significant decline in herbivorous urchins. Furthermore, invertebrate observations and species richness also significantly declined between years. The greatest differences were observed between the East and West sides of the Island. Hard coral cover differed significantly between the East and West, as did species abundance and variety. Urchins were the dominant herbivores on the West side of the Island while herbivorous fish belonging to the grazer functional group were dominant on the East.

4.1 Environmental Conditions

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

Coral damage was observed during both years and sides of Koh Seh, however, trash and fishing gear was mainly observed on the West. Coral predation was recorded at a medium level between years and sides, which may be largely a result of Butterflyfish corallivory. The amount of bleached and diseased corals differed significantly between years. Close to 30% of the coral population was bleached during 2016. Approximately 8% of corals also displayed signs of disease at this time. Bleaching events and coral diseases can develop as a result of environmental stressors (Rosenberg and Ben-Haim, 2002). Elevated water temperature and nutrification of the water can be a major contributors, and are problems that now threaten marine life in the Kep Archipelago (Harvell *et al*., 2001; Vega *et al*., 2014). Furthermore, the severity and scale of coral bleaching and disease is only expected to increase under climate change (Rosenberg and Ben- Haim, 2002; van Hooidonk *et al*., 2017). Disease prevalence on the reef was not, however, dissimilar to the extent of diseases on other reefs in other geographical locations. (Myers and Raymundo, 2009). For example, Ruiz-Morenol *et al*. (2012) describe most reefs in the Caribbean and the Pacific to be beneath a 10% threshold for coral disease.

4.2 Substrate

Substrate compositions varied greatly between sides of Koh Seh. Hard, reef-building, corals dominated the substrate on the West side of the Island, covering an average of 59.7% of the benthos. On the contrary, hard coral cover only made up 25.1% of the substrate on the East side of the Island. Here, zoanthids dominated in some areas, making up 34% of the reef benthos. The West also exhibited relatively high zoanthid cover at 14.5%. Cambodian reefs are known to vary considerably and in the past they have exhibited coral covers between 4.1% and 72.1% (Chou *et al*., 2002). Average coral cover on the Great Barrier Reef, which is an UNESCO – 'World Heritage Site', has been estimated at only 13.8% (De'ath *et al*., 2012). Furthermore, healthier sections of reef at Koh Seh may be able to provide buffering effects to other degraded sections/patches. Ecosystem connectivity (connectivity of species and system processes) is known to play an important role in resilience (Graham *et al*., 2011).

Nutrient indicator algae (macro algae) declined, correlating with a sudden increase of herbivorous fish during that time. Macro-algal growth was maintained at low levels by herbivores on both the East and West sides of Koh Seh. Herbivory is a process that is also considered critical for coral reef resilience (Pratchett *et al*, 2014; Nash *et al*, 2016).

The East exhibited higher coral rubble and sand covers than the West, however, these substrates covered less than 10% of total cover. Sand is often influenced by seasonal currents and wind direction at Koh Seh. The East side of the Island also experiences greater boating activity in closer proximity to the reef than the West, which may affect coral cover. Furthermore, sea currents that pass via Vietnamese waters can, at times, contain pollutants that are toxic to animals (as observed by MCC staff).

4.3 Fish

Combined total fish abundance did not significantly increase between 2016 and 2017 monitoring years. However, since 2014 fish species have been continuing to appear in increasing numbers as coral reefs in the Archipelago have received some protection from illegal fishing. Large increases in fish abundance appear to have been observed by MCC staff during this time. Increasing fish abundances at Koh Seh's pier may be attributed to food availability. MCC staff feed the reef fish with food scraps each morning, attracting many species to the area. Overspill of fish from the pier to the adjacent reefs was obvious (North Eastern Reef and South Eastern Reef). The East side of the Island, excluding fish counts from under the pier, exhibited an average fish abundance of 146.96 individuals per $100m^2$. This was still significantly greater than what was observed on the Western side, where there was an average of only 45.75 individuals per $100m^2$. This means that on average there are more than three times the amount of fish on the eastern side of the Island than the West.

Species that displayed significant increases in abundance between years included snapper, emperor and sergeant fish species. Larger snapper and emperor species are considered highly mobile and can easily move between reef systems. Snapper are known to be able to travel hundreds of kilometres, making them efficient at recruiting to new reefs that host suitable refuge (Green *et al*., 2015). The observed increase in sergeant fish (important herbivore) may be attributed to higher macro-algal growth during 2016, or to a higher rate of algal production in a system experiencing elevated nutrient levels (Russ, 2003). Wrasse, carpet eel blenny and sweeper species significantly declined between monitoring years. Low hard coral cover and the structural complexity of reef habitat, particularly on the East, may have contributed to the observed declines (Russ *et al*., 2017). However, carpet eel blenny and sweeper observations may even be expected to vary between years. Because the cryptic nature of carpet eel blenny's, observations can be difficult. However, sweeper tend to school, and sightings can be less frequent than some other reef species at times, but when sighted, they may be present in relatively large numbers.

4.4 Invertebrates

Total invertebrate abundance significantly decreased between monitoring years, with seven species experiencing significant declines. Total mean invertebrate abundance decreased from 170.81 individuals per $100m^2$ during 2016 to 73.63 individuals per $100m^2$ in 2017. It is unclear why there were fewer invertebrate observations during 2017. However, complex ecological interactions and environmental stressors likely contributed to the observed outcome (Jackson and Hughes, 1985; Pinnegar *et al*., 2000; Dulvy *et al*., 2004). On the contrary, many invertebrates may have been missed by surveyors, as species can be cryptic and are often more difficult to observe than fish. The West exhibited an invertebrate abundance of 122.46 individuals per $100m^2$. That was significantly greater than the East, which displayed a relatively low average abundance of 24.79 individuals per $100m^2$. Average invertebrate abundance in 2016 exceeded both 2017 East and West average abundances. Although, the observed substrate compositions during 2017, particularly the reduced hard coral cover (with associated high zoanthid cover) on the East, may help to explain a lower invertebrate abundance on that side of Koh Seh (Idjadi and Edmunds, 2006). Furthermore, community structure and small spatial ranges amongst invertebrate groups may also help to explain invertebrate distribution. For example, Netchy *et al*. (2017) found that on a Florida reef mobile invertebrate species had formed distinct communities with unique, but overlapping, habitat requirements.

Feather duster worms, christmas tree worms, flatmworms, *Drupella*, turbo/other gastropods, boring bivalves, and the *Diadema* sea urchin declined between 2016 and 2017. There were no population increases for any invertebrate species/group between those years. Many invertebrate species are sensitive to water quality, such as the boring bivalves. High levels of suspended sediment are frequently observed in the water around Koh Seh. However, at times this is actually thought to benefit particulate feeders, such as the feather duster and christmas tree worms (Birkeland, 1977; Harty, 2011). Gastropods, such as *Drupella* and turbos (and other gastropods) are often targeted by invertebrate harvesting divers. The *Diadema* sea urchin, has also been targeted by fishers in recent times. Their decline, however, also coincides with an increase in abundance of herbivorous fish, which compete with the urchins for food resources (Hay and Taylor, 1985). Large numbers of the *Diadema* sea urchin are present on reefs in the Archipelago, most likely due to a combination of there being low numbers of herbivorous fish and few large macrophagous predators on reefs (due to overharvesting) (Alvarado *et al*., 2016; Nash *et al*, 2016; Kuempel and Altieri, 2017).

4.5 Functional Groups

While the Koh Seh reef did not exhibit any changes in total fish abundance, herbivorous fish abundance significantly increased between years, while herbivorous urchins decreased. Herbivores are considered important for maintaining coral reef resilience by controlling algal growth, which helps to prevent coral-algal phase-shifts (Mumby *et al*, 2006; Green and Bellwood, 2009; Edwards *et al*., 2014; Pratchett *et al*, 2014).

There was a significant increase from an average of 37.51 herbivorous fish per 100m^2 to 61.03 per 100m^2 between 2016 and 2017. Many of these fish were associated with the pier and were likely attracted to the site because of food availability. However, with the pier data excluded, the East exhibited an average of 60.95 herbivorous fish per 100m^2. This was significantly greater than the West which exhibited an average of 23.83 herbivorous fish per 100m^2. Here, an overspill effect has occurred and greater numbers of fish can be observed on sections of reef that at are adjacent to the pier.

Although herbivorous fish abundance increased on Eastern reefs, diversity remained low.

Herbivorous fish counts included two major groups, rabbitfishes and sergeant fish, of which species are predominantly grazers. Batfish are browsers and were also observed on two occasions. Other important herbivorous fishes belonging to these functional groups, as well as scraper and excavator functional groups, were either represented poorly or completely absent from the system. Each functional group plays a particular role in the maintenance of substrate and control of algal growth on a reef system (Green and Bellwood, 2009). Parrotfish, which are some of the most important algal eating fishes (with species belonging to scraper, excavator and browser functional groups), are thought to have been completely fished out of the Kep Archipelago (Hughes *et al*, 2010; Plass-Johnson *et al*, 2015). Urchins have responded to low herbivores fish numbers throughout the Kep Archipelago, and are now the primary herbivores of most reefs.

Average urchin abundance was recorded at 68.54 sea urchins per 100m^2 during 2016, declining to an average of 27.63 urchins per 100m^2 in 2017. The observed decline in total urchin abundance was due to a decline of the declining *Diadema* sea urchin, which is the most important urchin on coral reefs in the Archipelago. In 2016, total urchin abundance was significantly greater than total herbivorous fish abundance. As herbivorous fish increased in number between years, urchins decreased, eventually becoming significantly less abundant than herbivorous fish in 2017. Increased resource competition between the two herbivore groups may have contributed to the observed decline in total urchin abundance between years (Hayand Taylor, 1985; McClanahan *et al*., 1994). Disease has also been known to affect populations of *Diadema* sea urchin (and other urchins) on coral reefs globally (Clemente *et al*., 2014; Lessios, 2016). Urchins actually remained the dominant herbivore group on the West side of the Island where there was an average of 42.25 individuals per 100m^2. This was significantly greater than herbivorous fish abundance on the West, which remained low during 2017. On the East side of Koh Seh, however, where herbivorous fish were present in significantly greater numbers, average urchin abundance was observed at only 13 individuals per 100m^2. Numbers of the *Diadema* sea urchin on coral reefs in the Kep Archipelago have, in recent times, been relatively high as populations likely exploded in response to reduced numbers of herbivorous fishes. This has been accredited to overfishing, which is known to effect herbivore community structures and coral reefs globally (Edwards *et al*, 2014). Unfortunately, herbivorous fish groups, especially large bodied fish, are often the most susceptible to fishing (Edwards *et al*., 2014). On the East side of Koh Seh, where very little fishing is practiced and food is readily available, increases of sergeant fish and rabbitfish may be responsible for the observed decline in urchin abundance. As herbivorous fish recover and functional roles are reassumed, urchin populations may be expected to decrease across the Archipelago to reflect more compositions more typical of herbivore groups. For example, on coral reef systems in the Caribbean, where herbivore functional groups are better represented than in the Kep Archipelago, the *Diadema* sea urchin is rarer than other herbivorous species (but remains the most important herbivorous urchin and a key bioeroder), with their abundance and distribution believed to be mediated by the herbivorous fish with which they share a mutualistic relationship (Cramer *et al*., 2017). The return of herbivorous fishes, and in particular, parrotfish, to the Archipelago is critical for coral reef health and for the future of coral reefs in the Kep Archipelago (Hughes *et al*, 2010; Plass-Johnson *et al*, 2015; Nash *et al*., 2016; Cramer *et al*., 2017).

4.6 Diversity

Fish species richness was recorded at an average of 11.55 species per 100m^2 in 2017, which was not significantly different from the previous year. Invertebrate species richness, however, significantly decreased between years, changing from an average of 6.75 species per 100m^2 during 2016 to an average of 4.69 species per 100m^2 in 2017. A decline in invertebrate species richness may be partly attributed to a decline in either the abundance or observations (or both) of invertebrate species during this time. There were no differences in invertebrate species richness between sites, indicating that the decline was not likely to be site specific, but rather uniform cross the Koh Seh reef. On the contrary, fish species richness was significantly greater on the East side of the Island, compared to the West, where fish are present in greater abundances.

Climatic variables that control primary productivity and the geomorphic context of a reef environment have been found as important determinants of coral reef diversity (Yeager *et al*., 2017). The geomorphology or structural complexity of reef habitat is considered especially important for mediating fish diversity (Darling *et al*., 2017; Richardson *et al*., 2017). However, it is likely that routine fish feeding from the pier on the East side of Koh Seh helps drive the observed patterns of fish abundance and diversity as opposed to the structural complexity of the eastern reef. The East exhibited areas of poor coral health that were less structurally complex than the West, and was dominated by zoanthids in parts. Despite this, large numbers of fish congregated around the pier and adjacent reefs, while fish abundance and diversity remained low on the West where coral assemblages were healthier and more structurally complex, but fish were not fed. Contrastingly, in the absence of fish feeding, a study by Cruz *et al*. (2015) found that coral dominated reefs exhibited greater fish species diversity than reefs that had transitioned into zoanthid dominated states. Although, coral species diversity appeared low on the Koh Seh reef and was largely characterised by varieties of massive (i.e. ball or boulder shaped) corals.

4.7 Research Limitations

High sediment loads have been identified as a problem around Koh Seh. Suspended sediment often affects the turbidity and clarity of the water has been attributed to trawling activities disturbing the seafloor. Because of this, MCC divers were often faced with conditions that were not suitable for scientific surveys. The minimum recommendation required for an accurate reef survey is a visibility of 3m.

An important consideration remains to be the comparability of the data between both monitoring years. Because sample sizes for the pier differed between years, this effected the type of statistical analyse that could be used to compare the data.

There was a slight change to the invertebrate species group in 2017. Turbos received their own category as they were the predominant gastropod recorded under the group titled ‘other’ gastropods during 2016. Therefore, ‘other’ gastropods and turbos were compared between years. Furthermore, it is difficult to interpret and understand the differences observed in invertebrate abundance and diversity, especially for the less mobile, cryptic species that often remain well hidden in reef structures. Fluctuations in their observations may be expected and inference should arguably be made only with sufficient data.

It is important to note that actual species richness (and abundance) is likely 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 are currently listed on MCC's species monitoring list were considered in the analysis. This measure however does provide a credible diversity estimate for the ecosystem by monitoring species richness within a selected sample group (monitoring list). The species included on MCC's species monitoring list are recognised as keystone species, or being important to the Archipelago and/or 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 Seh system and the reef is now beginning to show some signs of recovery, following protection from illegal fishing. It is important that functional groups and ecosystem processes are provided with increased protection. Coral and zoanthid cover should be closely monitored over time. With low numbers of herbivorous fish recorded on the reef and an absence of some major functional groups, it is important that herbivore diversity be promoted and ecosystem herbivory maintained beneath critical levels to prevent a system phase-shift. Moreover, the unsustainable harvest of the *Diadema* sea urchin could have serious consequences for reefs in the Archipelago. It is of utmost importance that management provides the necessary foundations for recovery. The establishment of the MFMA should ensure a more effective management, concurrent with strategies that confront the major issues surrounding the region. These include both, fishing stressors exerted upon the Kep Archipelago and any existing disparities between stakeholder groups. Unenforced regulations and policies are expected to be addressed with the implementation of the MFMA, and management is to be constructed as to engage and allow the participation of the local communities in protecting the sustainability of their marine resources. This is critical as to avoid further social-ecological traps where the practicing of damaging activities can become increasingly difficult to remedy. Koh Seh, Koh Mak Prang and Koh Angkrong coral reefs will continue to be monitored over time in order to assess the effectiveness of this conservation in maintaining and improving ecosystem health.

6. References

Alvarado, J. J., Cortés, J., Guzman, PIER. M., & Reyes-Bonilla, PIER. (2016). Density, size, and biomass of Diadema mexicanum (Echinoidea) in Eastern Tropical Pacific coral reefs.

Alvarez-Filip, Lorenzo., Cote, I. M., Gill, J. A., Watkinson, A. R., & Dulvy, N. K. (2011). Region- wide temporal and spatial variation in Caribbean reef architecture: is coral cover the whole story?. *Global Change Biology*, *17*(7), 2470-2477.

Anderson, T. L. (2013). One World, One Ocean, One Mission. *Earth Common Journal*, *3*(1).

Bartley, R., Bainbridge, Z. T., Lewis, S. E., Kroon, F. J., Wilkinson, S. N., Brodie, J. E., & Silburn, D. M. (2014). Relating sediment impacts on coral reefs to watershed sources, processes and management: a review. *Science of the Total Environment*, *468*, 1138-1153.

Birkeland, C. (1977). The importance of rate of biomass accumulation in early succession stages of benthic communities to the survival of coral recruits. In *Proc. 3rd Int. Coral Reef Symp.* (pp. 16-21).

Brander, L. M., Rehdanz, K., Tol, R. S., & Van Beukering, P. J. (2012). The economic impact of ocean acidification on coral reefs. *Climate Change Economics*, *3*(01).

Brown, L. A., Furlong, J. N., Brown, K. M., & La Peyre, M. K. (2014). Oyster reef restoration in the northern Gulf of Mexico: effect of artificial substrate and age on nekton and benthic macroinvertebrate assemblage use. *Restoration ecology*, *22*(2), 214-222.

Bruno, J. F., & Selig, E. R. (2007). Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. *PLoS one*, *2*(8), e711.

Cesar, PIER., Burke, L., & Pet-Soede, L. (2003). *The economics of worldwide coral reef degradation*. Cesar environmental economics consulting (CEEC).

Chou, L. M., Tuan, V. S., Philreefs, PIER. T., Cabanban, A., & Suharsono, K. I. (2002). Status of Southeast Asia coral reefs. *Status of coral reefs of the world. Australian Institute of Marine Science, Townsville*, 123-153.

Clemente, S., Lorenzo-Morales, J., Mendoza, J. C., López, C., Sangil, C., Alves, F., ... & Hernández, J. C. (2014). Sea urchin Diadema africanum mass mortality in the subtropical eastern Atlantic: role of waterborne bacteria in a warming ocean. *Marine Ecology Progress Series*, *506*, 1-14.

Coen, L. D., Brumbaugh, R. D., Bushek, D., Grizzle, R., Luckenbach, M. PIER., Posey, M. PIER., ... & Tolley, S. G. (2007). Ecosystem services related to oyster restoration. *Marine Ecology Progress Series*, *341*, 303-307.

Cramer, K. L., O'Dea, A., Clark, T. R., Zhao, J. X., & Norris, R. D. (2017). Prehistorical and historical declines in Caribbean coral reef accretion rates driven by loss of parrotfish. *Nature communications*, *8*, 14160.

Cruz, I. C., Loiola, M., Albuquerque, T., Reis, R., José de Anchieta, C. C., Reimer, J. D., ... & Creed, J. C. (2015). Effect of phase shift from corals to Zoantharia on reef fish assemblages. *PloS one*, *10*(1), e0116944.

Darling, E. S., Graham, N. A., Januchowski-Hartley, F. A., Nash, K. L., Pratchett, M. S., & Wilson, S. K. (2017). Relationships between structural complexity, coral traits, and reef fish assemblages. *Coral Reefs*, *36*(2), 561-575.

Davis, J. P., Pitt, K. A., Fry, B., Olds, A. D., & Connolly, R. M. (2014). Seascape-scale trophic links for fish on inshore coral reefs. *Coral Reefs*, *33*(4), 897-907.

De'ath, G., Fabricius, K. E., Sweatman, PIER., & Puotinen, M. (2012). The 27–year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences*, *109*(44), 17995-17999.

Dulvy, N. K., Freckleton, R. P., & Polunin, N. V. (2004). Coral reef cascades and the indirect effects of predator removal by exploitation. *Ecology letters*, *7*(5), 410-416.

Edwards, C. B., Friedlander, A. M., Green, A. G., Hardt, M. J., Sala, E., Sweatman, PIER. P., ... & Smith, J. E. (2014). Global assessment of the status of coral reef herbivorous fishes: evidence for fishing effects. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1774), 20131835.

Fabricius, K. E., De'ath, G., Humphrey, C., Zagorskis, I., & Schaffelke, B. (2013). Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. *Estuarine, Coastal and Shelf Science*, *116*, 57-65.

Graham, N. A. J., Nash, K. L., & Kool, J. T. (2011). Coral reef recovery dynamics in a changing world. *Coral Reefs*, *30*(2), 283-294.

Grabowski, J. PIER., & Peterson, C. PIER. (2007). Restoring oyster reefs to recover ecosystem services. *Ecosystem engineers: plants to protists*, *4*, 281-298.

Green, A. L., & Bellwood, D. R. (Eds.). (2009). Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience: a practical guide for coral reef managers in the Asia Pacific Region (No. 7). IUCN.

Green, A. L., Maypa, A. P., Almany, G. R., Rhodes, K. L., Weeks, R., Abesamis, R. A., ... & White, A. T. (2015). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews*, *90*(4), 1215-1247.

Hansen, M. C. et al. 2008. "Humid Tropical Forest Clearing from 2000 to 2005 Quantified by Using Multitemporal and Multiresolution Remotely Sensed Data." Proceedings of the National Academy of Sciences 105: 9439–9444; Forestry Department, FAO. 2006.Global Forest Resources Assessment 2005: Progress Towards Sustainable Forest Management. Rome: FAO.

Harty, M. (2011). Christmas tree worms (Spirobranchus giganteus) as a potential bioindicator species of sedimentation stress in coral reef environments of Bonaire, Dutch Caribbean. *Physis: J Mar Sci*, *9*, 20- 30.

Harvell, D., Kim, K., Quirolo, C., Weir, J., & Smith, G. (2001). Coral bleaching and disease: contributors to 1998 mass mortality in Briareum asbestinum (Octocorallia, Gorgonacea). *Hydrobiologia*, *460*(1-3), 97-104.

Hay, M. E., & Taylor, P. R. (1985). Competition between herbivourous fishes and urchins on Caribbean reefs. *Oecologia*, *65*(4), 591-598.

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

Hoegh-Guldberg, O. (2011). Coral reef ecosystems and anthropogenic climate change. *Regional Environmental Change*, *11*(1), 215-227.

Hodgson, G. (1990). Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*. *Coral Reefs* **9**, 41-43.

Huang, D., Licuanan, PIER. PIER., Hoeksema, B. PIER., Chen, C. A., Ang, P. O., Huang, PIER., ... & Yeemin, T. (2015). Extraordinary diversity of reef corals in the South China Sea. *Marine Biodiversity*, *45*(2), 157-168.

Hughes, T. P., Graham, N. A., Jackson, J. B., Mumby, P. J., & Steneck, R. S. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution*, *25*(11), 633- 642.

Idjadi, J. A., & Edmunds, P. J. (2006). Scleractinian corals as facilitators for other invertebrates on a Caribbean reef. *Marine Ecology Progress Series*, *319*, 117-127.

Jackson, J. B., & Hughes, T. P. (1985). Adaptive strategies of coral-reef invertebrates: coral-reef environments that are regularly disturbed by storms and by predation often favor the very organisms most susceptible to damage by these processes. *American Scientist*, *73*(3), 265-274.

Knowlton, N., Brainard, R. E., Fisher, R., Moews, M., Plaisance, L., & Caley, M. J. (2010). Coral reef biodiversity. *Life in the World's Oceans: Diversity Distribution and Abundance*, 65-74.

Kuempel, C. D., & Altieri, A. PIER. (2017). The emergent role of small-bodied herbivores in pre-empting phase shifts on degraded coral reefs. *Scientific reports*, *7*, 39670.

Lee, S. PIER., Primavera, J. PIER., Dahdouh- Guebas, F., McKee, K., Bosire, J. O., Cannicci, S., ... & Mendelssohn, I. (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biogeography*, *23*(7), 726-743.

Lessios, PIER. A. (2016). The great Diadema antillarum die-off: 30 years later. *Annual review of marine science*, *8*, 267-283.

Madani, S., Ahmadian, M., KhaliliAraghi, M., & Rahbar, F. (2012). Estimating Total Economic Value of Coral Reefs of Kish Island (Persian Gulf).*International Journal of Environmental Research*, *6*(1).

MAFF (2011). The Strategic Planning Framework for Fisheries: 2010 - 2019 Cambodia. In: ADMINISTRATION, F. (ed.). Kingdom of Cambodia

Marine Conservation Cambodia. (2016). Koh Seh Marine Environmental Assessment. *Unpublished manuscript*.

McClanahan, T. R., Graham, N. A., MacNeil, M. A., Muthiga, N. A., Cinner, J. E., Bruggemann, J. PIER., & Wilson, S. K. (2011). Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. *Proceedings of the National Academy of Sciences*, *108*(41), 17230-17233.

McClanahan, T. R., Nugues, M., & Mwachireya, S. (1994). Fish and sea urchin herbivory and competition in Kenyan coral reef lagoons: the role of reef management. *Journal of Experimental Marine Biology and Ecology*, *184*(2), 237-254.

McCulloch, M., Fallon, S., Wyndham., Hendy, E., Lough, J., Barnes, D. (2003). Coral record of increased sediment flux to inner Great Barrier Reef since European settlement. *Nature* **421**, 727-730.

Miller, R. PIER. (2013). Review: The Perfect Protein: The Fish Lover's Guide to Saving the Oceans and Feeding the World. *Electronic Green Journal*, *1*(36).

Mora, C. (2008). A clear human footprint in the coral reefs of the Caribbean. *Proceedings of the Royal Society B: Biological Sciences*, *275*(1636), 767-773.

Mumby, P. J., Dahlgren, C. P., Harborne, A. R., Kappel, C. V., Micheli, F., Brumbaugh, D. R., ... & Gill, A. B. (2006). Fishing, trophic cascades, and the process of grazing on coral reefs. *science*, *311*(5757), 98-

Mumby, P. J., & Hastings, A. (2008). The impact of ecosystem connectivity on coral reef resilience. *Journal of Applied Ecology*, *45*(3), 854-862.

Myers, R. L., & Raymundo, L. J. (2009). Coral disease in Micronesian reefs: a link between disease prevalence and host abundance. *Diseases of aquatic organisms*, *87*(1-2), 97-104.

Nash, K. L., Graham, N. A., Jennings, S., Wilson, S. K., & Bellwood, D. R. (2016). Herbivore cross-scale redundancy supports response diversity and promotes coral reef resilience. *Journal of Applied Ecology*, *53*(3), 646- 655.

Netchy, K., Hallock, P., Lunz, K. S., & Daly, K. L. (2016). Epibenthic mobile invertebrate diversity organized by coral habitat in Florida. *Marine Biodiversity*, *46*(2), 451-463.

Nordlund, L. M., Jackson, E. L., Nakaoka, M., Samper-Villarreal, J., Beca-Carretero, P., & Creed, J. C. (2017). Seagrass ecosystem services–What's next?. *Marine pollution bulletin*.

Olds, A. D., Albert, S., Maxwell, P. S., Pitt, K. A., & Connolly, R. M. (2013). Mangrove- reef connectivity promotes the effectiveness of marine reserves across the western Pacific. *Global Ecology and Biogeography*, *22*(9), 1040-1049.

Ostroumov, S. A. (2005). Suspension-feeders as factors influencing water quality in aquatic ecosystems. In *The comparative roles of suspension-feeders in ecosystems* (pp. 147-164). Springer, Dordrecht.

PIC (2017). Situation of marine fisheries and the establishment of fishing communities. *Briefing note, senate commission 1.* Kingdom of Cambodia.

Pinnegar, J. K., Polunin, N. V. C., Francour, P., Badalamenti, F., Chemello, R., Harmelin-Vivien, M. L., ... & Pipitone, C. (2000). Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. *Environmental Conservation*, *27*(2), 179-200.

Plass- Johnson, J. G., Ferse, S. C., Jompa, J., Wild, C., & Teichberg, M. (2015). Fish herbivory as key ecological function in a heavily degraded coral reef system. *Limnology and Oceanography*, *60*(4), 1382-1391.

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

Richardson, L. E., Graham, N. A., Pratchett, M. S., & Hoey, A. S. (2017). Structural complexity mediates functional structure of reef fish assemblages among coral habitats. *Environmental Biology of Fishes*, *100*(3), 193- 207.

Rodgers, C. S. (1990). Response of coral reefs and reef organisms to sedimentation. *Marine Ecology* **62**, 185- 202

Rosenberg, E., & Ben- Haim, PIER. (2002). Microbial diseases of corals and global warming. *Environmental microbiology*, *4*(6), 318-326.

Royal Government of Cambodia (2014). National Strategic Development Plan 2014-2018. Phnom Penh: Royal Government of Cambodia.

Russ, G. R. (2003). Grazer biomass correlates more strongly with production than with biomass of algal turfs on a coral reef. *Coral reefs*, *22*(1), 63-67.

Russ, G. R., Aller- Rojas, O. D., Rizzari, J. R., & Alcala, A. C. (2017). Off- reef planktivorous reef fishes respond positively to decadal- scale no- take marine reserve protection and negatively to benthic habitat change. *Marine Ecology*, *38*(3).

Sarkis, S., van Beukering, P. J., McKenzie, E., Brander, L., Hess, S., Bervoets, T., ... & Roelfsema, M. (2013). Total Economic Value of Bermuda's Coral Reefs: A Summary. In *Coral Reefs of the United Kingdom Overseas Territories* (pp. 201-211). Springer Netherlands.

Siddig, A, Ellison, A, Ochs, A, Villar-Leeman, C & Lau, M 2016, 'How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in Ecological Indicators', *Ecological Indicators*, vol. 60, pp. 223 – 230.

Sigman, D & Hain, M (2012), ‘The Biological Productivity of the Ocean’,*Nature Education, vol. 3, no. 6*

Soede, C. P., Cesar, PIER. S. J., Pet, J. S. (1999). An economic analysis of blast fishing on Indonesian coral reefs. *Envrionmental Conservation* **26**, 83-93.

Spalding, M., Burke, L., Wood, S. A., Ashpole, J., Hutchison, J., & zu Ermgassen, P. (2017). Mapping the global value and distribution of coral reef tourism. *Marine Policy*, *82*, 104-113.

Teh, L. S., Witter, A., Cheung, PIER. PIER., Sumaila, U. R., & Yin, X. (2017). What is at stake? Status and threats to South China Sea marine fisheries. *Ambio*, *46*(1), 57-72.

Unsworth, R. K., & Cullen, L. C. (2010). Recognising the necessity for Indo- Pacific seagrass conservation. *Conservation Letters*, *3*(2), 63-73.

Unsworth, R. K., De León, P. S., Garrard, S. L., Jompa, J., Smith, D. J., & Bell, J. J. (2008). High connectivity of Indo- Pacific seagrass fish assemblages with mangrove and coral reef habitats. *Marine Ecology Progress Series*, *353*, 213-224.

van-Bochove, J. W., N. Ioannou, M. McVee, and P. Raines (2011) Evaluating the status of Cambodia’s coral reefs through baseline surveys and scientific monitoring. Cambodian Journal of Natural History 2 114-121.

van Hooidonk, R., Maynard, J., Tamelander, J., Gove, J., Ahmadia, G., Raymundo, L., ... & Planes, S. (2017). Coral Bleaching Futures: Downscaled Projections of Bleaching Conditions for the World’s Coral Reefs, Implications of Climate Policy and Management Responses.

Vega Thurber, R. L., Burkepile, D. E., Fuchs, C., Shantz, A. A., McMinds, R., & Zaneveld, J. R. (2014). Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. *Global change biology*, *20*(2), 544-554.

Wear, S. L. (2016). Missing the boat: Critical threats to coral reefs are neglected at global scale. *Marine Policy*, *74*, 153-157.

Yeager, L. A., Deith, M., McPherson, J. M., Williams, I. D., & Baum, J. K. (2017). Scale dependence of environmental controls on the functional diversity of coral reef fish communities. *Global Ecology and Biogeography*, *26*(10), 1177-1189.

APPENDIX A – Key Policy and Legislation

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

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

Policy Statement

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

Rules:

Article 49:

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

Article 52:

Shall be prohibited:

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

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

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

APPENDIX B – Species Monitoring List

Table B1: Fish species/groups monitored.

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

Table B2: Invertebrate species/groups monitored.

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

Table B3: Monitored substrate types.

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

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

2016	2017
Eight Banded Butterflyfish	Eight Banded Butterflyfish
Long-Beaked Coral Fish	Longfin Bannerfish
Unknown Butterflyfish	Long-Beaked Coral Fish
Other Butterflyfish	Ocellated Butterflyfish
Golden Rabbitfish	Spadefish
Virgate Rabitfish	Golden Rabbitfish
Java Rabbitfish	Virgate Rabitfish
Dusky Rabbitfish	Java Rabbitfish
Scatfish	Dusky Rabbitfish
Sergeant Fish sp.	Scatfish
Spanish Flag Snapper	Sergeant Fish sp.
Black-Spot Snapper	Spanish Flag Snapper
Other Snapper	Black-Spot Snapper
Monogram Monocle Bream	Brown stripes Snapper
Whitecheek Monocle Bream	One spot Snapper
Whitestreak Monocle Bream	Other Snapper
Other Bream	Monogram Monocle Bream
Emperor	Whitecheek Monocle Bream
Other Trevally	Other Bream
Jacks	Emperor
Mullet	Big Eye Trevally
Fusilier	Jacks
Orange-Spotted Grouper	Mullet
Blue-Lined Grouper	Great Barracuda
Chocolate Grouper	Yellowtail Barracuda
Honeycomb Grouper	Obtus Barracuda
Unknown Grouper	Fusilier
Doublebanded Soapfish	Orange-Spotted Grouper
Gold Spotted Sweetlips	Blue-Lined Grouper
Cleaner Wrasse	Chocolate Grouper
Weedy Surge Wrasse	Peacock Grouper
Other Wrasse	Honeycomb Grouper
Sweeper	Square-Tail Grouper
Cardinalfish	Gold Spotted Sweetlips
Toadfish	Cleaner Wrasse
Catfish	Weedy Surge Wrasse
Needlefish	Other Wrasse
Boxfish	Sweeper
Filefish	Squirrelfish / Soldierfish
Seahorse	Cardinalfish
Carpet Blenny Eel	Toadfish
	Needlefish
	Filefish
	Porcupinefish
	Seahorse
	Carpet Blenny Eel
	Herring Scad
	Other Scad
	Whiptail

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

2016	**2017**
Feather Duster Worm	Feather Duster Worm
Christmas Tree Worm	Christmas Tree Worm
Flatworm	Flatworm
True Crab	True Crab
Blue Swimmer Crab	Cowrie
Conch	Drupella
Cowrie	Top Shell
Drupella	Turbo
Top Shell	Nudibranch
Nudibranch	Giant Clam
Other Gastropods	Boring Bivalves
Boring Bivalves	Diadema Sea Urchin
Octopus	Pencil Urchin
Feather Star	
Diadema Sea Urchin	
Pencil Urchin	
Collector Urchin	

Fish species/groups added to, and removed from, the MCC species monitoring list for the 2017 monitoring year.

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

Additions	**Removals**
Ocellated Butterflyfish	Moray Eel
Brown stripes Snapper	
One spot Snapper	
Obtus Barracuda	
Herring Scad	
Other Scad	
Whiptail	
Gurnard	
Pipefish	
Shark Sucker	
Razorfish	

Invertebrate species/groups added to, and removed from, the MCC species monitoring list for the 2017 monitoring year.

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

Additons	Removals
Turbo	
Sea Hare	

The additional substrate type included for the 2017 monitoring year was 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* (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 between 2016 and 2017. 0 = none, 1 = low (1 piece), 2 = medium (2-4 pieces) and 3 = high (5+ pieces).

Impact Type	2016	2017
Coral damage: boat/anchor	0	0
Coral damage: dynamite	0	0
Coral damage: other	1	1
Coral predation	2	2
Trash: fishing gear	1	1
Trash: general	1	1

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

Impact Type	East	West
Coral damage: boat/anchor	0	0
Coral damage: dynamite	0	0
Coral damage: other	1	1
Coral predation	2	2
Trash: fishing gear	0	1
Trash: general	0	1

Bleaching and Disease

Table C3: Average percent of bleached and diseased corals within the population and per affected individual corals, between 2016 and 2017.

Scope	Impact	Year	Mean	SD	SE
Mean % of population	Bleaching	2016	0.28	0.31	0.04
		2017	0.01	0.02	0.00
	Disease	2016	0.08	0.07	0.01
		2017	0.03	0.11	0.02
Mean % of individul	Bleachng	2016	0.26	0.24	0.04
		2017	0.02	0.09	0.01
	Disease	2016	0.12	0.14	0.02
		2017	0.05	0.14	0.02

Table C4: Paired t-test outputs for average percent of bleached corals per population and bleaching per individually affected corals between 2016 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
% population			% individual		
	2016	*2017*		*2016*	*2017*
Mean	0.2823125	0.006875	Mean	0.26041667	0.02458333
Variance	0.09556035	0.00050279	Variance	0.05918174	0.00781684
Observations	48	48	Observations	48	48
df	47		df	47	
t Stat	6.11301454		t Stat	5.98101464	
P(T<=t) two-tail	1.8151E-07		P(T<=t) two-tail	2.8757E-07	
t Critical two-tail	2.01174051		t Critical two-tail	2.01174051	

Table C5: Paired t-test outputs for average percent of bleached corals per population and bleaching per individually affected corals between 2016 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
% population			% individual		
	2016	*2017*		*2016*	*2017*
Mean	0.0784375	0.02541667	Mean	0.12375	0.04791667
Variance	0.00435229	0.01285514	Variance	0.02099415	0.02084663
Observations	48	48	Observations	48	48
df	47		df	47	
t Stat	2.73840978		t Stat	2.62990637	
P(T<=t) two-tail	0.00869303		P(T<=t) two-tail	0.01150881	
t Critical two-tail	2.01174051		t Critical two-tail	2.01174051	

Table C6: Average percent of bleached and diseased corals within the population and per individual corals, between East and West sites, 2017.

Scope	Impact	Year	Mean	SD	SE
Mean % of population	Bleaching	East	0.01	0.02	0.00
		West	0.01	0.03	0.01
	Disease	East	0.00	0.00	0.00
		West	0.05	0.16	0.03
Mean % of individul	Bleachng	East	0.03	0.10	0.02
		West	0.02	0.07	0.01
	Disease	East	0.04	0.14	0.03
		West	0.05	0.15	0.03

Table C7: Two-sample t-test outputs for average percent of bleached corals per population and bleaching per individually affected corals East and West sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
% population			% individual		
	East	*West*		*East*	*West*
Mean	0.00541667	0.00833333	Mean	0.02833333	0.02083333
Variance	0.00022591	0.0007971	Variance	0.01074493	0.00519928
Observations	24	24	Observations	24	24
df	46		df	46	
t Stat	-0.4467382		t Stat	0.29098157	
P(T<=t) two-tail	0.65716036		P(T<=t) two-tail	0.77237342	
t Critical two-tail	2.0128956		t Critical two-tail	2.0128956	

Table C8: Two-sample t-test outputs for average percent of diseased corals per population and bleaching per individually affected corals East and West sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
% population			% individual		
	East	*West*		*East*	*West*
Mean	0.00083333	0.05	Mean	0.04166667	0.05416667
Variance	7.971E-06	0.025	Variance	0.01992754	0.02259058
Observations	24	24	Observations	24	24
df	46		df	46	
t Stat	-1.5231307		t Stat	-0.296981	
P(T<=t) two-tail	0.13457178		P(T<=t) two-tail	0.76781798	
t Critical two-tail	2.0128956		t Critical two-tail	2.0128956	

Substrate

Between Years

Table C9: Total average percent cover of substrates between 2016 and 2017.

Substrate	2016			2017		
	Mean	SD	SE	Mean	SD	SE
HC	42.83%	0.24	0.04	41.91%	0.21	0.03
SC	0.00%	0.00	0.00	0.00%	0.00	0.00
RKC	0.28%	0.01	0.00	0.20%	0.01	0.00
NIA	6.25%	0.08	0.01	1.58%	0.03	0.00
SP	6.66%	0.04	0.01	9.11%	0.05	0.01
RC	11.57%	0.07	0.01	11.64%	0.06	0.01
RB	1.68%	0.03	0.00	3.21%	0.04	0.01
SD	2.35%	0.03	0.00	7.17%	0.07	0.01
SI	0.00%	0.00	0.00	0.05%	0.00	0.00
ZO	25.19%	0.19	0.03	23.83%	0.13	0.02
OT	1.73%	0.03	0.00	0.26%	0.01	0.00
SG	NA			0.00%	0.00	0.00

Table C10: Paired t-test outputs for average percent cover of hard corals, nutrient indicator algae, sponge, rock, coral rubble, sand, zoanthids, and other substrates between 2016 and 2017.

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
Hard Coral			Nutrient Indicator Algae			Sponge			Rock		
	2016	*2017*		*2016*	*2017*		*2016*	*2017*		*2016*	*2017*
Mean	0.4359375	0.42395833	Mean	0.06354167	0.01510417	Mean	0.0671875	0.09166667	Mean	0.115625	0.1171875
Variance	0.05550283	0.04624889	Variance	0.00606272	0.00089733	Variance	0.00202543	0.00288121	Variance	0.00480386	0.00404671
Observations	48	48	Observations	48	48	Observations	48	48	Observations	48	48
df	47		df	47		df	47		df	47	
t Stat	0.49267561		t Stat	4.27768419		t Stat	-2.9356707		t Stat	-0.1065103	
P(T<=t) two-tail	0.62453567		P(T<=t) two-tail	9.1929E-05		P(T<=t) two-tail	0.00513726		P(T<=t) two-tail	0.91563084	
t Critical two-tail	2.01174051		t Critical two-tail	2.01174051		t Critical two-tail	2.01174051		t Critical two-tail	2.01174051	
t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
Coral Rubble			Sand			Zoanthid			Other		
	2016	*2017*		*2016*	*2017*		*2016*	*2017*		*2016*	*2017*
Mean	0.0171875	0.03229167	Mean	0.02395833	0.071875	Mean	0.25625	0.2421875	Mean	0.01770833	0.00260417
Variance	0.0009882	0.00148825	Variance	0.0012223	0.00464428	Variance	0.03783245	0.0178233	Variance	0.00066379	0.00013935
Observations	48	48	Observations	48	48	Observations	48	48	Observations	48	48
df	47		df	47		df	47		df	47	
t Stat	-2.7178748		t Stat	-5.107758		t Stat	0.67691554		t Stat	3.54629399	
P(T<=t) two-tail	0.0091716		P(T<=t) two-tail	5.8381E-06		P(T<=t) two-tail	0.50177777		P(T<=t) two-tail	0.0008972	
t Critical two-tail	2.01174051		t Critical two-tail	2.01174051		t Critical two-tail	2.01174051		t Critical two-tail	2.01174051	

Between Sites

Table C11: Average percent cover of substrates between East and West sites, during 2017.

Substrate	East			West		
	Mean	SD	SE	Mean	SD	SE
HC	25.10%	0.07	0.01	59.69%	0.17	0.03
SC	0.00%	0.00	0.00	0.00%	0.00	0.00
RKC	0.10%	0.01	0.00	0.31%	0.01	0.00
NIA	2.19%	0.03	0.01	0.83%	0.03	0.01
SP	9.79%	0.06	0.01	8.54%	0.04	0.01
RC	13.33%	0.07	0.01	10.10%	0.05	0.01
RB	5.52%	0.04	0.01	0.94%	0.02	0.00
SD	9.79%	0.07	0.01	4.58%	0.06	0.01
SI	0.10%	0.01	0.00	0.00%	0.00	0.00
ZO	33.96%	0.09	0.02	14.48%	0.09	0.02
OT	0.00%	0.00	0.00	0.52%	0.02	0.00
SG	0.00%	0.00	0.00	0.00%	0.00	0.00

Table C12: Two-sample t-test outputs for average percent cover of hard corals, nutrient indicator algae, sponge, rock, coral rubble, sand, zoanthids, and other substrates between East and West sites, 2017.

t-Test: Two-Sample Assuming Equal Variances		
Hard Coral		
	East	*West*
Mean	0.25104167	0.596875
Variance	0.00480865	0.02729959
Observations	24	24
df	46	
t Stat	-9.4550581	
P(T<=t) two-tail	2.345E-12	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Nutrient Indicator Algae		
	East	*West*
Mean	0.021875	0.00833333
Variance	0.00110394	0.00063406
Observations	24	24
df	46	
t Stat	1.59130373	
P(T<=t) two-tail	0.11839098	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Sponge		
	East	*West*
Mean	0.09791667	0.08541667
Variance	0.00396286	0.0018433
Observations	24	24
df	46	
t Stat	0.80365778	
P(T<=t) two-tail	0.42572821	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Rock		
	East	*West*
Mean	0.13333333	0.10104167
Variance	0.00519928	0.00252604
Observations	24	24
df	46	
t Stat	1.79985669	
P(T<=t) two-tail	0.07844364	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Coral Rubble		
	East	*West*
Mean	0.05520833	0.009375
Variance	0.00157495	0.00037024
Observations	24	24
df	46	
t Stat	5.09102248	
P(T<=t) two-tail	6.4725E-06	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Sand		
	East	*West*
Mean	0.09791667	0.04583333
Variance	0.00456069	0.00351449
Observations	24	24
df	46	
t Stat	2.83941096	
P(T<=t) two-tail	0.00670797	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Zoanthid		
	East	*West*
Mean	0.33958333	0.14479167
Variance	0.00820199	0.00842278
Observations	24	24
df	46	
t Stat	7.40113158	
P(T<=t) two-tail	2.2878E-09	
t Critical two-tail	2.0128956	

t-Test: Two-Sample Assuming Equal Variances		
Other		
	East	*West*
Mean	0	0.00520833
Variance	0	0.00027061
Observations	24	24
df	46	
t Stat	-1.5510828	
P(T<=t) two-tail	0.12773541	
t Critical two-tail	2.0128956	

Fish

Species Totals

Table C13: Total mean fish species/group abundances (including pier data) per 100m^2 during 2016 and 2017.

Fish	2016			2017		
	Mean	SD	SE	Mean	SD	SE
Butterflyfish total	5.29	4.09	0.57	4.52	3.42	0.44
Spadefish	0.00	0.00	0.00	0.03	0.18	0.02
Rabbitfish total	18.92	34.42	4.77	22.45	35.16	4.54
Scatfish	1.08	2.58	0.36	2.78	7.68	0.99
Sergeant Fish sp.	18.59	8.11	1.13	38.58	49.87	6.44
Snapper total	7.55	14.49	2.01	23.10	54.09	6.98
Bream total	1.90	2.01	0.28	1.63	2.99	0.39
Emperor	0.41	1.04	0.14	1.32	2.11	0.27
Big Eye Trevally	0.00	0.00	0.00	0.28	1.03	0.13
Other Trevally	0.35	1.63	0.23	0.00	0.00	0.00
Jacks	1.31	3.00	0.42	1.62	4.77	0.62
Mullet	1.27	5.01	0.69	2.28	6.45	0.83
Great Barracuda	0.00	0.00	0.00	0.03	0.18	0.02
Yellowtail Barracuda	0.00	0.00	0.00	0.17	1.29	0.17
Obtus Barracuda	0.00	0.00	0.00	0.83	6.45	0.83
Fusilier	1.84	4.11	0.57	4.35	10.95	1.41
Grouper total	1.12	1.13	0.16	1.00	1.22	0.16
Doublebanded Soapfish	0.02	0.14	0.02	0.00	0.00	0.00
Gold Spotted Sweetlips	0.14	0.60	0.08	0.33	1.05	0.14
Wrasse total	6.63	3.77	0.52	1.60	2.16	0.28
Sweeper	32.04	70.71	9.81	3.97	17.07	2.20
Squirrelfish / Soldierfish	0.00	0.00	0.00	0.02	0.13	0.02
Cardinalfish	34.53	57.30	7.95	22.08	31.63	4.08
Toadfish	0.02	0.14	0.02	0.03	0.18	0.02
Catfish	0.04	0.20	0.03	0.00	0.00	0.00
Needlefish	4.71	21.95	3.04	1.28	6.13	0.79
Boxfish	0.08	0.27	0.04	0.00	0.00	0.00
Filefish	0.57	0.98	0.14	0.47	1.00	0.13
Porcupinefish	0.00	0.00	0.00	0.05	0.29	0.04
Seahorse	0.02	0.14	0.02	0.13	0.43	0.06
Carpet Blenny Eel	0.88	0.91	0.13	0.37	0.55	0.07
Total Scad	0.00	0.00	0.00	2.05	9.35	1.21
Whiptail	0.00	0.00	0.00	0.03	0.18	0.02

Table C14: Two-sample t-test outputs for total average abundances of fish species/groups (including pier data) between 2016 and 2017.

t-Test: Two-Sample Assuming Equal Variances		
Butterflyfish		
	2016	*2017*
Mean	5.29411765	4.51666667
Variance	16.7317647	11.6776836
Observations	51	60
df	109	
t Stat	1.09111166	
P(T<=t) two-tail	0.27762979	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Scatfish		
	2016	*2017*
Mean	1.07843137	2.78333333
Variance	6.67372549	59.0539548
Observations	51	60
df	109	
t Stat	-1.5125207	
P(T<=t) two-tail	0.13329548	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Snapper		
	2016	*2017*
Mean	7.54901961	23.1
Variance	210.012549	2925.75254
Observations	51	60
df	109	
t Stat	-1.9920596	
P(T<=t) two-tail	0.04886493	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Bream		
	2016	*2017*
Mean	1.90196078	1.63333333
Variance	4.05019608	8.9480226
Observations	51	60
df	109	
t Stat	0.54484084	
P(T<=t) two-tail	0.58697601	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Emperor		
	2016	*2017*
Mean	0.41176471	1.31666667
Variance	1.08705882	4.45734463
Observations	51	60
df	109	
t Stat	-2.7845444	
P(T<=t) two-tail	0.00632168	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Jack		
	2016	*2017*
Mean	1.31372549	1.61666667
Variance	9.01960784	22.7827684
Observations	51	60
df	109	
t Stat	-0.3919392	
P(T<=t) two-tail	0.69586836	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Mullet		
	2016	*2017*
Mean	1.2745098	2.28333333
Variance	25.0831373	41.5624294
Observations	51	60
df	109	
t Stat	-0.9083538	
P(T<=t) two-tail	0.36569532	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Fusilier		
	2016	*2017*
Mean	1.84313725	4.35
Variance	16.854902	119.960169
Observations	51	60
df	109	
t Stat	-1.5440793	
P(T<=t) two-tail	0.12546753	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Grouper		
	2016	*2017*
Mean	1.11764706	1
Variance	1.26588235	1.49152542
Observations	51	60
df	109	
t Stat	0.52430322	
P(T<=t) two-tail	0.60113225	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Wrasse		
	2016	*2017*
Mean	6.62745098	1.6
Variance	14.2384314	4.65084746
Observations	51	60
df	109	
t Stat	8.77507935	
P(T<=t) two-tail	2.6266E-14	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Needlefish		
	2016	*2017*
Mean	4.70588235	1.28333333
Variance	482.011765	37.5624294
Observations	51	60
df	109	
t Stat	1.15650055	
P(T<=t) two-tail	0.25000488	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Filefish		
	2016	*2017*
Mean	0.56862745	0.46666667
Variance	0.97019608	0.99887006
Observations	51	60
df	109	
t Stat	0.53920797	
P(T<=t) two-tail	0.59084306	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Carpet Eel Blenny		
	2016	*2017*
Mean	0.88235294	0.36666667
Variance	0.82588235	0.3039548
Observations	51	60
df	109	
t Stat	3.6731319	
P(T<=t) two-tail	0.0003731	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Rabbitfish		
	2016	*2017*
Mean	18.9215686	22.45
Variance	1184.43373	1236.01441
Observations	51	60
df	109	
t Stat	-0.5320669	
P(T<=t) two-tail	0.59576249	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Sergeant fish		
	2016	*2017*
Mean	18.5882353	38.5833333
Variance	65.8470588	2487.33192
Observations	51	60
df	109	
t Stat	-2.8296019	
P(T<=t) two-tail	0.00554944	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Sweeper		
	2016	*2017*
Mean	32.0392157	3.96666667
Variance	4999.75843	291.388701
Observations	51	60
df	109	
t Stat	2.97709345	
P(T<=t) two-tail	0.00358595	
t Critical two-tail	1.98196749	

t-Test: Two-Sample Assuming Equal Variances		
Cardinalfish		
	2016	*2017*
Mean	34.52941176	22.08333333
Variance	3282.774118	1000.213277
Observations	51	60
df	109	
t Stat	1.444259744	
P(T<=t) two-tail	0.151534279	
t Critical two-tail	1.98196749	

Combined Total Abundance

Table C15: Total mean fish abundance (including pier data) per 100m^2 between 2016 and 2017.

Year	Mean	SD	SE
2016	139.39	139.38	19.52
2017	108.63	98.54	12.72

Table C16: Two-sample t-test output for total mean fish abundance (including pier data) between 2016 and 2017.

t-Test: Two-Sample Assuming Equal Variances		
	2016	*2017*
Mean	139.392157	108.633333
Variance	19427.7231	9709.69379
Observations	51	60
df	109	
t Stat	1.35682004	
P(T<=t) two-tail	0.17764171	
t Critical two-tail	1.98196749	

Table C17: Total mean fish abundance per 100m^2 between East and West sites, 2017.

Site	Mean	SD	SE
East	146.96	92.23	18.83
West	45.75	30.22	6.17

Table C18: Two-sample t-test output for total mean fish abundance between East and West sites.

t-Test: Two-Sample Assuming Equal Variances		
	East	*West*
Mean	146.958333	45.75
Variance	8506.38949	912.978261
Observations	24	24
df	46	
t Stat	5.10870726	
P(T<=t) two-tail	6.098E-06	
t Critical two-tail	2.0128956	

Invertebrates

Species Totals

Table C19: Total mean invertebrate species/group abundance per 100m^2 during 2016 and 2017.

Invertebrates	2016			2017		
	Mean	SD	SE	Mean	SD	SE
Feather Duster Worm	0.41	0.97	0.14	0.11	0.37	0.05
Christmas Tree Worm	29.30	33.49	4.83	10.07	12.39	1.79
Flatworm	0.30	0.87	0.13	0.07	0.24	0.04
True Crab	0.84	0.86	0.12	0.59	0.74	0.11
Blue Swimmer Crab	0.09	0.35	0.05	0.00	0.00	0.00
Conch	0.02	0.14	0.02	0.00	0.00	0.00
Cowrie	0.05	0.20	0.03	0.02	0.14	0.02
Drupella	5.73	8.76	1.26	0.20	0.70	0.10
Top Shell	2.39	5.38	0.78	1.02	1.29	0.19
Nudibranch	0.91	1.28	0.18	0.70	1.15	0.17
Turbo/Other Gastropods	7.18	4.42	0.64	3.27	3.37	0.49
Giant Clam	0.00	0.00	0.00	0.02	0.14	0.02
Boring Bivalves	49.84	49.48	7.14	24.89	32.12	4.64
Octopus	0.09	0.28	0.04	0.00	0.00	0.00
Feather Star	0.02	0.14	0.02	0.00	0.00	0.00
Diadema Sea Urchin	55.55	70.55	10.18	24.82	22.04	3.18
Pencil Urchin	0.95	3.56	0.51	0.18	0.67	0.10
Collector Urchin	0.64	2.05	0.30	0.00	0.00	0.00

Table C20: Two-sample t-test outputs for total average abundances of invertebrate species/groups that were present between 2016 and 2017.

t-Test: Paired Two Sample for Means		
Feather Duster Worm		
	2016	*2017*
Mean	0.4375	0.10416667
Variance	0.93218085	0.13785461
Observations	48	48
df	47	
t Stat	2.18162638	
P(T<=t) two-tail	0.03417257	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Christmas Tree Worm		
	2016	*2017*
Mean	31.3125	10.9166667
Variance	1121.70878	153.48227
Observations	48	48
df	47	
t Stat	5.22530796	
P(T<=t) two-tail	3.9117E-06	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Flatworm		
	2016	*2017*
Mean	0.375	0.0625
Variance	0.75	0.05984043
Observations	48	48
df	47	
t Stat	2.33775882	
P(T<=t) two-tail	0.02370837	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
True Crab		
	2016	*2017*
Mean	0.77083333	0.5625
Variance	0.73359929	0.54920213
Observations	48	48
df	47	
t Stat	1.80913805	
P(T<=t) two-tail	0.07682804	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Drupella		
	2016	*2017*
Mean	5.25	0.1875
Variance	76.6595745	0.49601064
Observations	48	48
df	47	
t Stat	4.12086117	
P(T<=t) two-tail	0.00015198	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Top Shell		
	2016	*2017*
Mean	2.1875	0.95833333
Variance	28.9215426	1.65780142
Observations	48	48
df	47	
t Stat	1.61893206	
P(T<=t) two-tail	0.11215379	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Turbo/other gastropod		
	2016	*2017*
Mean	6.89583333	3.125
Variance	19.4995567	11.3457447
Observations	48	48
df	47	
t Stat	7.01170378	
P(T<=t) two-tail	7.8462E-09	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Nudibranch		
	2016	*2017*
Mean	0.83333333	0.66666667
Variance	1.63120567	1.33333333
Observations	48	48
df	47	
t Stat	0.7457969	
P(T<=t) two-tail	0.45950403	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Boring Bivalves		
	2016	*2017*
Mean	53.9583333	29.375
Variance	2448.72163	1031.51596
Observations	48	48
df	47	
t Stat	5.67770271	
P(T<=t) two-tail	8.2478E-07	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Diadema Sea Urchin		
	2016	*2017*
Mean	67.0833333	27.4375
Variance	4976.63121	485.740691
Observations	48	48
df	47	
t Stat	4.8123931	
P(T<=t) two-tail	1.5816E-05	
t Critical two-tail	2.01174051	

t-Test: Paired Two Sample for Means		
Pencil Urchin		
	2016	*2017*
Mean	0.875	0.1875
Variance	12.6648936	0.45345745
Observations	48	48
df	47	
t Stat	1.3048083	
P(T<=t) two-tail	0.1983109	
t Critical two-tail	2.01174051	

Combined Total Abundance

Table C21: Total mean invertebrate abundance per 100m^2 between 2016 and 2017.

Year	Mean	SD	SE
2016	170.81	137.04	19.78
2017	73.63	55.63	8.03

Table C22: Paired t-test output for total mean invertebrate abundance between 2016 and 2017.

t-Test: Paired Two Sample for Means		
	2016	*2017*
Mean	170.8125	73.625
Variance	18779.8152	3095.13298
Observations	48	48
df	47	
t Stat	7.20151513	
P(T<=t) two-	4.0466E-09	
t Critical two	2.01174051	

Table C23: Total mean invertebrate abundance per 100m^2 between East and West sites, 2017.

Year	Mean	SD	SE
East	24.79	19.15	3.91
West	122.46	31.33	6.39

Table C24: Two-sample t-test output for total mean invertebrate abundance between East and West sites, 2017.

t-Test: Two-Sample Assuming Equal Variances		
	East	*West*
Mean	24.7916667	122.458333
Variance	366.693841	981.389493
Observations	24	24
df	46	
t Stat	-13.031476	
P(T<=t) two-tail	4.7554E-17	
t Critical two-tail	2.0128956	

Herbivore Abundance

Totals Between Years

Table C25: Average herbivorous fish and urchin abundances per 100m^2 between 2015 and 2017.

Herbivore	2016			2017		
	Mean	SD	SE	Mean	SD	SE
Fish	37.51	36.78	5.15	61.03	73.94	9.55
Urchins	68.54	71.15	10.27	27.63	22.18	3.20

Table C26: Two-sample t-test outputs for total average herbivorous fish and urchin abundances between 2016 and 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Paired Two Sample for Means		
Herbivorous Fish			**Urchin**		
	2016	*2017*		*2016*	*2017*
Mean	37.5098039	61.0333333	Mean	68.5416667	27.625
Variance	1352.8149	5467.08362	Variance	5062.08333	491.81383
Observations	51	60	Observations	48	48
df	109		df	47	
t Stat	-2.0642964		t Stat	4.92418005	
P(T<=t) two-tail	0.04136346		P(T<=t) two-tail	1.0865E-05	
t Critical two-tail	1.98196749		t Critical two-tail	2.01174051	

Table C27: Two-sample t-test outputs for total average herbivorous fish abundance compared with average urchin abundance for 2016 and 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
	Fish	Urchin		Fish	Urchin
	2016	*2016*		*2017*	*2017*
Mean	37.5098039	68.5416667	Mean	61.0333333	27.625
Variance	1352.8149	5062.08333	Variance	5467.08362	491.81383
Observations	51	48	Observations	60	48
df	97		df	106	
t Stat	-2.7493784		t Stat	3.0210594	
P(T<=t) two-tail	0.00712248		P(T<=t) two-tail	0.00315748	
t Critical two-tail	1.98472319		t Critical two-tail	1.98259726	

Table C28: Average herbivorous fish and urchin abundances per 100m^2 between East and West sites, 2017.

Herbivore	East			West		
	Mean	SD	SE	Mean	SD	SE
Fish	60.96	49.64	10.13	23.83	11.27	2.30
Urchins	13.00	18.93	3.87	42.25	14.15	2.89

Table C29: Two-sample t-test outputs for total average herbivorous fish and urchin abundances between East and West sites, 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
Herbivorous Fish			**Urchin**		
	East	*West*		*East*	*West*
Mean	60.9583333	23.8333333	Mean	13	42.25
Variance	2464.38949	126.927536	Variance	358.521739	200.108696
Observations	24	24	Observations	24	24
df	46		df	46	
t Stat	3.57282553		t Stat	-6.0627435	
P(T<=t) two-tail	0.00084194		P(T<=t) two-tail	2.3317E-07	
t Critical two-tail	2.0128956		t Critical two-tail	2.0128956	

Table C30: 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		
	Fish	Urchin		Fish	Urchin
	East	*East*		*West*	*West*
Mean	60.9583333	13	Mean	23.8333333	42.25
Variance	2464.38949	358.521739	Variance	126.927536	200.108696
Observations	24	24	Observations	24	24
df	46		df	46	
t Stat	4.42202397		t Stat	-4.9890598	
P(T<=t) two-tail	5.9328E-05		P(T<=t) two-tail	9.119E-06	
t Critical two-tail	2.0128956		t Critical two-tail	2.0128956	

Species Richness

Totals Between Years

Table C31: Average species richness per $100m^2$, for fish and invertebrates, during 2016 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 C32: Two-sample t-test outputs for average fish and invertebrate species richness per 100m², between 2016 and 2017.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Paired Two Sample for Means		
Fish			**Invertebrates**		
	2016	*2017*		*2016*	*2017*
Mean	12.8039216	11.55	Mean	6.75	4.6875
Variance	11.2407843	26.0483051	Variance	2.14893617	2.47473404
Hypothesized Mean	0		Hypothesized Mean	0	
df	109		df	47	
t Stat	1.50033447		t Stat	6.9130251	
P(T<=t) two-tail	0.13641887		P(T<=t) two-tail	1.1075E-08	
t Critical two-tail	1.98196749		t Critical two-tail	2.01174051	

Between Sites

Table C33: Total average species richness per 100m², between East and West sites, 2017.

Group	East			West		
	Mean	SD	SE	Mean	SD	SE
Fish	13.88	2.98	0.61	8.21	3.81	0.78
Invertebrates	4.92	1.56	0.32	4.46	1.59	0.32

Table C34: Two-sample t-test outputs for average fish and invertebrate species richness per 100m², between East and West sites.

t-Test: Two-Sample Assuming Equal Variances			t-Test: Two-Sample Assuming Equal Variances		
Fish			**Invertebrates**		
	East	*West*		*East*	*West*
Mean	13.875	8.20833333	Mean	4.91666667	4.45833333
Variance	8.89673913	14.5199275	Variance	2.42753623	2.51992754
Observations	24	24	Observations	24	24
df	46		df	46	
t Stat	5.73681375		t Stat	1.00947543	
P(T<=t) two-tail	7.1696E-07		P(T<=t) two-tail	0.31802738	
t Critical two-tail	2.0128956		t Critical two-tail	2.0128956	