Koh Seh Marine Environmental Assessment, Kep Province, Cambodia

Photo credit: Liger Learning Center

Marine Conservation Cambodia

December 2016

A school of mullet at the north-eastern reef of Koh Seh, Kep Province, Cambodia (Brayden Cockerell, July 2016).

In partnership with:

The Fisheries Administration

Report by:

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I. Executive summary

In early 2014, the Kep Provincial government requested that Marine Conservation Cambodia (MCC) undertake annual marine assessments of the coral reefs within a geographical triangle encompassing the Kep Archipelagic islands of Koh Seh, Koh Mak Prang and Koh Angkrong. The purpose is to gain knowledge of the distribution and ecology of the reefs surrounding these islands. This report forms the third in the series of scientific assessments on the coral reef ecosystem of Koh Seh. From March to May 2016, MCC surveyors assessed five survey sites using an adapted and more in-depth version of the globally recognized Reef Check methodology (Hodgson *et al.* 2006).

The regeneration of the marine environment surrounding Koh Seh is evidence of the benefits of Cambodian fisheries law imposition, predominantly through the halting of illegal and destructive fishing methods. In saying this, environmentally damaging fishing techniques are still continuing, thought on a much lesser scale, within Koh Seh’s marine bioregion, and are still widespread throughout the Kep Archipelago.

The increased rate of rehabilitation is most notable at Koh Seh’s eastern reef, where substantial increases in fish populations and species previously unrecorded on this reef were found. The western reef of Koh Seh has also experienced increases in fish density and species richness, however, these increases were lower than those of the eastern reef. There wasa large increase in fish species abundance and richness between 2015 and 2016, relative to between 2014 and 2015 (MCC 2014; 2015). This is likely due to a time lag (snow ball effect) between initial protection (December 2013) and a noteworthy level of recovery. Surveys within MCC’s targeted conservation area, the eastern reef (and pier), revealed a large increase in fish biodiversity (nine newly recorded species) and moderate increases in fish abundance (four significant increases), relative to 2015 data. Of the nine new species recorded on Koh Seh’s eastern reef, only three were recorded on the western reef. Invertebrate surveys revealed a lack of species richness, as both the eastern and western reefs were dominated by a small number of species that are still regularly and unsustainably harvested by local fishers.

Overall, greater ecosystem health was observed at Koh Seh's eastern reef compared to the western reef. It is highly likely that the difference between the two reefs is directly related to the level of illegal and destructive fishing, of which the western reef experiences more. MCC’s legislated 300m by 150m conservation zone encompasses the majority of the eastern reef, within which MCC actively collaborate with the FIA to apply Cambodian fisheries laws.

The western reef is outside of this area and thus experiences a relatively lower level of protection against fishing vessels using illegal, unsustainable or destructive techniques. Important predator (grouper (*Serranidae* family)) and herbivore (rabbitfish (*Siganidae* family)) populations have increased and pelagic fish are returning to Koh Seh (e.g. trevally and jacks *Carangidae family*). Larger conservation areas are therefore required to facilitate the population increase of these important ecological and commercial species, which will lead to greater trophic stability and algae regulation, thereby improving ecosystem integrity.

Expansion of conservation efforts and areas, together with stricter fisheries law enforcement, are required in order to establish a healthy and productive marine bioregion encompassing Koh Seh. The higher fish density and diversity near Koh Seh has captured the attention of an increasing number of Khmer and Vietnamese fishers. By their own admission, Koh Seh contains a greater diversity and abundance of commercial fish species than anywhere else in Kep Province. MCC welcomes sustainable fishers, who are the main beneficiary of MCC's conservation efforts. Unfortunately, many fishers are still utilising destructive fishing gear, particularly trawling nets. This greatly hampers MCC's ability to rehabilitate Koh Seh's marine ecosystems, meaning these ecosystems can't achieve high functionality and productivity. This could be obtained through effective fisheries law enforcement and the implementation of the Kep first Marine Fishery Management Area in May 2017. This MFMA will be invaluable in delivering the protection desperately needed to induce restoration of Kep Province's marine ecosystems and greatly improve the livelihood of the coastal communities.

II. Acknowledgements

Marine Conservation Cambodia (MCC) has been working towards environmental conservation and securing community livelihoods in partnership with the Royal Government of Cambodia Fisheries Administration (RGC FiA), local authorities and coastal communities since 2008. Close collaboration with the provincial and national FiA, government bodies, local stakeholders and international institutions is the key to MCC's success.

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III. Research Team

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V. List of Abbreviations and Acronyms

FiA	Fisheries Administration
MCC	Marine Conservation Cambodia
MFMA	Marine Fisheries Management Area
PS	Per 20-meter Segment
RGC	Royal Government of Cambodia
USD	United States Dollar

Substrates:

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

1 Introduction

Coastal and marine ecosystems across the globe are sustaining critical damage from activities such as unsustainable fishing practices, lack of waste management infrastructure, and unchecked coastal development (van-Bochove *et al.* 2011). Global fisheries landings have been declining since the 1980s, due to shortages of fish stocks; this trend, in combination with a low degree of marine protection, virtually guarantee the collapse of more fish stocks (Pauly *et al.* 2002).

The nations bordering the South China Sea are home to over 5% of the world's human population (Talaue-McManus 2000), much of whom heavily rely upon the marine resources and services provided by this sea. These resources include seafood productionandemployment in fisheriesand tourism industries.The sea also provides ecological services including mitigation of coastal erosion, water filtration, carbon sequestration and roles in various nutrient cycles (carbon, nitrogen, phosphorus, etc.).

Human impacts including destructive fishing, overfishing, sedimentation, pollution (nutrient enrichment and contamination) and physical damage (anchors, boats etc.), are resulting in habitat destruction and rapid loss of biodiversity in Cambodia's marine environment (van-Bochove *et al.* 2011) and throughout the South China Sea. In Cambodia, the main consequences of this are the loss of ecosystem services (e.g. coastal protection and water filtration), reduced economic benefits for small-scale fishers and commercial fishing industries, decreased tourism, and the detrimental economic impacts that follow these.Effective fisheries and ecosystem management is urgently required to regulate the human activitiesthatare directly or indirectly responsible for these consequences.

Cambodia hosts a diverse marine environment with highly valuable coral reef, seagrass and mangrove ecosystems. Coral reefs are complex and highly productive habitats that provide shelter and breeding grounds for a multitude of commercial and non-commercial marine species. Unfortunately, these ecosystems are highly susceptible to environmental alterations. Anthropogenic impacts such as destructive fishing activities (e.g. overfishing, trawling, anchoring, dynamite, poison, long-lines, small mesh nets etc.), nutrient loading (e.g. untreated waste input, agricultural run-off), and contamination can induce significant coral reef degradation (Pauly *et al.* 2002). In fact, due to destructive fishing techniques and overfishing, 90% of coral reef ecosystems in Cambodia are at high risk, whilst 10% are at very high risk, according to a threat index used by Rizvi & Singer (2011). Anthropogenic factors such as those listed above, are particularly present in the shallow fringing reefs of Kep's marine environment, and can also strongly exacerbate natural stressors such as seasonally high water temperatures, coral bleaching, disease and predation.

Given the vital importance of coral reefs as a habitat and shelter to many marine species that thrive in coral reefs and related ecosystems, including most of the commercially important species, these impacts have vast consequences (van-Bochove *et al.* 2011). An additional benefit of coral reefs is their ability to act as natural wave barriers, protecting coastal communities from the effects of coastal erosion and flooding. This may be critical in the near future, with increasingly violent storm surges caused by climate change potentially damaging fishing boats and communities. Defense against issues impacting coral reefs are an important aspect of the 2016 integrated coastal management plan for Kep Province. This management scheme aims to protect highly valuable shorelines including those crucially important to fishing communities, aquaculture projects and tourism development. Alleviating the anthropogenic stresses on coral reefs would provide a natural and affordable soft engineering solution to these physical problems.

Seagrass meadows are among the most diverse and highly productive coastal ecosystems in the world (Duarte *et al.* 2004). Seagrasses play an important role in the general health of their surrounding marine environment, primarily because of therange of ecological services they deliver. They are a key player in nutrient cycling of carbon, phosphorus and nitrogen. For instance, decaying seagrass enriches the surrounding water with detritus food and nutrients, both of which are fundamental inputs into productive marine ecosystems. Seagrasses are highly influential in ocean productivity, which refers to the production of organic matter by harvesting light to turn inorganic carbon into organic carbon (Sigman& Hain 2012). Fifteen percent of the carbon storage in the ocean can be attributed to seagrasse meadows, who also export, on average, 24.3% of their net production to adjacent ecosystems (Duarte 2002). Seagrasses function as a habitat, food supply and nursery ground for many different commercial and non-commercial species. The blades of seagrasses give juvenile fish and benthic invertebrates a place to hide from predators, while the habitat providesideal settling substrate for sessile organisms. This is important as greater juvenile survival results in population restoration, leading to enhanced ecosystem functionality. Commercial landings of seagrass-utilising species in the US in 2005 produced a net USD $126 million (Hughes *et al.* 2007). A locally important commercial species that utilises seagrass is the world-renowned blue swimmer crab (*Portunus pelagicus*). This species brings economic and livelihood benefits to

Kep Province as a whole, including coastal communities, fishers, tourism industries, restaurants and many other parties. Unfortunately, blue swimmer crabs are reducing in size and number, with a continuation of this trend posing a risk to commercial and small-scale fishers (Cane & Muong 2015).

On average, there is more than one threatened associated species for every seagrass species across the globe (Hughes *et al.* 2009). Seahorses (*Hippocampus* spp.)frequently use seagrass for camouflage and as a holdfast. Four species of seahorse (*Hippocampus kuda, H. monhikei, H. spinosissimus*and *H. trimaculatus*) can be found withinthe seagrass bed of eastern Koh Seh, which has the highest reported diversity of seahorse species in Cambodia (MCC unpublished data). Furthermore, schools of trevally and jacks (Carangidae family), which were previously quite rare, are now routinely seen by MCC divers within this seagrass bed.Seagrass habitat is an ideal foraging ground for mega-herbivores (Orth *et al.* 2006) such as dugongs and turtles. These highly valued species, both of which were previously sighted in Kep's waters, may return with genuine and long-termmarine conservation.A similar approach is required for the Irrawaddy dolphins that are still present in the Kep Archipelago, which face great risk from unsustainable anthropogenic actions (e.g. overfishing, destructive fishing, agricultural run-off and coastal development).

Cambodia's economy is largely dependent on its coastal and marine sector (Wheeler *et al*. 2000), and thus, on its coral reef and seagrass ecosystems. In addition to the ecological benefits described above (e.g. carbon sequestration, nutrient cycling, habitat, sediment stabilization), seagrasses present the potential for acquisition of finances from carbon credits.With the imminent threat of global warming, the expansion of seagrass beds would greatly contribute to reducing Cambodia's carbon footprint. Carbon credit revenue from seagrass ecosystems is a commonly overlooked opportunity. These ecosystems hold the potential for the development of 'payment for ecosystem service' (PES) schemes, which in conjunction with carbon credits, help to combat climate change, improve livelihoods and conserve seagrass (Hejnowicz *et al.* 2015). This should be a priority for Cambodia, given a recent prediction by J. Chevillard, of the Cambodia Climate Change Alliance and UN Development Program, that 'The Kingdom's GDP could decrease by 3.5% per year by 2050 if access to climate concerned finance is not a priority' (Chevillard 2014).Steps such as acquiring carbon credits will become increasingly necessary within Cambodia to both strengthen its economy whilst mitigating the impacts of climate change and ocean acidificationin the near future.

Coral reefs contribute to Cambodia's economy by providing marine resources that are essential to fishing industries and by drawing tourists to the region. In 2003, the net annual valueof coral reef ecosystems globally was USD$29.8 billion (Cesar *et al.* 2003), while sustainable coral reef fisheries in South-East Asia alone were valued in 2002 at over USD$2.4 billion per year (Burke *et al.* 2002).Under the best protection scenario, an estimation of the 2008 value of recreational opportunities related to coral reefs in Cambodia's Ream National Park, was up to USD$699,636 per km^2 of healthy coral reef ecosystem (Conservation International 2008). Kep Province, and coastal Cambodia as a whole, contains viable economic opportunities for further profit from coral reef ecosystems. These opportunities could be reachedthrough an increase in the stock of commercial marine species, which would generate more revenue for fishers and the local economy. Additionally, the expansion of tourism industrieswould provide alternative livelihood for illegal fishers, as well as small-scale fishers whose main fishery has collapsed due to unsustainable fishing practices.Underpinning this is the need for a greater level of protection against human impacts (especially illegal fishing), in doing so enabling habitat restoration, increasing fish diversity and density, and therefore a greater potential for the fisheries and the tourism market.

Coral reefs and seagrass meadows are useful indicators of ecosystem health, and will be among the first marine organisms to reflect any change in the intensity of anthropogenic impacts, thus forming ideal candidates for studying long-term environment trends (Bjork *et al.* 2008). The dramatic decline in coral reef and seagrass cover and health in Cambodian waters should be taken as a warning sign. This decline indicates the need for management actions aimed at decreasing anthropogenic stressors and preserving the vulnerable remaining coral reef and seagrass habitats.The primary cause of habitat decline in Kep Province, and throughout Cambodia, is repeated destructive fishing practices. In fact, a key finding of MCC and the Kep Fisheries Department's 2015 interviews with four fishing communities throughout the Kep Archipelago, was that the majority of fishers agree that the primary factor causing decline in catch is illegal fishing and overharvesting. This is specifically referring to the activities of illegal, unregulated and unreported (IUU) vessels, with emphasis on the intense illegal trawling activity that frequently occurs in critically endangered habitats (e.g. seagrass - UNEP 2004). Although data for Cambodia is lacking, seagrass loss in the South China Sea is high with Indonesia (30 – 40%), the Philippines (30 – 50%) and Thailand (20 – 30%) experiencing declines of large magnitude (UNEP 2004). Trawling in Kep Province breaks numerous important fisheries laws, in particular Article 49; prohibition of trawling in inshore areas (<20m depth), and Article 52; prohibition of fishing that damages or disturbs coral reef or seagrass (FiA 2007) (see Appendix B for full article descriptions).The extensive root system of seagrasses helps to hinder sediment re-suspension, store nutrients and oxygenate sediments (Duarte 2002). Trawling gear rips seagrass from the benthos (seabed), destabilizing the associated sediment and leading to major biological and ecological problems (Mam 2002). These problems include potential microbial production (Gotner *et al.* 2000), higher nutrient and contaminant levels, smothering of respiratory and feeding organs, and exposure of anoxic sediment layers (Kaiser *et al.* 2001). Following this lies the high potential for the inception of a catastrophic perpetual cycle whereby eutrophication (increased nutrients), may accelerate the rate of coral reef (Littler *et al.* 2005) and seagrass decline, which can be further exacerbated by sediment re-suspension (Burkholder *et al.* 2007).

Due to the synergistic heightening of average water temperatures and trawling activity over the last decade in Cambodia (MCC, unpublished data), recovery from annual coral bleaching events in the Kep Archipelago may be strongly hampered. The consequences of this would be habitat degradation, reduced ecosystem services, lowered fish stocks and economic downfall. Similarly, greater levels of trawling activity have led to perpetual disturbance to seagrass habitats in this region(Ahmed & Chanthana 2015), greatly restricting their ability to recover.Under such circumstances, seagrass habitat recovery may never occur (Clarke & Kirkman 1989; Preen *et al.* 1997). Persistent trawling in a sandy bottom area (substrate suitable for seagrass growth) constantly disturbs the sea bed, up-heaving it, displacing it and eventually removing the sandy sediment layer, leaving silt and mud (Poiner *et al.* 1989). This remaining muddy sediment is not capable of supporting seagrass resettlement and growth. Mud habitat such as this is widely distributed throughout the Kep Archipelago as a result of trawling activity. Safeguarding of coral reef and seagrass ecosystems from illegal fishing activity, predominantly trawling, is thus vital in preserving and restoring their health and productivity. Protection of seagrass beds would align with prior targets to place 90km^2 of seagrass under sustainable management by 2016 (FiA 2006), and new goals formed in the developing National Plan of Action. Evidently, it is in the best interests of Cambodia's government and other pertinent authorities to protect Cambodia's remaining vulnerable coral reef and seagrass meadows.

In order to mitigate the anthropogenic practices adversely impacting Cambodia's marine environment (e.g. unsustainable fishing, pollution, etc.), and prepare for the increasing threats of climate change (e.g. sea level rise, increasing storm events, rising water temperatures), management decisions must be thoroughly calculated and implemented. Management of marine resources for conservation objectives and fisheries production is in a period of global change, with calls for a greater number of 'no-take' marine protected areas internationally. Marine Protected Areas (MPAs) are now internationally recognized as valuable tools for the protection and recovery of species and key habitats in decline, together with the associated ecosystem services (Pauly *et al.* 2002). In 1970, there were only 118 MPAs globally (Kelleher and Kenchington 1992). By 2008, the number of MPAs had grown to over 5,045 worldwide (Spalding *et al.* 2008). Zoning of commercial and subsistence fishing methods around the border of these 'no-take' MPAs, forms a Marine Fisheries Management Area (MFMA). When MFMA regulations are imposed in conjunction with marine fisheries laws, the implementation of such schemes have been shown to have positive effects in rebuilding depleted fish stocks (Pauly *et al.* 2002), in turn developing a sustainable and successful fisheries industry.

The Kep Provincial government has recognised the increasing pressure being placed on marine resources in the Kep Archipelago, and should aim to take action to restrict illegal and unsustainable fishing methods by working alongside MCC to implement the first MFMA in Kep Province (MCC 2016). The zoning area would include Koh Seh, Koh Mak Prang, Koh Angkrong and Koh Pou, and include a series of highly protected 'no-take' zones encompassing a portion of the coral reefs and seagrass meadows of these islands (area to be determined following consultation with relevant parties, e.g. fishing communities). Surrounding these zones would be regulated areas for small-scale family fishing, commercial fishing and tourism activities. The creation of an MPA/MFMA would align with Cambodia's Royal Decree on the Establishment of Fisheries Communities (adopted in 2005), which encourages local small-scale fishers to form community organizations for the purpose of promoting sustainable use of fisheries resources within locally defined areas. In order to optimize the impact of an MPA/MFMA, multi-level support is needed from government agencies, law enforcers, research groups and all relevant communities (Bustamante 2014). Fishing villages are directly linked to the MPA/MFMA's success, as their livelihood immediately depends on the productivity of the marine environment. Fishers also possess valuable local ecological knowledge that can contribute to informed management decisions (Andrew & Evans 2009). Accounting for this, together with the fact that local actions will greatly influence the regenerative capacity of the marine environment, widespread awareness regarding the aim and potential of the management plan is required. Experiences of other MPAs indicate that community involvement can significantly benefit the effectiveness of an MPA/MFMA, as participation in management actions leads to information exchanges, and the development of plans strategically designed to local conditions (Andrew & Evans 2009).

Effective management schemes, such as those required for the oversight of protected areas (e.g. MFMA/MPAs), should ideally be based on long-term and rigorous scientific research that unveils environmental, social and economic factors needing attention. Unfortunately, there is a lack of published literature based on research of this kind in Cambodia. The purpose of this paper, as well as of the prior Koh Seh marine environmental assessments (MCC 2014; 2015), is to compile more data on trends in tropical reef ecosystem recovery and degradationin Kep Province, by providing valuable information on these processes relative to Koh Seh. In order to obtain this information, MCC undertook coral reef surveys at multiple representative sites around Koh Seh. The results from different years and reef systems of this island contribute valuable insights regarding how a discrepancy in level of environmental protection affects habitat and species renewal over different temporal and spatial scales. The results of this report will highlightthe effectiveness of MCC's conservation efforts.Ultimately, long-term reef survey data should be utilized for management action to support further rehabilitation of coral reef habitats in Kep Province, and even coastal Cambodia in general. Ideally, this management action would manifest in the form of regulated zoning areas, such as the MFMA proposed by MCC for the Kep Archipelago (MCC 2016). Information provided in this research paper includes the general distribution of coral reef and seagrass habitat surrounding Koh Seh (refer to Figure 1 and Appendix A), the abundance and distribution of indicator reef fish and invertebrate families, the coverage and distribution of indicator reef substrates, the general condition of the reef survey sites in terms of visible impacts (e.g. fishing impacts, storm damage, trash), and finally, the main environmental and anthropogenic issues that require attention within Koh Seh's and Kep Province's marine bioregion.

Figure 1: Coral reef and seagrass habitats encompassing Koh Seh, Kep Province, Cambodia.

2 Methodology

2.1 *Site Selection*

Marine Conservation Cambodia's (MCC's) 2016 coral reef surveys of Koh Seh (10.357375N, 104.319890E), Kep Province, Cambodia were conducted at five sites (refer to Figure 2 and Appendix C) and spanned from March to May 2016. Three sites were conducted on the eastern side of the island, consisting of the north-eastern (10.212912N, 104.191614E) and south-eastern (10.212724N, 104.191624E) components of the overall eastern reef system, as well as the pier (10.212769N, 104.191656E), which collectively will be referred to as the eastern reef. The two reef sites were selected based upon sites surveyed in 2015 by MCC, with the 100-metre wooden pier on the island of Koh Seh being a new addition to the reef surveys as of 2016. The remaining two survey sites comprised of the south-western (10.212291N, 104.190960E) and north-western (10.213262N, 104.190931E) sections of the reef on the western side of Koh Seh, which will hereafter be referred to as the western reef. Initial surveys were performed to determine where a suitable stretch of reef occurred for MCC's western reef surveys. All sites were recorded using GPS and will continue to be used in future surveys.

One of the goals of MCC's reef surveys is to determine the level and consequences of human-induced impacts on coral reefs, following the recommendations of Reef Check International (Hodgson *et al.* 2006).The coral reef survey sites were chosen based on varying levels of anthropogenic impact, and environmental and topographical variation. This method allows for effective management action in response to comparable changes in and between the health of Koh Seh's coral reef ecosystem, as well as unveiling how environmental and topographical alterations affect them.The eastern reef is characterized,firstly, by a shallow fringing reef (0.5 – 2.5m depth) that can be exposed during low tide, and secondly, by a pierextending 100m from the shore and approximately 20m past the reef. It is the least impacted site, owing to MCC's active conservation efforts and protection against unsustainable fishing techniques. Illegal fishers still persist in their activities on this reef; however the majority of the fishers are utilising sustainable gear. Despite acting as the least impacted site for the purpose of this research paper, historically this reef was subject to anthropogenic stressors and direct habitat damage.Given the past dismal state of this reef, its recovery, as evidenced in this paper, buttresses the notionthat even short-term conservation action (<3 years) can producenoteworthy increases in marine life and environmental quality.The south-western and north-western reefs are slightly deeper (0.5 – 4.5m) and feature larger coral colonies. These reefs currently form the relatively more impacted survey sites, with the former being subjected to comparably more intense anthropogenic practices. The primary reason for this is the proximity of the south-western reef to what is often a number of fishing vessels, which use legal but typically unsustainable gear (e.g. crab nets). In addition to this, trawlers are frequently active within a few hundred meters south of Koh Seh.

Figure 2: MCC's 2016 coral reef survey sites of Koh Seh, Kep Province, Cambodia. See Appendix C for enlarged figure.

2.2 *Data Collection*

2.2.1 Changes in methodology

The method utilised in the 2016 reef surveys differs to that used by MCC in prior reef surveys of Koh Seh (MCC 2014; 2015). The previous methodology featured nineteen survey sites encompassing the island (refer to Appendix D), each of which was surveyed once. This method was used owing to a request by the Kep Provincial government for an assessment of the entire island's marine ecosystem state and habitat distribution.One replicate for each survey site is a low number and consequently, trends in ecosystem quality may be shown, howeverdata can be quite variable leading to inconclusive deductions. For example, a low number of replicates increase the risk of outliers which produce misleading results. For example, a large school of fish typically present on a reef may be by chance absent during one replicate, however the data would inaccurately show a low abundance of this species, leading to incorrect conclusions that could lead to poor management decisions.

Following the release of the 2015 report for Koh Seh's coral reef surveys (MCC 2015), additional reef surveys were conducted within the north and south-eastern reef, with three replicates performed. Accordingly, for 2016, three replicates of the same two sites, as well as three others, were used in order to produce comparable data on species/substrate abundance and distribution. The use of three replicates is more likely to compensate for outliers recorded on any single replicate, creating statistically stronger and more precise conclusions. The addition of a site, i.e. the pier, also acts tofortify the data collected, as a noteworthy proportion of Koh Seh's eastern fish populations were found within this site (personal observation). The combination of a larger number of replicates and sites will assist in forming meaningful inferences, ultimately leading to more appropriate management and conservation actions.

Species additions & removals

Owing to an increase in species biodiversity and abundance within the marine environment of Koh Seh, seventeen fish and three invertebrate species/categories were added to the survey data sheets for MCC's 2016 reef surveys. The seventeen fish species/categories include; dusky rabbitfish (*Siganus fuscescens)*, scatfish (*Scatophagus argus)*, monogram monocle bream (*Scolopsis monogramma)*, whitecheek monocle bream (*Scolopsis torquata)*, other bream (Nemipteridae family), big eye trevally (*Caranx sexfasciatus)*, jacks, mullet (Mugilidae family), orange-spotted grouper (*Epinephelus coioides)*, cleaner wrasse (*Labroide s*spp.), weedy surge wrasse (*Halichoeres margaritaceus)*, other wrasse (Labridae family), needlefish (Belonidae family), toadfish (Batrachoididae spp.), catfish (Plotosidae family), carpet blenny eel (*Congrogadus subducens)* and seahorses. Additionally, what was entirely categorized as 'other snapper' (Lutjanidae family) during the 2015 reef surveys, was in 2016 expanded to include two new categories; black-spot snapper (*Lutjanus ehrenbergii)* and Spanish flag snapper (*Lutjanus carponotatus)*, as well as retaining 'other snapper'. The three new invertebrate species/categories were boring bivalves (Bivalvia class), volute snails (*Volutidae spp.*) and blue-swimmer crabs. A number of fish and invertebrate species were removed from the 2016 reef survey data sheets. These species were not removed as a result of their population decline, but rather due to stable population numbers within, or their absence from, the reefs of Koh Seh. Species omitted include goby (*gobiidae spp.*), lizardfish/sandperch (*Synodontidae* *spp.*), (*Pinguipedidae spp.*), blenny (*Blenniidae spp.*), goatfish (*Mullidae spp.),* murex (*Muricidae spp.*) and synaptic sea cucumber (*Synaptidae spp.*).

2.2.2 Coral reef survey methodology

Field data collection followed the proceduresof Reef Check International (Hodgson *et al.* 2006). Before carrying out each survey,a checklist of general site conditions was completed. This included environmental parameters (temperature, visibility etc.), evident natural and anthropogenic impacts, fishing intensity and the degree of protection/law enforcement (see Appendix E). At all survey sites except the pier, a 100m transect line was laid along the reef, targeting areas of high coral cover (known-bias survey). Data was collected along four 20m segments of the transect, with a 5m gap between each (refer to Figure 3). For fish and invertebrate surveys, a 5m height (above line) by 5m width belt transect was the survey zone relative to the line. Substrate surveys were carried out as line transects, logging substrate data every 0.5m.MCC's pier in eastern Koh Seh was only surveyed for fish, and consisted of a 60m belt transect with three 18m segments and a 2m gap between each. Only two replicates were completed of the pier survey, as a result of frequent poor visibility. The data of one replicate was obtainedusing MCC's2016 reef survey methodology, whilst the other was the average of two video surveys.

The Reef Check methodology shows particular focus on the abundance of coral reef indicator species.Indicator species are living organisms that are easily monitored and whose status reflects or predicts the condition(s) of the environment where they are found (Siddig *et al.* 2016). Selection of these species was based on their economic and ecological value, in addition to their sensitivity to human impacts. MCC has adapted the species surveyed within the Reef Check methodology to include regional indicators, in addition to the global indicators already present. These indicators include a broad spectrum of fish, invertebrates and substrates that reflect the impacts of human activities such as overfishing, destructive fishing and pollution. Some reef survey categories include individual species, while others include any species belonging to a certain family. Scientific names for all surveyed species can be found in Appendix F.

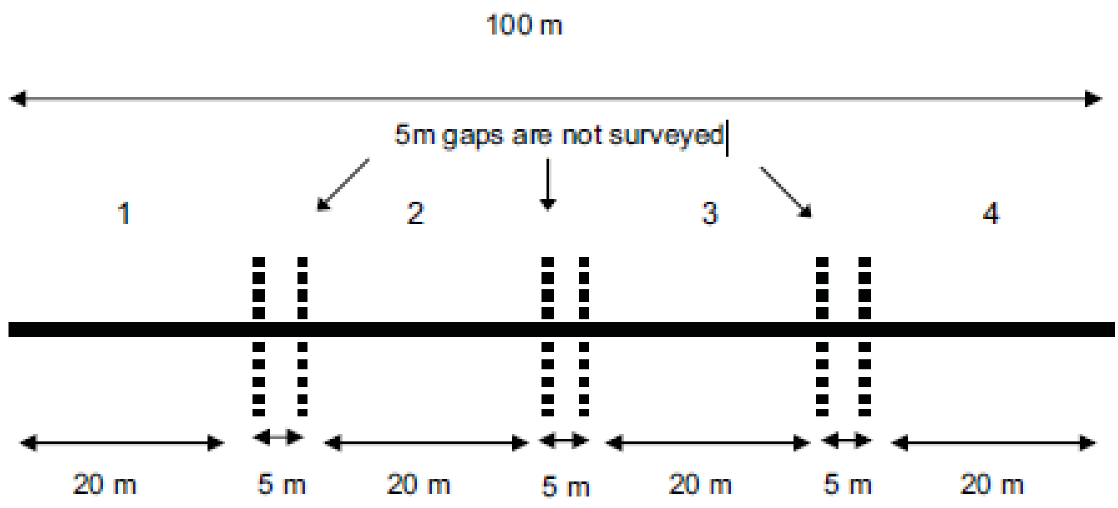

Figure 3: Reef Check reef survey transect method for fish, invertebrates and substrates.

2.2.3 Impact assessment

For each of the twelve surveys (excluding the pier – lack of reef for evaluating impacts), trained reef surveyors recorded any observable impacts from anthropogenic activities or natural events. Data was logged within the 20m segments described previously.

Coral bleaching, damage and trash

Coral bleaching was estimated both as the average percentage of thecoral population within the survey area, and within each bleached coral colony.The magnitude of coral damage from anchors, fishing and storms was recorded. Coral damage was ranked via four levels: 0= none, 1= low, 2= medium and 3= high. The presence of trash was documented, specifically plastics, rice bags, fishing nets, broken fishing traps and lines. Quantity of rubbish was based on four levels; 0 = none, 1 = one piece, 2 = two to four pieces and 3 = five or more pieces.

New impact assessments - coral disease and predation

Currently, the study of coral disease is in its infancy and those who devote their time and expertise to it are virtually 'learning as they go along' (Raymundo *et al.* 2008). In order to gain knowledge regarding the impacts of coral ailments on Koh Seh's reefs, trained surveyors recorded the incidence of coral disease as a new component of reef surveys in 2016. An additional reason for undertaking this impact assessment is a desire to contribute to the development of coral disease knowledge amongst the scientific community.Both the average percentage of the coral population suffering ailment in the survey area,and of the individual coral colonies,were noted. Coral predation was another new impact assessment recorded in 2016. This was added owing to the presence of the corallivorous (coral-eating) gastropods *Drupella*

(*Drupella* spp.) within Koh Seh's marine environment. Like coral damage, predation was categorized into four levels of damage: 0 = none, 1= low, 2= medium and 3= high.

2.3 *Data Analysis*

The abundance of fish and invertebrates was calculated from the mean number of individuals per 20-meter segment (p/s), averagedacross all three replicates of each site. Substrate composition was calculated from the mean percentage cover throughout all three site replicates. Two-tailed t-tests were utilised via Microsoft Excel to compare 2014 –2015– 2016 mean fish and invertebrate abundances, as well as to contrast the mean percentage cover of different substrate types for 2016. It should be noted that there are two 2015 datasets used in this report. One dataset was published in MCC's 'Koh Seh Marine Environmental Assessment 2015' (MCC 2015), and consisted of one replicate at each site. After publication of that report, additional reef surveys were conducted during April 2015 on the eastern Koh Seh reef using the same methodology described in this report. The dataset of the reef surveys in April 2015 was used for statistical comparisons for the 2016 eastern reef survey data. Conversely, for the western reef, the data collated from the 2016 surveys was compared to that published in MCC's previous Koh Seh environmental assessments (MCC 2014; 2015).For these assessments only five fish families were recorded, hence, despite a broader range of families recorded in the 2016 western reef surveys, only five fish families can be compared with the 2014 and 2015 data.The mean percentage of bleaching and disease displayed within coral colonies and throughout coral populations in the survey area was calculated for 2016. For the eastern Koh Seh reef, bleaching data was subsequently compared with that of 2015 via two-tailed t-tests. The averagerank of coral damage, predation and trash prevalence was determined within both the eastern and western reefs, and were statistically contrasted withtwo-tailed t-tests.

2.4 *Project limitations*

MCC surveyors faced numerous limitations whilst attempting to conduct the 2016 coral reef surveys of Koh Seh. The main constraint was the lack of visibility, often below the minimum level (5 meters) required for an accurate reef survey. A number of anthropogenic and environmental factors contributed to this. Primarily, trawling sediment was frequently present in the water column and greatly hampered visibility. Vessels trawling illegally were regularly observed and heard within the vicinity of the survey sites. The algaebloom and subsequent disaster that occurred in Kep Province during April 2016 (Cane & Sotheary 2016) created very turbid waters, which were unhealthy to be immersed in (refer to 'Kep's algae bloom' p 37). The natural spawning event of coral and other organisms in April 2016 also led to murky waters. Overall, these factors delayed and limited many of MCC's coral reef surveys. This resulted in an extended period of field data collection, which is not ideal for comparing species abundance and diversity, as seasonal differences in the marine environment (e.g. temperature) can show ecosystem and behavioural changes (e.g. bleaching, migration) that can confound the accumulated data. Additionally, surveys conducted in low visibility conditions likely produced overly conservative fish and invertebrate data.

MCC faced a small number of statistical limitations, which restrictedcomparisons with the data of preceding years.The 2016 substrate survey datacould not be compared with that of 2015. The reasons for this arethe alternate placement of the transect line in 2015, which covered more non-reef substrate such as sand and rubble; and thatzoanthids were not recorded specifically in 2015 (logged in 'other substrates'). The 2016 transect line was placed appropriately over a larger proportion of reef structure and zoanthids were classified as their own category. Consequently, substrate survey results for 2016 have set the baseline for future substrate trends in Koh Seh's marine environment.

3 Results

For readability and clarity of statistical comparisons, the north-eastern and south-eastern reefs have been combined into one; Koh Seh's 'eastern reef. Likewise, the north-western and south-western reefs form Koh Seh's 'western reef'. Little significant differences (≤1 – see Appendix H and Appendix JAppendix M) were recorded between the two components of each of these larger reef systems, except in the case of fish abundance amongst the north-eastern and north-western reefs, whereby four significant differences were calculated (see Appendix G).

Scientific names for all species recorded can be found in Appendix F.

3.1 *Fish Survey*

3.1.1 New fish species

Personal observations and data collected during the period of Marine Conservation Cambodia's (MCC's) 2016 reef surveys of Koh Seh have revealed nine completely new fish species to Koh Seh's marine environment, as compared to MCC's2015 reef surveys in April. These species include big eye trevally, boxfish (Ostraciidae family), spadefish (Ephippidae family), white spotted rabbitfish (*Siganus canaliculatus)*, dusky rabbitfish, paradise whiptail (*Pentapodus paradiseus)*, duskytail grouper (*Epinephelus bleekeri)* and longfin grouper (*Epinephelus quoyanus)*, in addition to a new species of jack/trevally. All of these fishwere observed or recorded within the eastern marine environment of Koh Seh, however only three (dusky rabbitfish, boxfish and jack/trevally) within the western.Overall, fifteen fish species were documented in the eastern reef that were not in previous years' surveys. This consisted of the fourteen fish species listed within 'Species additions & removals' (p11), plus someemperor species. The same comparison cannot be justified for the 2015 and 2016 western reef data, due to a smaller set of fish families surveyed in 2015 (see 'Data analysis p14).

3.1.2 Eastern reef

Data collated from MCC's 2015 and 2016 surveys of Koh Seh's eastern reef showed significant increases in the abundance and richness of fish species (refer to Figure 4, Figure 5, Figure 6, Figure 7, Figure 8).Sergeant fish (*Abudefduf* spp.) ($p=0.04$), emperor (*Lethrinus* spp.) ($p=0.01$), blue-lined grouper (*Cephalopholis formosa)* ($p<0.01$) and chocolate grouper (*Cephalopholis boenak*) ($p<0.01$) all displayed significantly greater 2016 population densities relative to 2015. In contrast, long-beaked coral fish (*Chelmon rostratus*) ($p<0.01$), total butterflyfish (Chaetodontidae family) (p=0.02) and snapper outside those recorded specifically (p<0.01) decreased significantly from 2015 levels. The significant decrease in total butterfly-fish was largely caused by that of long-beaked coral fish, as they are a type of butterflyfish. Apart from the snapper recorded on a species basis (i.e. black-spot snapper and Spanish flag snapper), no other snapper were recorded in the 2016 reef surveys of eastern Koh Seh. This is simply due to snapper species recorded as 'other' in 2015 being recorded asparticular species in 2016, such as the two species listed previously.All 2015 and 2016 mean fish abundance and t-test results pertaining to the eastern reef can be found in Appendix H andAppendix I.

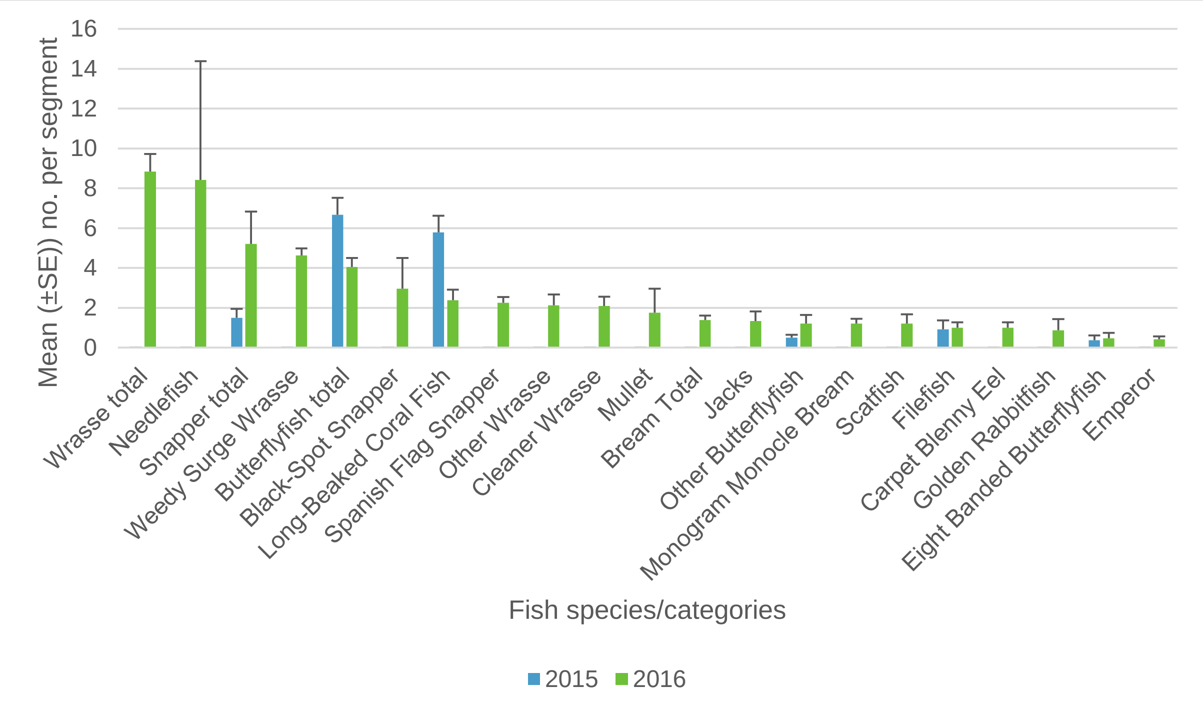

Figure 4: Mean (±SE) number per 20-meter segment of fish species/categories counted during MCC's surveys of eastern Koh Seh reef in 2015 (n=6) and 2016 (n=6).

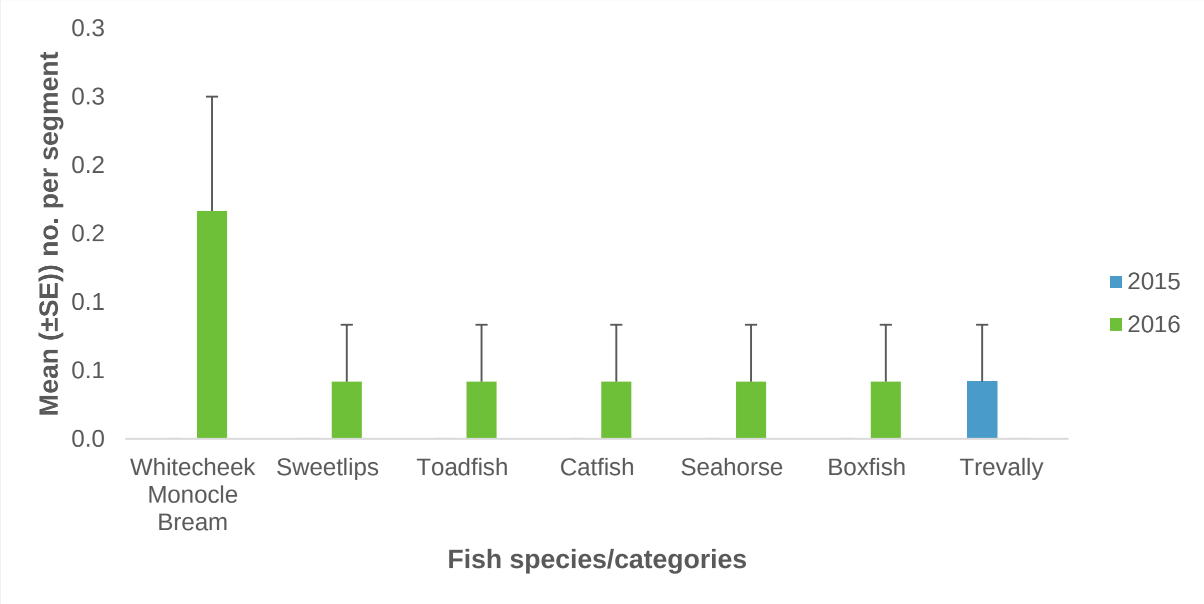

Figure 5: Mean (±SE) number per 20 meter segment of fish species/categories counted during MCC's surveys of eastern Koh Seh reef in 2015 (n=6) and 2016 (n=6). Note that trevally counted in 2015 were golden trevally.

Survey data indicated that the densest fish species was cardinalfish (Apogonidae family) (68.4 per 20m segment – p/s), followed by sweeper (*Pempheris* spp.) (68.1 p/s) (refer to Figure 6). Only sweeper displayed significantly higher abundance in 2016 as opposed to 2015 (15.2 p/s) ($p<0.01$), however cardinalfish population growth was also notable (2015 - 47.5 p/s) ($p=0.06$).

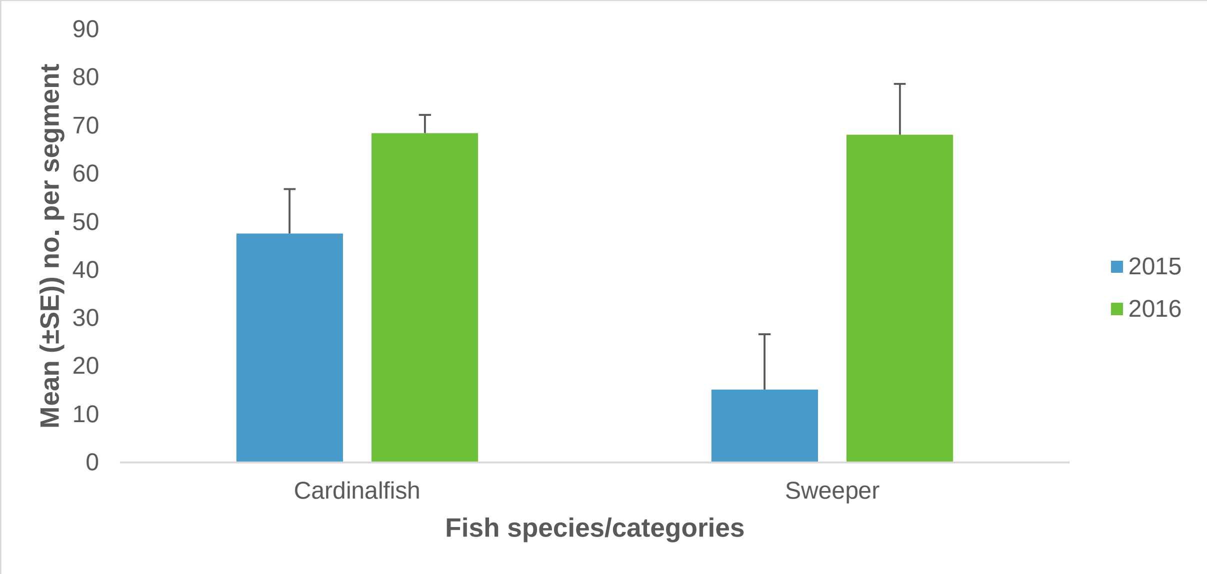

Figure 6: Mean (±SE) number per 20-meter segment of cardinalfish and sweeper counted during MCC's surveys of eastern Koh Seh reef in 2015 (n=6) and 2016 (n=6).

Populations of grouper evidenced a significant increase between 2015 and 2016 in eastern Koh Seh reef (refer to Figure 7). Together with the previously mentioned significant increases in blue-linedgrouper (0.04 to 0.5 p/s)($p<0.01$) and chocolate grouper (0.0 to 0.6 p/s) ($p<0.01$), total grouper abundance also increased significantly (0.21 to 1.21 p/s) ($p<0.01$).

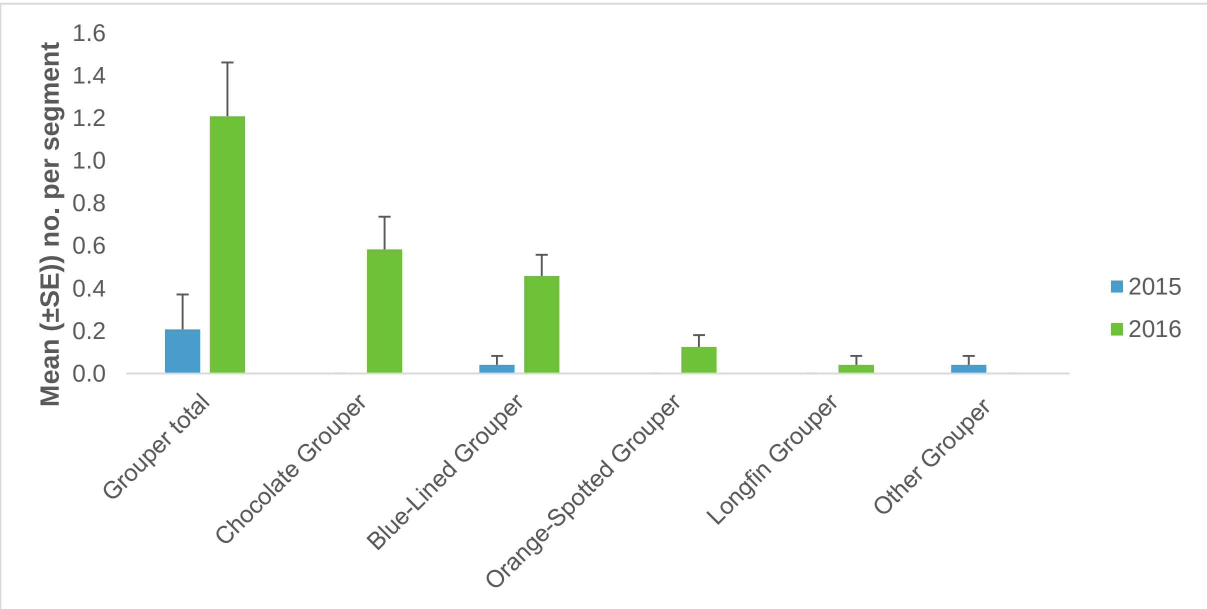

Figure 7: Mean (±SE) number per 20-meter segment of cardinalfish and sweeper counted during MCC's surveys of eastern Koh Seh reef in 2015 (n=6) and 2016 (n=6).

Rabbitfish and sergeant fishpopulations were noted at a highdensity in 2016 (refer to Figure 8). Relative to 2015, significant growth was displayed by sergeant fish (13.0 to 20.3 p/s; p=0.04), with virgate rabbitfish (*Siganus virgatus)* showing notable yet non-significant increase (0.2 to 15.0 p/s; p=0.07 – see Appendix I**Error! Reference source not found.**).

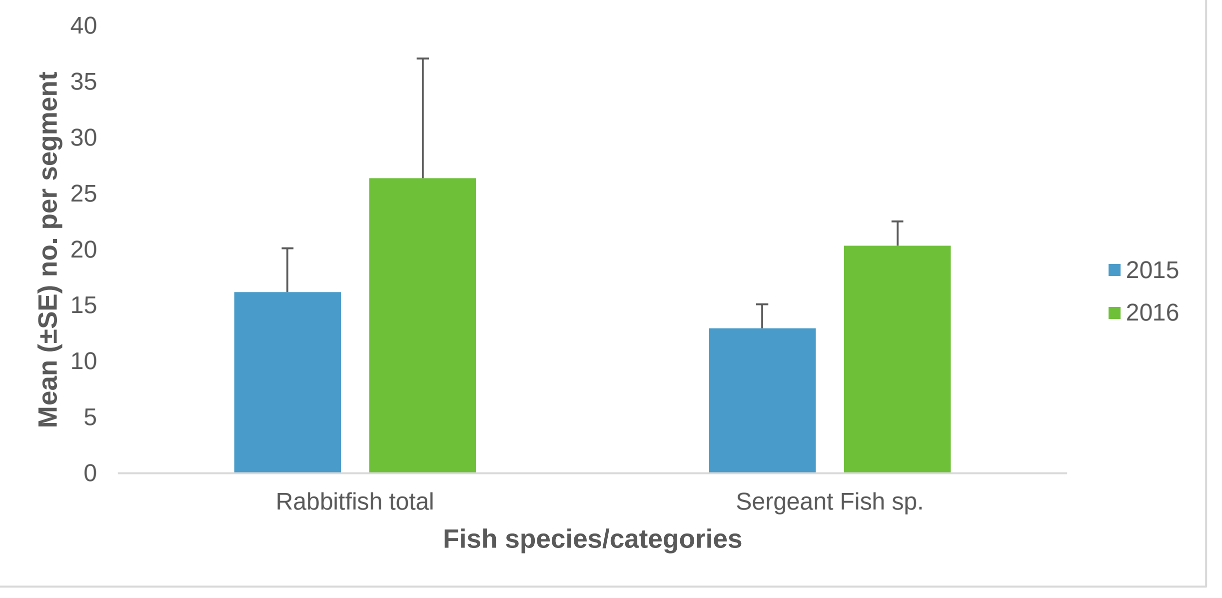

Figure 8: Mean (±SE) number per 20-meter segment of all rabbitfish and sergeant fish species counted during MCC's surveys of eastern Koh Seh reef in 2015 (n=6) and 2016 (n=6).

3.1.3 Western reef

Within the western reef of Koh Seh, MCC's 2016 data indicated that the majority ofsurveyed fish speciesgrew in population number (refer to Figure 9). Relative to MCC's 2014 reef surveys, the density of butterflyfish (1.4 to 6.8 p/s, p=0.02), snapper (1.2 to 4.8 p/s, p<0.01), grouper (0 to 0.8 p/s, p=0.02) and wrasse (0 to 4.9 p/s, p<0.01) weresignificantly greater. Significant population increases between 2015 and 2016 were exhibited by snapper (2.5 to 4.8 p/s, p=0.03), grouper (0.2 to 0.8 p/s, p=0.03) and wrasse (1.2 to 4.9 p/s, p<0.01). Refer to Appendix J for all mean 2014, 2015 and 2016 western reef fish abundances and t-test results.

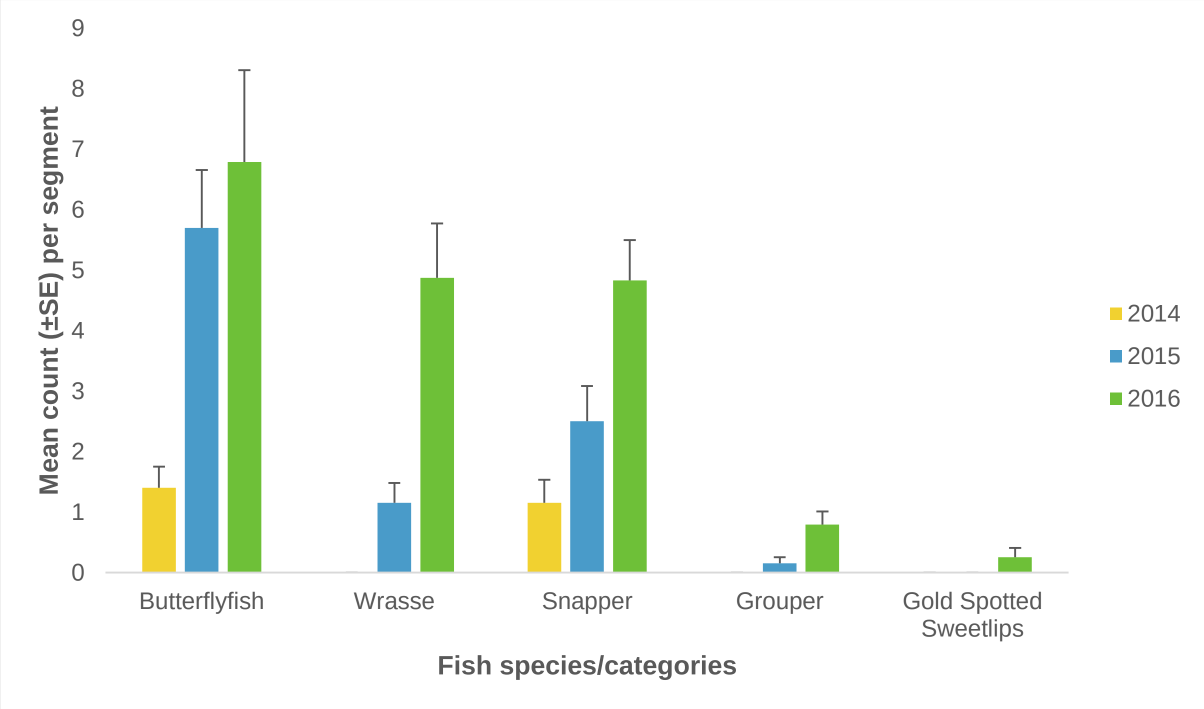

Figure 9: Mean (±SE) number per 20-meter segment of each fish species/category counted during MCC's reef surveys of western Koh Seh in 2014 (n=5), 2015 (n=5) and 2016 (n=6).

3.1.4 Easternreef vs. western reef

MCC's 2016 reef surveys of Koh Seh revealed a number of variations between the fish species richness and abundance in the eastern reef (and pier)relative to the western reef (refer to Figure 10, Figure 11, Figure 12). Sergeant fish (p=0.04), jacks (p=0.05), sweeper (p=0.007) and cardinal fish (p=0.004) were significantly more abundant in the eastern reef. Conversely, eight-banded butterflyfish (*Chaetodon octofassiatus*) (p=0.03) and fusilier (Caesionidae family) (p=0.05) were of greater density in the western reef. Sweeper, needlefish, big-eye trevally, cleaner wrasse, toadfish, seahorses and filefish (Monacanthidae family) were only recorded within the eastern reef. See Appendix K for mean fish abundance in the pier survey site, and Appendix L for eastern reef versus western reef t-test results.

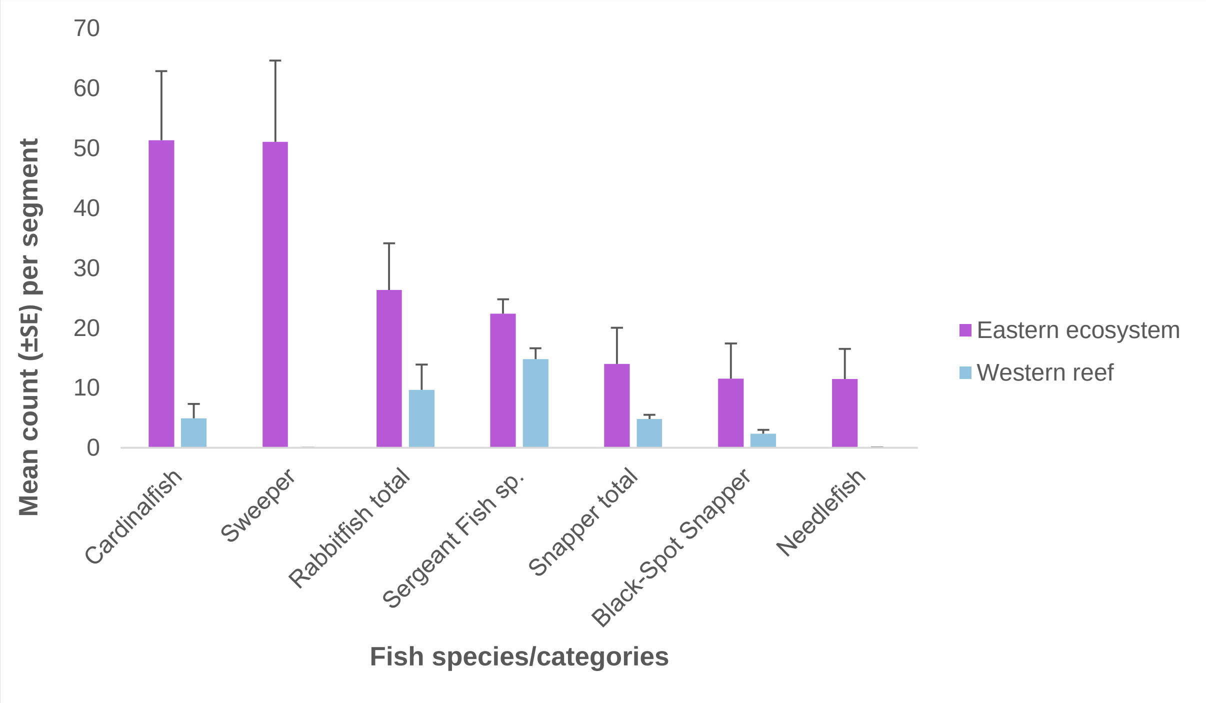

Figure 10: Mean (±SE) number per 20-meter segment of fish species/categories counted during MCC's reef surveys of Koh Seh's eastern reef (n=8) vs. western reef (n=6) in 2016.

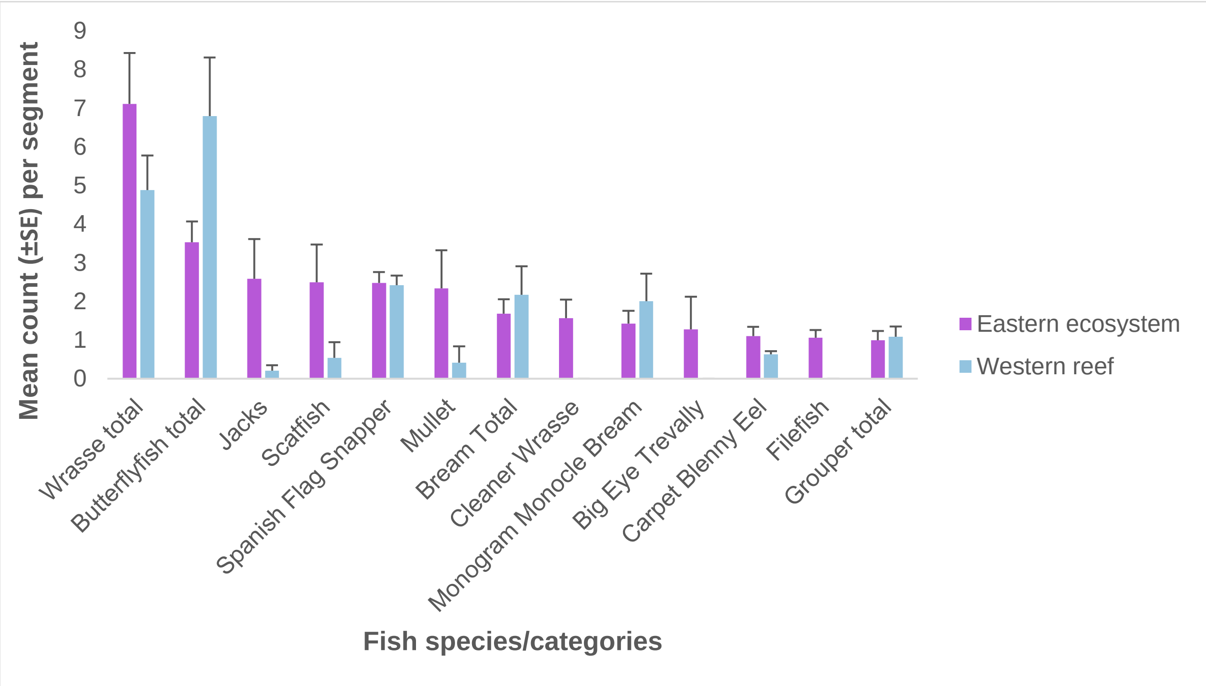

Figure 11: Mean (±SE) number per 20-meter segment of fish species/categories counted during MCC's reef surveys of Koh Seh's eastern reef (n=8) vs. western reef (n=6) in 2016

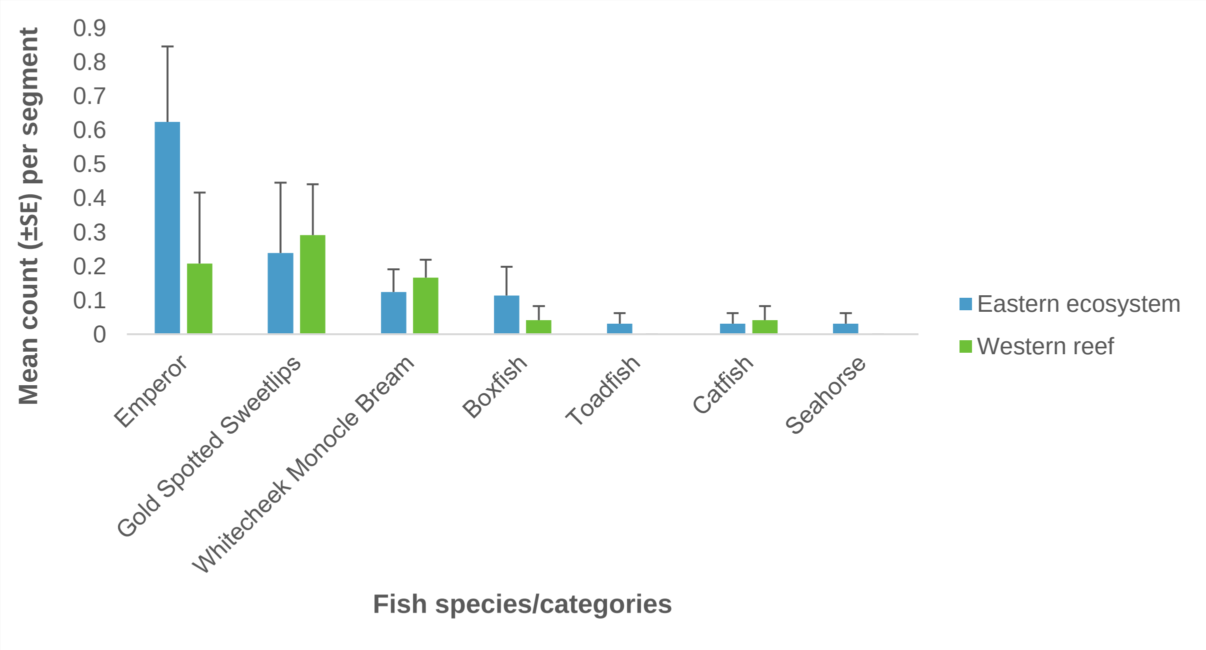

Figure 12: Mean (±SE) number per 20-meter segment of fish species/categories counted during MCC's reef surveys of Koh Seh's eastern reef (n=8) vs. western reef (n=6) in 2016.

3.2 *Invertebrate Survey*

3.2.1 New invertebrate species

During MCC's 2016 reef surveys, team scientists discovered two new invertebrate species (giant clam (*Tridacna* & *Hippopus* spp.) and feather star (Crinoidea order)) within the marine environment of Koh Seh. Both of these species were only surveyed within the western reef.

3.2.2 Eastern reef

MCC's 2016 invertebrate surveys of eastern Koh Seh reef revealed that the abundance of most species did not differ greatly compared to 2015 (refer to Figure 13, Figure 14). Between 2015 and 2016, the only significant difference recordedwas a decrease in xanthid crabs (*Xanthidae family*) (refer to Figure 14). Boring bivalves and blue swimmer crabs were not documentedin 2015 and thus their population numbers cannot be compared in this paper, but will be in subsequent years. Flower (*Toxopneustidae spp*.), collector (*Tripneustes* spp.) and pencil urchins (*Heterocentrotus mammilatus*) were all surveyed in 2015 but not in 2016, however this is a result of slight differences in the placement of each years' transect line.

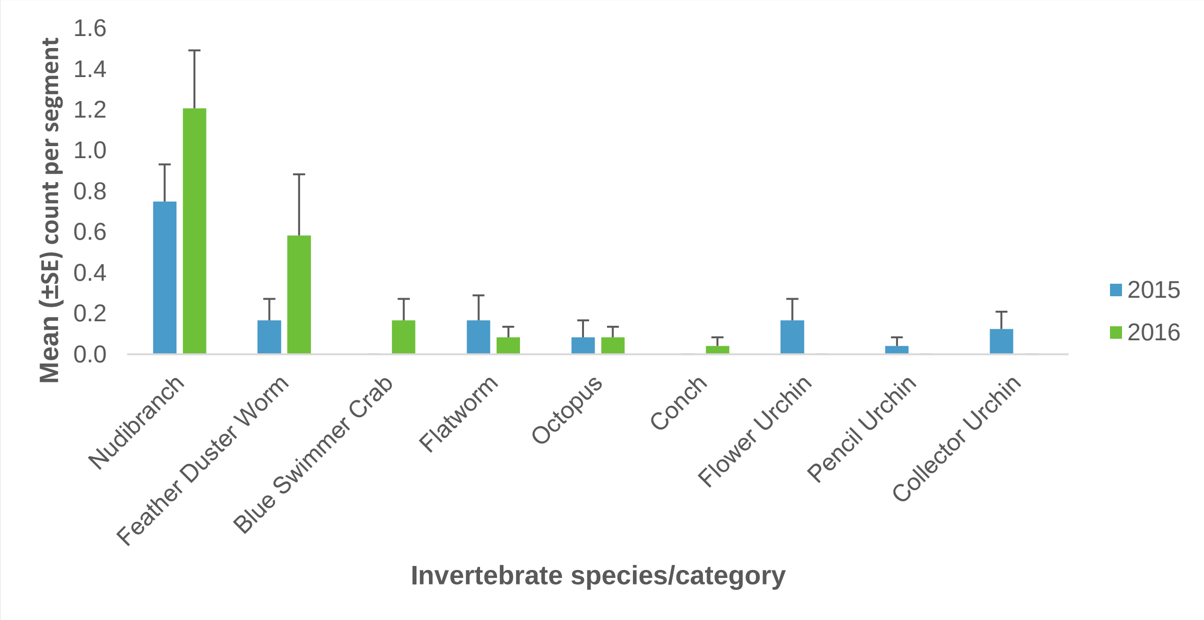

Figure 13: Mean (±SE) number per 20-meter segment of invertebrate species/categories counted during MCC's reef surveys of eastern Koh Seh in 2015 (n=6) and 2016 (n=6).

The eastern reef was largely dominated by gastropods (chiefly *Turbo* and *Drupella* species) (9.6 p/s), boring bivalves (8.9 p/s), *Diadema* urchins (*Diadema* spp.) (5.3 p/s) and Christmas tree worms (*Spirobranchus* spp.) (4.6 p/s) (refer to Figure 14). For a complete set of 2015 and 2016 mean invertebrate abundances and t-test results, see Appendix M andAppendix N.

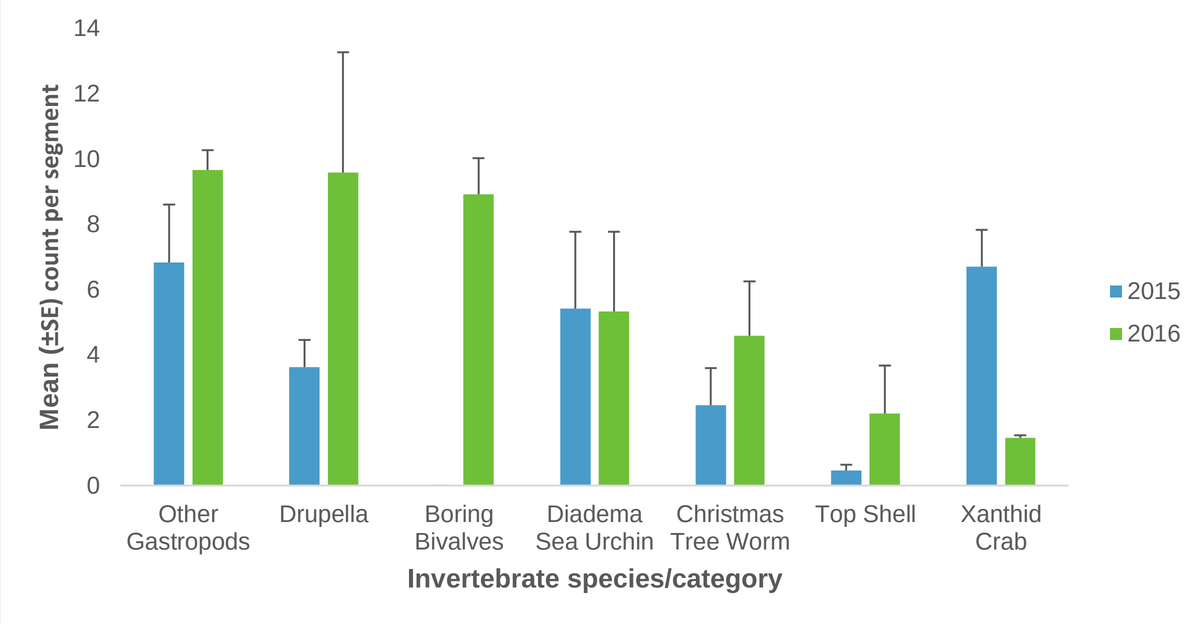

Figure 14: Mean (±SE) number per 20-meter segment of invertebrate species/categories counted during MCC's reef surveys of eastern Koh Seh in 2015 (n=6) and 2016 (n=6). Note that boring bivalves were not recorded in 2015.

3.2.3 Western reef

MCC's 2016 invertebrate survey results within Koh Seh's western reef were not contrasted with 2015, because of a slight difference in the placement of the transect line. Data collected during the 2016 surveys denoted that *Diadema* urchins (128.8 p/s), boring bivalves (99.0 p/s) and Christmas tree worms (58.0 p/s) were all relatively denser than other invertebrate populations ($p<0.001$) (refer to Figure 15).

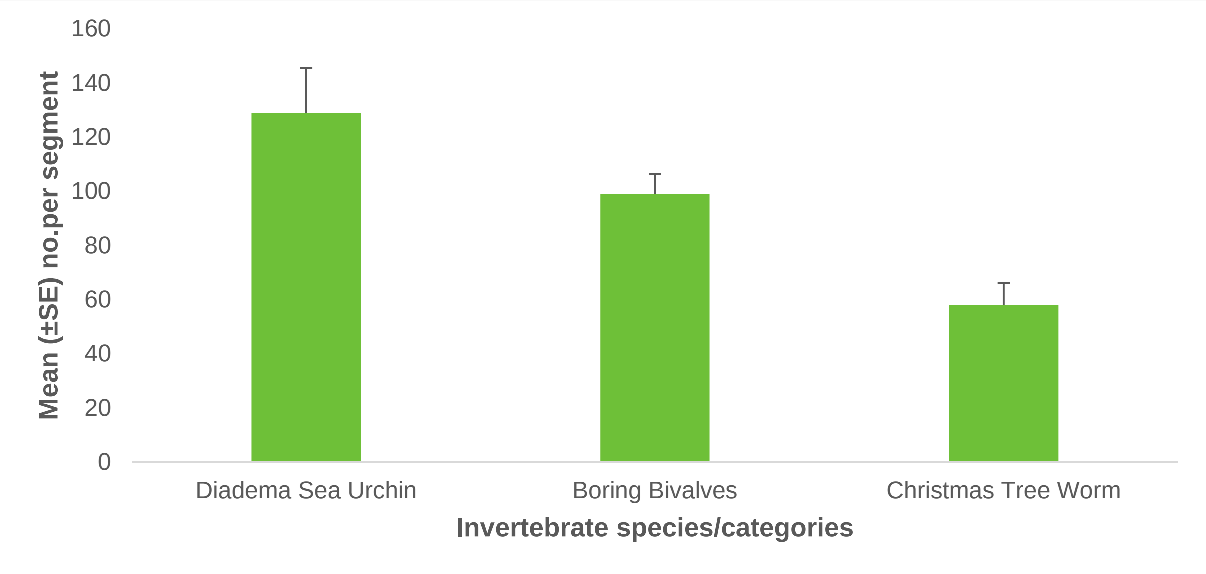

Figure 15: Mean (±SE) number per 20-meter segment of dominant invertebrate species/categories during MCC's reef surveys of western Koh Seh in 2016 (n=6).

Gastropods, including *Drupella* (0.9 p/s), *Trochus* spp. (top shell) (2.2 p/s) and those not recorded on a species basis (chiefly *Turbo* species) (4.1 p/s) were documented at a moderate abundance, as were pencil and collector urchins. All other species were logged at a comparatively lower population number, with giant clams (0.04 p/s), feather stars (0.04 p/s), xanthid crabs (0.08 p/s) and cowries (Cypraeidae family) (0.08 p/s) surveyed only twice or less (refer to Figure 16). See Appendix OAppendix O for all mean invertebrate abundances for MCC's 2016 surveys of the western reef.

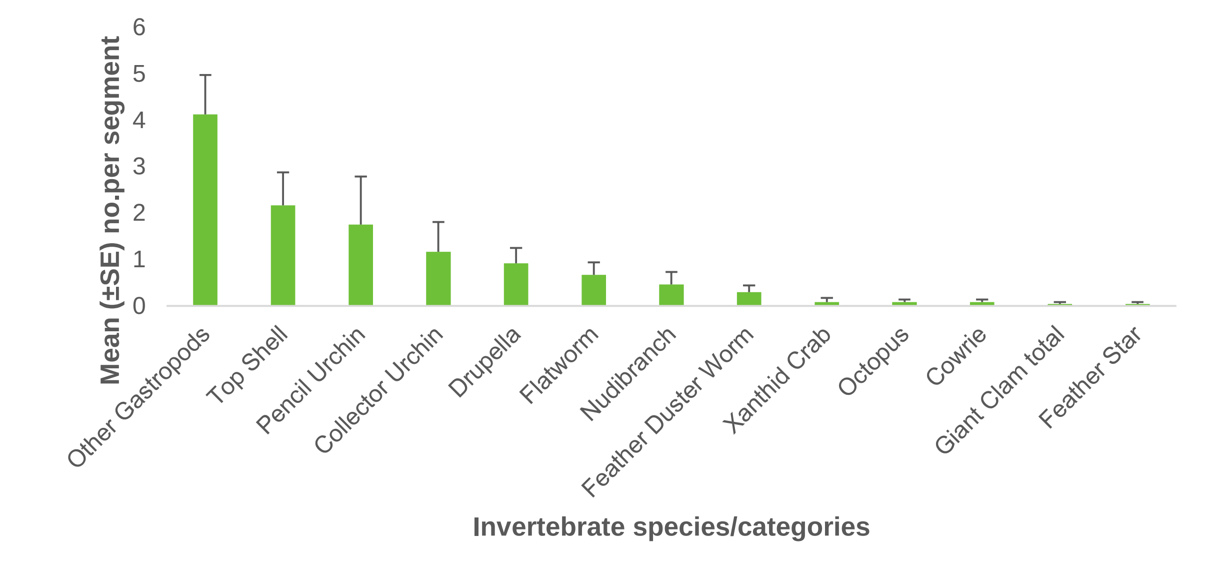

Figure 16: Mean (±SE) number per 20-meter segment of invertebrate species/categories during MCC's reef surveys of western Koh Seh in 2016 (n=6).

3.2.4 Eastern vs. western reef

MCC's 2016 reef survey data indicated a variety of differences in invertebrate abundance and diversity between the eastern and western reefs of Koh Seh (refer to Figure 17, Figure 18). The eastern reef exhibited significantly greater population numbers of xanthid crab (1.5 vs. 0.1 p/s, $p<0.001$) and gastropods outside those recorded specifically, consisting primarily of *Turbo* species (9.6 vs. 4.1 p/s, $p<0.001$).The2016 reef surveys of Koh Seh also revealed a significantly lower quantity ofChristmas tree worms (4.6 vs. 58.0 p/s), boring bivalves (8.9 vs. 99.0 p/s), *Diadema* sea urchins (5.3 vs. 128.8 p/s) and collector urchins (0 to 18.1 p/s)in the eastern reef, compared to the western reef ($p<0.001$) (refer to Figure 17).Blue swimmer crab and conch (Strombidae family) were only surveyed on the eastern reef, whilst cowrie, feather star, giant clam, pencil urchin and collector urchin were only surveyed on the western reef. See **Error! Reference source not found.** for all 2016 eastern reef vs. western reef invertebrate t-test results.

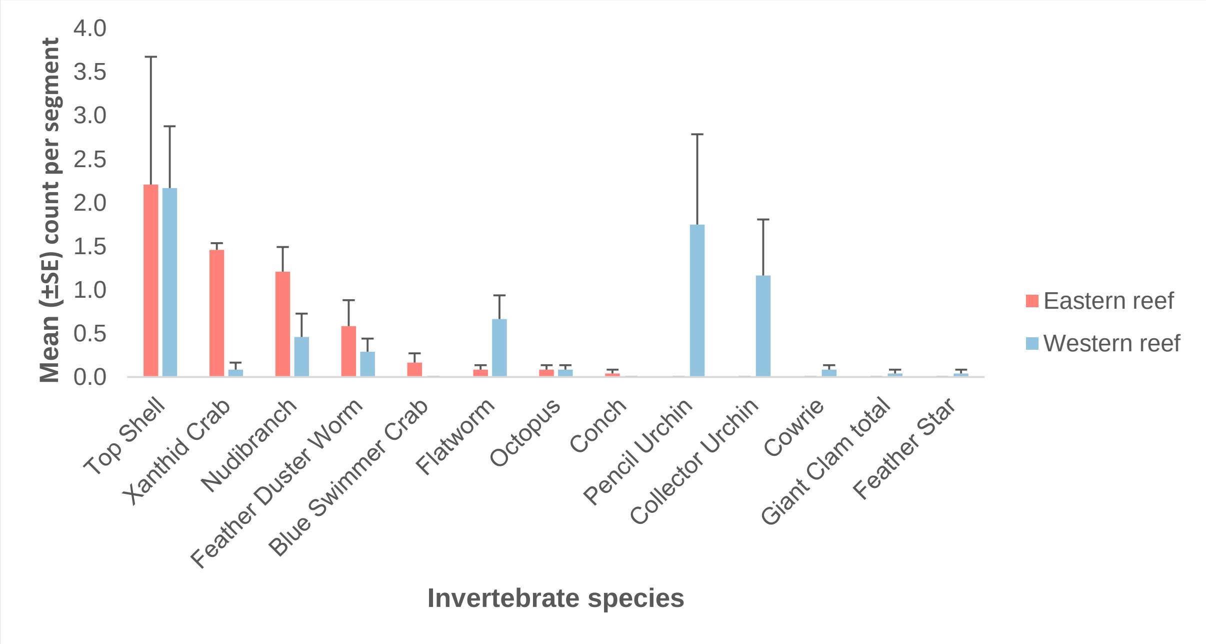

Figure 17: Mean (±SE) number per 20-meter segment of each invertebrate species/category during MCC's reef surveys of eastern (n=6) and western (n=6) Koh Seh in 2016.

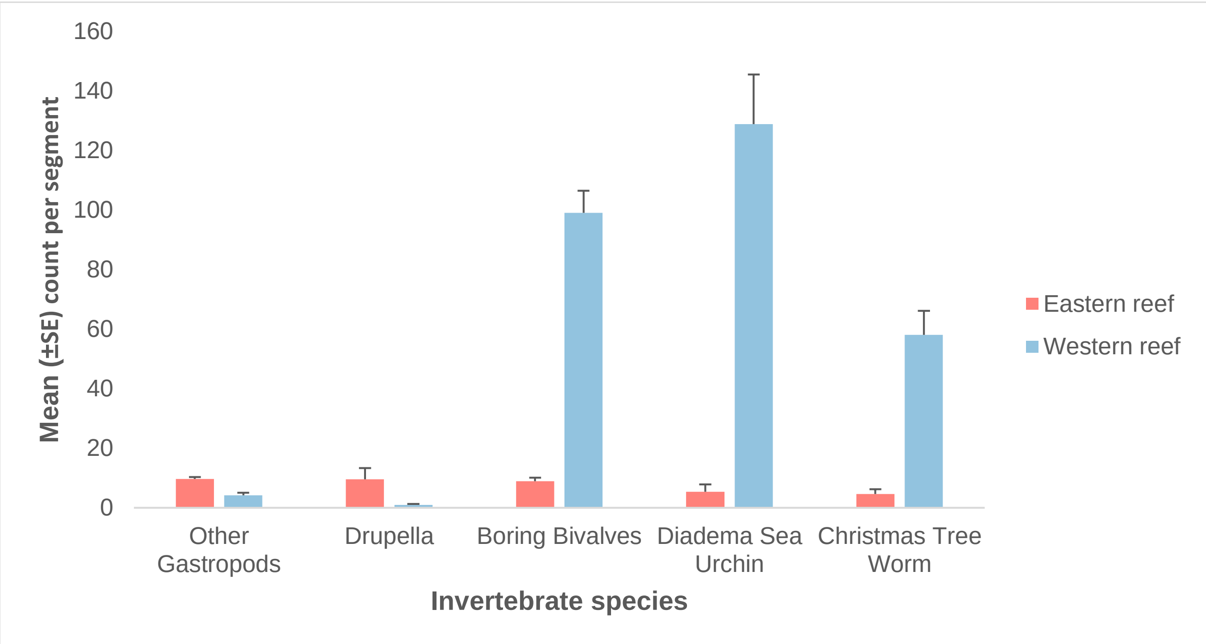

Figure 18: Mean (±SE) number per 20-meter segment of each invertebrate species/category during MCC's reef surveys of eastern (n=6) and western (n=6) Koh Seh in 2016.

3.3 *Substrate Survey*

The following abbreviations were used in the graphs of this section; HC = Hard Coral, NIA = Nutrient Indicator Algae, OT = Other, RB = Rubble, RC = Rock, RKC = Recently Killed Coral, SC = Soft Coral, SD = Sand, SI = Silt, SP = Sponge, ZO = Zoanthids.

3.3.1 Eastern reef

Within the eastern reef of Koh Seh, zoanthids were the dominant substrate (refer to Figure 19), revealing a significantly higher coverage (41.9%) than the low coverage shown by hard coral (21.9%) ($p<0.001$). Nutrient indicator algae (9.3%), rock (9.1%) and sponges (6.7%) displayed a similar low level ofabundance, which was significantly lesser than that of hard coral ($p<0.001$). Excluding sponges,these substrates wereof a significantly greater coverage than that of sand (4.6%) and rubble (3.4%) ($p<0.05$). The remaining living substrates accounted for a comparably low level of cover (3.1%), followed by recently killed coral, which was recorded onvery minor levels (0.1%) ($p<0.001$) during 2016 reef surveys.Soft coral and silt were not documented during these surveys.For a complete list of mean percentage cover and t-test results for substrate forms see Appendix Q and Appendix R.

Figure 19: Mean (±SE) percentage cover of substrate types during MCC's reef surveys of eastern Koh Seh in 2016 (n=6).

3.3.2 Western reef

MCC's 2016 reef surveys of western Koh Seh reef revealed a reef structure dominated by hard coral colonies (65% - moderate-high cover), relative to the other substrates recorded ($p<0.001$ for all) (refer to Figure 20). Rock (14%) showed the second highest coverage (14%), followed by zoanthids (10%), sponge (7%) and nutrient indicator algae (4%). Recently killed coral (1%) and other living substrates (1%) showed very low coverage compared to the previously listed substrates ($p\leq0.02$), whilst soft coral, rubble, sand and silt were not documented during these surveys. See Appendix S for a list of all mean substrate coverage percentages and t-test results.

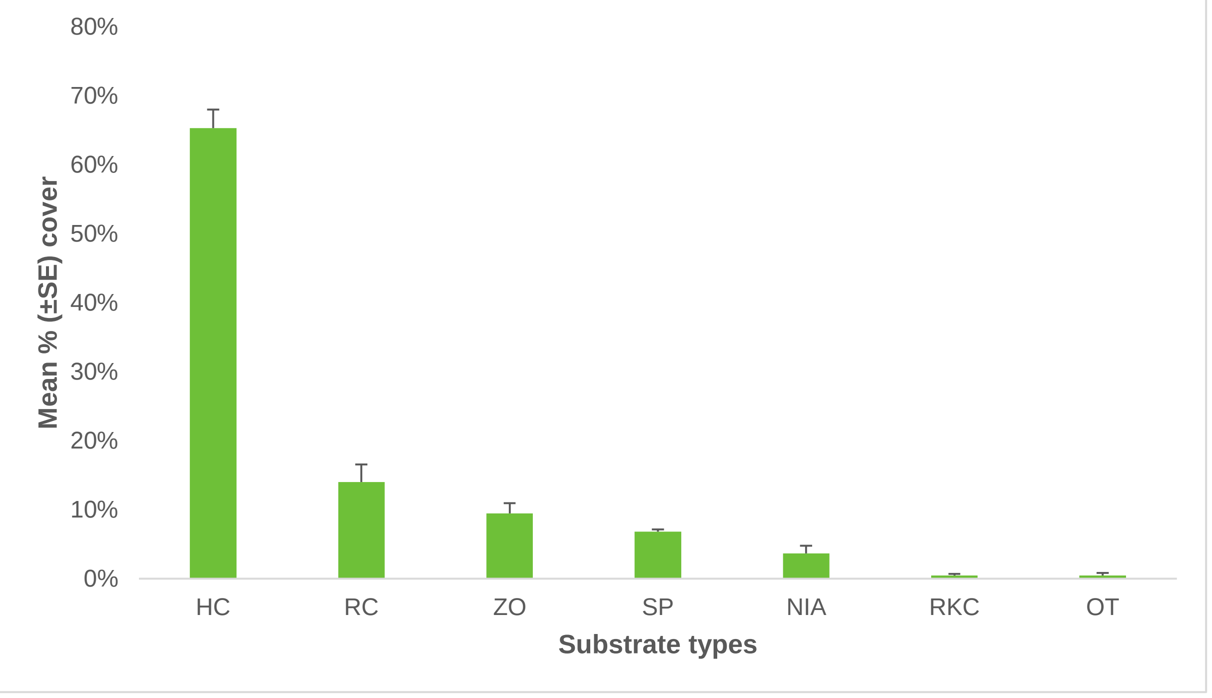

Figure 20: Mean (±SE) percentage cover of substrate types during MCC's reef surveys of western Koh Seh in 2016 (n=6).

3.4 *Impact assessment:*

Owing to differences in the timing of surveys, topography and environmental conditions, some impacts were not compared between the eastern and western reef. Coral bleaching could not be contrasted as the western reef was surveyed during a seasonal period of higher water temperature, resulting in increased coral bleaching. Furthermore, given the link between coral bleaching and disease outbreak, suggested to be warm water temperature (Miller *et al.* 2009), the incidence of coral disease was not compared between these two reefs either.

3.4.1 Eastern reef

The average percentage of coral bleaching exhibited by individual coral colonies (8.3%) and the entire coral population (4.8%) during MCC's 2016 reef surveys of eastern Koh Seh is considered to be relatively low for this reef. Bleaching was not significantly lower than that documented in 2015 (10.8%& p=0.61; 9.8%& p=0.14) (refer to Figure 21). Relatively large measures of error, especially for estimates of bleaching for coral populations, hindered statistical comparisons and thus the formation of meaningful conclusions. This may be due to a variable distribution of coral bleaching within a relatively small area or more likely, the highly subjective nature of this measure.

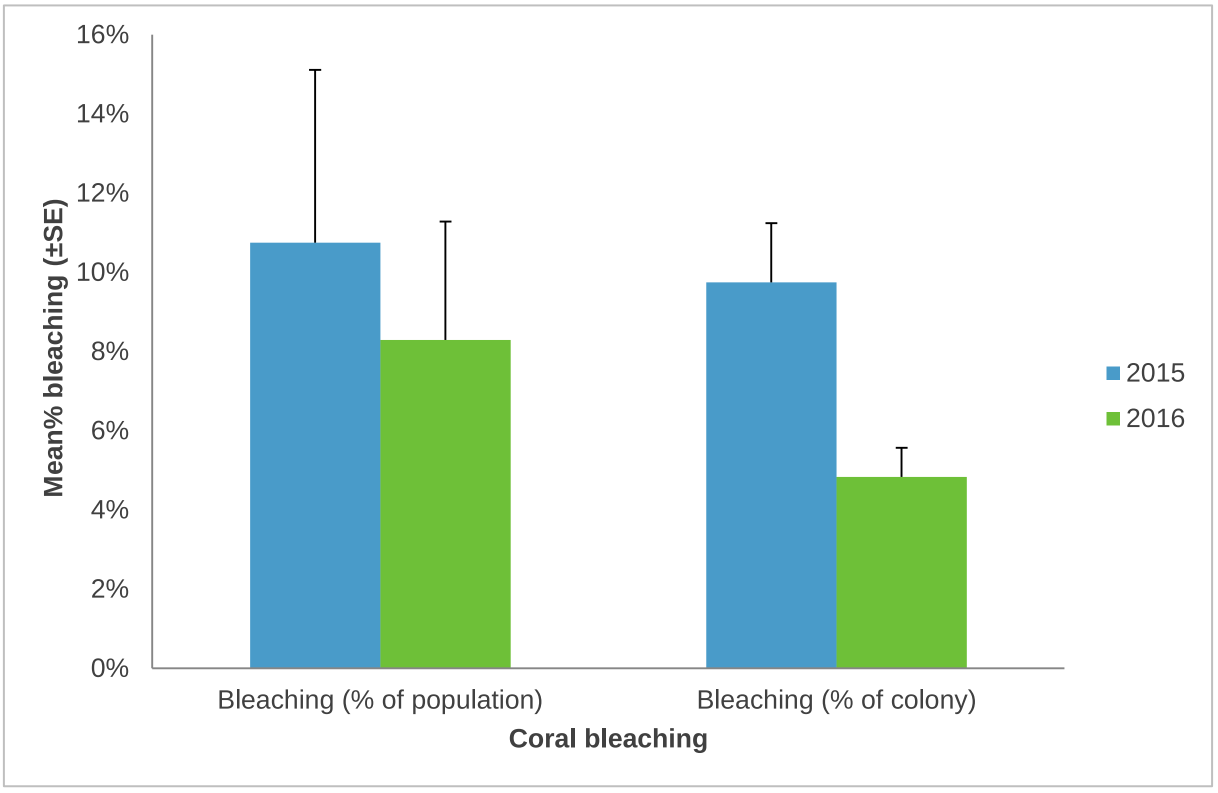

Figure 21: The mean (±SE) percentage of bleaching recorded for the coral population and within coral colonies during MCC's 2015 (n=6) and 2016 (n=6) reef surveys of eastern Koh Seh.

The trash abundance rank (0 – 3) within the south-eastern (0.6) reef was determined to be significantly larger than that of the north-eastern (0.2) (p=0.05). Despite this, the very low quantity of trash noted in both reefs implies that this result is not of great practical importance. Coral damage was documented on an extremely low level during MCC's surveys of Koh Seh's eastern reef (0.1).Coral disease and predation were not measured in 2015, hence the 2016 reef surveys provide a standard against which future survey data can be contrasted. For the eastern Koh Seh reef, coral disease was prevalent on a moderate level, with an average of 6.8% of coral colonies and 9.4% of the coral population (refer to Figure 22). For a complete set of impact assessment means and t-test results, see Appendix T and Appendix U.

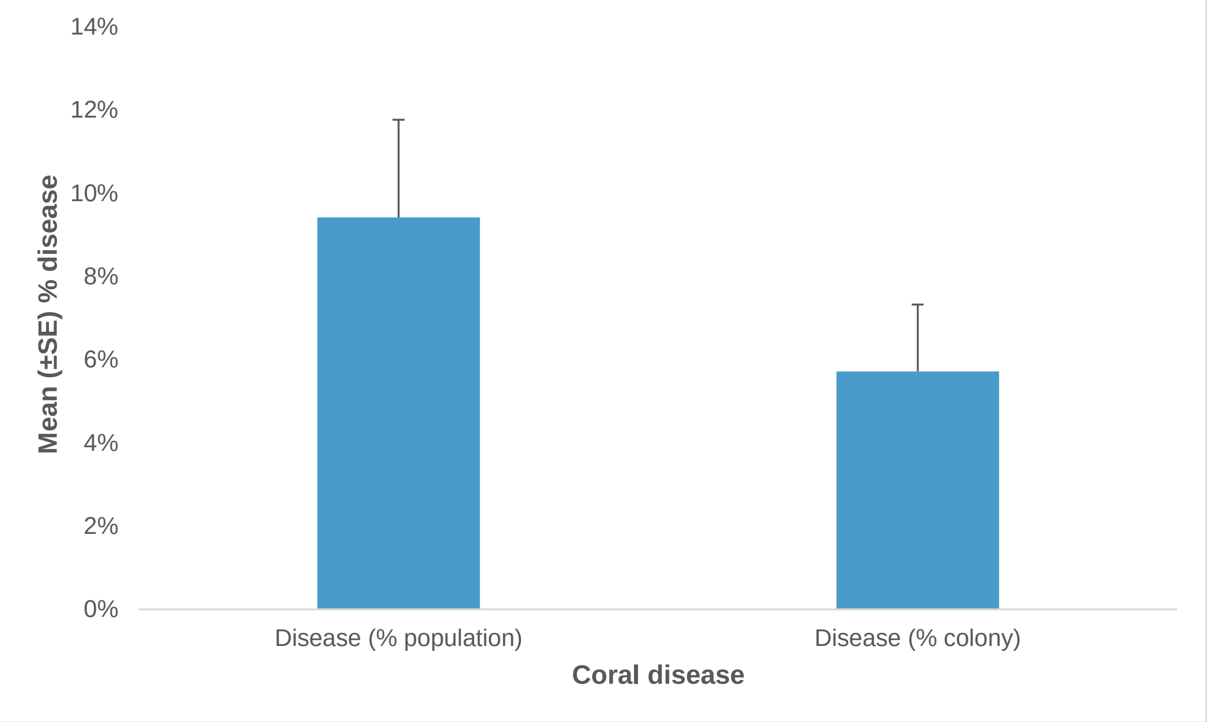

Figure 22: The mean percentage of disease recorded for the coral population and within the coral colonies during MCC's 2016 reef surveys of eastern Koh Seh (n=6).

3.4.2 Western reef

The western reef of Koh Seh was subjected to moderate-high levels of bleaching during MCC's 2016 surveys of this reef, occurring in April and May 2016. On average, bleaching occurred in 53% of the population, with 43% of tissue within the coral colonies showing bleaching (refer to Figure 23). See Appendix V for all mean western reef impact assessment values.

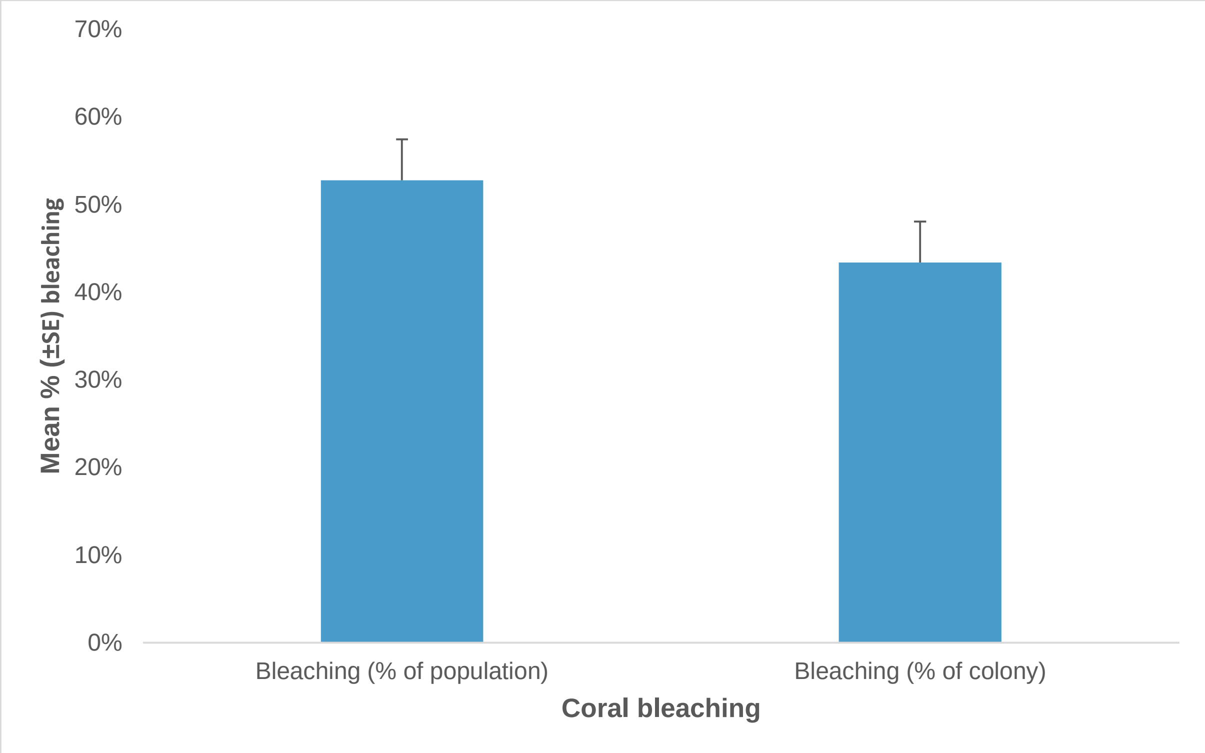

Figure 23: The mean (±SE) percentage of bleaching recorded for the coral population and within coral colonies during MCC's 2016 reef surveys of western Koh Seh (n=6).

The north-western and south-western reefs of Koh Seh exhibited a moderate mean incidence of disease within the respective coral populations (8% and 4%), and a relatively higher mean level of disease within coral colonies (11% and 22%) (refer to Figure 24).

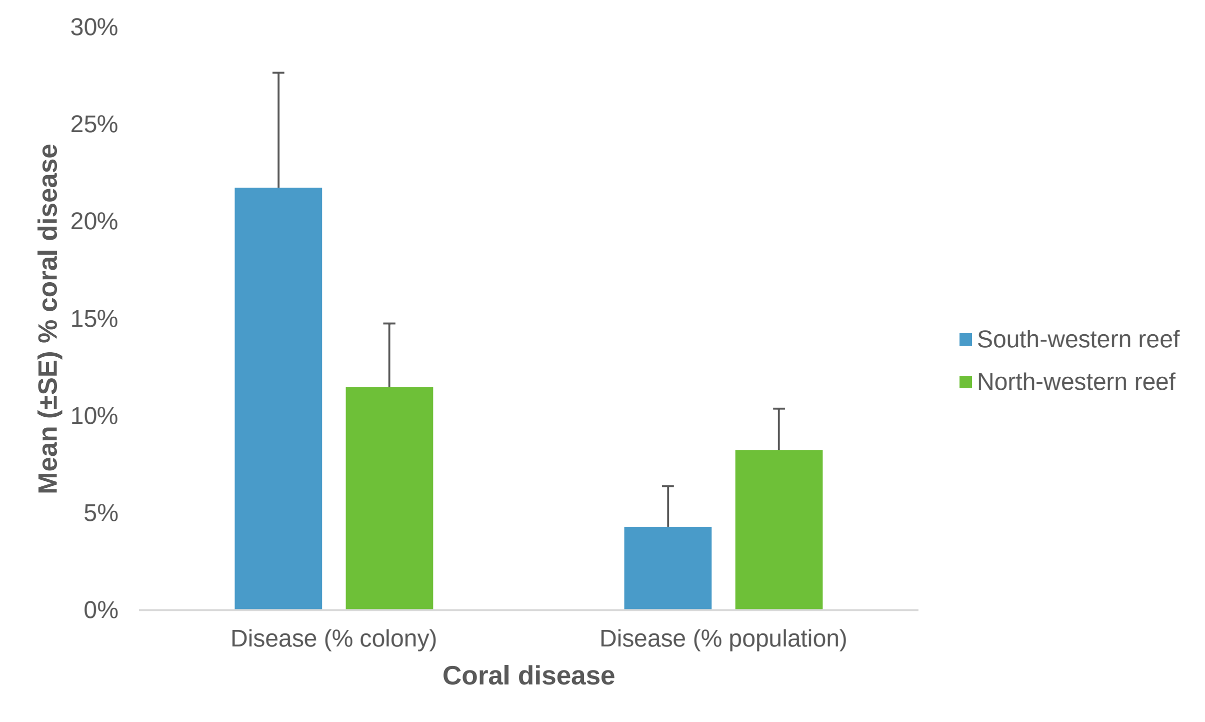

Figure 24: The mean percentage of disease recorded for the coral population and within the coral colonies during MCC's 2016 reef surveys of eastern Koh Seh (n=6).

3.4.3 Eastern vs. western reef

MCC's data from 2016 reef surveys signified that the eastern reef of Koh Seh was subjected to significantly more predation than the western reef (1.5 vs. 0.2 – predation ranked from 0 to 3) ($p<0.001$).Coral predation impact of 1.5 classifies as medium-low, whilst 0.2 is very low. All other impact measures were either not comparable (bleaching and disease) or were not significantly different (trash and damage: $p>0.5$). See Appendix W for all eastern versus western reef impact assessment t-test values.

4 Discussion

4.1 *Key ecological concepts*

The following section covers some important ecological processes relevant to Koh Seh's marine ecosystems, as well as tropical ecosystems in general, for easier comprehension of the discussion by the reader.

4.1.1 Trophic cascades

Trophic levels refer to the different levels of the food chain in marine and terrestrial environments. This begins with primary producers (plants and algae) at level one, progressing through to herbivores (two), meso-predators (three) and large predators (four). In marine environments, seagrass beds and coral reefs are made up of primary producers that are vital in maintaining the high productivity of these two ecosystems both of which provide habitat, shelter and food for an array of marine species. Without producers forming the base of the food chain, all organisms of higher trophic levels cannot sustain themselves, and thus, the food web and ecosystem will collapse. Likewise, the removal of top and meso-predators from a food chain, which is primarily occurring through intensive fishing (Pinnegar *et al.* 2000), creates an imbalance throughout other trophic levels. This has a high risk of leading to ecosystem degradation through 'trophic cascades'. Overharvesting of predators and meso-predators can lead to an overabundance of herbivores, which can rapidly alter coral and seagrass habitats through overconsumption. Given the complexity of trophic interactions, sometimes cascades can occur in an unpredictable fashion. For example, the depletion of urchin predators (e.g. the triggerfish *Balistapus undulatus*) in Kenya was documented to result in enlarged urchin (*Echinometra mathaei*) populations. Unexpectedly, turf algae increased (theorized to withstand predation by this urchin), together with an associated decline in hard coral cover (McClanahan & Shafir 1990). 'No-take' reserves may prevent or reverse this trend, and possibly also increase the population numbers of coral-associated fish, for instance parrotfish (Scarinae spp.) (Pinnegar *et al.* 2000). A standard example of a trophic cascade was evidenced through the correlation of increased Crown-of-Thorns seastars (*Acanthaster planci*) with decreases in their fish predators (Ormond *et al.* 1990). Provided that Crown-of-Thorns seastar outbreaks are considered among the most damaging disturbances observed on coral reefs (Kayal *et al.* 2012), trophic cascades involving them should be of major concern. Clearly, affecting the abundance or behaviour of any key part of the food chain can lead to ecosystem and region-wide effects through trophic cascades. Fisheries should consider the consequences of over fishing their target species and destructive fishing methods, in order to avoid these devastating impacts.

4.1.2 Herbivory and algae regulation

Herbivory is a primary factor in determining the structure of coral reef communities (Lewis & Wainwright 1985) through its ability to mediate coral-algae competition (McCook *et al.* 2001). Grazing is vital to healthy coral reefs as it modulates the level of algae, as well as the ability of algae to colonize available space. Decreased abundance of grazing fishand invertebrates (e.g. rabbitfish, parrotfish, *Diadema* urchins, etc.) can lead to algal proliferation, and thus, can greatly contribute to coral death (Szmant 2002). Lewis (1986) demonstrated that a reduction in herbivorous fish for just 10 weeks can significantly increase the abundance of macroalgae, with correlated declines in hard coral (*Porites* species – present in Koh Seh), available space, turf algae and coralline algae. Macroalgae can compete with coral via shading, abrasion, allelopathy, in addition to competitive exclusion for space and light (McCook *et al.* 2001). Turf algae can also present problems to coral colonies in high nutrient waters, such as that of Koh Seh, through overgrowth of coral colonies (Vermeij *et al.* 2010).Turf algaerapidly colonizes available substrate in Koh Seh, as was clearly evidence during the multiple visual inspections of newly immersed underwater structures, and thus it could become a significant issue if too widespread. MCC team scientists regularly witness rabbitfish feeding on turf algae, and hence moderating its abundance. Two further benefits of herbivory include a possible reduction in sediment retention (Rasher *et al.* 2012), and improved resilience and recovery of coral from disturbances, for instance coral bleaching (Hughes *et al.* 2003), which is detailed in the next paragraph.

4.1.3 Coral bleaching

Coral bleaching is the phenomenon of symbiotic zooxanthellae being expelled from coral tissue (Coles & Brown 2003). It is thought to be primarily instigated by high water temperature (Hoegh-Guldberg *et al.* 2007), however alterations in salinity, light, sediment and acidity may also be causal factors (Glynn 1993). Given the rise of global oceanic temperatures in the last century (Hoegh-Guldberg 1999), coral bleaching is gaining significant awareness by the scientific and environmental community, who are collaborating to mitigate the causes and negative impacts associated with this phenomenon. Coral bleaching impairs coral growth, calcification, overall lifespan and reproduction of corals, as well as resulting in declines of coral cover and species richness (Ostrander *et al.* 2000; Loya *et al.* 2001). These consequences are devastating to the entire marine environment, for instance, complete ecosystem shift from coral and algae co-dominant to algae dominant (Ostrander *et al.* 2000), as well as negatively affecting coral feeding fish (Pratchett *et al.* 2004). Coral bleaching is exacerbated by numerous human-driven stressors, for example climate change, ocean acidity, eutrophication and sedimentation. Overall, the sources of these stressors need to be minimized in order for coral species to acclimate and adapt rapidly enough to survive future bleaching events.

4.1.4 Kep's algal bloom

During March to April 2016, a natural seasonal bloom of algae in Kep Province resulted in near ecosystem collapse, evidenced by mass fish death, green algae 'sludge' on the sea surface along with unsafe waters and marine products. Normally, the seasonal bloom would provide an influx of additional food, resulting in bottom-up benefits to ecosystems, however numerous factors are suspected to have caused the opposite. These factors included destructive fishing techniques, overfishing, excessive nutrients (Littler *et al.* 2005) and a lack of plankton/filter feeders, with trawling (especially electrified) very likely being the main source of these consequential effects. Marine Conservation Cambodia (MCC) strongly conjectures that electric trawling was the main culprit in producing extensive mortality of algae, transforming this natural food resource into an anoxic green sludge. MCC attempted to alert relevant authorities of the looming environmental disaster, however this was not heeded, leading to economic downfall for Kep Province over a key holiday period (Khmer New Year). Fortunately, Koh Seh escaped any notable impacts of this algae bloom. With high probability,this was a result of MCC's conservation efforts, which demonstrably improved ecosystem health of Koh Seh. The presence of plankton and filter feeders (e.g. cardinalfish, fusilier, oysters, mussels etc.), together with protection against trawling, were very likely two significant factors in minimizing the local environmental consequences.

4.1.5 Connectivity

Connectivity is a new global approach for effective MFMA/MPA design, because of its ability to maximise the potential rehabilitation of the specific region, whilst improving conservation efforts and the practise of other activities (e.g. fishing). Connectivity is the exchange of individuals (i.e. larvae or fish) dispersed between marine populations (Cowen & Sponaugle 2009), helping to replenish and bolster each other against environmental and anthropogenic impacts. Larvaldispersal between the subpopulations in protected areas should help in the formation of metapopulations (large populations consisting of at least two smaller but connected subpopulations) (Treml *et al.* 2015). Dispersal within metapopulations increases genetic diversity, leading to overall improved health of the subpopulations that comprise them, as well as strengthening their resilience against catastrophic events such as natural disasters and destructive fishing. MCC views connectivity as an invaluableaspect necessary to establish an effective and interconnected MFMA, such as the one proposed by MCC's for the Kep Archipelago (MCC 2016). As part of this MFMA, nearby Conservation Zones that contain an abundance of species would create the potential for larval connections between these zones (refer to Figure 25). With high likelihood, this would lead to greater diversity and resilience of marine species, inside and outside of the Conservation Zones. Clearly, connectivity could lead to numerous region-wide benefits for fishers, coastal communities, tourists and other parties.

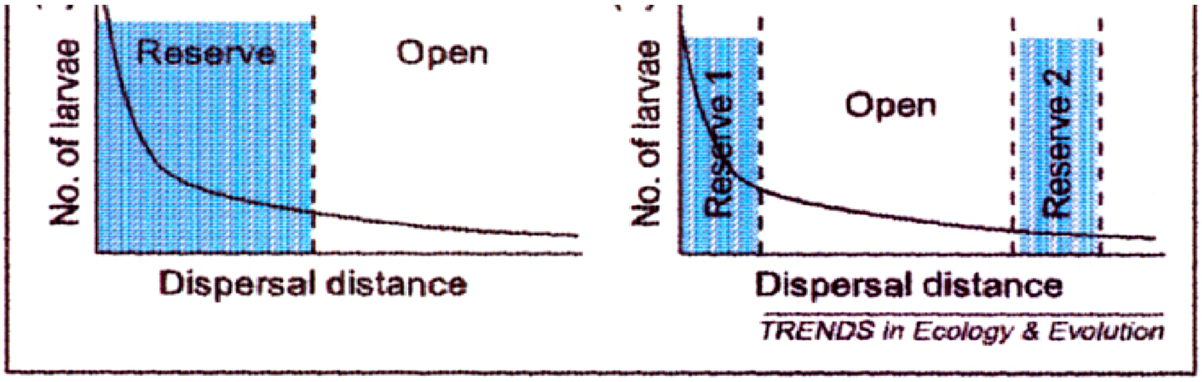

Figure 25: The number of larvae that settle at a particular distance from the original point of dispersal (Sale et al. 2005). MCC's proposed MFMA would follow the design on the right, by incorporating connected Conservation Zones.

4.2 *Summary of key results*

MCC's 2016 reef surveys depicted a marine environment where the signs of recovery are increasing each year. The large increase in fish species abundance and richness between 2015 and 2016, relative to 2014 – 2015 (MCC 2014; 2015), is indicative of a lag time between initial protection (December 2013) and a noteworthy level of recovery. Important predator and herbivore populations have increased, leading to greater trophic stability and algae regulation, thereby improving ecosystem integrity. The higher level of ecosystem rehabilitation is mainly found in Koh Seh's eastern reef (and pier), where the survey data displayed numerous increases in fish populations, with many previously unrecorded and completely new species to this reef. The western reef of Koh Seh also showed notable increases in fish abundance, however species richness was evidently lower compared to the eastern reef. It is very likely that the difference in recovery rate between Koh Seh's east and west is directly related to the level of exposure to illegal and destructive fishing techniques. MCC's legislated 300m by 150m conservation zone encompasses the majority of the eastern reef, within which MCC actively attempts to apply Cambodian fisheries laws. The western reef is outside of this area and thus experiences a relatively lower level of securityagainst fishing vessels using illegal, unsustainable or destructive techniques.The results of MCC's surveys of the eastern reef give strong evidence for the potential of the western reef to regenerate at a faster rate if protection is enhanced (i.e. enforcement of fisheries laws).The western reef contains a moderate-high percentage of live coral cover (Gomez & Yap 1988), which is a positive sign given the correlation between this and fish species richness, density and population density (Bell & Galzin 1984; Carpenter *et al.* 1981).Furthermore, the presence of un-colonised rock substrate (14%) allows for coral settlement and expansion. Overall, these factors create astrong possibility for this reef to host a greater variety of marine species, and hence improved ecosystem health and productivity.

The regeneration demonstrated by the marine environment of Koh Seh gives solid evidence as to the potential benefits of Cambodian fisheries law imposition, predominately through the halting of illegal and destructive fishing methods. In saying this, environmentally damaging fishing techniques are still continuing, though on a much lesser scale, within Koh Seh's marine bioregion and are still widespread throughout the Kep Archipelago.The increasing fish density and diversity around Koh Seh has captured the attention of an increasing number of Khmer and Vietnamese fishers. By their own admission, Koh Seh contains more abundant commercial fish species than anywhere else in Kep Province. MCC welcomes sustainable fishers, who are the main beneficiary of MCC's conservation efforts. Unfortunately, many fishers are still utilising destructive fishing gear, particularly trawling nets. This greatly hampers MCC's ability to rehabilitate Koh Seh's marine ecosystems, and thus,the capability of these ecosystems achieve high functionality and productivity. This could be obtained through effective fisheries law enforcement, ideally in concert with regulated zoning and management. MCC's proposed MFMA for the Kep Archipelago (MCC 2016) offers a zoning framework that should be utilised primarily to safeguard the collapsing yet crucial ecosystems of Kep Province, as well as to boost recovery of those surrounding Koh Seh. This management plan overcomes another factor hampering the recovery of Koh Seh's marine environment, which is the limited marine area over which MCC holdsjurisdiction (300m by 150m). Given that pelagic and long-distance migratory fish are returning to Koh Seh (e.g. trevally and jacks), a larger conservation area is required to facilitate the population increase of these important ecological and commercial species. The western reef would also greatly benefit if it was encompassed into MCC's conservation zone, and may show a similar recovery rate to that of the eastern reef.

4.3 *Fish*

4.3.1 New species

MCC documented a number of fish species that were either;

1. Not recorded prior to the 2016 reef surveys (but still present in Koh Seh's marine environment) or;
2. Observed for the first time ever within Koh Seh's marine environment (either surveyed or simply witnessed) (see 'New fish species' p 16).

Clearly this is a positive sign, giventhe correlation between higher fish diversity and ecosystem stability (McCann 2000). All new fish species were observed within the eastern reef, yet only three were found in the western reef. This demonstrates not only the potential for even small-scale conservation to greatenfish species richness, but how the intensity of conservation effort may be proportionally reflected in the return of fish species to the conserved marine area. Despite the encouraging sign of new fish species, a variety of fish species may not compensate for a lack of functional diversity in marine ecosystems. Koh Seh still lacks several marine fish guilds that perform important ecosystem functions, including parrotfish (Scarinae sub-family) and large fauna (e.g. sharks, dugongs, turtles etc.). The absence of just the humphead parrotfish (*Bolbometopon muricalum*) can potentially cause widespread regional changes in ecosystem function (Bellwood *et al.* 2003). MCC is hopeful that with further protection of Koh Seh's marine environment, functionally significant species will return and increase ecosystem function.

Of the nine completely new fish species to Koh Seh's marine ecosystem, six are commercially fished, and thus hold potential economic and livelihood benefits for fishers. Each previously unrecorded/new fish species observed within MCC's 2016 surveys or outside of them is given a brief ecological description below:

1. <u>Species not recorded prior to MCC's 2016 surveys:</u>
    - Dusky rabbitfish (see 'Herbivory and algae regulation' p 36)
    - Emperor (medium to large-sized fish, which feed mainly on benthic invertebrates. A few species are nocturnal predators and larger species occasionally prey on fish (Allen *et al.* 2005)).

- Boxfish (squarish shaped and slow swimming fish that feed on a variety of benthic invertebrates (Allen *et al.* 2005)).
- Jacks/trevallies (ravenous predators that form large-distance travelling schools or may be solitary (Allen *et al.* 2005)).
- Longfin grouper (see 'Trophic cascades' p 35)

2. New species observed or surveyed (since February 2015):
    - White-spotted rabbitfish (*Siganus canaliculatus*) (see 'Herbivory and algae regulation' p 36)
    - Paradise whiptail (*Pentapodus paradiseus*) (small to medium sized fish, which commonly hunt solitarily and are opportunistic bottom feeders (Allen *et al.* 2005)).
    - Spadefish (moderately sized omnivorous fish that feed on small invertebrates and algae (Wood & Aw 2002)).
    - Duskytail grouper (see 'Trophic cascades' p 35).

4.3.2 Eastern reef

The significant increase in the abundanceof threegroups of fish species (grouper, emperor and sergeant fish) is a very encouraging result, however it is likely amodest estimate of the fish population increases. This is due to the fact that fourteen fish species were added to MCC's 2016 surveys (see 'Species additions & removals' p 11), and thus previous data for which to compare the abundance of these fish is not available. The population growth helps to affirm that MCC's safeguarding of this reef against unsustainable fishing is producing ecosystem benefits. Key herbivore and predator species increased in abundance, which is of great importance to maintaining ecosystem stability. The abundance of commercial fish also increased (e.g. groupers and trevallies/jacks), supporting the notion that conservation can improve livelihood for fishers.

Cardinalfish and sweeper were the densest fish populations recorded during the 2016 surveys, both of which increased notably from 2015 levels (significant for sweeper). These species are small reef fish that form large schools during the day, then hunt solitarily at night (Kuiter & Debelius 2006). They feed on plankton, and their regulation of plankton levels is extremely important to ecosystem functionality.These species potentially contributed to the lower level of detrimental impacts experienced within Koh Seh's eastern reef during the algae bloom in Kep Province (refer to 'Kep's algae bloom' p37).

In stating this, MCC's safeguarding of the marine environment against illegal fishing was almost certainly the primary factor.As compared to 2015 levels, grouper species increased considerably.This is significant given the widespread overfishing of groupers in Southeast Asia (Kuiter & Debelius2006), and the resulting caged aquaculture of grouper species in Cambodia (Limsong 2001).Groupers are important predators; small groupers (<20cm Total Length - TL) feed mainly on crustaceans and large groupers (>30cm TL) on fish, with medium sized groupers (20 – 30cm TL) preying on both (Eggleston *et al.* 1998). This allows grouper species to moderate a range of fish and crustacean populations, leading to greater trophic and ecosystem stability (see 'Trophic cascades' p 35). With the relatively large fishing community present in the shallow waters of the Kep Archipelago (<10m depth), marine ecosystems with trophic stability are essential to sustain local catch of commercial fish and invertebrate species. Currently, the overfishing of predatoryfish is very likely leading further trophic cascades and consequences for the environment, fishers, communities, restaurants and tourism industries. Marine natural resource zoning, such as that achieved by an MFMA, is recommendedfor the Kep Archipelago. Itwould provide protection of marine environments sufficient for predator stocks to recover, and re-stabilization of trophic levels. Supporting this are two case studies; first of which was located in the Exuma Cays Land and Sea Park (ECLSP) in the Bahamas Archipelago, established in 1959. A ban on fishing since 1986 was linked to a seven-fold increase in the Nassau grouper (*Epinephelus striatus*) abundance over less than 30 years relative to other areas of this archipelago (Mumby *et al.* 2006).Secondly, a small no-take area in Indonesia, Wakatobi Marine National Park, showed an increase in grouper population density of 30% over a five-year period of protection (Unsworth 2007).

Furthermore, Unsworth (2007) concluded that a no-take area covering a reef system of only 500 meters in length was large enough to increase the quantity of top predatory fish. This is aligned to MCC's request to the National Fisheries Department for a 500 metre by 500 metre scientific research zone. Based upon this evidence, MCC's small-scale protection of eastern Koh Seh reef has very likely boosted grouper populations within the area. Expansion of strictly protected areas through the Kep Archipelago may result in similar increases in grouper density, together with other predators, as found in the case studies. Greater catch would follow, increasing economic benefits for fishers and fishing industries. This could be achieved through marine area management, i.e. an MFMA/MPA zoning scheme, such as that recommended by MCC (MCC 2016).

Rabbitfish and sergeant fish species act as important grazers in marine ecosystems (Allen *et al.* 2005), hence the increase in their density is a step towards a more balanced ecosystem (see 'Herbivory and algae regulation' p 36).One environmental condition that greatly enhances algae growth is a high concentration ofnutrients (Littler *et al.* 2005), which can be found around Koh Seh and throughout the Kep Archipelago. The main local and regional factors that cause this are trawling, habitat destruction, agricultural run-off and land clearing in Vietnam and Cambodia. Frequent and intense trawling disturbs the sea bed and destroys the seagrass ecosystems within the Kep Archipelago and Cambodia (Ahmed & Chanthana 2015; UNEP 2004), causing stored nutrients to enter the water column (Kaiser *et al*. 2001). Trawling has decimated many formerly abundant benthic filter feeders (sponges, bivalves, sea cucumbers etc. documented by MCC as late as 2008), thereby hampering the uptake and recycling of nutrients (Officer *et al.* 1982). These factors can increase the chance of a potential algae proliferation, with abundant grazing fish populations being valuable in assisting to mitigate the likelihood of this event occurring (Littler *et al.* 2005), thus improving ecosystem stability.

The only significant decrease in fish abundance observed during MCC's 2016 reef surveys was the long-beaked coral fish in the eastern reef of Koh Seh. The main reason for the apparent decline is uncertain, however there are a number of factors that likely produced a decline in the sample data, but not in the actual population. Firstly, the large increases in fish density and diversity may have increased the level of competition for reef resources, causing minor shifts in microhabitat use by certain fish species. The long-beaked coral fish feeds on small benthic creatures, algae, plankton or coral polyps (Kuiter & Debelius 2006). Increases in the abundance of species who share some of these food resources, for instance virgate rabbitfish, sergeant fish species and the territorial damselfish (Pomacentridae spp.) (personal observation), may have caused the long-beaked coral fish to have been shunted away from the reef edge, whether deeper or shallower. Secondly, the 2015 transect line covered less reef structure and more reef edge habitat, i.e. sand and seagrass. It is possible that the long-beaked coral fish is more abundant slightly off the reef edge within eastern Koh Seh, however there is a lack of data, observations or scientific literature to support this statement. It is unlikely that this species' abundance has legitimately decreased since 2015 but since the data shows it as a possibility, it must be explored. Possible causes of long-beaked coral fish decline may be a reduction in coral quality or the increase in predators of the various life stages of this species. Given the similar level of coral bleaching between 2015 and 2016 within the eastern reef, coral health may not have declined and therefore may not explain the potential decrease in long-beaked coral fish.

4.3.3 Western reef

MCC's 2016 surveys of the western reef of Koh Seh indicated that a steady recovery of key fish populations is occurring in this region. Increases innoteworthy predator populations (mainly snapper and grouper) demonstrates a strengthening of trophic stability and ecosystem resilience (see 'Trophic cascades' p 3535). The first recording of a gold-spotted sweetlips (*Plectorhinchus flavomaculatus*) within the western reef is a positive sign, given that sweetlips act as nocturnal predators of benthic crustaceans (Allen *et al.* 2005). This behavior may contributeto the regulation of crab populations in western Koh Seh, which in turn, could assist fish population recovery, as the local crabshave been observed to prey upon fish eggs (personal observation). The growth of the wrasse population is ecologically significant for similar reasons. Most wrasse feed on hard-shelled invertebrates, for instance crabs, shrimp and small gastropods (Allen *et al.* 2005), helping to moderate the population levels of these species.

4.3.4 Eastern reef vs. western reef

The eastern reef (and pier) 2016 surveys found a higher abundance offourfish species, as well as a greater fish richness, relative to the western reef.Of these four species, the most noteworthy is jacks, which are an important commercial and predatory species. Big-eye trevally is also a significant species for this reason, and were only found in the eastern reef. High densities of sweeper and cardinalfish are important with regards to plankton regulation, and sergeant fish assist in maintaining a healthy coverage of algae (see 'Herbivory and algae regulation' p 36). Eight-banded butterflyfish and fusilier were both at a significantly higher abundance in the western reef, compared to the eastern reef. This is very likely due to the topography of the western reef, which is slightly deeper and contains a greater coverage of live coral with larger coral colonies. Coral polyps are a part of the diet of many butterflyfish speciesand fusilier prefer large coral structures as their habitat where they seek protection at night (Allen *et al.* 2005; Wood & Aw 2002). It is highly probable that these two fish species are more abundant in the western reef because the habitat there is more suitable.

Sevengroups of fish species were only recorded within the eastern reef, including sweeper, needlefish, big-eye trevally, cleaner wrasse, toadfish, seahorses and filefish. The comparatively greater species richness documented in this reef was likely an indication of itshigher quality habitat space. Firstly, fishing pressure is lower within the eastern reef encompassing MCC research and no-take area, and thus it is reasonable to expect a more diverse fish community there. Secondly, eastern Koh Seh contains a relatively moderate-sized seagrass bed, in which the juveniles of many fish species can develop and mature (e.g. wrasses, filefishes, seahorses, etc. – personal observation). Given the lack of any notable seagrass habitats within western Koh Seh, it is plausible that this has contributed to a lower recorded species richness of reef fishes. Secondly, a number of these seven groups of fish species may have only been recorded in the eastern reef due to a potentially greater quantity of resources like, prey species. A growing population of small prey fish is evident within Koh Seh's eastern reef (personal observation), however the same has not been observed within the west. Active predators such as needlefish and trevally are frequently seen hunting for small prey items, and this may assist in explaining their apparentexclusivity in the eastern reef. Greater levels of plankton may also be present, and thus explain the large schools of sweeper. Another possibility is that a number of these species are sometimes present within Koh Seh's western reef but were not surveyed. This would very likely be a result of survey methodologies inherently containing a probability of not detecting all species within the survey area. For instance, a small population of seahorses reside near this reef. Furthermore, it is likely that long-distance pelagic fish such as big-eye trevally sometimes pass over this reef, and also a chance that cryptic toadfish may have remained undetected during surveys.

4.4 *Invertebrates*

4.4.1 New invertebrate species

The two completely new invertebrate organismsthat were discoveredduring MCC's 2016 reef surveys were the giant clam and feather star, both of which were only observed within Koh Seh's western reef. The re-appearance of the giant clam within Koh Seh's marine bioregion is encouraging. This clam acts as an important filter-feeder in marine environments by removing plankton and other particulate matter (Wood & Aw 2002). The giant clam was also an important commercial species between the 1960s and the 1980s in the Indo-Pacific region (Lucas 1994). As a result of overfishing, giant clam species have suffered considerable decline and many species are now threatened (Shang *et al.* 1990). This has led to investigation into and the establishment of mariculture for giant clam species, especially in Australia, Okinawa (Japan), Taiwan, the Pacific islands and the Philippines (Heslinga *et al.* 1984; Shang *et al.* 1990; Gomez & Mingoa-Licuanan 2006). Although this is a very long-term objective, with enhanced protection of Kep's Provincial marine environment, it is possible that mariculture of giant clam may be a viable future venture. This would translate into economic and livelihood benefits through mariculture and potentially tourism employment. The second new invertebrate species, the feather star, is a member of the Crinoid family. Members of this family typically act as filter feeders, capturing food particles and plankton from the water column (Colin & Arneson 1995). Given the high sediment suspension within the water throughout Kep Province, a higher diversity and density of filter feeders is key to ensuring clearer and less polluted waters.

The lowdiversity of invertebrates recorded in the marine environment of Koh Seh is likely caused by a variety of human-based activities, with overharvesting and illegal fishing of main concern. Invertebrates are often fished at high levels for both food (e.g. blue swimmer crab, sea cucumber, gastropods (*Trochus*, *Turbo* spp.)and for other commercial uses, such as jewellery and tourist souvenirs. Vietnamese and Khmer shell collectors regularly poach valuable invertebrate species around the periphery of MCC's conservation zone, potentially decreasing invertebrate species richness and abundance within this zone. The low richness of invertebrates is concerning because many invertebrates play an important role in coral reef ecosystems. For example, many invertebrates consume algae, which is vital to keep coral and algae coverage balanced (see 'Herbivory and algae regulation' p 36). This problem is compounded in high nutrient ecosystems, and those where there are few herbivorous fish to feed on algae in the absence of invertebrates. Measures to protect and rehabilitate invertebrate populations are required in order to enhance the overall health of Koh Seh's marine bioregion. One strategy is the implementation of regulated zoning areas, i.e. an MFMA/MPA, for instance that recommended by MCC for the Kep Archipelago (MCC 2016). This zoning scheme would very likely induce the growth of key invertebrate populations through the establishing of 'no-take' conservation zones. This would help to ensure that economically significant invertebrate species (e.g. blue swimmer crabs) not only survive, but are plentiful enough to provide employment and food for Cambodians for numerous future generations.

4.4.2 Eastern reef

MCC's 2016 Koh Seh reef surveys revealed that the eastern reef had similar invertebrate population densities to those logged in 2015. The only significant differencewas the apparent decrease in xanthid crabs, which is more likely due to misidentification or the alternate placement of the transect line during MCC's 2015 eastern reef surveys. Conch was the only previously unrecorded species surveyed, with more detail on Conch explained in the next section (see 'Eastern vs. western reef' p 48).

Within the eastern reef of Koh Seh, data collected by MCC indicated that gastropods (predominately *Turbo* and *Drupella* species), boring bivalves, *Diadema* sea urchins and Christmas tree worms were highly abundant, relative to the other invertebrates recorded. *Turbo* species, the main gastropod recorded within 'other gastropods', are widespread grazers throughout temperate and tropical marine environments; however in Cambodia they are an endangered species.Information on the importance of grazing and algae moderation in coral reef habitats is described under 'Herbivory and algae regulation' (p 36) and in this sections paragraph covering *Diadema* urchins.

Despite a non-significant increase, the *Drupella* population within Koh Seh's eastern reef needs to be monitored carefully, as they are abundant and a predator of coral (Turner 1994). Historically, outbreaks of *Drupella* have been the cause of extensive coral damage, reaching levels similar to that of the crown-of-thorns seastar (Turner 1994). Evidently, this gastropod population has the potential to cause widespread damage if not monitored, especially in conjunction with the numerous stressors that the coral population of eastern Koh Seh are already exposed to (eutrophication, sedimentation, high water temperature, etc.).Given that the 2016 transect line covered a larger proportion of reef structure relative to 2015, it is extremely likely that the growth of the *Drupella* population denoted by the 2016 survey data is exaggerated. In stating this, it is likely that *Drupella* have increased in number (non-significant), due to MCC protecting eastern Koh Seh reef from Vietnamese and Khmer shell collectors. Boring bivalves are molluscs with two shells hinged together, which burrow into hard substrate such as coral and rock. Boring bivalves can act as major contributors to biological destruction of coral reefs through bio-erosion (Appukuttan 1972; Colin & Arneson 1995; Hutchings 1986), which is removal of calcium carbonate substrate by biological agents. Bio-erosion can cause coral colonies to have weaker basal attachments (Highsmith 1981), as well as lower capacity to bend and compress (Scott & Risk 1988). A greater skeleton density can lessen damage caused by bio-erosion (Highsmith 1981), however skeletal density has been determined to be relatively low in massive corals (Hughes 1987). Given the prevalence of this growth form in eastern Koh Seh, boring bivalve density on corals needs to be monitored carefully in order to avoid excess coral demise. MCC's 2016 reef surveys have provided a baseline estimate of boring bivalve populations, from which future years' surveys can use in order to find trends in boring bivalve distribution and abundance.

Diadema urchins are echinoderms that act as significant grazers in coral reef habitats (Colin & Arneson 1995). The relative abundance of these urchins is likely influenced by the densityof herbivorous fish populations (similar ecological niche), thepresence of turf algae as a food source, and also the low number of macro-invertebrate predators (Tuya *et al.* 2004). Other contributing factors may be reef structure complexity and a high recruitment rate (Clemente *et al.* 2007). Despite their relative dominance, *Diadema* urchins vitally contribute to preventing algal proliferation in the eastern reef. Morrison (1988) discovered that removal of *Diadema* urchins from a shallow reef environment with low density of herbivorous fishes can produce rapid growth of erect and filamentous algae. The role of *Diadema* urchin is important in balancing algae levels within the eastern reef of Koh Seh, which greatly benefits the health of the coral populations within this reef.Christmas tree worms are a type of Polychaete worm that live within a tube buried into often living coral skeleton.These worms project their feeding appendages and feed upon particulate matter in the water column. Coral disease and tissue loss are associated with tube worms (Raymundo *et al.* 2008), and in Koh Seh, coral disease is often adjacent to the tubes of these worms (personal observation). Given this association, the density of Christmas tree worms within coral colonies in eastern Koh Seh needs to be examined in order to avoid the spread of coral disease.

4.4.3 Western reef

MCC'swestern reef survey data revealed a small number of invertebrates to be highly prevalent. These species included boring bivalves, *Diadema* urchins and Christmas tree worms. Information on the ecology of these three invertebrates is listed above (see 'Eastern reef' p 46). The high abundance of boring bivalves and Christmas tree worms in Koh Seh's western reef was likely due to the moderate-high coral coverage. Coral colonies provide a substrate in which these organisms can bore, hence a greater amount of potential boring substrate has very likely allowed dense populations of these species to form. The high density of *Diadema* urchins in the western reef may have been influenced by extensive coverage of turf algae on coral and rock substrate upon which these urchins feed, and possibly the greater depth of the site.

4.4.4 Eastern vs. western reef

The invertebrate data from MCC's 2016 reef surveys shows that the Koh Seh's eastern and western reefs contained a relatively similar composition of invertebrate species. A significantly higher abundance of gastropods (mainly *Turbo* species) and xanthid crabs (Xanthidae family) were present within the eastern reef, compared to the western reef. The ecology of *Turbo* species is described above (see 'Eastern reef' p 46). Xanthid crabs are effective and agile predators that typically consume large quantities of barnacles, larvae, eggs and algae

(Ray-Culp *et al.* 1999). Small invertebrates such as xanthid crabs may utilise seagrass habitat as shelter (Caribbean Fishery Management Council 1998; Ray-Culp *et al.* 1999).Following this, the greater density of xanthid crabs recorded within the eastern reefcould likely have beena result of the seagrass bedpresent at this locality. Blue swimmer crabs and conch were only found in the eastern reef, and conversely, cowries, feather stars, giant clams, pencil urchins and collector urchins only found in the western reef. Blue swimmer crabs are likely at a higher density within the eastern reef owing to the presence of a moderate-sized seagrass bedon this side of the island. Blue swimmer crabs are an economically important species within Kep Province. The presence of large blue swimmer crabs in Koh Seh's marine environment (confirmed by local fishers) represents the potential positive effect of protection against overfishing, and especially illegal and destructive fishing, on commercial species. Collector and pencil urchins were likely only observed during western reef surveys as a result of the transect line covering more non-reef structure, for example sand and rubble, where these urchins are found.

4.5 *Substrate*

4.5.1 Eastern reef

MCC's 2016 reef surveys of eastern Koh Seh found a reef dominated by zoanthids, with low coral cover. Zoanthids are a type of black coral, in which the polyps are colonial and cover the surface of a black skeleton (Colin & Arneson 1995). Unlike hard coral, zoanthids lack a calcium carbonate skeleton and thus do not contribute to the building of reef structure. Zoanthids are able to compete aggressively with other sessile species by utilising potent toxins (Sammarco 1985). Suchanek (2002) demonstrated that *Palythoa caribaeorum,* a species of zoanthid, is able to overgrow many different types of colonial invertebrates including hard corals, hydrozoansand encrusting sponges. Furthermore, this species can potentially grow up to 4mm per day. Within shallow coastal reefs (<3 metre depth), such as those found at eastern Koh Seh, zoanthids may show a competitive edge over certain types of algae (Costa Jr. 2000). Furthermore, Rabelo (2013) demonstrated that some species of zoanthids are capable of recolonizing substrate within a few months. With all of their competitive advantages, it is highly plausible that zoanthids outcompeted algae and prevented a phase shift of the eastern reef from coral- to algae-dominated substrate in the past. Competitive exclusion of algae may still be currently occurring today. Clearly, these characteristics of zoanthids have allowed them to dominate the coral reef of eastern Koh Seh, as well as to influence the level of other sessile invertebrates and algaethrough competitive interactions. Intriguingly, MCC team scientists have witnessed the increasing overgrowth of zoanthids by species of anemone and soft coral (see figure 26). Scientific literature is very sparse on these specific competitive interactions, however soft corals have been documented to show adept competition via chemicals (Web & Coll 1983) and ability to alter orientation and growth patterns (La Barre & Coll 1983). Future reef surveys may build evidence on a lesser known aspect of potential reef rehabilitation. To continue on this point, rabbitfish species have been observed feeding on algae filaments attached to zoanthids, possibly damaging zoanthid polyps in the process. The clear increases in rabbitfish populations may be another factor that moderates the abundance of zoanthids within eastern Koh Seh reef. It is possible that species of soft corals, anemones and rabbitfish could play a key synergistic role in disrupting the dominance of zoanthids within the eastern reef. Consequently, balancing the levels of different sessile organisms would very likely act to improveoverall ecosystem health.

Figure 26: A soft coral colony spatially competing with zoanthids. MCC has observed a clear expansion in this colony, suggesting that it is out-competing the zoanthids.

According to coral cover standards in Gomez & Yap (1988), the live coral coverage of Koh Seh's eastern reef is low. The potential expansion of hard and softcoral organisms in this reef is most likely being hampered by sedimentation and high nutrient levels. Nutrient enrichment and sedimentation stress form two significant factors leading to coral death (Szmant 2002), and thus also reduce growth and quality. High levels of sediment in the water column decrease photosynthetic production and respiration and reduce energy reserves by causing the production of metabolically expensive mucous (Riegl & Branch 1995). High nutrient concentrationsenhance algal proliferation, and although the level of algae around Koh Seh is not high, algae is frequently observed directly or indirectly competition with corals (e.g. colonization of damaged&dead coral patches, competitive exclusion of space). Within Cambodia, trawling is a major cause of sedimentation and excess nutrient input, with these consequences spreading vast distances (see 'Project limitations' p 14). To enhance the recovery of vital coral species, ecosystems must be protected against these adverse impacts. Coral reef recovery wouldgenerate greater habitat complexity and cover, both of which are correlated with increased fish density and diversity (Luckhurst & Luckhurst 1978; Neely 2008). A marine management plan based on zoningof the Kep Archipelago, as in MCC (2016), provides recommendations on establishing conservation and fishing areas, which are safeguarded against the devastating effects of trawling and other destructive fishing methods. This scheme willproduce a diversity of thriving coral colonies, leading to rich and productive ecosystems that would benefit, fishers, locals and tourists alike.

Recently killed coral (<1 year) was recorded very infrequently during 2016 reef surveys. This is a good indicator that recovery occurred following the 2015 seasonal bleaching event (March – May 2015). No soft coral was documented during these surveys. Soft corals are a group of octocoral, in which the polyp contains eight tentacles (or multiples thereof) and calcareous spicules are used for structural support (Colin & Arneson 1995). Despite no record in our surveys, MCC is aware of a low but growing number of colonies (<15) distributed around Koh Seh. A small number of colonies appear to be overgrowing zoanthids (see Figure 26). If so, they are demonstrating an ecologically significant phenomenon, by acting as one of only two sessile organisms observed by MCC to potentially out-compete zoanthids. Given the lack of octocoral predators (Wylie & Paul 1989), as well as the ability of many soft corals to rapidly colonize available substrate (Colin & Aneson 1995), there is hope that soft coral abundance willincrease in the near future. In contrast, some soft coral species have been shown to lag behind hard corals in recovery (Fabricius 1995), thus future substrate surveys will provide interesting information regarding the expansion and colonization rate of soft coral in Koh Seh's marine environment.

4.5.2 Western reef

MCC's 2016 reef surveys of western Koh Seh found a reef dominated by coral colonies, which showed a moderate-high coverage according to standards in Gomez & Yap 1988. The relatively healthylevel of coral coverage within the more impacted western reef of Koh Seh, implies that there is potential for it to recover and thrive. Research in the Indo-Pacific region has demonstrated correlative increases in fish diversity, with coral cover and coral species richness (Komyakova *et al.* 2013). This is especially true regarding butterflyfish/coralfish (Chaetodontidae spp.) and parrotfish species (Scarinae sub-family) found in this region, which feed upon dead and living coral structure. Furthermore, juveniles of many fish species prefer to settle near live coral (Komyakova *et al.* 2013), reinforcing the potential for fish populations to regenerate in Koh Seh's western reef. Similar to the eastern reef of Koh Seh, the western reef survey data indicated very low levels of recently killed coral (<1 year), and no recording of soft coral. More information on the ecological implications of this is detailed in the previous section (see 'Eastern reef' p 49).

4.6 *Impact assessment*

External disturbances, such as bleaching, disease and predation (seeFigure 27) may lead to coral mortality, which subsequently increases the likelihood of algal overgrowth and inhibition of coral recruitment (McCook *et al.* 2014). Thus, it is important that these phenomena impacting coral be measured in order to assess the health of coral colonies and populations, as well as monitor any changes over time.

4.6.1 Eastern reef

Given the shallow topography and warm water temperature characteristic of Koh Seh's eastern reef, it is vital that the levels of coral bleaching are monitored. MCC's 2015 and 2016 surveys of the eastern reef revealed a similar and relatively lowaverage level of coral population bleaching (9.8% and 4.8%) and bleaching within coral colonies (10.8% and 8.3%). Since these surveys were carried out at a similar time of year (March-April), a similar level of coral bleaching was expected, ifother environmental conditions remained similar. Following MCC's 2016 surveys, MCC scientists observed population bleaching levels rapidly rise to at least 65% during the end of April and into May. Despite the results, bleaching within this reef is a significant stressor that could lead to widespread coral mortality, especially given rising sea temperatures and acidity.Research on the ability of coral species to adapt to the increase in these environmental parameters is varied, with some papers suggesting that the capacity of adaptation has already been reached (Hoegh-Guldberg 1999), whilst others state that it is dependent on factors such as the species of coral and intrapopulation genetics (Hughes *et al.* 2003). In past years, thisreef has demonstrated the ability to recover from bleaching (personal observation). One highly relevant factor here is the high proportion of massive and submassive coral growth forms within these reefs, which show a comparatively greater tolerance to bleaching (Loya *et al.* 2001).

A key step to reducing anthropogenic effects that exacerbate bleaching and cause demise of coral reefs would be the implementation of a zoning scheme for the Kep Archipelago, as outlined in MCC (2016). By regulating fishing activities and establishing conservation zones for coral reef habitats, human-induced stressors upon marine ecosystems would be minimized. In turn, this would be expected tolowercoral bleaching and stimulate greater recovery of bleached corals. An additional benefit of this MFMA scheme would be enhanced connectivity (see ‘Connectivity’ p 37) between coral populations throughout the Kep Archipelago, which is theorized to enhance recovery from bleaching (Hughes *et al.* 2003).

MCC’s 2016 survey data indicated greater trash prevalence in the south-eastern reefrelative to the north-eastern reef. Given the very low trash quantity logged, the practical significance of this is questionable, however the result is explainable. The south-eastern reef is adjacent to an ever-present number of small-scale fishing boats. Fishers on these vessels often dump rubbish in this area, some of which is likely dispersed onto the nearby south-eastern reef. MCC’s new impact assessment of coral disease revealed that the eastern reef contained a relatively moderate prevalence of disease.The Coral Disease Working Group of the Global Environmental Facility Coral Reef Targeted-Research Program (2007) quotes various papers estimating the 2002 – 2006 regional disease prevalence average of Australia, Palau, East Africa (all 5%), the Philippines (8%), in addition to the Caribbean and Yucatan peninsula (up to 20%). Based on these statistics, the incidence of disease for the eastern Koh Seh coral population is moderate (9.4%). The level of coral disease will need to be monitored carefully in future surveys to ensure disease prevalence does not rise and cause coral mortality, resulting in adverse ecosystem effects. This is important given the density of Christmas tree wormstogether with warm water temperature, both of which are potential predecessors of disease (Raymundo *et al.* 2008; Miller *et al.* 2008).

4.6.2 Western reef

MCC's surveys of western Koh Seh revealed that this reef contained a moderate-high level of coral bleaching throughout the population (53%) and within the colonies (43%). MCC surmises that this was primarily a result of the timing of these surveys, which were conducted during April and May 2016, a period of seasonally elevated water temperature (32 - 33◦C). This notion was reinforced by observations of increased bleaching present in the eastern reef during this period. Given that coral bleaching within western Koh Seh is likely exacerbated by other anthropogenic activities such as destructive fishing and eutrophication, the potential demise of coral colonies is far greater. For example, trawling causes widespread seabed disturbance (Ahmed & Chanthana 2015), resulting in suspension of sediment that abrades against and deposits on corals, thereby increasing bleaching risk. This is especially true in combination with the rise of oceanic temperatures and acidity, two factors strongly linked to coral bleaching (Hoegh-Guldberg *et al.* 2007). Overall, the synergism of these adverse effects could potentially cause widespread coral mortality, not only in Koh Seh's western reef, but throughout the Kep Archipelago. The ability of coral species to adapt to changing environmental conditions, as well as the mitigation of damaging human-based impacts, are vital in preventing this catastrophic event.

According to statistics given by The Coral Disease Working Group of the Global Environmental Facility Coral Reef Targeted-Research Program (2007) ('Eastern reef' p 52), the disease frequency within the coral populations in the south-western and north-western reefs was at a moderate level (4% and 8% respectively). Conversely, the prevalence of disease within coral colonies in the south-western reef appeared to be relatively moderate-high (22%). This is most likely a result of the greater density of fishers on and adjacent to this reef. The increased amounts of anthropogenic stressors added to, and maintained conditions in which pathogens could thrive.

Figure 27: Bleached and diseased corals in Koh Seh's marine environment, Kep Province, Cambodia (Brayden Cockerell, 2016).

4.6.3 Eastern vs. western reef

Most impact assessments were either not contrasted between the eastern and western reef, or were not significantly different. As previously stated, justification for a lack of statistical comparison in regards to bleaching and disease is the higher water temperature that was present within the western reef relative to the eastern reef. This was a consequence of a delay in western reef surveys, which therefore experienced seasonally elevated water temperature.

The relatively higher predation rate of the coral colonies within the eastern reef of Koh Seh, as compared to the western, was likely caused by a number of factors. *Drupella* were recorded at a greater density in the eastern reef, and although this was not significant (p=0.07), this could still form a viable explanation for the higher magnitude of coral predation. Another explanation may be that with lower coral cover in eastern reef, coral predation is more noticeable to the surveyor compared to the western reef. Coral predation, in conjunction with the current stressors of unsustainable and destructive fishing techniques, high water temperature, sedimentation and excess nutrients, have the potential to cause significant coral mortality. Accordingly, coral predation intensity needs to be evaluated regularly in order to ensure the adverse impacts on coral colonies and populations are minimized.

4.7 *MFMA/zoning implementation*

MCC's surveys of Koh Seh have clearly shown that the eastern reef, which experiences the highest level of protection, contained the greatest fish and invertebrate richness. Compared to the western reef, the eastern reef had larger populations of predatory (grouper) and grazing fish (rabbitfish), leading to greater trophic and ecosystem stability. Improved stability strengthens ecosystem resilience, which expands the ability of the ecosystem to resist degradation through environmental and anthropogenic stressors. This is important given the variety of pressures that Koh Seh's reefs are exposed to; illegal and destructive fishing, sedimentation and excess nutrient input, storms, among others.

The comparatively better condition of Koh Seh's eastern marine reef is very likely due to MCC's focused protection in this region, i.e. within MCC's legislated 300m by 150m conservation zone. This protection regime has chiefly targeted destructive fishing, with emphasis on trawling, since December 2013. Fish and shrimp trawling frequently damage coral communities and seagrass meadows in Cambodia (Ahmed & Chanthana 2015) and throughout South-East Asia (McManus 1997; UNEP 2004), causing widespread detrimental effects. In Cambodia, trawling disturbs significant amounts of sediment (Ahmed & Chanthana 2015) and indiscriminately catches fish, invertebrates and habitat-forming organisms (seagrasses, sponges, corals etc.), resulting in sometimes higher than 80% by-catch and extensive harm (MCC 2016).

The development of new trawling technologies, like higher horsepower engines, along with the utilisation of electric and pair trawling, have exponentially enlarged the destruction caused by trawling vessels. In surveys conducted by Ahmed & Chanthana (2015), 81.8% of Cambodian fishers claimed that illegal fishing has been on the rise. Due to MCC's protection of a portion of the eastern Koh Seh reef against the increased use of trawling and other illegal fishing methods (e.g. tube fishing, rat-tail traps, gill nets etc.), this reef is evidently recovering notably. Marine life is beginning to flourish relative to reefs on islands near Koh Seh and the Kep Archipelago.

Unsustainable and environmentally damaging fishing activities occasionally still occur within MCC's small conservation zone, greatly slowly recovery of this ecosystem (see Figure 28). Vietnamese trawlers and air-tube fishermen encroach on the area, desperately turning to

Cambodian waters to fish. The marine environment of Vietnam has been unsustainably fished, lacks marine resources, and thus has declined in productivity (Pomeroy 2011). Illegal, unsustainable and destructive fishing has hindered MCC's ability to conduct research for many years. For instance, trawling causes surrounding waters to become turbid, thus reducing visibility, and delaying, prolonging or preventing MCC's research activities (e.g. coral reef surveys, seahorse research, habitat mapping etc.);while also negatively affecting the local marine organisms. On top of that, fishers illegally capture species within MCC's small protected area that are a key component of MCC's research (e.g. seahorses).

The development of MCC's marine research could lead to the acquisition of more grants and projects, as well as a greater level collaboration with national and international scientific bodies. A key step in this development is the enlargement of MCC's currently restrictive research area. As MCC progresses further in this field, conservation effort will be financially easier, and national and international awareness of Cambodia's precious marine ecosystems will increase. This in turn will facilitate MCC's acquisition of further research grants and projects, as well as promoting marine eco-tourism within the Kep Archipelago. There is far more potential for recovery within the reefs of Koh Seh, especially that of the western reef. Many ecologically important and human-valued species are still absent from Koh Seh's marine environment, for example sharks, rays, turtle, dugongs, parrotfish, lobster, commercial sea cucumber and anemone fish. All of these species were once present within the Kep Archipelago, and may once again return through greater levels of fisheries law enforcement and more widespread conservation effort on the vulnerable, but high potential marine ecosystems in this bioregion.

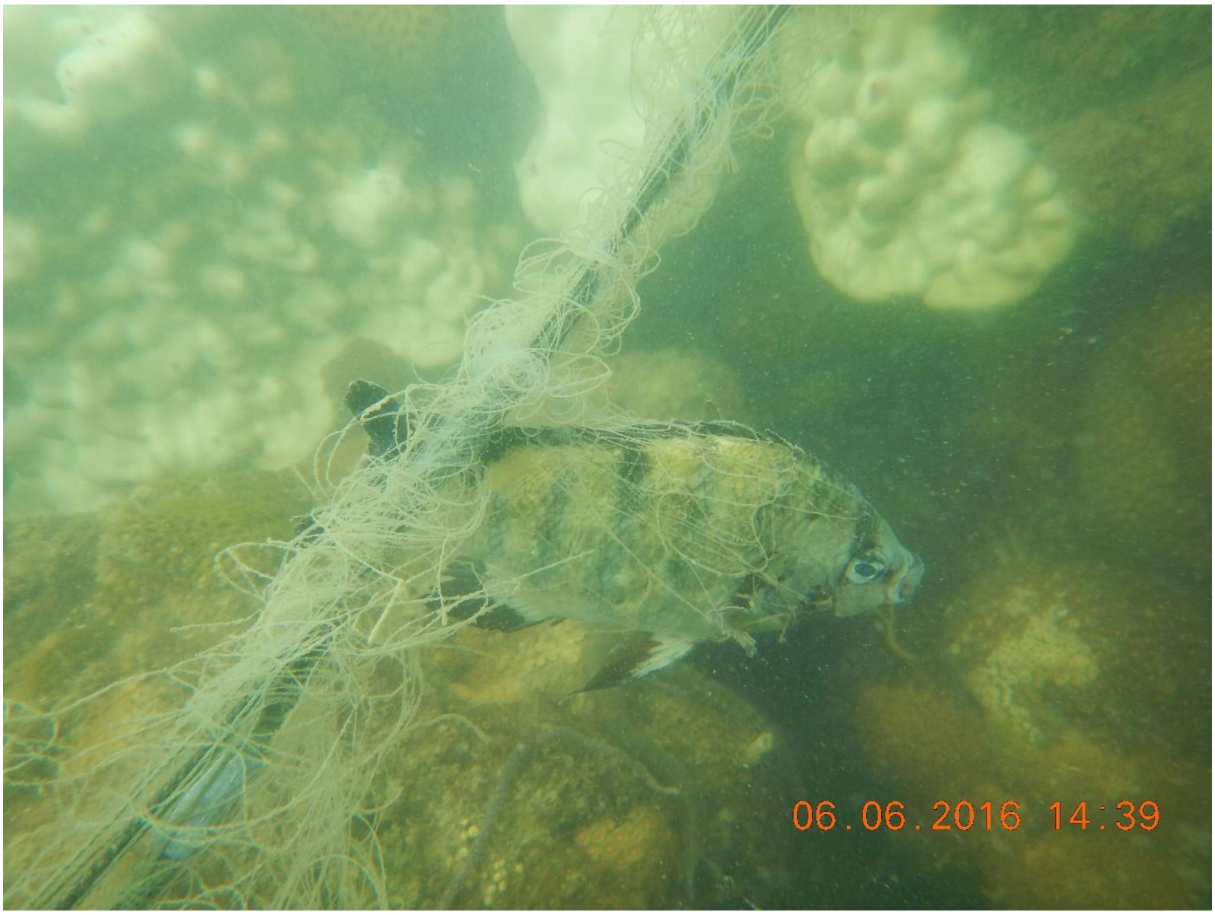

Figure 28: Sergeant fish trapped in a fishing net indiscriminately laid upon Koh Seh's north-eastern reef (Brayden Cockerell June 2016).

MCC's MFMA zoning proposal for the Kep Archipelago (MCC 2016) outlines a feasible scheme which should be used to amplify ecosystem recovery and fisher livelihood throughout this region. The improvement of health within Koh Seh's eastern reef through small-scale MCC protection provides substantial evidence for the potential benefits of this proposed MFMA (MCC 2016).

By establishing no-take conservation zones throughout Kep Archipelagic islands where fish and invertebrate species can recover, the diversity and density of marine life within, and outside these zones will very likely increase (i.e. spill-over will occur). This process was documented to increase fisheries catch within 200 – 250m of Apo Island no-take marine reserve in the Philippines within four years of protection (Russ *et al.* 2004). These conservation zones parallel the regulations typically applied to MPAs, which are currently the best management tool for conserving coral reefs and other marine systems (Hughes *et al.* 2003).Although stage 1 of the zoning scheme only encompasses Koh Seh, Koh Angkrong, Koh Mak Prang and Koh Pou, local conservation efforts like this can greatly help in maintaining and enhancing resilience, as well as limiting the longer-term damage from bleaching and related human impacts (Hughes *et al.* 2003).

Implementing the MFMA would also potentially create the abiotic and biotic conditions necessary for the return of many highly valued marine species that play significant ecological roles, such as those listed in the previous paragraph. Another advantage of establishing the MFMA would be the improvement of the rare Irrawaddy dolphin population. In turn, this could open a lucrative market for tourism industries to undertake dolphin-based activities (e.g. dolphin watching tours, swimming with dolphins etc.), benefitting the local economy. The entrance of new tourism businesses would translate into alternate and more sustainable forms of employment for current illegal and/or desperate fishers. Reduced fishing pressure and destructive fishing activities would renew the Kep Archipelago's susceptible marine habitats. Improved habitat, along with greater commercial species richness would support small-scale fishers who can utilise the surrounding regulated fishing zones, as well as more tourism opportunities, with both creating economic benefits. Most importantly, the enforcement of laws concerning illegal and destructive fishing within the MFMA will remove the primary source of frequent and large-scale ecosystem destruction in Cambodia.

5 Conclusion

When Marine Conservation Cambodia (MCC) first arrived on Koh Seh, Kep Province in December 2013, the marine ecosystem of this island was in a dismal state (MCC 2014). Many ecologically and economically important species were absent, and thus the ecosystem functions that they carried out were also lacking (MCC 2014). The fish populations of that time were low compared to now. The research conducted in this report shows the return of a noteworthy number of marine species, primarily fish (see 'New fish species' p 16). Additionally, an increasing quantity of fish species were recorded (refer to Figure 4 - Figure 9). These two factors evidence the ability of small-scale conservation efforts to induce notable ecosystem recovery in a period of two years. Despite the promising results, ecosystem recovery could be greatly enhanced but numerous factors impede this.

Illegal and destructive fishing practices are still active within the vicinity of Koh Seh, chiefly air-tube fishers and trawlers. The adverse impacts of trawling can be widespread, as suspended sediment takes a long time to settle, and afterwards stresses organisms and increase the risk of diseases. Trawling sediment, and its environmental consequences, are frequently observed on Koh Seh's protected reefs. The high quantities of nutrients and sediment released during activities such as trawling are linked to impaired photosynthesis, smothering of marine organisms (e.g. corals) and increased algal blooms(Kaiser *et al.* 2001; Littler *et al.* 2005).

The most significant aspect of MCC's conservation efforts is unequivocally the enforcement of Cambodian fisheries laws against illegal fishing vessels. These illegal vessels, in particular trawlers, have been witnessed by MCC to frequently cause large-scale damage throughout the Kep Archipelago. Repeated trawling of sensitive marine environments, especially seagrass areas, have set back habitat rehabilitation in some areas by years, if not decades. Clearly, a delay between conservation efforts and this rehabilitation is almost certainly owing to the long-term harm caused by destructive fishing techniques.MCC strongly conjectures that widespread application of Cambodian fisheries laws in Kep Province would result in long-term and large-scale ecosystem recovery.

Owing to many years of anthropogenic stressors (illegal and destructive fishing, overharvesting, pollution etc.), enforcement of these laws is necessary in Kep's marine bioregion. By stimulating recovery of vital habitats such as coral reefs and seagrass beds, an increase of marine organism populations would occur. This pattern of habitat and species renewal is demonstrated clearly through MCC's 2016 reef surveys of Koh Seh. To facilitate a similar trend in ecosystem renewal, MCC strongly suggests the implementation of marine zoning as proposed in MCC's stage 1 Marine Fisheries Management Area (MFMA) for the Kep Archipelago (MCC 2016).

The main purpose of this paper is to assess the benefits, feasibility and need for this MFMA, which encompasses Koh Seh, Koh Angkrong, Koh Mak Prang and Koh Pou. This zoning scheme is based upon the location and state of particular marine habitats, especially valuable coral reef and seagrass areas. Establishment of 'no-take' conservation zones would allow for habitat restoration, species recovery and promote connectivity between these zones, enhancing the resilience of the species within them. Another advantage of 'no-take' zones would be the 'spill-over' of commercially fished species into zones where fishing is permitted, thereby bringing economic and livelihood benefits to fishing communities and industries. Importantly, illegal fishing vessels would not be permitted within any zone of this MFMA, in accordance with Cambodian fisheries laws. As the positive impacts of conservation and integrated fisheries management within this area become apparent, these sustainable practices could extend beyond the defined zones. Finally, with efficient integration of management plans (e.g. MFMA, National Plan of Action etc.), and cooperation between involved parties, the Kep Archipelago could become a model of sustainable marine resource management and conservation.

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7 Appendices

Appendix A Map of coral reef and seagrass habitats of Koh Seh

Coral reef and seagrass habitats encompassing Koh Seh, Kep Province, Cambodia. Seagrass is indicated by the coloured green patch and coral reef by the dark colour encircling the island (already visible in satellite image).

Appendix B Cambodia's Law on Fisheries

Full article description based upon the Kingdom of Cambodia's Law on Fisheries (FiA 2007)

Chapter 9 – Marine Fishery Exploitation:

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 FiA 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.

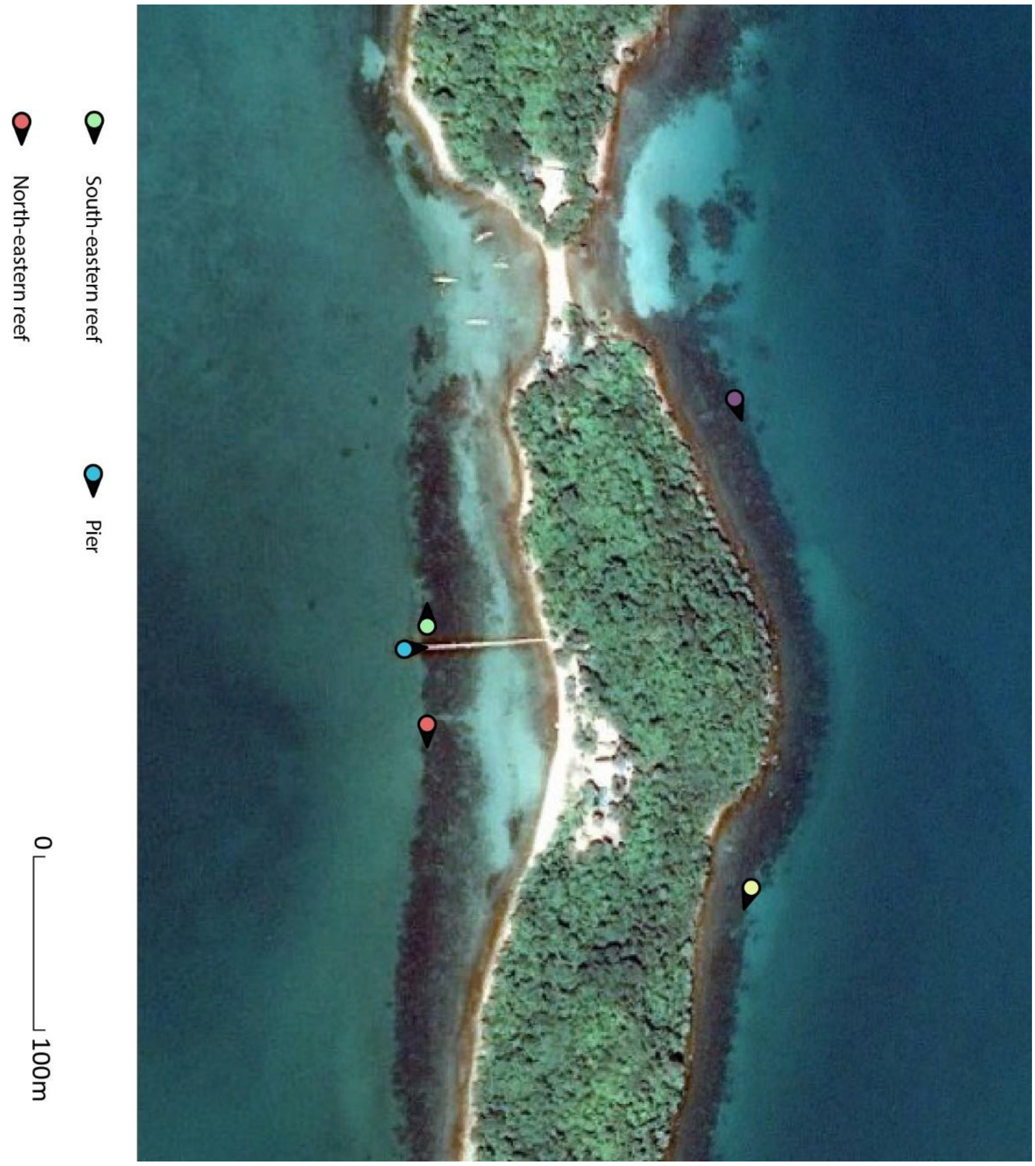
3 – Making port calls and anchoring in a coral reef area.

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 if given from the Minister of Agriculture, Forestry and Fisheries.

Appendix C Survey sites 2016

MCC's 2016 reef survey sites around Koh Seh, Kep Province, Cambodia:



## Appendix D	Survey sites 2015

MCC's 2015 reef survey sites around Koh Seh, Kep Province, Cambodia:

Appendix E Site conditions 2016

Part A: General site conditions table filled before each of MCC's reef surveys of Koh Seh.

Vis. = Visibility, Rec. Maj. Storms = Recent Major Storms, Silt. Freq. = Siltation Frequency.

Survey conditions			
Air temp. (◦C)	Water temp. (◦C)	Vis. (m)	Rec. Maj. Storms
31	30	3	No
30	30	4	No
32	31	5	No
30	30	1.5	No
31	31	4	No
31	31	5	No
31	31	3	No
N/A	N/A	N/A	No
N/A	N/A	N/A	No
N/A	33	1.5	No
N/A	33	1.5	No
N/A	N/A	N/A	No

Part B: General site conditions table filled before each of MCC's reef surveys of Koh Seh.

Invert. (food/curio) = Invertebrate fishing for food/curio, Pro. Enforced = Protection enforced.

Fishing				Po
ert. (food)	Invert. (curio)	Small-scale	Commercial	Sewage
Med	Low	Low	Low	Low
Med	Low	Low	Low	Low
Med	Low	Low	Low	Low
Low	None	Low	None	Low
Low	None	Low	None	Low
Low	None	Low	None	Low
High	Med	High	High	High
High	Med	High	High	High
High	Med	High	High	High
High	Med	Low	High	Low
High	Med	Low	High	Low
High	Med	Low	High	Low

Appendix F Common and scientific names of fishes and invertebrates

Common and scientific names of each fish and invertebrate species/category recorded or observed during the period of MCC's 2016 reef surveys of Koh Seh:

COMMON NAME	SCIENTIFIC NAME
Eight Banded Butterflyfish	*Chaetodon octofassiatus*
Long-Beaked Coral Fish	*Shelmon rostartus*
Unknown Butterflyfish	*Chaetodontidae* family
Other Butterflyfish	*Chaetodontidae* family
Butterflyfish total	*Chaetodontidae* family
Spadefish	*Ephippidae* family
Golden Rabbitfish	*Siganus guttatus*
Virgate Rabbitfish	*Siganus virgatus*
Java Rabbitfish	*Siganus javus*
Dusky Rabbitfish	*Siganus fuscescens*
White-spotted Rabbitfish	*Siganus canaliculatus*
Other Rabbitfish	*Siganidae* family
Rabbitfish total	*Siganidae* family
Scatfish	*Scatophagus argus*
Sergeant Fish spp.	*Abudefduf* spp.
Spanish Flag Snapper	*Lutjanus carponotatus*
Black-Spot Snapper	*Lutjanus ehrenbergii*
Other Snapper	*Lutjanidae* family
Unknown Snapper	*Lutjanidae* family
Snapper total	*Lutjanidae* family
Paradise Whiptail	*Pentapodus paradiseus*
Monogram Monocle Bream	*Scolopsis monogramma*
Whitecheek Monocle Bream	*Scolopsis torquate*
Other Bream	*Nemipteridae* family
Unknown Bream	*Nemipteridae* family
Bream Total	*Nemipteridae* family
Emperor	*Lethrinus* spp.
Golden Trevally	*Gnathanodon spesiosus*
Big Eye Trevally	*Caranx sexfasciatus*
Other Trevally	*Carangidae* family
Jacks	*Carangidae* family
Mullet	*Mugilidae* family
Fusilier	*Caesionidae* family

Orange-Spotted Grouper	*Epinephelus coioides*
Blue-Lined Grouper	*Cephalopholis formosa*
Chocolate Grouper	*Cephalopholis boenak*
Longfin Grouper	*Epinephelus quoyanus*
Duskytail Grouper	*Epinephelus bleekeri*
Other Grouper	*Serranidae* family
Grouper total	*Serranidae* family
Gold Spotted Sweetlips	*Plectorhinchus flavomaculatus*
Cleaner Wrasse	*Labroides* spp.
Weedy Surge Wrasse	*Halichoeres margaritaceus*
Other Wrasse	*Labridae* family
Unknown Wrasse	*Labridae* family
Wrasse total	*Labridae* family
Sweeper	*Pempheris* spp.
Cardinalfish	*Apogonidae* family
Toadfish	*Batrachoididae* spp.
Catfish	*Plotosidae* family
Needlefish	*Belonidae* family
Boxfish	*Ostrasiidae* family
Filefish	*Monacanthidae* family
Seahorse	*Hippocampus* spp.
Carpet Blenny Eel	*Congrogadus subducens*
Feather Duster Worm	*Sabellastarte* spp.
Christmas Tree Worm	*Spirobranchus* spp.
Flatworm	*Platyhelminthes phylum*
Xanthid Crab	*Xanthidae* family
Blue Swimmer Crab	*Portunus pelagicus*
Conch	*Strombidae* family
Cowrie	*Cypraeidae* family
Drupella	*Drupella* spp.
Top Shell	*Trochus* spp.
Nudibranch	*Nudibranchia* order
Other Gastropods	Mainly *Turbo* spp.
Giant Clams	*Tridacna* & *Hippopus* spp.
Boring Bivalves	*Bivalvia* class
Feather Star	*Crinoidea* order
Diadema Sea Urchin	*Diadema* spp.
Pencil Urchin	*Heterocentrotus mammilatus*
Collector Urchin	*Tripneustes* spp.
Volute Snails	*Volutidae* spp.

Appendix G Results of t-test for Koh Seh's western reef

MCC's 2016 t-test results for Koh Seh's north-western reef (NWR) vs. the south-western reef (SWR) surveys:

Significant differences are highlighted in yellow with the reef region containing the significantly greater abundance of the relevant species/substrate in brackets.

FISH	NWRvs.SWR
Eight Banded Butterflyfish	0.77
Long-Beaked Coral Fish	0.64
Unknown Butterflyfish	0.42
Other Butterflyfish	0.64
Butterflyfish total	0.36
Golden Rabbitfish	0.14
Virgate Rabitfish	0.37
Java Rabbitfish	0.10
Dusky Rabbitfish	0.13
Rabbitfish total	0.10
Scatfish	0.53
Sergeant Fish sp.	0.88
Spanish Flag Snapper	0.78
Black-Spot Snapper	0.23
Other Snapper	0.37
Snapper total	0.19
Monogram Monocle Bream	0.23
Whitecheek Monocle Bream	0.12
Bream Total	0.35
Emperor	0.37
Jacks	0.80
Mullet	0.37
Fusilier	0.69
Blue-Lined Grouper	0.37
Chocolate Grouper	0.88
Unknown Grouper	0.37
Grouper 10-20cm	0.56
Grouper 20-30cm	1
Grouper 30-40 cm	0.12
Grouper total	0.59
Gold Spotted Sweetlips	0.47

Weedy Surge Wrasse	0.07
Other Wrasse	0.77
Wrasse total	0.49
Cardinalfish	0.10
Catfish	0.37
Needlefish	0.37
Boxfish	0.37
Carpet Blenny Eel	0.16

INVERTS	NWR vs. SWR
Feather Duster Worm	0.81
Christmas Tree Worm	0.89
Flatworm	0.42
Xanthid Crab	0.37
Cowrie	1
Drupella	0.24
Top Shell	0.06
Nudibranch	0.19
Other Gastropods	0.41
Giant Clam 10-20 cm	0.37
Giant Clam total	0.37
Boring Bivalves	0.46
Octopus	1
Feather Star	0.37
Diadema Sea Urchin	0.03 (SWR)
Pencil Urchin	0.08
Collector Urchin	0.11

SUBSTRATE	NWR vs. SWR
HC	0.25
SC	0
RKC	0
NIA	0.07
SP	0.64
RC	0.66
RB	0
SD	0.37
SI	0
ZO	<0.01(SWR)
OT	0.68

Appendix H Fish abundance at Koh Seh's eastern reef 2015 and 2016

MCC's 2015 and 2016 mean fish abundance data for Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef (ER) surveys:

Values are the average number of fish recorded per 20-m segment of the survey belt transect. NOTE THAT SPECIES MARKED BY AN ASTERIX (*) WERE NOT RECORDED IN 2015, BUT WERE STILL PRESENT.

FISH	2015		2016		2015	2016
	MEAN SER	MEAN NER	MEAN SER	MEAN NER	MEAN ER	MEAN ER
Eight Banded Butterflyfish	0.33	0.42	0.58	0.33	0.38	0.46
Long-Beaked Coral Fish	7.50	4.08	2.42	2.33	5.79	2.38
Other Butterflyfish	0.42	0.58	1.00	1.42	0.50	1.21
Butterflyfish total	8.25	5.08	4.00	4.08	6.67	4.04
Golden Rabbitfish	0.00	0.00	0.00	1.75	0.00	0.88
Virgate Rabbitfish	0.17	0.17	1.42	28.50	0.17	14.96
Java Rabbitfish	18.50	13.42	2.00	20.08	15.96	11.04
Rabbitfish total	18.67	13.75	3.42	49.33	16.21	26.38
Scatfish*	0.00	0.00	0.83	1.58	0.00	1.21
Sergeant Fish sp.	15.00	10.92	20.75	19.92	12.96	20.33
Spanish Flag Snapper*	0.00	0.00	1.92	2.58	0.00	2.25
Black-Spot Snapper*	0.00	0.00	0.67	5.25	0.00	2.96
Other Snapper	1.58	1.42	0.00	0.00	1.50	0.00
Snapper total	1.58	1.42	2.58	7.83	1.50	5.21
Monogram Monocle Bream*	0.00	0.00	1.17	1.25	0.00	1.21
Whitecheek Monocle Bream*	0.00	0.00	0.00	0.33	0.00	0.17
Bream Total	0.00	0.00	1.17	1.58	0.00	1.38
Emperor	0.00	0.00	0.25	0.58	0.00	0.42
Golden Trevally	0.00	0.08	0.00	0.00	0.04	0.00
Jacks	0.00	0.00	1.33	1.33	0.00	1.33
Mullet*	0.00	0.00	0.75	2.75	0.00	1.75
Orange-Spotted Grouper*	0.00	0.00	0.08	0.17	0.00	0.13
Blue-Lined Grouper	0.08	0.00	0.50	0.42	0.04	0.46
Chocolate Grouper	0.00	0.00	0.42	0.75	0.00	0.58
Longfin Grouper	0.00	0.00	0.00	0.08	0.00	0.04
Other Grouper	0.08	0.00	0.00	0.00	0.04	0.00
Grouper 10-20cm	0.00	0.00	0.42	0.75	0.00	0.58
Grouper 20-30cm	0.00	0.00	0.50	0.50	0.00	0.50

Grouper 30-40 cm	0.08	0.00	0.00	0.08	0.04	0.04
Grouper 40-50 cm	0.00	0.00	0.08	0.08	0.00	0.08
Grouper >50 cm	0.08	0.00	0.00	0.00	0.04	0.00
Grouper total	0.42	0.00	1.00	1.42	0.21	1.21
Sweetlips	0.00	0.00	0.00	0.08	0.00	0.04
Cleaner Wrasse*	0.00	0.00	2.92	1.25	0.00	2.08
Weedy Surge Wrasse*	0.00	0.00	5.08	4.17	0.00	4.63
Other Wrasse*	0.00	0.00	1.75	2.50	0.00	2.13
Wrasse total	0.00	0.00	9.75	7.92	0.00	8.83
Sweeper	23.33	7.00	91.50	44.67	15.17	68.08
Cardinalfish	52.25	42.83	74.50	62.33	47.54	68.42
Toadfish*	0.00	0.00	0.00	0.08	0.00	0.04
Catfish*	0.00	0.00	0.00	0.08	0.00	0.04
Seahorse*	0.00	0.00	0.00	0.08	0.00	0.04
Needlefish*	0.00	0.00	16.42	0.42	0.00	8.42
Boxfish	0.00	0.00	0.00	0.08	0.00	0.04
Filefish	1.50	0.33	1.42	0.58	0.92	1.00
Carpet Blenny Eel*	0.00	0.00	1.08	0.92	0.00	1.00

Appendix I Results of t-test for fish species at eastern reef 2015 vs. 2016

MCC's 2015 vs. 2016 t-test results for fish species recorded within Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef (ER) surveys:

Significant differences are highlighted in yellow (increase 2015 – 2016) or green (decrease 2015 – 2016). For 2016 SE vs. NE, the reef region containing the significantly greater abundance of the relevant species in brackets. NOTE THAT SPECIES MARKED BY AN ASTERIX (*) HAVE SIGNIFICANTLY INCREASED OWING TO THE FACT THAT THEY WERE NOT RECORDED IN 2015, HOWEVER THEY WERE STILL PRESENT.

FISH	2015 - 2016 SER	2015 - 2016 NER	2015 - 2016 ER	2016 SE vs. NER
Eight Banded Butterflyfish	0.73	0.87	0.83	0.71
Long-Beaked Coral Fish	0.01	0.13	0.01	0.95
Other Butterflyfish	0.40	0.34	0.15	0.68
Butterflyfish total	0.02	0.39	0.02	0.94
Golden Rabbitfish	0	0.11	0.14	0.11
Virgate Rabbitfish	0.21	0.01	0.07	0.04 (NER)
Java Rabbitfish	0.05	0.67	0.56	0.24
Rabbitfish total	0.07	0.02	0.39	0.02 (NER)
Scatfish*	0.12	0.15	0.03	0.48
Sergeant Fish sp.	0.18	0.18	0.07	0.87
Spanish Flag Snapper*	0.02	<0.01	1.48	0.29
Black-Spot Snapper*	0.37	0.10	0.08	0.15
Other Snapper	0.01	0.20	0.01	0
Snapper total	0.35	0.06	0.07	0.10
Monogram Monocle Bream*	<0.01	0.07	<0.01	0.89
Whitecheek Monocle Bream*	0	0.02	0.07	0.02 (NER)
Bream Total	<0.01	0.03	<0.01	0.45
Emperor	0.16	0.06	0.01	0.27
Golden Trevally	0	0.37	0.34	0
Jacks	0.19	0.12	0.02	1
Mullet*	0.37	0.31	0.18	0.47
Orange-Spotted Grouper*	0.37	0.12	0.05	0.52
Blue-Lined Grouper	0.01	0.07	<0.01	0.72
Chocolate Grouper	0.01	0.06	<0.01	0.33
Longfin Grouper	0	0.37	0.34	0.37
Other Grouper	0.37	0	0.3	0
Grouper 10-20cm	0.01	0.10	<0.01	0.33

Grouper 20-30cm	0.03	0.03	<0.01	1
Grouper 30-40 cm	0.37	0.37	1	0.37
Grouper 40-50 cm	0.37	0.37	0.14	1
Grouper >50 cm	0.37	0	0.34	0
Grouper total	0.16	0.05	0.01	0.47
Sweetlips	0	0.37	0.34	0.37
Cleaner Wrasse*	<0.01	0.04	<0.01	0.06
Weedy Surge Wrasse*	<0.01	<0.01	<0.01	0.23
Other Wrasse*	0.03	0.07	<0.01	0.55
Wrasse total	<0.01	<0.01	<0.01	0.35
Sweeper	0.0	0.01	0.01	<0.01 (SER)
Cardinalfish	0.37	0.02	0.06	0.11
Toadfish*	0.37	0	0.34	0.37
Catfish*	0	0.37	0.34	0.37
Seahorse*	0	0.37	0.34	0.37
Needlefish*	0.20	0.13	0.19	0.21
Boxfish	0	0.37	0.34	0.37
Filefish	0.93	0.25	0.88	0.12
Carpet Blenny Eel*	<0.01	0.19	<0.01	0.79

Appendix J Fish abundance and results of t-test at western reef 2014, 2015 and 2016

MCC's 2014, 2015 and 2016 mean fish abundance data and t-test results for Koh Seh's western reef (WR) surveys:

Values are the average number of fish recorded per 20m segment of the survey belt transect. Significant increases are highlighted in yellow.

FISH	2014 MEAN WR	2015 MEAN WR	2016 MEAN WR
Butterflyfish	1.4	5.7	6.79
Snapper	1.15	2.5	4.83
Grouper	0	0.15	0.79
Gold Spotted Sweetlips	0	0	0.25
Wrasse	0	1.15	4.88

FISH	T-test 2015 vs. 2016	T-test 2014 vs. 2015	T-test 2014 vs. 2016
Butterflyfish	0.58	0.01	0.02
Snapper	0.03	0.1	<0.01
Grouper	0.03	0.21	0.02
Gold Spotted Sweetlips	0.19	0	0.17
Wrasse	0.01	0.03	<0.01

Appendix K Fish abundance for pier surveys 2016

MCC's 2016 mean fish abundance data for the pier surveys:

Values are the average number of fish recorded per 18m segment of the survey belt transect.

FISH	MEAN PIER
Long-Beaked Coral Fish	2
Butterflyfish total	2
Golden Rabbitfish	1
Virgate Rabitfish	2.25
Java Rabbitfish	8.25
Dusky Rabbitfish	10.75
Unknown Rabbitfish	3.92
Rabbitfish total	26.2
Scatfish	6.33
Sergeant Fish sp.	28.6
Spanish Flag Snapper	3.2
Black-Spot Snapper	37.25
Snapper total	40.42
Monogram Monocle Bream	2.10
Other Bream	0.5
Bream Total	2.60
Emperor	1.25
Big Eye Trevally	5.08
Jacks	6.33
Mullet	4.08
Fusilier	0.17
Blue-Lined Grouper	0.17
Chocolate Grouper	0.17
Grouper 20-30cm	0.17
Grouper 30-40 cm	0.17
Grouper total	0.33
Gold Spotted Sweetlips	0.83
Weedy Surge Wrasse	0.25
Other Wrasse	1.67
Wrasse total	1.92
Needlefish	20.67
Boxfish	0.33

Filefish	1.25
Carpet Blenny Eel	1.42

Appendix L Comparison of fish species abundance between eastern and western reef

A t-test was carried out to compare abundance of fish species recorded in Koh Seh's eastern (ER) and western reefs (WR) in 2016.

MCC's 2016 t-test results for fish species recorded within Koh Seh's eastern reef (ER) vs. western reef (WR) surveys:

Significant differences are highlighted in yellow, with the reef containing the significantly larger fish population in brackets.

FISH	ER vs. WR
Eight Banded Butterflyfish	0.03 (WR)
Long-Beaked Coral Fish	0.25
Unknown Butterflyfish	0.26
Other Butterflyfish	0.14
Butterflyfish total	0.09
Golden Rabbitfish	0.36
Virgate Rabitfish	0.06
Java Rabbitfish	0.66
Dusky Rabbitfish	0.39
Unknown Rabbitfish	0.41
Rabbitfish total	0.12
Scatfish	0.13
Sergeant Fish sp.	0.04 (ER)
Spanish Flag Snapper	0.87
Black-Spot Snapper	0.21
Other Snapper	0.26
Snapper total	0.22
Monogram Monocle Bream	0.44
Whitecheek Monocle Bream	0.65
Other Bream	0.25
Bream Total	0.46
Emperor	0.21
Big Eye Trevally	0.22
Jacks	0.05 (ER)
Mullet	0.14
Fusilier	0.05 (WR)
Orange-Spotted Grouper	0.10
Blue-Lined Grouper	0.12

Chocolate Grouper	0.14
Longfin Grouper	0.41
Unknown Grouper	0.26
Grouper 10-20cm	0.48
Grouper 20-30cm	1
Grouper 30-40 cm	0.89
Grouper 40-50 cm	0.21
Grouper total	0.80
Gold Spotted Sweetlips	0.85
Cleaner Wrasse	0.01 (ER)
Weedy Surge Wrasse	0.07
Other Wrasse	0.27
Wrasse total	0.22
Sweeper	<0.01 (ER)
Cardinalfish	<0.01 (ER)
Toadfish	0.41
Catfish	0.84
Seahorse	0.41
Needlefish	0.06
Boxfish	0.50
Filefish	<0.01 (ER)
Carpet Blenny Eel	0.12

Appendix M Invertebrate abundance at eastern reef 2015 and 2016

MCC's 2015 and 2016 mean invertebrate abundance data for Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef(ER) surveys:

Values are the average numbers of invertebrates recorded per 20m segment of the survey transect line. NOTE THAT SPECIES MARKED BY AN * WERE NOT RECORDED IN 2015, BUT WERE STILL PRESENT.

INVERTEBRATES	2015		2016		2015	2016
	MEAN SER	MEAN NER	MEAN SER	MEAN NER	MEAN ER	MEAN ER
Feather Duster Worm	0	0.33	0.67	0.5	0.17	0.58
Christmas Tree Worm	0.75	4.17	1.25	7.92	2.46	4.58
Flatworm	0	0.33	0.08	0.08	0.17	0.08
Xanthid Crab	5.25	8.17	1.58	1.33	6.71	1.46
Blue Swimmer Crab*	0	0	0.17	0.17	0	0.17
Conch	0	0	0	0.08	0	0.04
Drupella	4.08	3.17	10.92	8.25	3.63	9.58
Top Shell	0.17	0.75	3.5	0.92	0.46	2.21
Nudibranch	0.42	1.08	1.08	1.33	0.75	1.21
Other Gastropods	7.25	6.42	8.75	10.58	6.83	9.67
Boring Bivalves*	0	0	7.92	9.92	0	8.92
Octopus	0.17	0	0.08	0.08	0.08	0.08
Flower Urchin	0.17	0.17	0	0	0.17	0
Diadema Sea Urchin	0.17	10.67	0.5	10.17	5.42	5.33
Pencil Urchin	0	0.08	0	0	0.04	0
Collector Urchin	0.25	0	0	0	0.13	0

Appendix N Results of t-test for invertebrate species recorded at eastern reef 2015 vs. 2016

MCC's 2015 vs. 2016 t-test results for invertebrate species recorded within Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef(ER) surveys:

Significant differences are highlighted in yellow (increase 2015 – 2016) or green (decrease 2015 – 2016). NOTE THAT SPECIES MARKED BY AN ASTERIX (*) HAVE SIGNIFICANTLY INCREASED OWING TO THE FACT THAT THEY WERE NOT RECORDED IN 2015, HOWEVER THEY WERE STILL PRESENT.

INVERTEBRATES	2015 - 2016 SER	2015 - 2016 NER	2015 - 2016 ER
Feather Duster Worm	0.29	0.71	0.22
Christmas Tree Worm	0.75	0.14	0.32
Flatworm	0.37	0.35	0.55
Xanthid Crab	0.01	0.02	<0.01
Blue Swimmer Crab	0.37	0.37	0.14
Conch	0	0.37	0.34
Drupella	0.37	0.35	0.15
Top Shell	0.33	0.69	0.26
Nudibranch	0.21	0.64	0.20
Other Gastropods	0.71	0.05	0.16
Boring Bivalves*	<0.01	<0.01	<0.01
Octopus	0.68	0.37	1
Flower Urchin	0.37	0.37	0.14
Diadema Sea Urchin	0.12	0.85	0.98
Pencil Urchin	0	0.37	0.34
Collector Urchin	0.16	0	0.17

Appendix O Invertebrate abundance at western reef

MCC's 2016 mean invertebrate abundance data for Koh Seh's western reef (WR) surveys:

INVERTS	2016 WR MEAN
Feather Duster Worm	0.29
Christmas Tree Worm	58.04
Flatworm	0.67
Xanthid Crab	0.08
Cowrie	0.08
Drupella	0.92
Top Shell	2.17
Nudibranch	0.46
Other Gastropods	4.13
Giant Clam 10-20 cm	0.04
Giant Clam total	0.04
Boring Bivalves	99.00
Octopus	0.08
Feather Star	0.04
Diadema Sea Urchin	128.83
Pencil Urchin	1.75
Collector Urchin	1.17

Appendix P Comparison of invertebrates species abundance between eastern and western reef

MCC's 2016 t-test results for invertebrate species recorded within Koh Seh's eastern reef (ER) vs. western reef (WR) surveys:

Significant differences are highlighted in yellow, with the reef containing the significantly higher abundance of the species in brackets.

INVERTS	ER vs. WR
Feather Duster Worm	0.41
Christmas Tree Worm	<0.01 (WR)
Flatworm	0.06
Xanthid Crab	<0.01 (ER)
Blue Swimmer Crab	0.14
Conch	0.34
Cowrie	0.14
Drupella	0.07
Top Shell	0.98
Nudibranch	0.08
Other Gastropods	<0.01 (ER)
Giant Clam total	0.34
Boring Bivalves	<0.01 (WR)
Octopus	1
Feather Star	0.34
Diadema Sea Urchin	<0.01 (WR)
Pencil Urchin	0.12
Collector Urchin	0.10

Appendix Q Substrate cover at eastern reef 2015 and 2016

MCC's 2015 and 2016 mean substrate percentage cover recorded within Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef (ER) surveys:

Values are the average percentage cover by substrate types recorded per 20m segment of the survey transect line.

Substrate types: HC = Hard Coral, NIA = Nutrient Indicator Algae, OT = Other, RB = Rubble, RC = Rock, RKC = Recently Killed Coral, SC = Soft Coral, SD = Sand, SI = Silt, SP = Sponge, ZO = Zoanthids.

SUBSTRATE	2016 MEAN % SER	2016 MEAN % NER	2016 MEAN % ER
HC	19.79	23.96	21.88
SC	0	0	0
RKC	0.21	0	0.10
NIA	7.08	11.46	9.27
SP	5.83	7.5	6.67
RC	7.71	10.42	9.06
RB	4.38	2.5	3.44
SD	5.21	3.96	4.58
SI	0	0	0
ZO	47.92	35.83	41.88
OT	1.88	4.38	3.13

Appendix R Results of t-test for substrate cover recorded at eastern reef

MCC's t-test results for substrate coverage recorded within Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef (ER) surveys:

Significant differences are highlighted in yellow with the substrate type/reef region showing significantly greater coverage in brackets.

Substrate types: HC = Hard Coral, NIA = Nutrient Indicator Algae, OT = Other, RB = Rubble, RC = Rock, RKC = Recently Killed Coral, SC = Soft Coral, SD = Sand, SI = Silt, SP = Sponge, ZO = Zoanthids.

SUBSTRATE	2016 T-Test: SER vs. NER
HC	0.31
SC	0
RKC	0.37
NIA	0.30
SP	0.46
RC	0.29
RB	0.24
SD	0.42
SI	0
ZO	0.08
OT	0.01 (NER)

SUBSTRATE	2016 ER
HC VS. ZO	<0.01 (ZO)
HC VS. NIA	<0.01 (HC)
NIA vs. RC	0.93
NIA vs. SP	0.25
NIA vs. SD	0.04 (NIA)
RC vs. SD	0.08 (RC)
SP vs. SD	0.11
SD vs. OT	0.14
RKC vs. OT	<0.01 (OT)

Appendix S Substrate cover at western reef and results of t-test comparing eastern and western reef

MCC's 2016 mean substrate percentage cover recorded within Koh Seh's north-western (NWR), south-western (SWR) and overall western reef (WR) surveys. Additionally, eastern reef (ER) versus overall western reef (WR) t-test results are presented:

Significant differences are highlighted in yellow with the substrate type showing significantly greater coverage in brackets.

Substrate types: HC = Hard Coral, NIA = Nutrient Indicator Algae, OT = Other, RB = Rubble, RC = Rock, RKC = Recently Killed Coral, SC = Soft Coral, SD = Sand, SI = Silt, SP = Sponge, ZO = Zoanthids.

SUBSTRATE	MEAN % NWR	MEAN % SWR	MEAN % WR
HC	62%	68.67%	65%
SC	0%	0%	0%
RKC	0%	1%	1%
NIA	5.67%	1.67%	4%
SP	6.67%	7%	7%
RC	12.67%	15.33%	14%
RB	0%	0%	0%
SD	0.33%	0%	0%
SI	0%	0%	0%
ZO	12.67%	6.33%	10%
OT	0.33%	0.67%	1%

SUBSTRATE	NWR vs. SWR	ER vs. WR
HC	0.25	<0.01
SC	0	0
RKC	0	0.14
NIA	0.07	0.03
SP	0.64	0.88
RC	0.66	0.11
RB	0	<0.01
SD	0.37	<0.01
SI	0	0
ZO	<0.01	<0.01
OT	0.68	<0.01

SUBSTRATE	WR T-Tests
HC vs. RC	<0.01 (HC)
RC vs. SP	0.04 (RC)
NIA vs. RKC	0.02 (NIA)
RC vs. ZO	0.16
ZO vs. SP	0.11

Appendix T Coral bleaching(2015 & 2016), disease (2016) and predation (2016) recorded eastern reef

MCC's 2015 and 2016 mean coral bleaching, disease (2016) and predation (2016) recorded within Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef (ER) surveys:

N/A = Not Available.

CORAL IMPACTS	2015		2016		2015	2016
	MEAN SER	**MEAN NER**	**MEAN SER**	**MEAN NER**	**MEAN ER**	**MEAN ER**
Bleaching (% pop.)	12.0%	7.50%	5.50%	4.17%	9.75%	4.83%
Bleaching (% col.)	18.00%	3.50%	10.42%	6.17%	10.75%	8.29%
Disease (%pop.)	N/A	N/A	6.08%	12.75%	N/A	9.42%
Disease (%col.)	N/A	N/A	7.05%	6.58%	N/A	6.82%
Coral predation (0–3)	N/A	N/A	1.83	1.58	N/A	1.71
Trash	N/A	N/A	0.58	0.21	N/A	0.40
Damage	N/A	N/A	0.17	0	N/A	0.08

Appendix U Results of t-test for coral bleaching, disease and predation recorded at eastern reef 2015-2016

MCC's 2015 and 2016 t-test results for coral bleaching, disease and predation recorded within Koh Seh's north-eastern (NER), south-eastern (SER) and overall eastern reef (ER) surveys:

Significant differences are highlighted in yellow with the substrate type/area showing greater coverage in brackets. N/A = Not Available.

CORAL IMPACTS	2015–2016 SER	2015–2016 NER	2015–2016 ER	2016 NER vs. SER
Bleaching (% pop.)	0.37	0.21	0.14	0.42
Bleaching (% col.)	0.33	0.28	0.61	0.17
Disease (%pop.)	N/A	N/A	N/A	0.17
Disease (%col.)	N/A	N/A	N/A	0.88
Coral predation (0–3)	N/A	N/A	N/A	0.61
Trash	N/A	N/A	N/A	0.05 (SER)
Damage	N/A	N/A	N/A	0.37

Appendix V Coral bleaching, disease and predation at western reef

MCC's 2016 mean coral bleaching, disease and predation within Koh Seh's north-western (NWR), south-western (SWR) and overall western reef (WR) surveys:

CORAL IMPACTS	MEAN NWR	MEAN SWR	MEAN WR
Disease (% population)	4%	8%	6%
Disease (% colony)	22%	11%	17%
Bleaching (% of population)	31%	75%	53%
Bleaching (% of colony)	26%	60%	43%
Predation	0.33	0	0.17
Trash	0.17	0.58	0.38
Damage	0.42	0	0.21

Appendix W Results of t-test for impact assessments between eastern and western reefs

MCC's 2016 t-test results for impact assessments recorded within Koh Seh's eastern reef (ER) vs. western reef (WR) surveys:

Significant differences are highlighted in yellow, with the reef containing a significantly impact being shown in brackets. Bleaching is not comparable due to the timing of the surveys being different between the two reefs, and thus seasonal differences in the water temperature confounding MCC's data. Disease was also not compared in this report owing to the relationship between water temperature and pathogen prevalence, however the t-test values are still given.

Impact	ER vs. WR
Disease (% population)	0.29 (NOT COMPARABLE)
Disease (% colony)	0.02 (WR) (NOT COMPARABLE)
Bleaching (% of population)	NOT COMPARABLE
Bleaching (% of colony)	NOT COMPARABLE
Predation	<0.01 (ER)
Trash	0.94
Damage	0.52