QATAR UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

ASSESSMENT OF TEMPORAL VARIATION OF FISH ASSEMBLAGES BETWEEN NATURAL AND ARTIFICIAL REEFS

BY

MOHAMED SHAREIF MOHAMED SALIH MOHAMED

A Thesis Submitted to

the College of Arts and Sciences

in Partial Fulfillment of the Requirements for the Degree of

Masters of Science in Environmental Sciences

June [2021]

COMMITTEE PAGE

The members of the Committee approve the Thesis of
Mohamed shareif Mohamed defended on 29/04/2021.

Radhouane Ben Hamadou
Thesis/Dissertation Supervisor

Pedro Range
Committee Member

Mohammed Nejib Daly Yahia
Committee Member

Fahad Al-Jamali
Committee Member

Approved:

Ibrahim AlKaabi, Dean, College of Arts and Sciences

ABSTRACT

MOHAMED, Mohamed Shareif, Salih., Masters: January : 2020, Environmental Sciences

Title: Assessment of Temporal Variation of Fish Assemblages Between Natural and Artificial Reefs.

Supervisor of Thesis: Radhouane, Ben Hamadou .

Well-defined coral reefs and patches with high density of fishes were reported in the Arabian Gulf. Due to environmental and anthropogenic disturbances, especially due to coastal development, coral reef cover starts to decline, and conservation efforts were established to restore these systems which is consider as a habitat for about 25% of all marine species. Deployment of artificial reefs was one of the proposed approaches. In this study, temporal variation of fish abundance, diversity and biomass were investigated in three sites which included live, dead, and artificial reef sites. The effectiveness of two survey methods (BRUV and UVC) was assessed. Artificial reefs recorded the lowest fish species richness with only 13 taxa., while live coral site was the highest with 21 taxa recorded. However, this was associated with low abundance and relatively lower frequency of these species. The dead reef site had a lower species richness, with only 14 species recorded. The interaction of time and site variation was significant in the study at the artificial reef site only. Artificial reefs could expectance a rapid increase in fish abundance however this could come on the expenses of the community structure, the method variation was significant. The study showed UVC methodology has a significant and relevant advantage over BRUVs by providing estimates of the absolute abundances.

DEDICATION

This thesis is dedicated to my Family.

ACKNOWLEDGMENTS

I would like to express my genuine gratitude to my supervisors, Dr. Radhouane Ben Hamadou and Dr. Pedro Range for their support and assistance throughout the development of this study. They paved the way during a challenging time to successful finish this thesis it been an honor to have the opportunity to work along with creative, supportive, and experienced researchers. I would like also to extend my gratitude to my committee members Prof. Mohammed Nejib Daly Yahia and Dr. Fahad Al-Jamali for their support. I would also like to acknowledge the staff at Dr. Radhouane marine lab Dr. Elizabeth Anne Goergen for her support during this study her comments and advice were extremely valuable for this study.

Finally, I would like to thank Qatar University staff and Professors who helped me throughout my study in this great institution, as well as my friends and colleagues for their enthusiasm and positive energy that they had during the courses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

The Arabian Gulf is considered as one of the hottest seas worldwide, it is the water body separating the Arabian Peninsula and Iran, extending from the Kuwait and Iranian coastlines in the north, to Musandam and the Strait of Hormuz in the south. The Arabian Gulf well-defined *Acropora* patches with high density were reported, along with the *Acropora* spp. cover, other coral genera (e.g., *Dipsastraea, Favites, Porites, Anomastrea*) were recorded in the area. However, this was the coral reef status in the area before the mass mortality events that took place on this region starting from the last century still occurring up to date. (Riegl and Purkis 2012c). Besides the extreme thermal stress (35-37ºC sea surface temperature during summer) and the high salinity registered in this area, marine habitats suffer from massive destruction and deterioration due to the enormous coastal development and the increase of the offshore resource's exploitation (Riegl and Purkis 2012; Sheppard and Loughland 2002).

The urban expansion in the Gulf coastal area has been a common development characteristic in the region Figure 1, such evolution led to an adverse impact on the natural ecosystems. About two third of sabkhas were lost in the process, in many areas' beaches were transformed to seawalls, such transformation results in loss of nesting habitats of various species including endangered, migratory species such as turtles (Burt 2014). Projects such as ports, industrial plants, desalination plants or artificial islands are the main driver of the manmade habitat destruction in the Arabian Gulf (Sheppard et al. 2010). During the 1990's, more than 40% of the coastal construction and development that have been conducted in the region led to a significant loss in biodiversity (Al-Ghadban and Price, 2002). Recently, many other large coastal development projects were established, such as The Pearl in Qatar or The World and Palm Island in Dubai, UAE both shown in Figure 1, which exacerbated the marine biodiversity degradation and the habitat quality deterioration in the region (Burt 2014; Burt, Bartholomew, and Feary 2012). The main disturbance from these coastal development projects is influencing coral reef habitats. For instance, in the 1970s Doha Bay in Qatar used to have extensive cover of corals, especially *Acropora* sp. However, this coral cover did not survive due to major coastal development projects (Sheppard et al., 1992). Coral reefs in the Gulf exhibit high adaptability to extreme hydrological conditions with a significant resilience to high temperature and salinity, but this ability to overcome any additional anthropogenic stressors is becoming increasingly difficult (Riegl and Purkis 2012a).

Figure 1 Cases of significant coastal expansion in the Arabian Gulf. From top left: Tarut Bay - Saudi Arabia, Tarut Bay-Bahrain, Doha- Qatar, Dubai- UAE, and Kuwait City-Kuwait (Burt 2014).

Coral reef ecosystem supports wide range of fish species worldwide. Indeed, coral reefs are considered as the main habitat for about 25% of all marine species, what put this habitat as a priority for urgent conservation plans globally (Moati et al. 2008). Coral reef associated species in Qatar contribute to about 97% of the landings economic value. Qatar fisheries will be seriously affected by the loss of coral reef habitat, since about 18 commercial fishery species are known to live in coral reef during either their the whole or part of their life cycle. Thus, for sure the loss of these habitats will have adverse effects on the fisheries sector, which has annual production with a value over 249 million QAR.(Burt et al. 2017). Coral reef restoration in Gulf were developed though many mitigation techniques, one of these common techniques is the use of artificial reefs to maintain or restore the ecological system in the deteriorated area. However, the main question to what extended could artificial reefs maintain or restore the fish diversity, abundance, and the community structure, will both systems have similar response to the environmental variables such as coral cover and seasonal variation.

CHAPTER 2: LITERATURE REVIEW

Natural Coral Reef

Coral reefs provide shelter for new fish larvae and diverse resident species. Most studies are connecting the physical complexity with the fish diversity, however not to the fish abundance (e.g. Darling et al. 2017; Ferrari et al. 2018). Some studies emphasized that substratum coral diversity does not has a direct correlation with high fish species abundance (McManus et al. 1981), in contrast other studies strongly corelate live coral cover to both fish abundance and diversity (Bell and Galzin 1984). Fish assemblage's richness and diversity have been linked with coral site characteristics such as site physicals complexity and coral species diversity, richness, abundance, size, dispersion (Agudo-Adriani et al. 2019). The consulted literature did not show the connection of both species' richness and fish assemblages to the coral cover and diversity, not as the complexity contribution since it is much easier to compare considering the challenges in classifying coral colonies. Some studies suggest that the more diverse live coral exist this will indirectly support more fish diversity by increasing the microhabitat in the site (Galzin and Legendre 1987; Williams 1986).

Several studies showed that the live coral cover has a positive effect on species richness, however not all agreed on this correlation, some indicate the effect of the depth as main driver of the difference. Chabanet et al. (1997) suggest that only in disturbed locations, live coral cover might limit the fish density. Few studies have discussed the population dynamics and the multispecies interaction is coral reef site and how it contributes to larval dispersion and larval successful development also the density-dependent process. Such mechanisms are difficult to be traced since it has the possibility to occur in any life stage a species (Carr et al. 2002). Live coral cover has been linked powerfully with abundance of obligate coral-dwelling species, corallivorous fishes, and other species which depend on coral as their recruitment. The species richness will increase as the live coral cover increases, the fish species richness reaches 20 % (Komyakova, Munday, and Jones 2013a; Pratchett et al. 2008)

It has been well documented that coral reef fish assemblages and biodiversity are affected by the physical structure of the reef. However, the live coral cover has much more effects than only provides the physical structure.   Coral reefs are known for their ecological services which they provide for the resident fish assemblages. Corals provides essential resources such as nutrition, shelter and living space (Artim and Sikkel 2013; Komyakova, Munday, and Jones 2013b).

About 8% of the total reef habitat worldwide is in the Gulf area, the coral reef has the most divers invertebrate and fish compared to other coastal ecosystems. A study in UAE concluded that coral reef supports the fish biomass significantly higher than soft sediment habitat. Coral reef site support the system by 290 metric tons per squire kilometer, on the other hand the soft sediment does not exceed 0.8– 1.4 metric tons per square kilometer (Burt 2013, 2014; Feary et al. 2013).

Live corals effect on fish ectoparasite prevalence is one of the aspects that were not investigated enough. Stony coral species feed on zooplankton, the level of zooplankton consumption varies between different coral species, also the sites with dead and coral colonies varies in plankton consumption level. Gnathiid (Figure 2) is an example of fish ectoparasite that is common blood-feeding parasites. Live corals might therefore affect the density and the composition of zooplankton, and in this case ectoparasites that infest the benthic and demersal fishes. Live corals have a mucus layer that trap the zooplankton even when it is not consumed by the polyp tentacles. In studied dead corals, these have showed significantly more *Gnathia sp.* than the live coral site, were the Top-down control was exerted by corals on Ganthiids (Artim and Sikkel 2013).

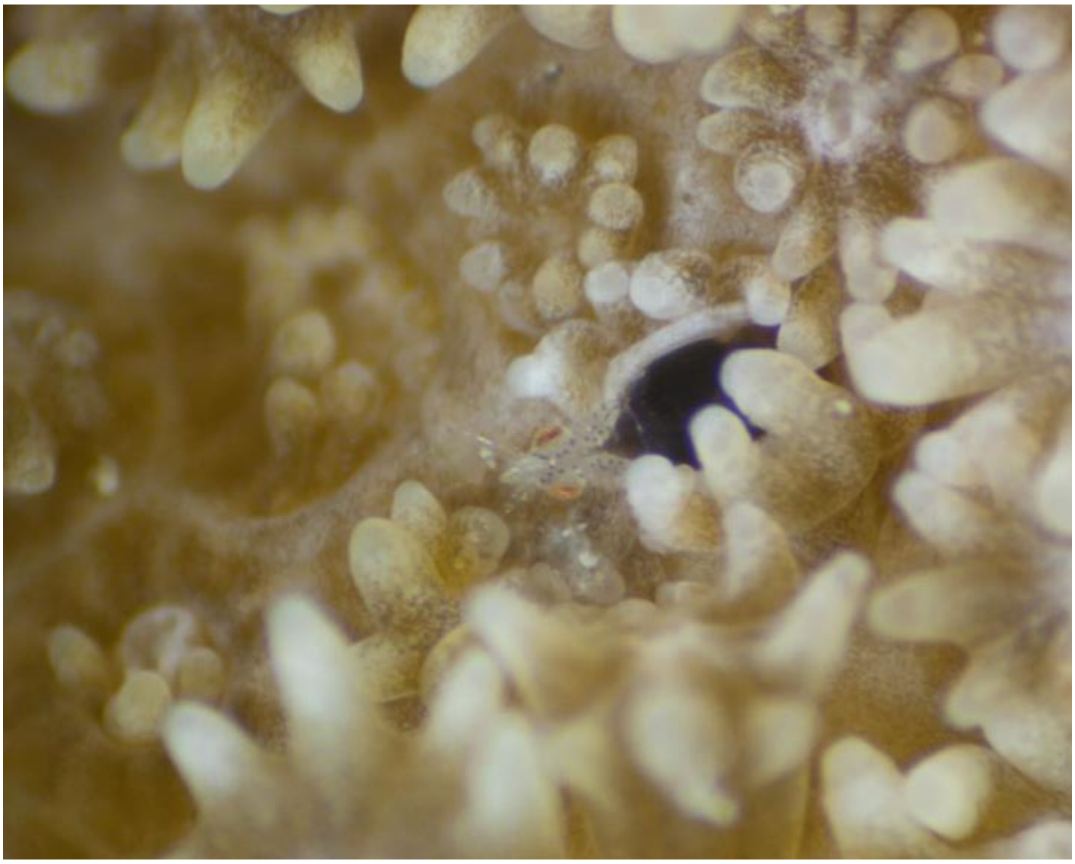


Figure 2 A stage 1 gnathiid larvae trapped in a fatal encounter with a coral polyp and prior to ingestion (Artim and Sikkel 2013).

Reef Deterioration and Consequences

During the 1997/1998 an abnormal raise in sea surface temperature led to a massive coral bleaching and resulting in a higher coral mortality (Ateweberhan et al. 2010; Lindahl et al. 2001). A study was conducted to assess the effect of coral community on the structure complexity on the fish community, the study took place in Tanzanian coral reef (Lindahl et al. 2001). The fish communities were investigated in a transplantation location which has 88% dead coral cover. The diversity was not affected, however, the fish community composition experienced clear shift. The fish abundance increased by 39%, this was linked to the increase in the macroalgae abundance which took advantage from the dead coral skeletons, especially most of the fish community was from herbivorous species. This study concludes that the fish species diversity, abundance, and community compositions experienced an obvious chance due to the complexity provided by the dead and the live coral. The ability of the reef to sustain a diver's fish population even after the coral bleached or died as long as the reef sustain it complex structure (Lindahl et al. 2001)**.**

Dead corals provide shelter to the existing organisms because it still forms a complex bed structure, moreover the dead skeleton from a bleached or fragile tissue is considered as a recruitment foundation for the new settled polyps. However, coral skeleton will be more fragile and vulnerable to weathering, wave actions and any other natural destructive incidence (Komyakova et al. 2013). This could eliminate the main feature that degraded reef site have which is the habitat complexity. The inter-relation that links the species richness, hard coral cover and habitat complexity does not allow the assessment of each variable effect on the structure of the fish (Komyakova et al. 2013).

However, the growth of algae and collapsing of the reef structure might reduce the complexity of the reef and the available habitat for the reef associated fish assemblages. A study by Feary et al. (2007) compare the fish assemblages between 3 type of natural colonies 1) live, (2) degraded and (3) dead colonies with recent algae growth. Results conclude that the average abundance was lowest in the dead colonies, furthermore the recorded species in the dead colonies are not related with living reefs. Algae growth on dead colonies induced the change in the structure of the existing fish assemblages since most of the recorded were new recruits and juveniles.

The 1997/1998 El Niño Southern Oscillation (ENSO) affected the coral reefs worldwide presented the response of fish assemblages before and after this massive bleaching event, (Garpe et al. 2006) . The change within the sites were strong where the substrate has damaged. Short-term assessment showed that one site starts to recover, however long-term monitoring showed that both total abundance and taxonomic richness had decreased in all stied sites. Furthermore, the tropic structure of the species has change since an increase in Herbivore abundance as an instant reaction to bleaching but was successively reduced in eroded habitat (Garpe et al. 2006)

Coral reef in the Arabian Gulf also suffered from a series of bleaching events due different phenomena, since the Arabian Gulf characterized by the wide range of sea water temperature, the bleaching events occurred during low temperature for coral as well as heat stress events Figure 3. The combination of both possibilities is an additional source of stress on regional coral reef. The decrease of coral cover and the transformation from wide reef cover to remote batches might also increase the stress in these ecosystems through decreasing the connectivity between sites and the inflow of new recruits to the system.

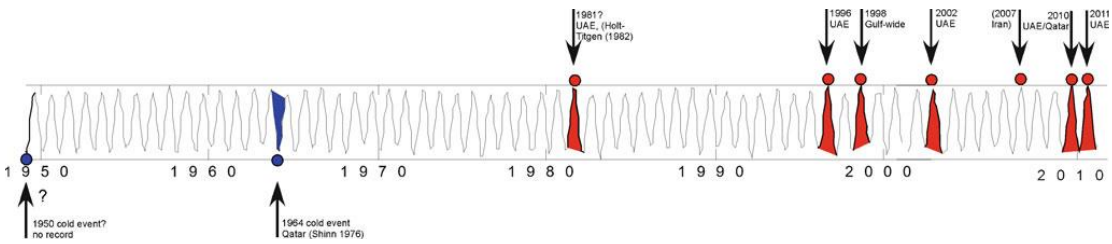


Figure 3 Arabian Gulf mortality/bleaching events between (1949-2011) and HadISST1 temperature data, 1×1° grid. The blue color is for the mortality due to cold, red is mortality due to heat stress (Riegl and Purkis 2012b).

Along with the natural stressors, manmade activities had also magnified the level of stress on the natural habitats. Manmade pressure such as ports, industrial plants, desalination plants or artificial islands are the main driver of habitat destruction. Overfishing in the gulf is a critical topic since there are different commercial important fish and shrimp species are experiencing an unsustainable harvesting, some of these species exert an top-down control on the algae (herbivours) which compete with corals over space. Moreover, about half of the exiting desalination plants worldwide are available in the Gulf to secure a freshwater supply for the resident populations in the area, (about 5 billion m3 annually) which result in more than 1000 m^3/s of discharged brine back to the environment. Such discharge will contribute to increase temperature and salinity in additional to the elevated level of other toxic pollutants (Burt 2014).

During the 90's of the last century more than 40% of the coastal development in the Gulf area led to a significant loss in biodiversity. Moreover, ongoing large coastal development projects were established, especially the artificial island or sea development that had exacerbated the degradation of marine biodiversity and the habitat integrity in the region (Al-Ghadban and Price 2002; Burt et al. 2012; Sheppard et al. 2010).

The Arabian Gulf fisheries had also increased the pressure on the natural fish habitats, fisheries in the area are considered multi-species and multi-gear sector. Even if it is often described as an artisanal, due to use of traditional methods, however the scale of operations is clearly reaching commercial use (Al-Abdulrazzak et al. 2015). All fisheries sectors are available in the Gulf from recreational, traditional, commercial, and industrial. Fishing from the shore or the use of small boats could be considered as a recreational fishing. Both recreational and traditional fishing in the region is benign in their impact on the available resources. Fishing operations conducted by wood dhows targeting the demersal species through traps (gargoor) usually conducted for reef associated species. Most of benthic trawlers were banned or restricted in most parts of the region. The Gulf population has increased dramatically in the last decades, this increases the pressure on the available fishery stocks due to the increase of demands. The food security issues also gained more attention however the fishery regulations are still not well established in the region, assessment and monitoring of the socks are not implemented in many parts of the Gulf (Grandcourt 2012).

The decline in coral reef cover could have different effects on coral based on magnitude of the coral cover decline, the coral cover threshold for which could result fish species richness to decline is 20% of live coral cover. Te most valuable species would be coral dwelling which will have up to 62% if only 10% of the coral cover declined abundance of obligate coral-dwelling species, corallivorous fishes, and other species which depend on coral as their recruitment. (Komyakova et al. 2013b).

Artificial Reefs

Ongoing degradation of coral reefs led to increase the concerns about the critical situation in the Gulf and the need for an effective restoration plan. Artificial reefs (ARs) are indeed regarded as potential part of mitigation plans, essentially to mitigate the significant loss of habitat and to recover fish biodiversity in the affected sites (Seaman 2002). Artificial reefs could be defined as submersible structure, which is deployed and located in the seabed, intentionally to simulate the characteristics of the natural reefs to protect, restore, enhance, and maintain the ecological significancy of reef sites and the living resources of the inhabitant organisms. Such definition is considered by The European Artificial Reef Research Network (EARRN).

A review conducted by Baine (2001) showed that the majority of literature related to the use of artificial reefs were from North America, with 38% concentrated in the United States. Europe was second with 29% of the papers included in the review. In Europe, the leading country in artificial reefs studies form the reviewed papers was Italy. Artificial reefs, as mentioned previously, consists of any man-made structure that is used to mimic the natural reef's structure, however there are many types of artificial reefs used globally Figure 4. Commonly used structures are shown in Figure 4, different shapes are used as well as different materials to enhance the coral reef mimicry characteristics of the artificial reef. Artificial reef materials vary from concrete, natural rock and stone, vessels, quarry rock, tires and plastic. In a review (Fabi et al. 2011), which included 249 artificial reefs to investigate the most used material in artificial reefs, concrete was the most used including concretes of all shapes: cubes, blocks and pipes (Fabi et al. 2011). Mix of concrete and other material (such as vessels, tires and plastic) has also been used. Natural material (such as stone and rock) was the second commonly used as an artificial reef. The rest of materials included a variety not limited to the previously mentioned (such as train cars, dock gates, mineral accretion, oil platforms, etc.).

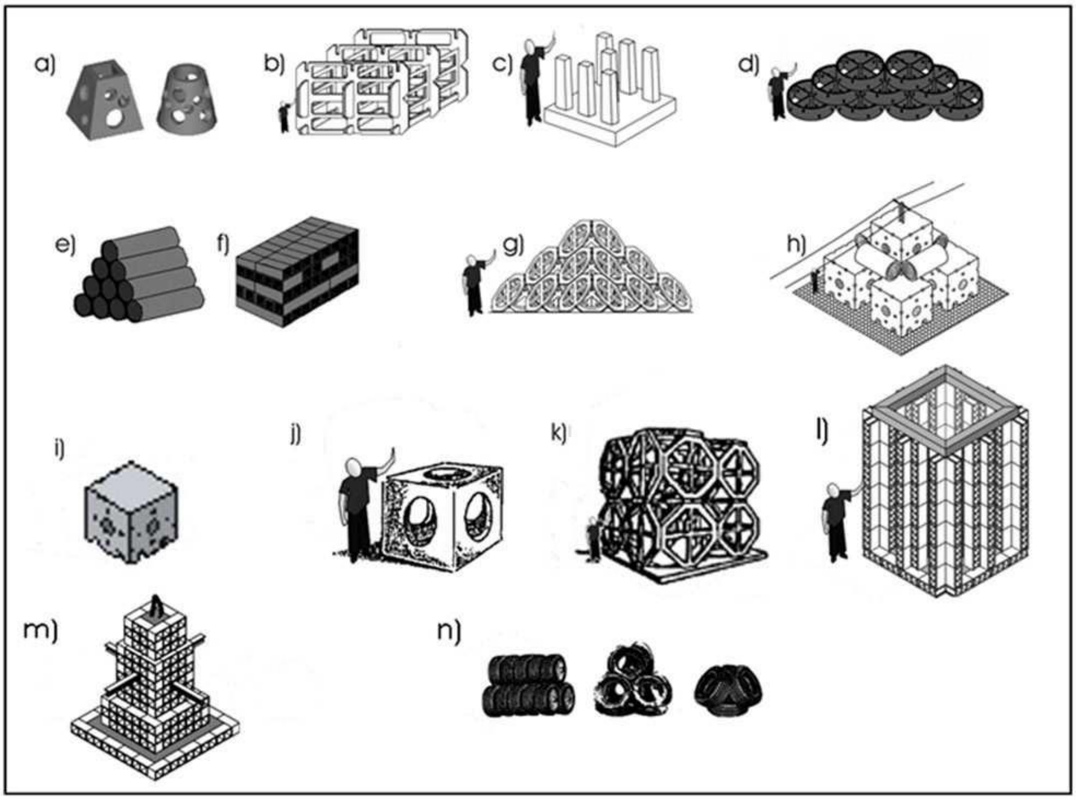


Figure 4 Diffetent types of artivicial reefs structures form (Fabi et al. 2011).

Artificial reefs are developed for different purposes such as fishing and recreational diving. In Europe, for example, there is the OSPAR guidelines on artificial reefs in relation to living marine resources. The existence of such guidelines could advise on the selection of artificial reef material, how to develop a suitable design, monitoring plans/approaches and build a useful scientific experiment that could add a collective knowledge and have a sort of connection and addressing related issues. That also could result in developing national or regional regulations, aiming to standardize the implementation of these restoration techniques based on a scientifically acquired conclusions. The existence of such guidelines, even if it is not legally binding, should allow to have a standardized plan for the deployed reefs and implement an environmental impact assessment followed by a monitoring plan to assess the effectiveness of the used designs and strategies. All this will enhance the overall evaluation of the use of artificial reefs as an environmental restoration tool.

The installation of artificial reefs is usually associated with the desire of providing an additional suitable habitat, along with other secondary aspects of enhancing the tourism and fisheries (Hammond et al. 2020). Furthermore, the advocates of the artificial reefs suggest that by introducing these manmade structures, the commercial fisheries will be enhanced due to the fish aggregation and productivity at these sites (Hopkins 2007). However, ARs compared to the natural reef are commonly limited in size and their distribution is quite restricted (Burt et al. 2013). Three hypotheses for the interaction between adjacent natural and artificial reefs were examined in Perkol-Finkel et al. (2006): **1)** Given appropriate time both reefs will have similar fish community structure; **2)** Similar community structure will exist only if both have similar physical structure feature; **3)** both will be different regardless of temporal or structure feature. Obtained results corroborated the second hypothesis, demonstrating that regardless of the age of the artificial reefs it will have similar structure only when it has a similar structural feature to neighboring natural reefs (Burt et al. 2009). Furthermore, the habitat complexity enhances the fish attraction toward the artificial reef since it has more three-dimensional structure than that of the natural habitat (Granneman and Steele 2015). The use of the artificial reef in fisheries enhancement has been implemented in several location worldwide. In the Gulf of Mexico, the use of the Artificial reef to enhance the production of the red snapper has shown a significant positive contribution to increase biomass and abundance (Szedlmayer 2007). In the Arabian Sea, fishermen in Oman use artificial reef called shad, which act as a fishing ground for Senat Al-Bahar – the 'code of the sea'. These techniques were used for centuries and were transferred throughout fishermen's generations (Al-Oufi et al. 2000).

Granneman and Steele (2015) conducted a study in California comparing the fish assemblages between natural and artificial reefs. Their findings state that artificial reefs can replicate natural reefs if they have similar physical structure, moreover the increase in the habitat complexity in ARs more than the natural reef can support more densities of some species compared to what is found at natural reefs.

Concerns about Artificial Reefs

The concerns on artificial reefs remained despites it recorded success. The manufactured/engineered/artificial structures will not be able to provide similar ecological services as the natural habitat (rocky reefs, mangroves, seagrass, and another natural habitat) that they meant to replace or support. In fact, the immigration of non-indigenous species for the man-made structure and cause a dramatic and unexpected change in the artificial structure is one of the main concerns (Hammond et al. 2020).

Other studies suggested that artificial reefs are acting as a fish aggregator and increasing the concentration of the biomass around them rather than increasing the existing fishery stocks (Grossman, Jones, and Seaman 1997; Koop et al. 2001; Polovina 1989). In Japan about 6400 artificial reef units were deployed between the 1976 and the 1987, but despite this large-scale operation the landings records did not showed any measurable increase (Polovina 1989). Moreover, some of the negative effects of artificial structure on reef fish populations were highlighted in Grossman, Jones, and Seaman (1997) such as increasing threats of overexploitation by attracting fishing activities to unexploited stocks. Also, by increasing the catch rates by concentrating the previously exploited stocks. However, in the Arabian Gulf artificial reefs contains different fish, coral, compared to the natural reefs (Burt et al. 2009; Feary, Burt, and Bartholomew 2011). Regardless of these negative points on ARs, they are still considered as one of the main measures to mitigate the habitat loss due to the coastal development. In recruitment experiment conducted by Arney et al. (2017), the authors concluded that creation of artificial structures away from the natural reef might benefit the fisheries management by allowing the juvenile fish to recruit and grow.

Also, productivity of natural and artificial reefs was investigated by Glenn et al. (2017), the study compared the productivity of red snapper female between two habitats natural and artificial reefs in Gulf of Mexico. Results showed that the potential productivity of female fishes in natural reefs were higher than those in artificial reefs. They conclude that the potential reason is the difference of either size or the structure (complexity) of each type of the reefs. According to the authors, the density of snappers is generally higher in artificial reefs, which lead to increase the competition for resources, so that higher competition might result in having a major effect on the productivity and fecundity of the existing individuals. Moreover, the fishes collected from the artificial reefs were smaller at age and have lower nutritional state than the ones found in the natural reefs. Thus, this concludes that as density increases red snapper become more vulnerable to overexploitation by decreasing their reproduction fitness and the ability to recover the sock biomass.

In addition, studies showed a trend of differences in growth rates, reproductive parameters and feeding habits for Red Snapper between different type of habitats natural and artificial reefs (Schwartzkopf and Cowan 2017). A study conducted by Schwartzkopf and Cowan (2017) , conclude that reproductive output is strongly linked to the nutritional condition, where better nutritional availability could increase the reproductivity and in contrast the limited availability of resources lead to stress individuals and reduce reproduction outputs. Red snapper females in natural reefs are reaching maturity earlier and that could be related to their ability to favor the reproductive potential over the somatic growth, in the contrast Red Snapper at the artificial reef, in order to survive, are enforced to prefer the somatic growth over reproduction (Simonsen et al. 2015).

There are several factors contributing to the productivity in marine ecosystems the understanding of these factors is a key to evaluate the contribution of each factor. Quantifying the production of artificial reefs is one of vial to achieve a reasonable management program. To be able to choose a side in the production vs attraction argument long-term studies should be performed including modelling and simulation of the possible processes that could occur in these new established ecosystems (Smith et al. 2016).

Artificial reefs in the Gulf

One of the key elements to determine the success of the use of artificial reef is the site selection process. Since about 50% artificial reef deployment programs reported failure due to poor site selection. Deployment location selection in the Arabian Gulf region should consider different limitations such as 1) Navigation, transport and pipelines since the Gulf area has a significant area cover by either of pipelines or navigational rotes since most of the oil and gas exploitation is happening offshore. 2)

Reclamation, dredging and industry the poor- and low-quality environment will be also a source of failure for the deployed artificial reefs so avoiding such locations will increase the success potential of the planed artificial reef. 3) Areas shallower than 5m depth, such shallow water in the gulf will be vulnerable to the extreme surface temperature in the summer (Erftemeijer, De Graaff, and Boot 2004).

As degradation of coral reefs had rapidly increased during the last two decades, the need for restoration technique has emerged and several studies were conducted to establish effective restoration approaches. The use of artificial reefs as a tool to maintain and mitigate the loss of natural habitats has be promoted to be the most technically and environmentally appropriate technique (Baine 2001; Fabi et al. 2011; Polovina 1989). In Kuwait, three 25m^2 structure were deployed and after only one year it was occupied by more than 50 species of fishes, where more than 50% of the biomass were from commercially significant species such as *Epinephelus tauvina* and *Sphyraena jello* (Downing and Tubb 1985). In Qatar, the use of artificial reef as a mitigation or compensation measure of degraded habitats is commonly practiced by the industrial sector, however, the real impact of these measure is still not clearly assessed (Richer 2008).

A study was conducted to investigate the role of recruitment in shaping communities in the Gulf, it showed the key role of stochastic processes to the benthic communities' structure inducing the processes associate with artificial structure (Burt et al. 2012). During that study, the variation of coral recruitment abundance was higher at the sites that distanced apart from other coral site more than 10 km away, that was suggested to be caused by the variance in planktonic larval supply or the higher juvenile mortality rates caused by higher water temperature in the area (Jebel Ali). That also highlights the importance of investigating these natural factors toward achieving more realistic plans for ecological engineering. Moreover, the study showed that the coral recruitment could be higher depending on the substrate material, in which the effect of selection of artificial reef material could induce the successful coral settlement in the designated artificial structures. Apart from the substrate material the man-made structure such as breakwater in the case of that study, the wave exposure could influence the development of fish community either direct or indirect effect.

Reef Fish Population Connectivity in The Arabian Gulf

Fish larvae and eggs spend the first weeks of their development phase in the open water, affected by the currents and tides before settling in the appropriate reef and leave the pelagic zone. Pelagic processes in this early stages are responsible for the population connectivity and allow the recovery of the harvested fish (Simpson et al. 2013). Most of the demersal marine teleost's fish have a bipartite life cycle such cycle starts by an adult introducing propagules which will undergo a pelagic phase. During the larval pelagic phase, movement of larval between coral patches prior to settlement and transforming to juveniles. Therefore, this stage is critical for dispersal and have the highest opportunity of interpopulation connectivity occurrence (Torquato et al. 2019).

As mentioned previously, marine water temperature in the Arabian Gulf has a wide range between summer and winter in which the sea surface temperature could reach more than 20 ºC difference between both seasons (Sheppard et al. 1992). Fish metabolism is affected directly by the temperature and could lead to reduce their fitness. Also, this impacts due to climate change and other environmental stressors which could have a major effect on all marine species are believed to be more exacerbating to coral reefs communities. Indeed, in the case of coral reefs fish the climate change has magnified affect where it could strongly lead to mass deterioration of their habitat moreover, most of the reef fish species are experiencing higher temperatures and they are already living close to their thermal maxima (Nay et al. 2020). The seasonal variation in the Arabian Gulf could with such wide range could give an indication on how fish could react and tolerate such temperature change. The migration pattern is one of the mitigations adopted by fish experiencing such metabolic stress, fish migration had been documented in previous studies. Such behavior could induce the structural changes of reef fish communities, such changes could have wide implications on fisheries and food security of neighboring countries (Vaughan et al. 2021).

A study comparing two fish species size-at-age between to different adjacent environment Arabian Gulf and Oman Sea. Otolith were used to investigate the effect on individual growth rate by temperature, salinity, and productivity. Both species were showing similar trend by having smaller size-at-age and lower maximum size in Arabian Gulf, this promote the life-history trade-off between growth and the required metabolic process by species in such extreme environment (Erftemeijer et al. 2004).

Survey Methods for Reef Fish Communities

Sampling methodology varies in several ways effort, technique, targeted data and other. However, to achieve an accurate and an effective stock (or biomass) evaluation for both aquaculture and fisheries industries and to develop an advanced and effective biodiversity management approaches for sensitive area (such as marine protected areas and restricted areas with valuable economic and environmental services), it is essential to develop monitoring strategies and also by implementing the most effective surveys to monitor fish communities. Fish assessment and surveys are conducted to study the status, growth trends, disturbance impact and seasonal variation of the reef fish assemblages, these surveys are performed through quantitative techniques to assess reef fish population (Wetz et al. 2020).

Different survey methods commonly used to assess the reef fish assemblages, these methods can be divided into fishery-dependent and fishery-independent methods. Fishery-dependent (catch based methods) are valuable to investigate the status reef associated fish and it will provide descriptive picture of the species which have been harvested through the selected gear. The data produced form a catch-based technique suffer from a strong bias of the sampling approach. Each gear will have different selectivity; for an example, the landing of hook-and-line fisheries are mainly targeting large predators caused by the higher selectivity of this type of gear. However, traps landings include a wide sizes and trophic levels that is due to the low selectivity of this type of fishing gear which result in more diverse group of species than other highly selective gears (Caldwell et al. 2016).

Fishery-independent, which is an in-situ survey-based technique, both targeted and non-targeted species are recorded. Such methods allow us to understand the magnitude of the environmental disturbance in a dynamic ecosystem in the coastal areas such as coral reefs and seagrass. The aim of such in-situ methods is to quantify the composition of the fish assemblages in the investigated habitat. The acquired data includes number of species, number of individuals (N), estimates of density, diversity, and size classes for individuals. Even though that fishery independent methods have some operational difficulties, especially the behavioral and morphological characteristics affect the species-specific ability. Also, diurnal, and nocturnal sampling is absent in the in-situ sampling since its usually select the active species in the daylight hours, furthermore, identifying active species through visual censing is difficult due to the crypsis behavior by some species to avoid predation. Crypsis mechanisms include camouflage and of hiding within the reef substrate (Caldwell et al. 2016).

Underwater visual census (UVC) includes different techniques such as belt transect, stationary point count, or timed swim, Towed diver and Under water video which includes remote, baited, laser videogrammetry, stationary, stereo, and towed systems. Researchers have used different methods to study the reef fish ecology and management in term of population dynamics, richness, diversity, seasonal variation, and other aspects on the reef fish assemblages. Visual methods have been known by their ability to evaluate the relative abundance, biomass, and population length data. That why such methods were selected to study the demersal species especially when the substrate is hosting a sensitive ecological system such as corals reef since these methods are less destructive than other traditional fishing techniques. (Samoilys and Carlos 2000)

Belts transect (Figure 5), is a method conducted through SCUBA diving along a transect with known length and width. Divers will maintain a speed at ~6 m min^{-1} along the transect. The estimated number of each species is recorded during the survey. (Brock 1954, 1982; Minte-Vera et al. 2008). Stationary point count (Bohnsack and Bannerot 1986), in this method the sampling units could be considered as an imaginary cylinder with known diameter. The survey in this method is conducted by a scuba diver positioned in the center of the imaginary cylinder and for the first 5 minutes all spotted species should be listed, no counting will be done during this period except the species that are highly mobile. After this initial period, listing of new identified species will stop, and quantitative data will be collected for each of the recorded specie. The quantitative data of each species should be collected in a single 360° rotation, the rotation should be done with minimum disturbance to avoid fish escape, that could affect the count. It is recommended to reduce the bias and to eliminate the error from diver’s variations that 2 divers perform the censuses simultaneously (Bohnsack and

Bannerot 1986; Minte-Vera et al. 2008).

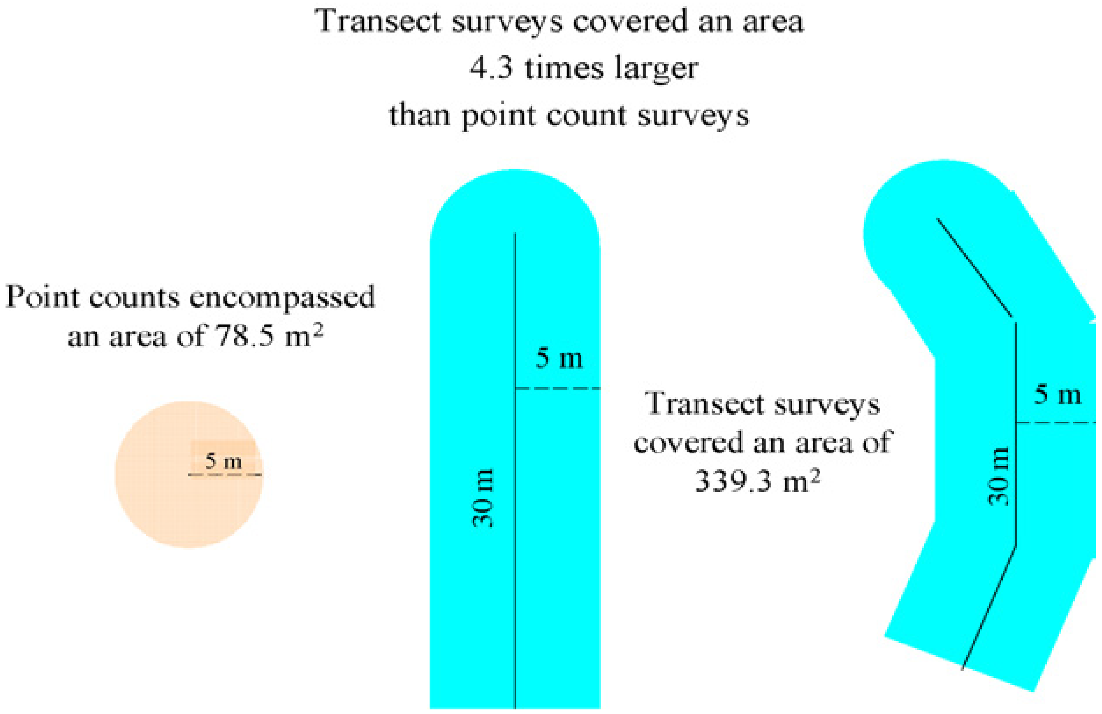


Figure 5 Illustration of Point Counts Survey and The Belt Transect Surevy (Colvocoresses and Acosta 2007).

Timed swim is a technique where the underwater censuses are conducted by scuba divers swimming parallel to the reef with a direct visual contact with the seabed at speed of 20 m per minute. Divers are recommended to swim down current to minimize the disturbance produced during the movement (Caldwell et al. 2016; Richards et al. 2011; Robbins et al. 2006). Towed Diver, divers use a buoyancy tow-board which is used for recording the observations during the survey. Such survey is designed for studying reef fish population through large water bodies. The towed board could be customized to have digital video camera, stopwatch, and fixed places for writing slate to facilitate the diver tasks during the survey. Also, a magnetic telegraph device could be added to the board which will allow the communication between the diver and the boat. Temperature and depth recording instrument could be an optimal addition to the board. The tow boards are connected along 60 m lines which could be shortened in shallow areas. The survey could start with the divers with 32%–36% NITROX air tanks and attached to the board and been towed behind by a boat at speed of 1.5 kt. Tack points should be collected through a GPS in relatively high frequency 5-s interval is fine. Divers will record the observe fish species to the lowest taxon possible (Chancerelle et al. 2008; Richards et al. 2011).

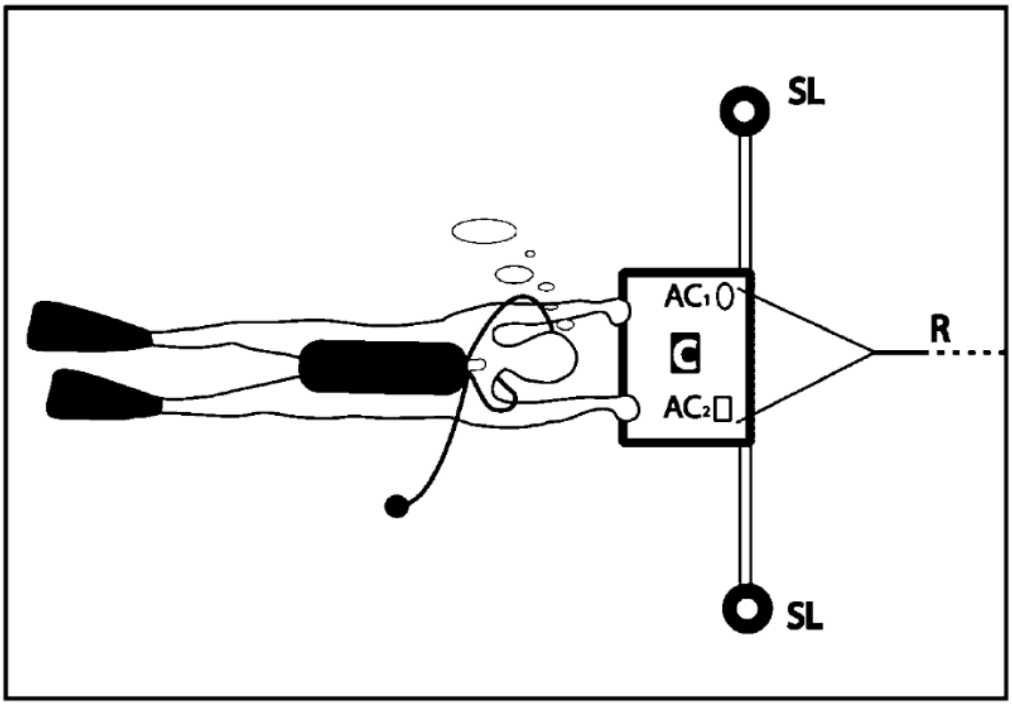


Figure 6 illustarion on towed diver method (from Chancerelle et al. 2008)

Underwater video systems were developed to enhance the fish surveys and add more types of collected data. There are active and passive types of underwater video systems, diver-operated stereo-video system (stereo-DOVs) could be an example of the active survey systems. In this technique two divers will dive with two cameras. The diver will hold the system and swim in along sampling transect with a steady speed of ~3 s/m (20 m/min) while holding the camera above the ground by 0.5m at lease with a slight angle to the seabed so it could provide the optimal vision (Goetze et al. 2019).

The passive systems include a remote video technique in which a camera with or without a bait is used to collect video images from a selected sampling point for a pre-decided duration. The baited tchnique was described in Gladstone et al. (2012).

In a survey that was conducted by Caldwell et al. (2016) to identify preferable method selected in research, 180 scientists had contributed and shared their views. The collected responses represent about 191 countries, with different status island and mainland. The survey emphasized that based on projects, about 49.8% have applied the belt transect method, and 20.2 % employed the stationary count technique, 19% of projects were conducted through the timed swim method. Both belt transect and stationary count were the most reported methods to evaluate the fish assemblages.

Researchers selected their survey methods based on the targeted information, cost, and operational effort. Methodological inconsistency adds a great restriction and barrier in comparing the collected data or establishing a single database to establish long-term reef fish community monitoring. Method selection should be well investigated to select the ideal survey method furthermore, joint communication and partnerships on regional scale will facilitate reaching an unified approach in quantifying reef fish assemblages, at least at the regional level. The regional reefs have variety of interactions and connections, thus regional collaborations will enhance the understanding of the population dynamic and how the reef fish community is tolerating the existing stressors (Caldwell et al. 2016). The long-term monitoring is the best way to study the ecological changes since the response to stress and changes in the ecological variables might give wrong indication if a set of short-term observations were only considered (Garpe et al. 2006).

Study Objective

During this study, our aim is to evaluate the following:

- Estimate the variation of fish abundance, biomass, and biodiversity between the natural and artificial reefs.
- Measure the seasonal variation in term of fish assemblages between the artificial, dead/degraded, and live reefs.
- Test the effectiveness of two fish surveys method (i.e. UVC and BRUV) in characterizing reef-associated fishes.

CHAPTER 3: METHODOLOGY

Study Area

Three sites were selected for dead, live, and artificial reefs (Table 1). The natural reefs are in Sheraho Island (Jazeerat-Sheraho), the artificial is located south of Wakrah and mainly consist of reef balls deployed in clusters on a sandy bottom. Sampling visits were designed to include the temporal variation, with one visit per site per season, in March (late winter when temperature reaches the lowest annual values) and October (late summer when temperature reaches the highest annual values). Sampling took place in year 2020 during COVID 19 pandemic which added some restriction in conducting several site visits to replicate the seasonal samples, each site was visited once during the two seasons.

Since these three types of habitat had different coral cover and different fish communities, two survey methods were included in this study: Baited Remote Underwater Video system (BRUV's) and Underwater Visual Census (UVC) Stationary point Count techniques. The use of two sampling methods was selected to reduce the effect of the methodology on the accuracy of the species richness due to behavioral traits. Also, allowed to conduct a comparison between both methods regarding their efficiency, accuracy, and the type of acquired data.

Table 1 Selected Study Sites

N.	Location	Latitude (N)	Longitude (E)	Type	Depth
1	Sharoah	25.033	52.22568	dead reef	~ 6m
2	Sharoah	25.03213	52.22474	live reef	~ 8m
3	South-Wakrah	25.09739	51.65042	Reefballs	~ 7m

A

B

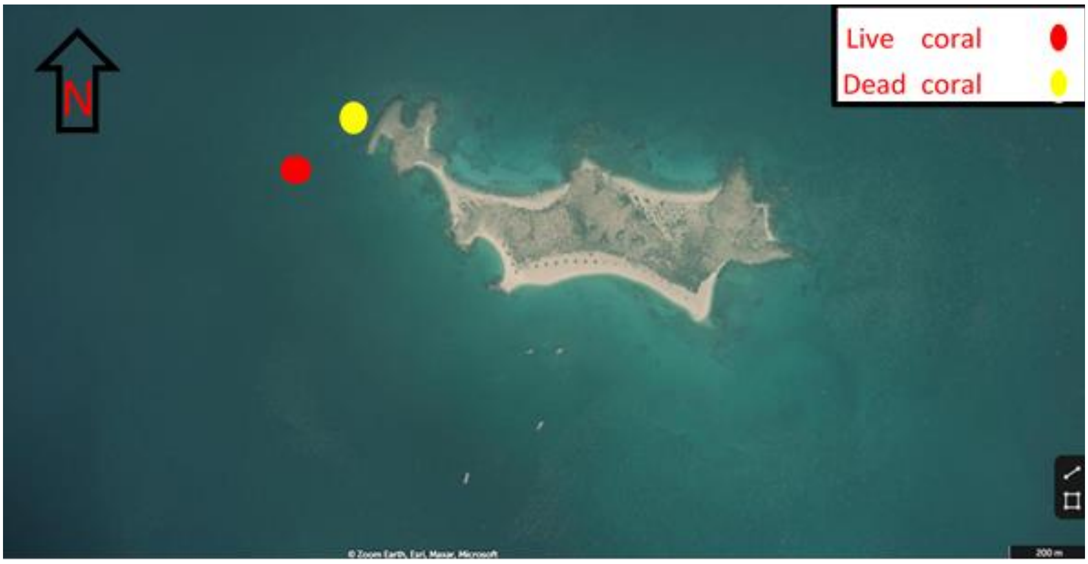


Figure 7 Study Area Map, A both Location natrual and artificial sites. B Sheraoo Island and both Dead and Live reefs locations.

Equipment and Materials used during this study are listed below.

List of material

- Transect measuring tape 30m length.
- Camera frame with 40 cm ×60 cm quadrat.
- 6 BRUV Structure.

- 6 Go PRO HD camera.
- HD camera Nikon 7000 with external flash.
- Waterproof datasheets, slate, and pencil.
- Scuba diving gears.
- Water temperature data logger
- Identification keys for training before the sampling.
- GPS to record site position.
- Fish Bait (fresh sardines, tuna slices).
- Laptop for processing the video and cover images digital.

Substrate Cover

The substrate cover was conducted through photo-quadrats technique in the study area. Three transect of 30 meters were laid at each site of the randomly selected fish survey points and photos were collected at 3 meters interval (Leujak and Ormond 2007). The substrate cover survey was conducted for the dead and live coral (natural sites) only since the artificial reef site was mainly covered sand and only the existence of the reef balls was the exception in that homogeneous substrate. Reefballs site consisted of clustered reef balls deployed on a sandy seafloor. The reef balls are in a shape of dome with multiple holes with a variable height ranging from xx-2 meter for some units.

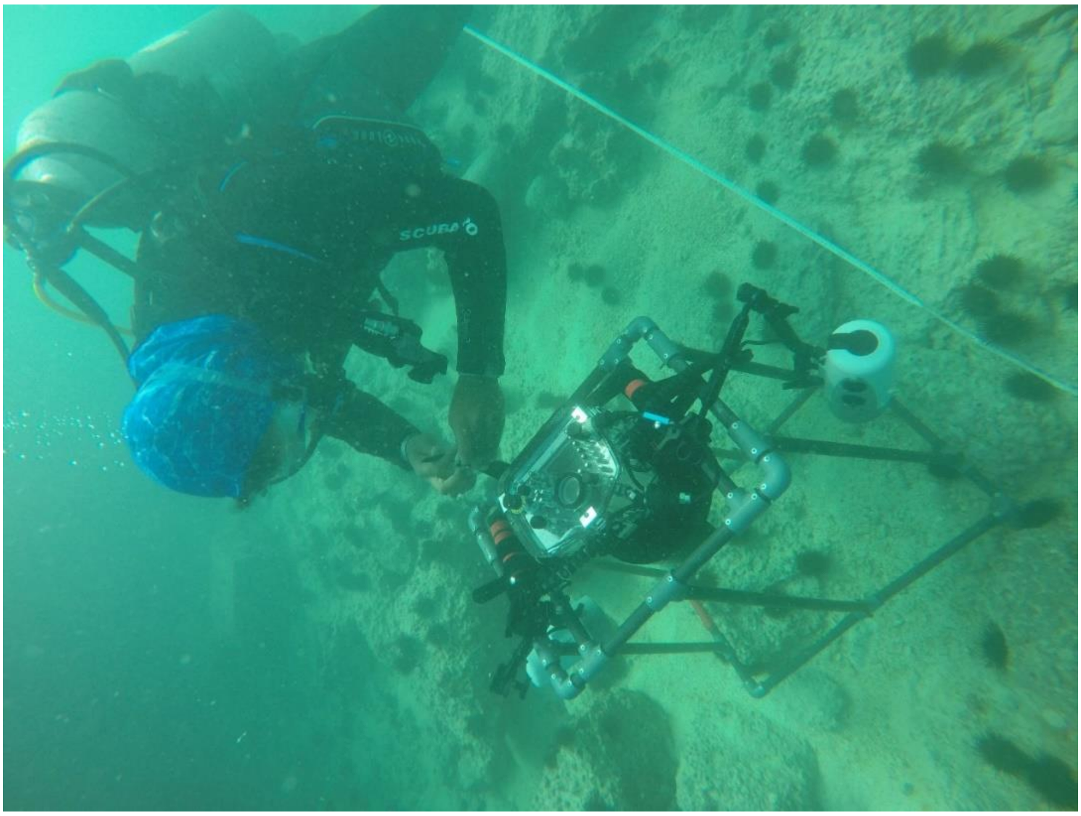


Figure 8 Photo-quadrat Collected Along The Survey Transect marked by the white tape

The acquired photos from the field survey were pre-processed through Adobe Lightroom software to adjust the contrast and select the best photos of each quadrant. A total of 66 substrate photos were processed thorough Coral Net platform, by laying random 50 digital points in the image to develop a representative cover percentage of the area. Substrate cover/identification categories were developed to avoid the dynamic change of the reefs, such as bleaching. The classifiers considered in this study were the live coral, dead coral, macroalgae, dead coral with algae growth, turf, sand, bivalve, sponge, coral rubble, rock, urchin, and coralline algae.

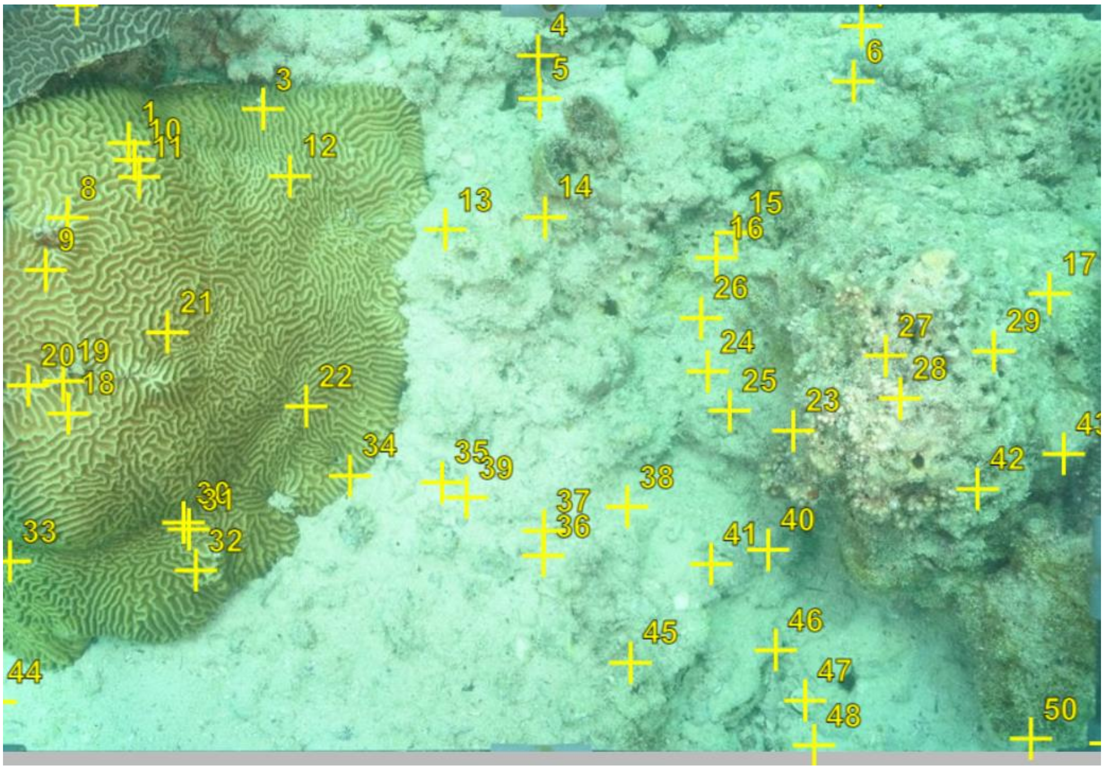


Figure 9 Photo Quadrat With a Random 50 Overlayed Points.

Baited Remote Underwater Video (BRUV)

During these surveys, the BRUV full setup includes a camera, a bait-pole with bait, float system to facilitate surface retrieval and a PVC frame to hold all these items together (Malcolm et al. 2007). Single camera BRUV's systems were used, the structures were assembled from PVC pipes and a camera (GoPro- Hero 6) that was attached to the structures in a PVC housing with a wide-angle and red-filter. The bait was placed in a mesh bag attached to a bait arm of PVC tube with 50 mm diameter (Figure 10). Three BRUV units with temperature loggers were deployed per site and the camera recorded videos for 60 minutes, however, to standardize the used time between the sites and to eliminate the interference of deployment and retrieval activity the count time was 40 minutes. Recommended bait was described in (Gladstone et al. 2012). In this study, sardines and kingfish slices were used at each site simultaneously to maximize the fish attraction and minimize the biases due to diet variations. The used bait during the experiment was standardized for all locations. At each site 3 sampling replicate were collected during each sampling event.

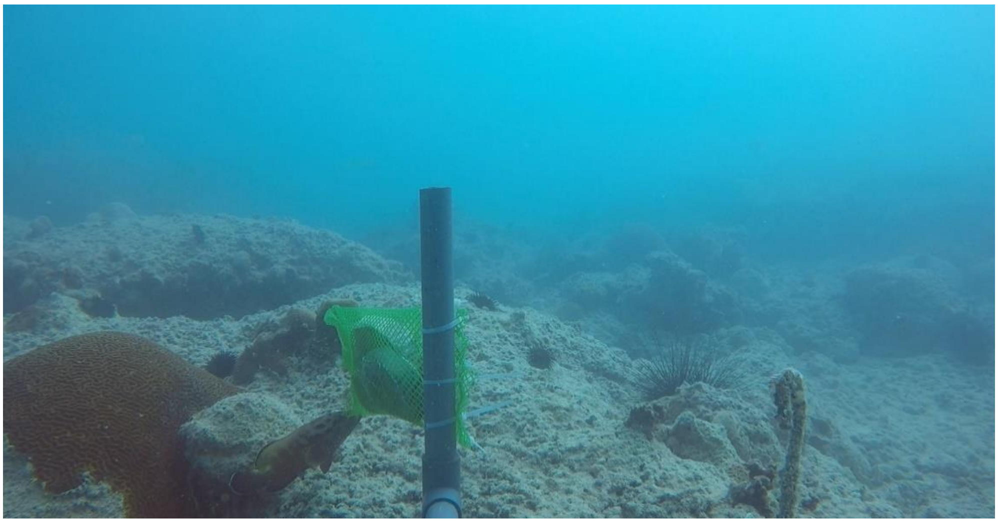


Figure 10 BRUV's structure underwater at the three sites.

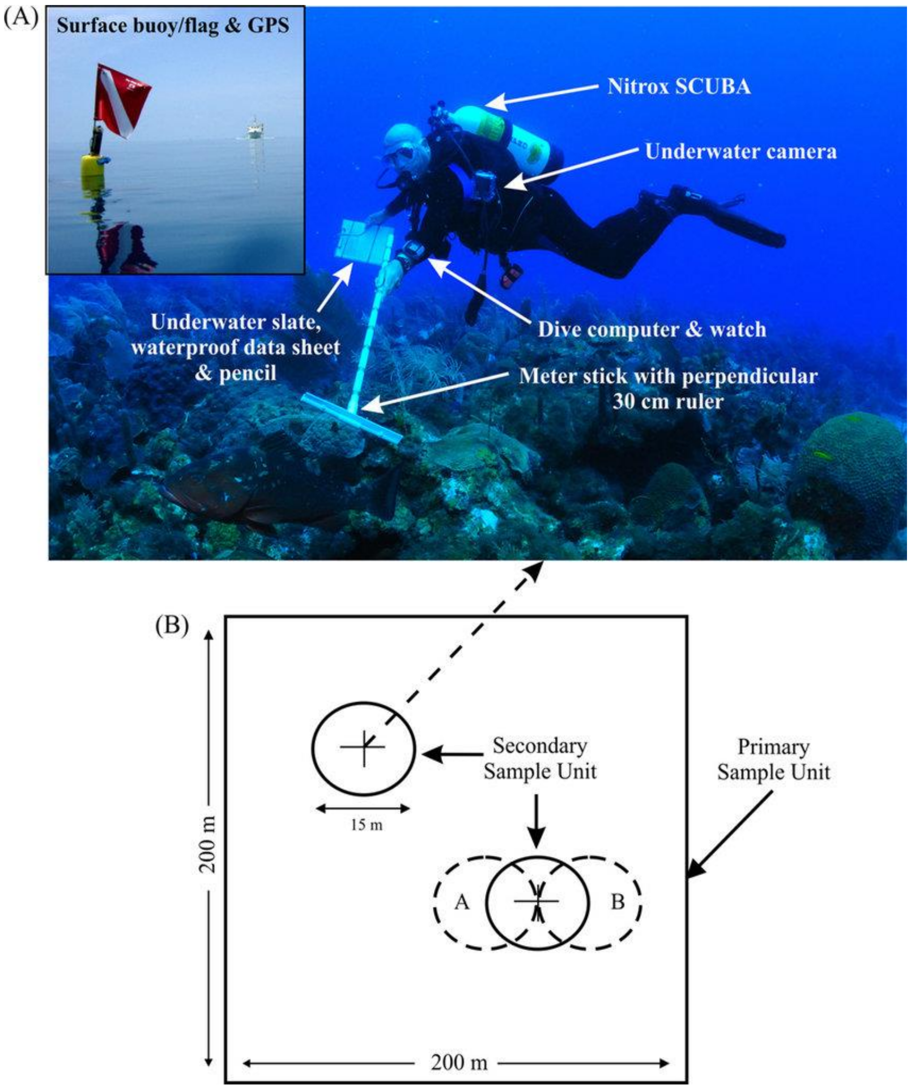
Sampled videos were processed at the lab using the VLC media player software to identify the species at the lowest taxonomic level possible. The species list was prepared and the maximum occurrence of specimens of the same species at one time (one frame) was noted as MaxN. This data allows the calculation of the Relative abundance for each identified species. The recorded data throughout the video procesing consist of Duration of Deplyment, MaxN, Species Identification and the time of both first sighting and MaxN.

Underwater Visual Census (UVC)

The UVC has been used in all three sites and at both sampling months, this method was implemented by collecting a series of separate samples. This includes species compositions, abundance, frequency of occurrence and average fish length these data were collected at the same sampling time. The stationary technique allows the diver to record more accurate data than other sampling techniques such as belt transects, towed diver and other moving sampling techniques (Caldwell et al. 2016). The prior relative knowledge about the local fish species minimized the training period required**.**

The UVC was selected to provide a quantitative data for the surveyed site illustrated in Figure 11**Error! Reference source not found.**. The fish count was conducted in a circular area by a SCUBA diving trained observer, three stationary counting points were selected randomly at each site. The surveyor started descending, when the reef is visible to the surveyor, starts the stopwatch and start counting fishes. The observer should maintain position in a center of imaginary circle (or cylinder) while simultaneously approximate the extent of the circle radius- usually 10m (Samoilys and Carlos 2000). To improve the quality of the results and to minimize the error source, an identification key was also attaching to the observer writing pads. At each site 3 sampling replicate were collected during each sampling event.

The sampling here was conducted in an imaginary cylinder with a diameter of 5 meter and a high of 5 meters as well the count starts after 2 minutes of arriving the station to reduce the fish dispersion because of diver movement. The largest mobile species were counted first, followed by the smaller mobile species. The counting time was predefined for a period of 5 min, all fish species observed within the chosen area and during this period were recorded. Data were recorded on waterproof paper with a printed data sheet. The first observed schools were counted first, this would increase the chances in avoiding double count of the same schools again in case the same school reappear again. After the counting period ends, the listing of new species stops, descriptive statistics for the previously listed species were generated. That include the estimation of number of each individual species, size, the minimum, maximum, and average length of all species.



(C)

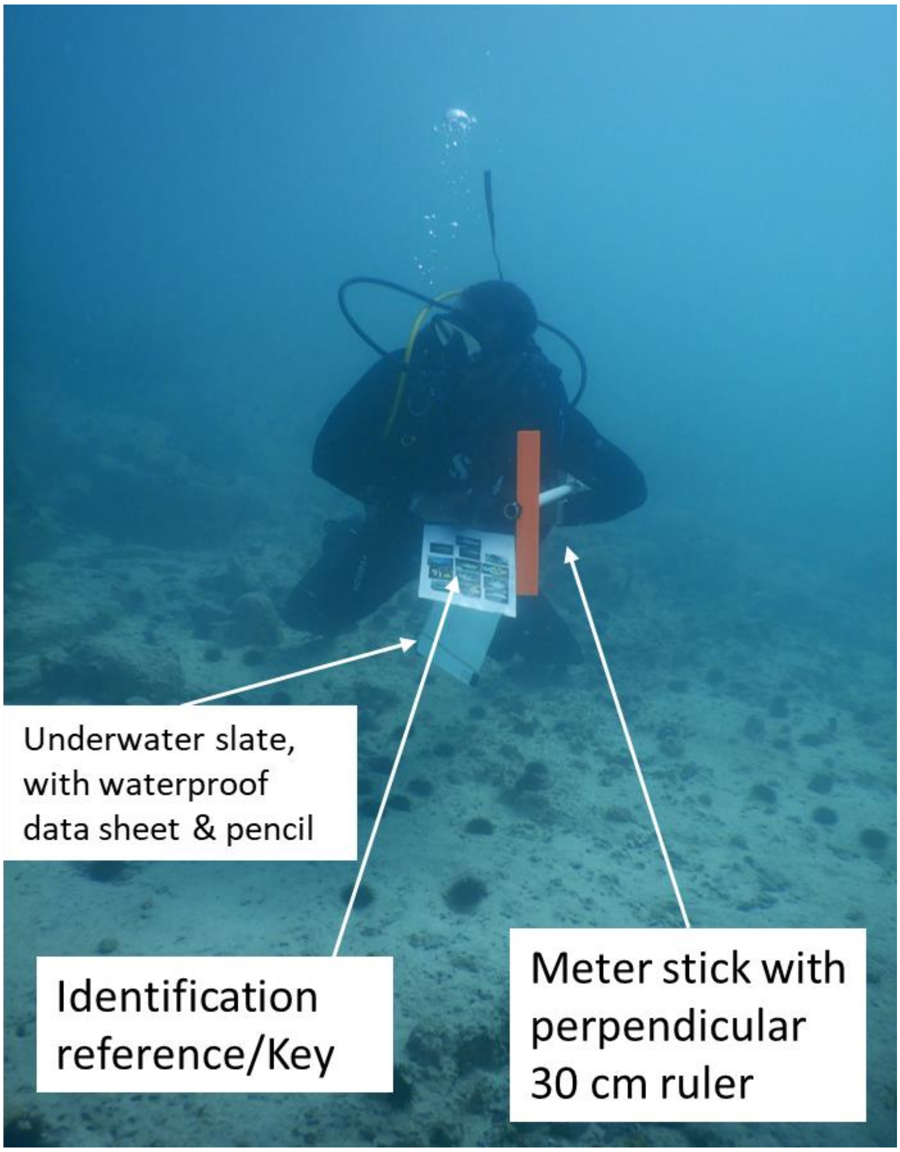


Figure 11 A & B Stationary Visual Censing Method Illustration Reported in (Smith et al. 2011), C Photo from the survey during this study.

Advantages of this technique were summarized in (Bohnsack and Bannerot 1986):

- Quantitative data fish length, abundance, and community composition.
- From operational aspect, the method is considered simple, fast, objective and repeatable.
- An index of biomass is generated from length data for each species by species-specific length weight relationships.

Length Weight Relationship in Fishbase

FishBase develop the Length-Weight relationship WLR from a data of more than 1,000 studies using the length-weight equation $W = a L^b$, where “a” stands for the intercept and “b” is the relationship slope. This formula is used to calculate the species-specific WLR. The measuring units for weight is *g* and *cm* for the total length of the fish. The plot below Figure 12 shows an example of the linear regression of the log-transformed equation: $\log(W) = \log(a) + b \log(L)$ (le Cren 1951).

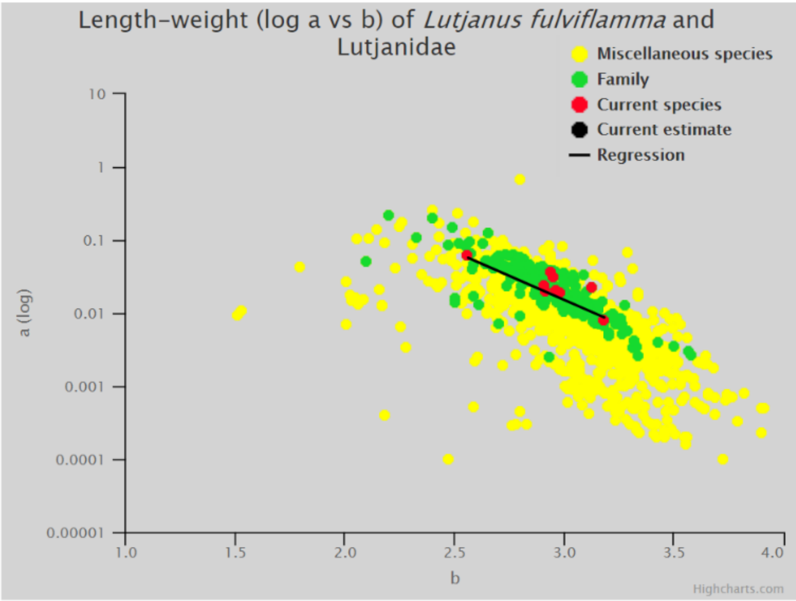


Figure 12 Graph from Fishbase.org showing the length-weight relationships (log a vs. b)

This formula was used to estimate the biomass of the reef fish assemblages from the UVC data which record an estimated species total length. This estimation is not possible through the BRUV’s method used during this study, since it consists of single camera system not stereo-BRUV which may allow the fish length measurement, given a calibration exercise is conducted. The biomass estimation was obtained through the average size data recorded for each species during the survey. The average sizes were extrapolated by assuming that all individual of the same species had the same average size, which is not the actual value, however, to have an approximate biomass estimation, this approach was adopted since the original stationary fish count technique does not record the size groups.

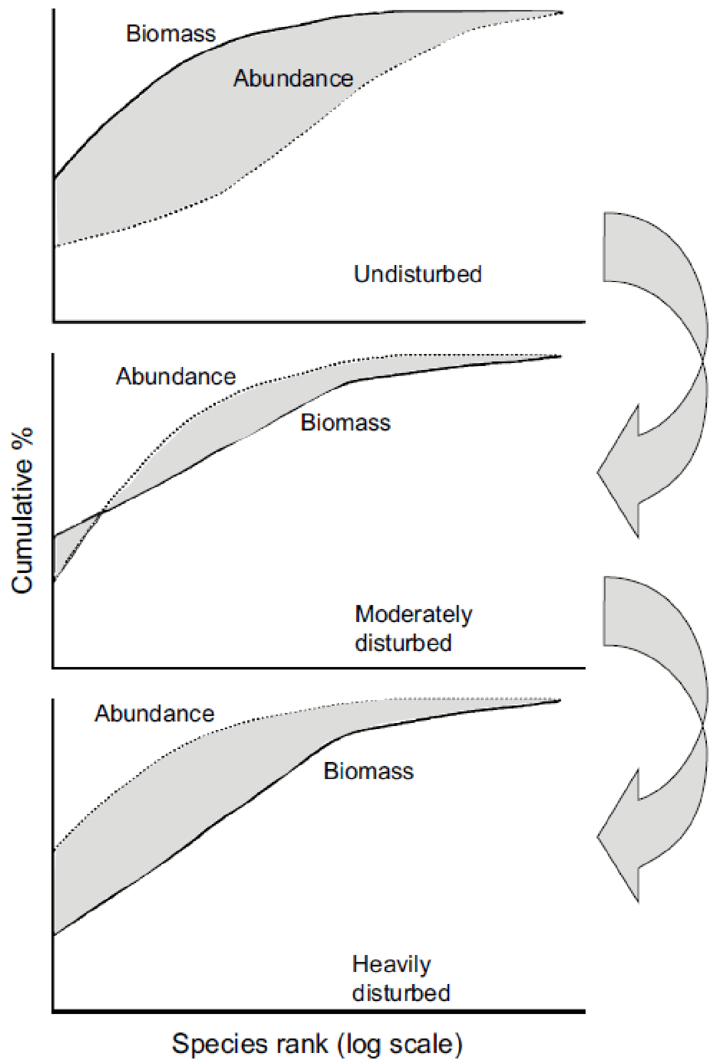


Figure 13 ABC curve Interpretation(da Rocha et al. 2015)

The WLR data were gathered to develop the ABC curves, the curve background is the r- and k-selection, were in the undisturbed/neutral states, the targeted community expected that k-selected species will dominate these species, have main features such as slow growing, delayed maturity and large). In this scenario, the biomass curve will be placed above the abundance curve. However, when the pressure is increased on the system and the ecosystem is being degraded, the slow growing species will not be able to resist and adapt. Thus, the system will be slightly dominated by r-selected species that are opportunistic, fast growing, and of small size. In the disturbed community biomass curve will show below the abundance curve. The difference could be observed by the W statistic, negative values show an indication that the biomass is below the abundance curve and conclude that the community is disturbed (da Rocha et al. 2015).

Data Analysis

The study design was established based on three factors: type of habitat (Live, dead and artificial reef), temporal variation and the used method (UVC and BRUV). The recorded date was analyzed through univariate and multivariate analyses.

Multivariance And Univariance analysis were conducted. To compare species diversity index between both methods t-test was used, One-way ANOVA approach was used to determine differences between the species richness between the different sites. Multivariate analysis was developed through Distance-based permutational multivariate analysis of variance (PERMANOVA) on square root transformed data. Primer 6 software was used to conduct the statistical analysis and to develop non-metric multidimensional scaling (nMDS) on Bray-Curtis dissimilarity distance measures driven from the abundance data for fish assemblage and method comparison. It was developed to enable the visualization of the variation of the species abundance across the different sites and methods. Transformation of the data collected from both methods was conducted by standardizing the data to reduce the variance of the abundance records, since the pre-analysis show great difference between both methods in reporting abundances (Malcolm et al. 2007). Similarity percentage was obtained through SIMPER to establish the dissimilarity of fish assemblages between the used methods. Abundance and biomass relationship also were evaluated through similarity analysis

SIMPER. Similarly, percentage is to identify the most responsible variable for contributing to the dissimilarity shown in Bray-Curtis dissimilarity between groups.

Abundance-Biomass Comparison (ABC) curve was plotted to evaluate the community structure (disturbance indicator) of each site. The ABC curves were developed, and W-statistics was calculated using PRIMER software for both seasons separately to capture the potential seasonal variation between the three sites included in the study (da Rocha et al. 2015).

CHAPTER 4: RESULTS

Temperature

In order to identify possible correlation between seawater temperature and fish reef, sampling events were selected to be during two different seasons, with a significant difference in seawater temperature. The sampling activities were conducted during the months of March and October 2020. Average water temperatures at all sites in March-20 were between 20-22 ºC; however, during the late-summer sampling, in October, the average temperature at all sites ranged between 33-34 ºC.

The average temperature was similar in all sites, during both seasons of the sampling events. The temperature variation was obvious as shown in Figure 14.

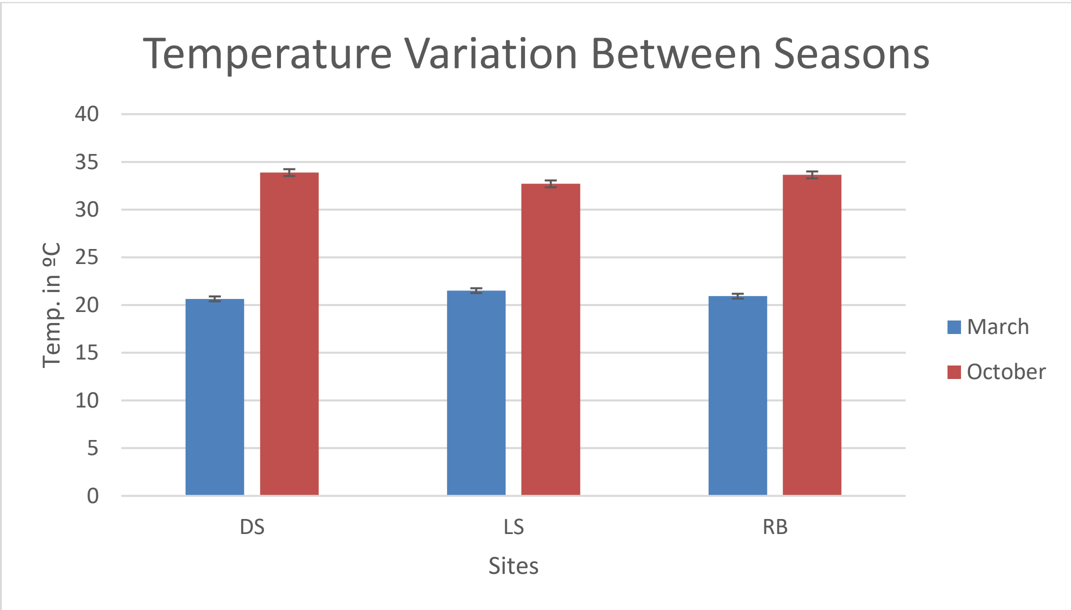


Figure 14 Variation of Average Water Temperature, SE ± Between March and October Sampling. DS: Dead Coral Site; LS: Live Coral Site and RB: Reefballs

Substrate Cover

The substrate cover of the study areas was characterized through the photo transects at Live reef site (LS) and Dead reef site (DS). However, at the artificial reef site reefballs (RB) the substrate cover was not evaluated due to the nature of the site since the artificial reef units were deployed on a sand bed.

Both natural sites had sand as a dominant substate cover, 51.8% in live site and 39.4% in the dead site. Following the sand cover, the dead reef was covered mainly by hard substrate/rocks, sea urchins and dead colonies, respectively. In DS, live coral cover was about 0.3% while the dead coral cover accounted for 10.2% Figure 15. Along with the dead coral formation the substrate 3D structure of the site was relatively high since rocks/hard substrates were sharing a major proportion to the substrate cover. LS substrate cover was dominated by sand, turf algae, live coral, dead coral, and sponge. Live coral cover was more than 8.1% and dead coral 4.2%.

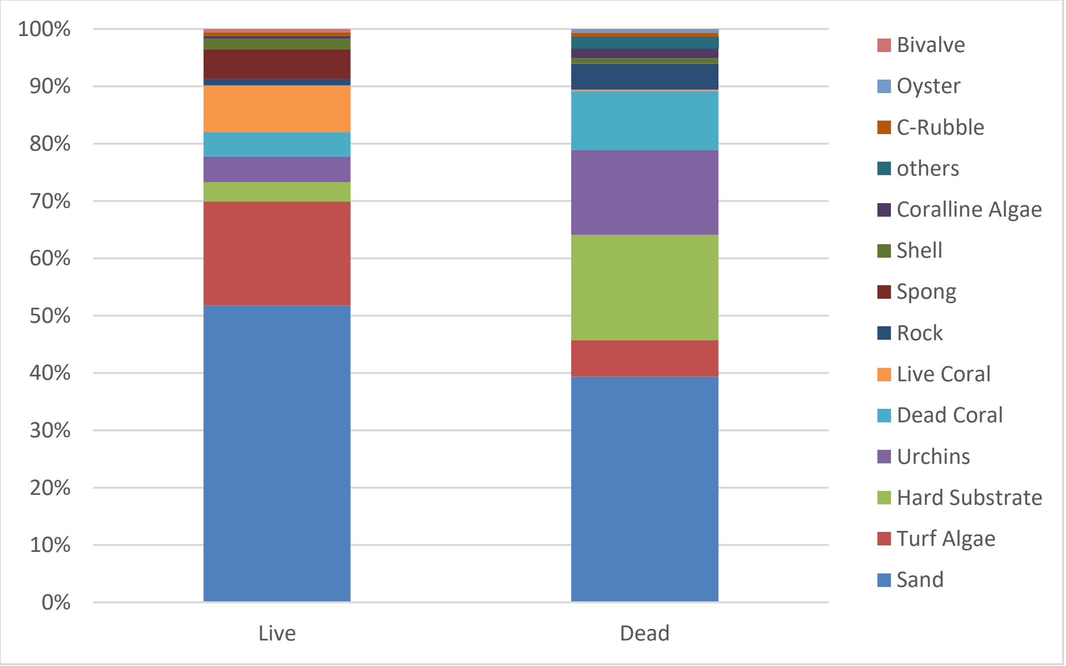


Figure 15 Substrate Cover Percentage in both sites: Live and Dead Reef Sites

As mentioned before, at RB the reef units were deployed in clusters with no significant substrate features (sandy flat substrate), at the site with no other described epifauna group.

Method Comparison

A total of 23 taxa belonging to 16 families were identified during the study; 22 taxa were recorded from BRUVs and only 17 taxa were recorded during UVC sampling event as shown in Table 2. The total of counted individual was 2127 throughout the study from both sampling events and from all different sites including the records from both sampling methods. The total of counted individual at the three sites from the two different methods was 1476 from UVC and 846 from BRUV's, total species numbers and species richness were higher in BRUV's. BRUV's diversity was significantly higher than UVC t-test ($t=1.73$, $p<0.05$).

Moreover, the frequency of recording of each species also varies, about 5 species were recorded only once during the survey all these species were recorded by BRUV. These five species are *Abudefduf vaigiensis, Ecsenius pulcher, Gerres oyena, Gerres longirostris,, Gnathanodon speciosus* and *Scomberoides sp.*. In contrast three species which had the highest frequency were *Lutjanus sp., Pomacanthus maculosus* and *Scolopsis ghanam*, these three species were recorded in all sites by both methods and in all different sampling seasons.

Fish community were significantly different on each method, the grater dissimilarity was in *Carangoides bajad* , *Scolopsis ghanam,, Lutjanus sp. and Pomacanthus maculosus* as these four species were the main contributors to the dissimilarity between methods. The nMDS plot in Figure 16 shows the separation of methods on the nMDS ordination.

Table 2 Species List Between Different Sites (LS: Live Coral Site , DS: Dead Coral Site, RB, Reefballs) Records, Family, Genus, Species. ** Δ = Recored Only By BRUVS; ∇ Recored Only By UVC; ■ Recorded By Both Methods.

#	Taxonomic id.	Family	LS	DS	RB	Freq. %	Total Count
1.	*Abudefduf vaigiensis*	**Pomacentridae**		Δ		2.78	1
2.	*Acanthopagrus bifasciatus*	**Sparidae**	■	■	■	58.33	58
3.	*Carangoides bajad*	**Carangidae**	■	■	■	52.78	139
4.	*Cephalopholis hemistiktos*	**Serranidae**	■	■	■	72.22	55
5.	*Chaetodon nigropunctatus*	**Chaetodontidae**	■	■	■	19.44	12
6.	*Cheilodipterus novemstriatus*	**Apogonidae**	■	■	■	22.22	66
7.	*Cryptocentrus lutheri*	**Gobiidae**		∇	∇	8.33	4
8.	*Diplodus sargus kotschyi*	**Sparidae**	■		■	13.89	17
9.	*Ecsenius pulcher*	**Gobiidae**		Δ		2.78	1
10.	*Epinephelus coioides*	**Serranidae**	■		■	44.44	26
11.	*Gerres oyena*	**Gerreidae**	Δ			2.78	1
12.	*Gerres longirostris*	**Gerreidae**	Δ			2.78	3
13.	*Heniochus acuminatus*	**Chaetodontidae**	■			5.56	3
14.	*Lethrinus sp.*	**Lethrinidae**	■			16.67	45
15.	*Lutjanus sp.*	**Lutjanidae**	■	■	■	100	1196
16.	*Parupeneus margaritatus*	**Mullidae**	■	■		16.67	21
17.	*Platax teira*	**Ephippidae**	Δ	Δ		2.78	4
18.	*Plectorhinchus sordidus*	**Haemulidae**	■			11.11	5
19.	*Pomacanthus maculosus*	**Pomacanthidae**	■	■	■	86.11	146
20.	*Rhabdosargus sp.*	**Sparidae**	■	■	■	30.56	50
21.	*Scolopsis ghanam*	**Nemipteridae**	■	■	■	91.67	251
22.	*Scolopsis taeniatus*	**Nemipteridae**	■		■	27.78	22
23.	*Scomberoides sp.*	**Scombridae**	Δ			2.78	1

Table 3 Dissimilarity in Fish Assemblages Between Methods (SIMPER).

Species	Group BRUVS Av.Abund	Group UVC Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Scolopsis ghanam	19.51	56.64	10.28	1.28	20.28	20.28
Carangoides bajad	41.74	6.51	8.70	1.09	17.16	37.44
Lutjanus sp.	86.76	83.24	4.97	0.75	9.81	47.25
Pomacanthus maculosus	21.34	22.14	4.69	1.22	9.25	56.50
Cephalopholis hemistiktos	17.48	7.21	3.29	0.70	6.49	62.99
Cheilodipterus novemstriatus	0.76	16.12	3.04	0.57	5.99	68.98
Rhabdosargus sp.	12.57	2.75	2.94	0.55	5.81	74.78
Scolopsis taeniatus	8.32	7.23	2.32	0.54	4.57	79.35
Acanthopagrus bifasciatus	8.09	8.62	2.23	1.15	4.39	83.74
Lethrinus sp.	3.77	9.28	2.11	0.47	4.16	87.90
Parupeneus margaritatus	4.90	2.06	1.33	0.55	2.63	90.53

The SIMPER analysis results show that the dissimilarity between metods was mainly driven by *Carangoides bajad* and *Scolopsis ghanam.* Two species contributed >37% to the average dissimilarity between seasons Table 3 . BRUV's seems to have an advantage in recording *Carangoides bajad* and the UVC seemed more suited to *Scolopsis ghanam. Lutjanus* Sp. seemed to be equally represented in both methods.

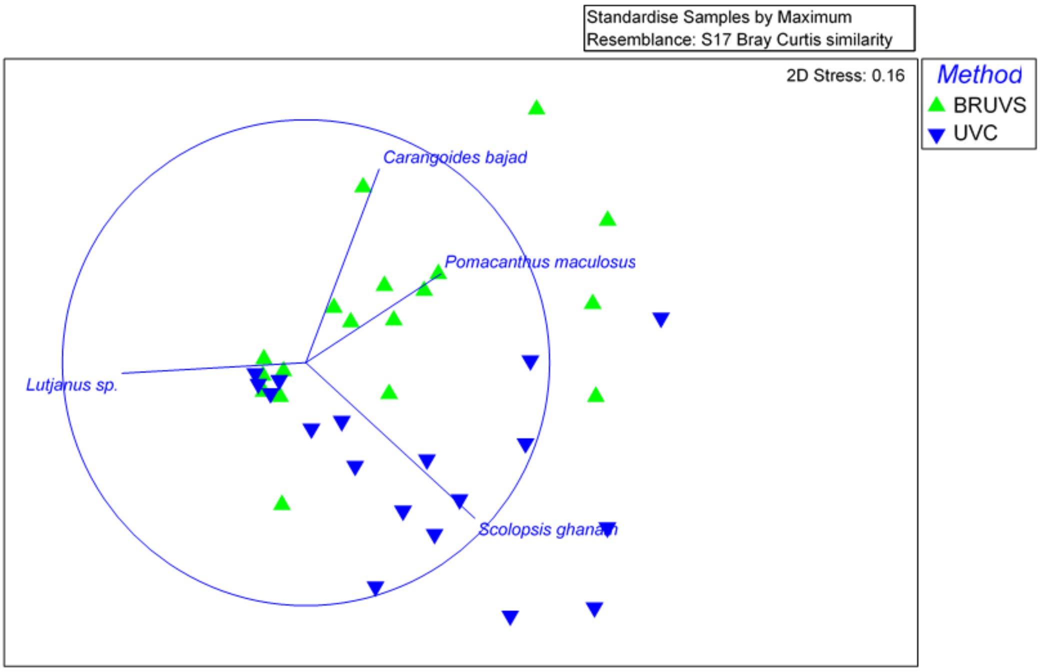


Figure 16 non-metric multidimensional scaling (nMDS) on Bray-Curtis similarity with vector overlay showing the power and direction of species correlation with axis based on a Spearman rank correlation of $r > 0.5$.

Fish Assemblages

The highest total count of individuals (Max n) was 1113 counted resident individuals at the RB, the highest abundance when compared to the other natural sites. LS was second with 561 recorded individuals and the lowest was the DS with 453 N. Diversity (Shannon Index) was higher at Live coral site Figure 1416 , however this was not statically significant (p>0.05).

Among the three sites, Live Coral site had the highest number of recorded species taxa with a 21 different species, Dead coral site had about 14 species, however the Reef ball site had the lowest number of species with 13 different species as presented in However, since the variation in th enumber of species also was higher within the live site (12-5), this variation lead the average of recorded species to be 8 species per sample. In the reefballs site the average species count was 7.33 species per sample with (10-4 max, min Sp. between twelve sampling units). Dead reef site had the lowest species count with avrage of 5.5 species per sample (8-3 max, min Sp. between twelve sampling units). The average number of species differed significantly among sampling sites,as shown in Table 4.

Table 4 One way ANOVA Summary for Recorded Species Per Site

Groups	*Count*	*Sum*	*Average*	*Variance*
DS	12	66	5.5	3
LS	12	96	8	4.909091
RB	12	87	7.33	2.386364

Table 5 One way ANOVA for Recorded Species Per Site

ANOVA *Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	39.5	2	19.75	5.754967	0.007177	3.284918
Within Groups	113.25	33	3.431818			
Total	152.75	35				

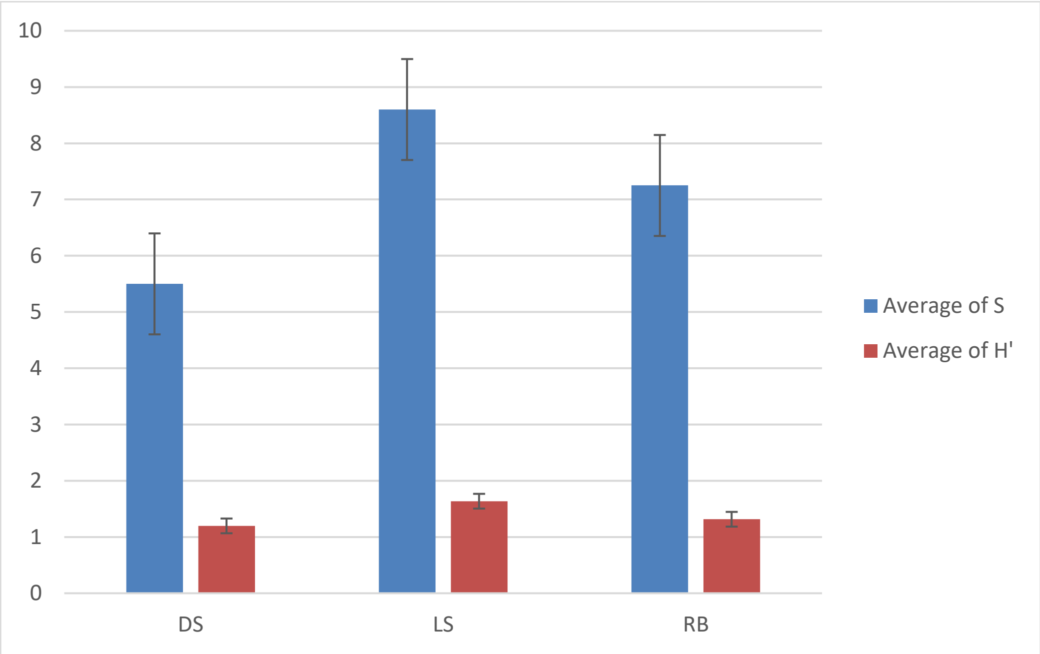


Figure 17 Average of Species Richness (S) and Diversity (Shannon H’) (±SE) at each of the study sites. DS: Dead coral site; LS: Live coral site and RB: Reefballs.

Seasonal Variation

Seasonal variation among sites was higher at the reefballs and this pattern was detected with both methods. However, UVC allowed a stronger increase in total fish abundance in October (late Summer). The seasonal variation showed inconsistent at the natural sites, taking closer look on the seasonal variation at the live Coral site, both methods had different trend one is suggesting that abundance increased from March to October, the other indicate the opposite. Contrasting with the live reef site, the abundance at the Dead reef site using both methods appeared to be similar (Figure 18, Figure 19).

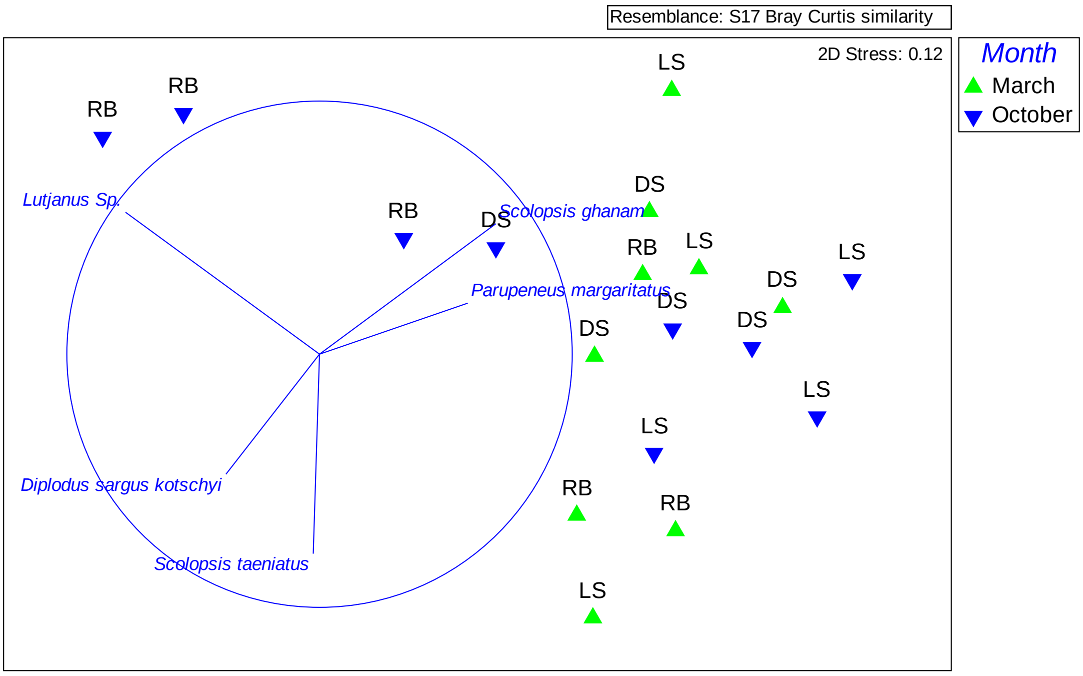


Figure 18 non-metric multidimensional scaling (nMDS) on Bray-Curtis similarity with vector overlay showing the power and direction of species correlation with axis based on a Pearson's rank correlation of $r > 0.5$ contribution to overall UVC abundance seasonal dissimilarity

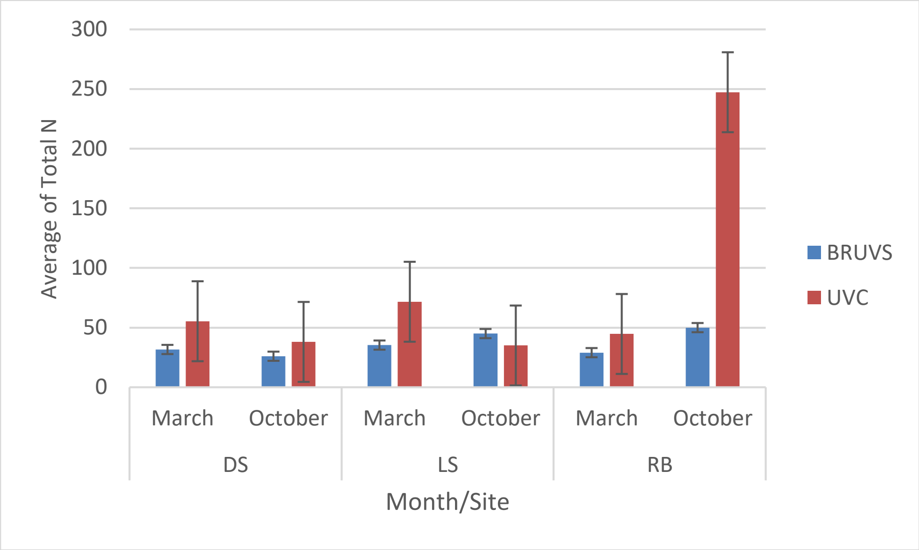


Figure 19: Average of recorded individuals in march and october by bruvs and uvc survey methods at the 3 sites: RB=reefballs DS= dead coral site, LS= live coral site

The PERMANOVA test showed a significant difference in fish community structure, when fish abundance was measured using UVC and BRUV (

Table 6). The temporal variation was not significant, as well as the site difference did not show significant variation. The PERMANOVA test also showed a significant interaction between Time and Site s. The main contributer to the Reefballs difference between both sampling events was *lutjauns Sp.* (Figure 21) however even when the contribution of *lutjanus Sp.* is eleminated the reefballs still had the higher abundace in October.

Table 6 PERMANOVA Table Of Results, Results Of PERMANOVA On Standardised (Max) Abundance Data, Based On Bray–Curtis Similarities, With Three Factors: Method Or Me (BRUV, UVC), Site Or Si (Live, Dead, Artificial Reef) And Time Or Sa (Cold And Warm Season). Significant Differences Are Depicted By A * Sign Over The P-Value

Factor	df	MS	Pseudo-F	P(perm)
Me	1	6096.5	5.8085	0.004*
Si	2	3844.6	2.1064	0.202
Sa	1	3700.8	2.0276	0.235
Method×location	2	872.66	0.62406	0.73
Method×Time	1	417.67	0.29868	0.893
Location × Time	2	1825.2	2.2279	0.037*
Method×Time×location	2	1398.4	1.7069	0.107
Res	24	819.26		
Total	35			

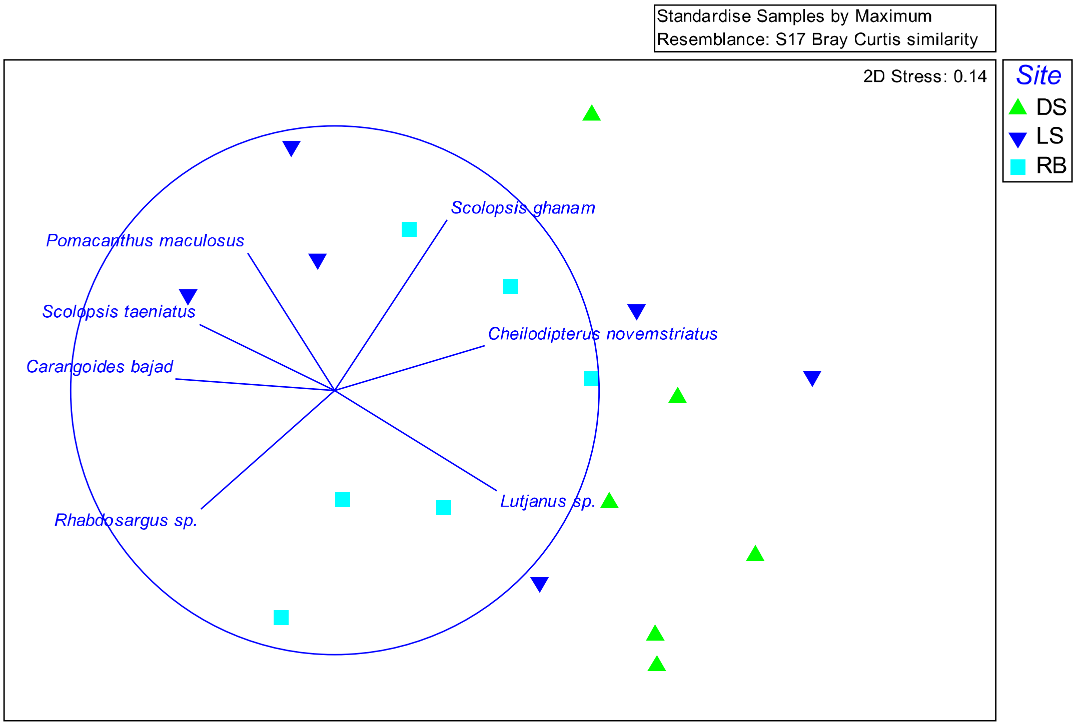


Figure 20 non-metric multidimensional scaling (nMDS) on Bray-Curtis similarity overlaid with vectors for fish abundances with axis based on a Spearman rank correlation of r > 0.5. March

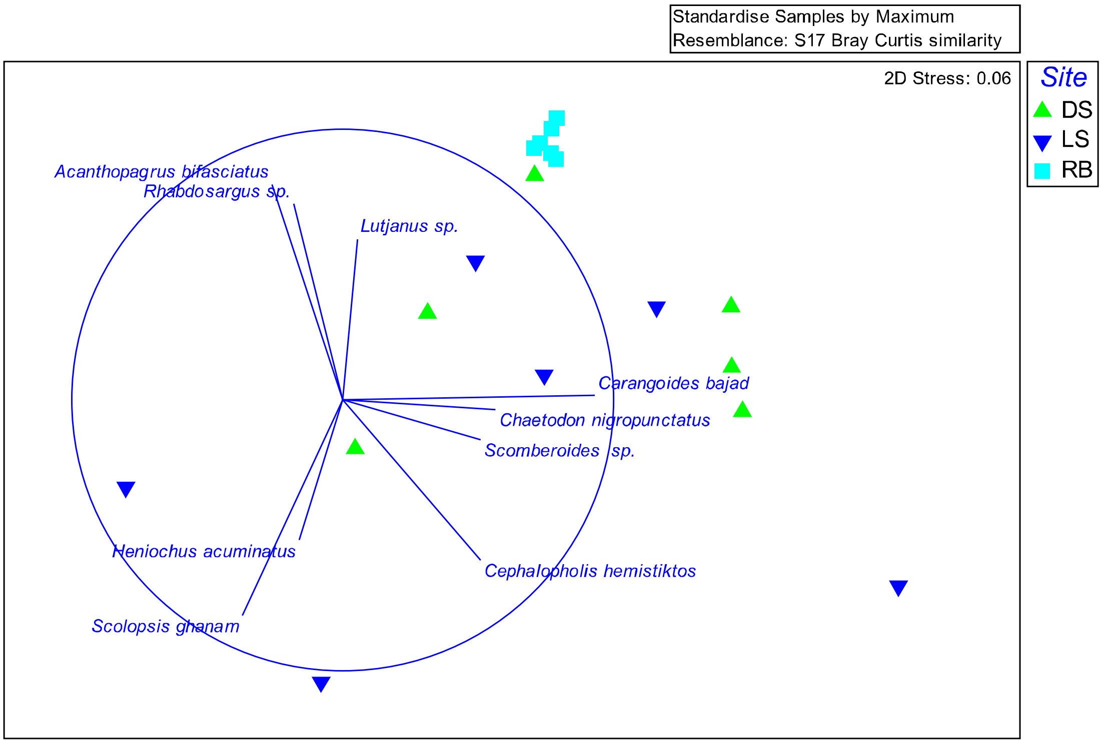


Figure 21: non-metric multidimensional scaling (nMDS) on Bray-Curtis similarity overlaid with vectors for fish abundances with axis based on a Spearman rank correlation of r > 0.5. October.

Length-weight relationship (LWR) and Biomass

The Length-weight relationship was driven from the UVC data only, since it was the only used method during this study that produced estimation of species length. Total length collected data were used to estimate the biomass of the population. In October, the RB site had the highest abundance and the highest biomass among the 3 sites. The average size of recorded species between the different sites are shown in Figure 22.

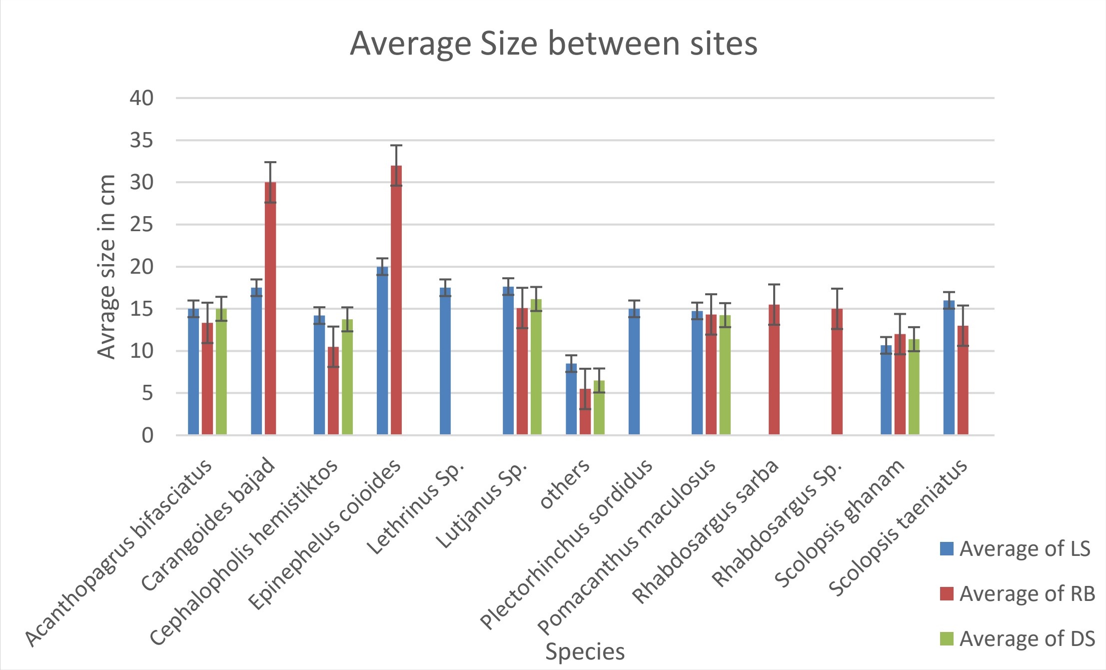


Figure 22: Average size of each species between sites from UVC data.

The PERMANOVA result shows that the fish community showed a was significant dissimilarity between sites ($p<0.05$), this is obvious at the Reefballs site which recorded higher abundance specially in October which recorded an average of 250 resident individuals at the site (Figure 23). Moreover, the site x month interactions were also significant ($p<0.05$).

A

B

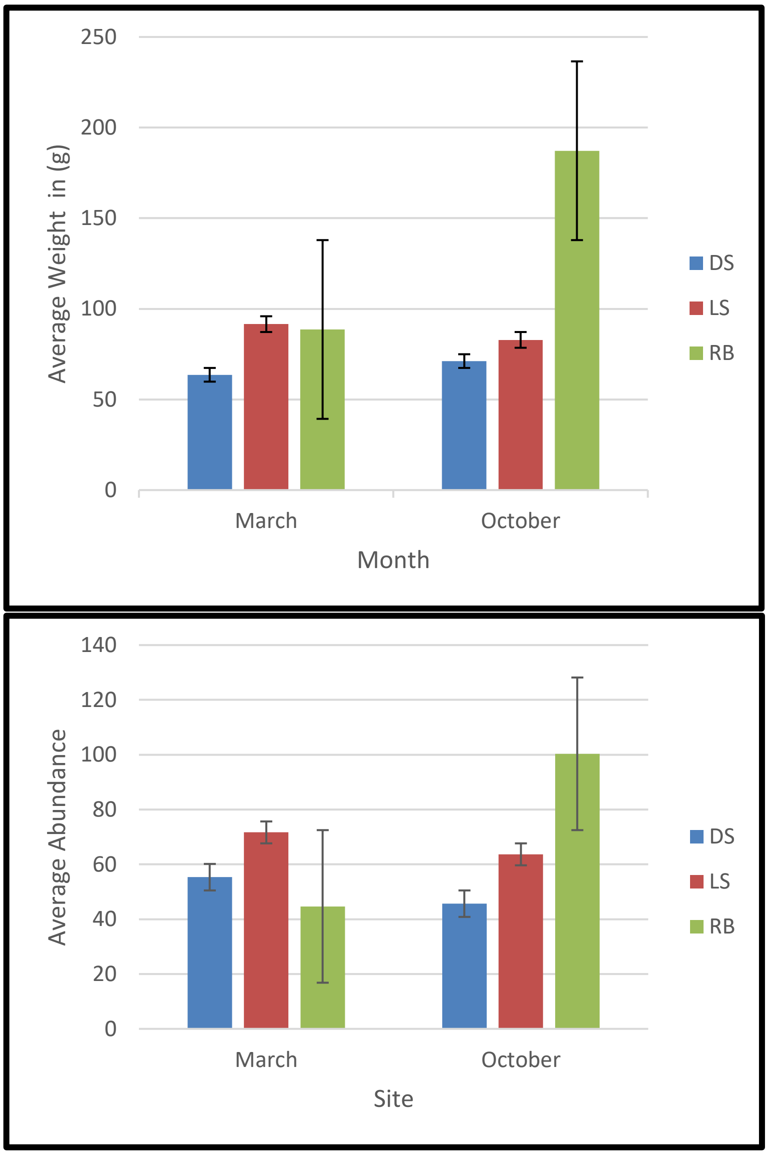


Figure 23: A: The Average SE ± individual weight in the three study sites during the 2 sampling months; B: The Average SE ± of total individuals in the three study are during different months

Table 7 PERMANOVA Results From The Biomass Dataset. With Si: Site And Mo: Month.

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Si	2	7633.7	3816.8	1.8049	0.057	998
Mo	1	3988.4	3988.4	1.8861	0.083	998
SixMo	2	6312.3	3156.2	1.4925	0.137	998
Res	12	25376	2114.7			
Total	17	43310				

However, biomass seasonal variation was not significant at all sites, sampling time and site x time interaction. The main species contributing to the biomass variation between the sites are indicted in the nMDS plot (Figure 24). First, *Lutjanus sp.* which is driving the whole pattern, followed by *Pomacanthus maculosus*, *Acanthopagrus bifasciatus and Cephalopholis hemistiktos* in a decreasing effect on the dissimilarity.

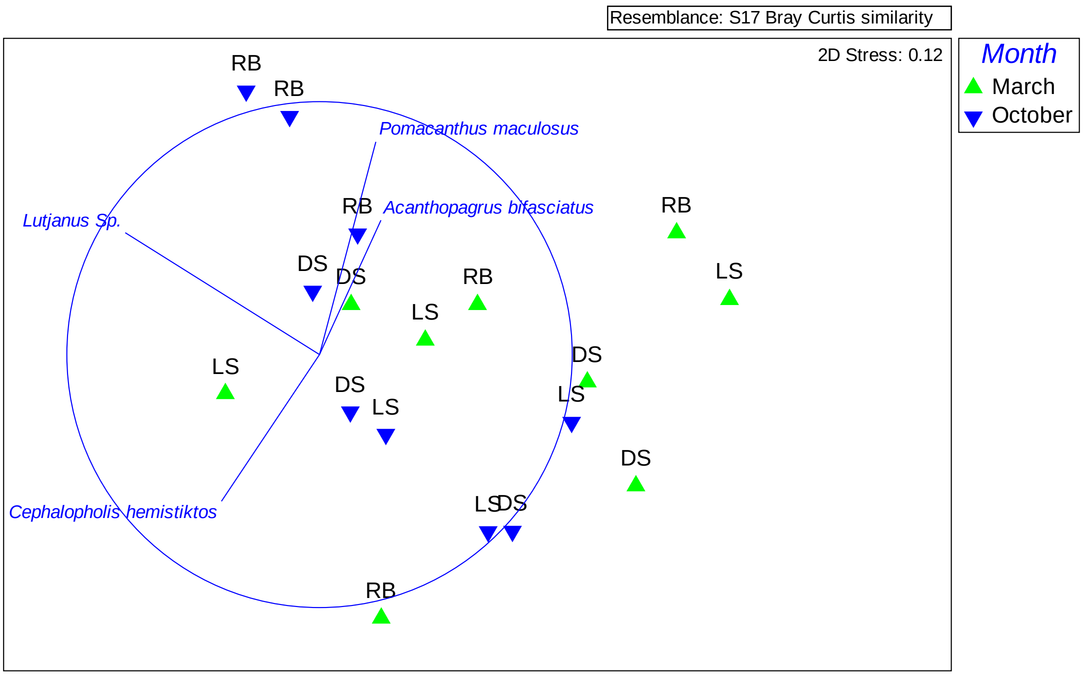
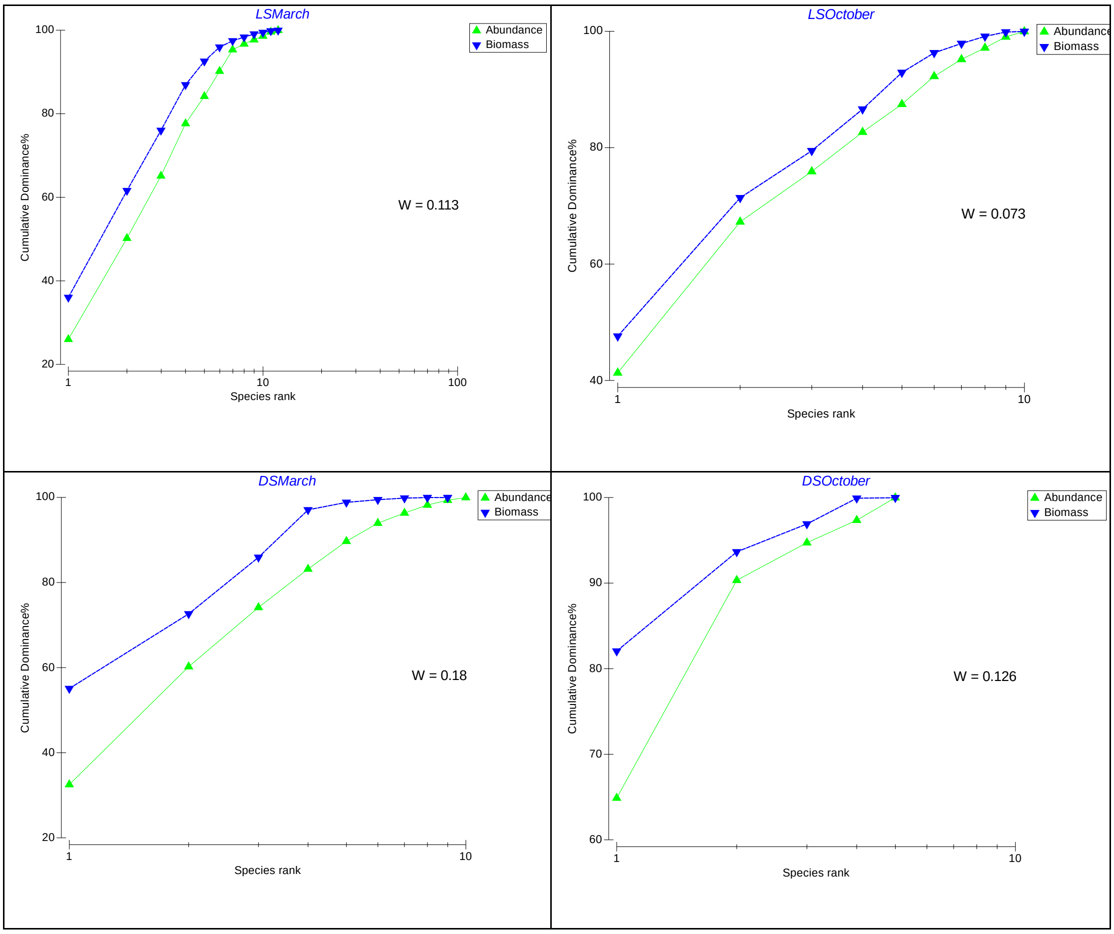


Figure 24 non-metric multidimensional scaling (nMDS) on Bray-Curtis similarity with vector overlay showing the power and direction of species correlation with axis based on a Pearson's rank correlation of r > 0.5 contribution to overall Biomass seasonal dissimilarity

Positive W statistics result in both natural sites, in which the biomass curve is above the abundance curve, this indicate those sites are less disturbed sites regarding the community structure. However, in the artificial site the W statistics were showing negative values at both seasons, where the biomass curve is generally below the abundance curve. However, the very fast saturation of the abundance curve is clear in October. This emphasis that assemblage is totally dominated by small fishes, ABC plot are shown in

Figure 25.



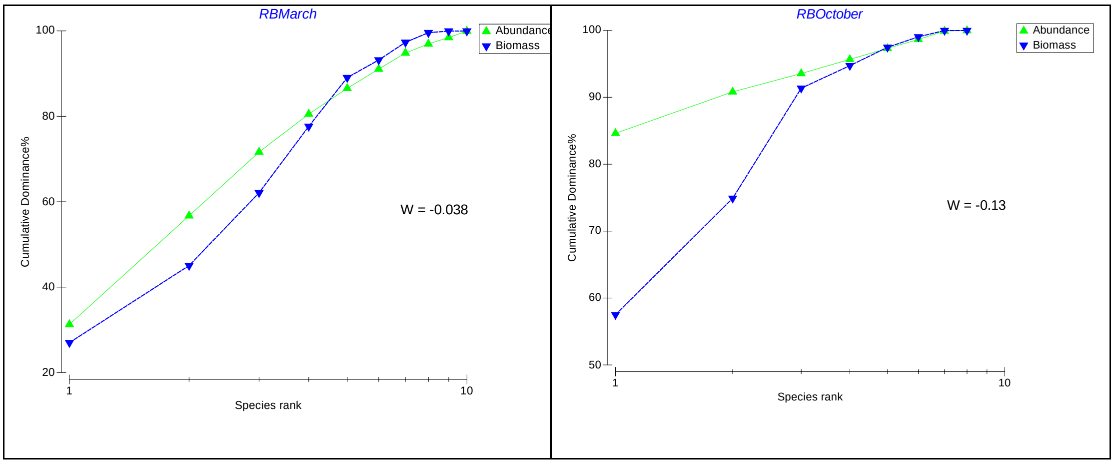


Figure 25 ABC curves plot for the three sites (LS: Live site, DS: Dead site, RB: Reef Balls) in March and October.

CHAPTER 5: DISCUSSION

Fish Assemblages in Natural and Artificial Reefs

Resident fish species richness in the Live reef site was higher than the other sites, with 21 taxa recorded. However, this was associated with low abundance and relatively lower frequency of these species. The dead reef site had a lower species richness, with only 14 species recorded. In contrast the reefballs the had the lowest species richness only 13 taxa were recorded at the site, however with a higher species frequency than other sites with an average of 7.3 species per site compared to 8 per site at the live reef which had more divers taxa. Natural reef sites commonly have higher species richness than the artificial reefs (Rooker et al. 1997 & Burt et al. 2009).

Total fish abundance was significantly higher at the Reef ball site than at the two natural reef sites This is due to the structure of the reef ball site, which is characterized by complex topography formed by the man-made structure which form the three-dimension complexity in the site. However, this complexity does not extent on the surrounding area it is only covers small proportion of a very low complexity area, which leads to concentrate the fish assemblages around the artificial reefs and is considered as one of the main disadvantages of artificial reefs (Burt et al. 2013). Dead corals provide shelter to the existing organisms because they still form a complex bed structure, which will allow them to maintain resident fish species, even when live coral cover declines (Komyakova et al. 2013). However, the dead reef site included in this study was also characterized by having rocky and hard substrate in addition of dead coral and sand, this combination also decreases the effect of coral deterioration on the site complexity level since these rocky formations also form shelter to the resident fish species.

During this survey, the temporal variation was significant in the artificial reef's abundance increases at the warmer temperature. Unlike the artificial reefs the temporal variation at both natural sites showed lower abundance in October (late Summer). In a previous study Vaughan et al. (2021) naturel reefs have shown seasonal fish abundance variation, average abundance variation was reported with a high significancy in which the average abundance tends to be greater in the summer than the winter season. Furthermore, among others, *L. ehrenbergii* and *L. fulviflamma* recorded significant average abundance variation in whole duration of the study, which was three years. In (Bohnsack et al. 1994) artificial reefs fish assemblages had major seasonal variation on fish abundance compared to the other natural reefs included in the study along with the spring and summer recruitment episodes.

Live Coral Site had more fish diversity than the other sites, this could be related to other direct and indirect services provided by the coral colonies (Bell and Galzin 1984). One of these is the composition of zooplankton which will decrease the density of the parasitic and infectant plankton from the system. This might reduce the illness and mortality of fish species and provide much habitable environment for the resident species (Artim and Sikkel 2013). The food availability also could be one of the driving factors of this diversity in the Live Site system since the system is undisturbed and it can support wide range of species and trophic level. In contrast the Dead Coral Site and RB do not have the live coral cover to provide such services, the main feature in both is the complexity of the seabed. However, the Dead Coral Site was adjacent to Live Coral Site thus both were expected be more similar than the RB which is far from both sites.

Comparison of survey methods

Each method had different characteristic and complementary in describing reef associated fish species. BRUVs sampled a wider species range than UVC. The mobile species mainly contributed to this difference toward the BRUVs, since UVC method was more sensitive to the cryptic species. Similar trend was reported in (Lowry et al. 2012), despite that a different UVC method was used “Belt Transect” instead of stationary count point in our study. Regarding the fish abundance the UVC had more ability of representing more accurate count of the fish form BRUVs as in the UVC the Diver has the 360º two estimate the total fish count in the contrary of the BRUVs which only recognize the single Frame of each species MaxN (maximum count of each species in a single frame). This could be obvious also at sites that has more complex and uneven topography or plenty of shelter places were fish could hide or do not appear in the camera frame. Reefballs site during October sampling can be an evidence of such bias, however both methods showed higher values during the second sampling, but the significant change was recorded only by the UVC. The use of bait in BRUV systems actually led based attraction of piscivorous and omnivorous fish and underestimate numbers of herbivorous species.

The highest recorded number of individuals was always detected through UVC technique, except at Live Site in October that was the only time were BRUVS had higher number of individuals, apart from that UVC had superior BRUVS on recording the highest MaxN. As Mentioned, the BRUVs had better species detection in this study that could be related to both the detected fish behavior and the time, since the fish behavior as cryptic or mobility could affect detection of the species as well as the time of the survey. UVC, the stationary fish count use only the first 5 mints in compromising the species list and all the newly arrived fish species that are detected after this period is not recorded however BRUVs has longer time frame which allow to have wider window for detecting new species. As mentioned earlier both methods were complementary however the source of variability between methods is the species characteristic, thus, to be able to evaluate the method information such as species behavior and life history should be included to validate the findings.

The previous studies, the comparison usually includes the transect belt method to represent the UVC to against BRUV, the belt transect method as mentioned in (Colvocoresses and Acosta 2007) covers more areas than the stationary count and actively search for species which increase its ability to detect more cryptic species than any other UVC methods. In contrast the stationary count is conducted in a single point with minimum or no movement for the diver/surveyor still cryptic species will be detected but it will be lower than the belt transect. Single point counts are, therefore, more similar to the BRUV's. In fact, although both are conducted in one point, they are different in some other features. UVC has the advantage of 360 ˚ view, and minimal maneuver of the diver to optimize his visual count on other hand the BRUV has the long duration and the bait attraction as main advantages.

Biomass Variation

Species composition between the sites was clearly different with 21 species recorded at Live Coral Site , Dead Coral Site had about 14 species, the lowest was Reefballs which 13 recorded species. *Lutjanus* was the dominant fish genus in all sites and times of sampling. Even though Reefballs had the lowest species richness, the abundance was extremely high compared to other sites, this was due to the abundance of *Lutjanus* at the site which form the main dominate species at the site in both sampling events. Regarding the average individual total length of *Lutjanus sp.* was higher in the natural sites compered by the artificial reefs. Previous studies on *Lutjanus sp.* investigate an adjusting natural and artificial reef to evaluate if the growth and reproductive parameters could differed substantially between the two sites. Parameter such as growth rates, feeding regime, and some reproductive indicators, such difference could affect the community structure (Glenn et al. 2017).

The abundance biomass plot as shown in

Figure 25, emphasize that the community structure is not normal at the artificial reef, since both sampling events had the biomass curve below the abundance curve. This could be related to many possibilities such as the difference between the natural and artificial sites where artificial sites were dominated by smaller individuals of the same species in assemblages, when compared to natural reefs (da Rocha et al. 2015)

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

Natural and artificial reefs were different in many aspects, such species richness, diversity, community structure and abundance. Furthermore, Reefballs were more affected by the seasonality natural reefs were less affected by the seasonal variation compared to the reef balls. In this study both types of reefs where not adjacent should be considered during this comparison even though both had similar depth range and seasonal temperature change, since the spatial effect is also present here as a source of variation and different sources of pressures on the sites. The Artificial reefs here are costal sites which experiencing the anthropogenic pressures in higher magnitude that the reefs in Sheraoh which is a remote island located in the far east of Qatar EEZ. Seasonal variation was conducted in 1 year so seasonal replicational data were not acquired. However, the variation within the season between sites indicate different trends which need more investigation. Moreover, the design of the study was affected many logistic issues which limit the selected sites to represent each habitat type once, however the use of only one site for each habitat limit ability to identify the different patterns such as site specific and general features. The use of more 2 or three replicate of each habitat type will have a significant added value to such study in the future.

The use of Artificial reefs in the Gulf

There is a need of a regional plan in the gulf for artificial reef construction and utilization, for example in Europe there is OSPAR guidelines on artificial reefs in relation to living marine resources such guidelines could be constructed from a regional or international convention. The existence of guidelines could advise on the selection of artificial reef material, how to develop a suitable design, monitoring plans/approaches and build a useful scientific experiment that could add a collective knowledge and have a sort of connection and addressing related issues. That also could result in developing a national regulation which legalize the implementation of these restoration techniques based on a scientifically acquired conclusions. The existence of such could facilitate the decision-making process and avoid the possible adverse effects of the artificial reefs.

Sampling Procedure

Sampling methodology showed a significant difference in reporting species richness and resident populations in the reefs since the BRUVS and UVC had reported different number of individuals which was higher in the UVC, however the number of recorded species was more in the BRUVS. UVC and BRUVS both had their advantages and disadvantages; however, the main source of variation was the limited MaxN of BRUVs since its limited to maximum in a single frame thus UVC that has the wider recording angel could have more abundance data reported than the BRUVs. Therefore, I may conclude that the UVC methodology has a significant and relevant advantage over BRUVs by providing estimates of the absolute abundances, while BRUVs should only be used to estimate relative abundances, extracted from the most populated single frame.

Other approaches to study the reef fish systems could involve modelling, fish productivity can be estimated by calculating fish growth, survivorship, and recruitment.

Artificial Reefs Production vs. Attraction' debate

The roots of 'production versus attraction' debate is based on many uncertainties, I assume that the aggregation mechanism of the artificial reef is undeniable however, as demonstrated in the literature the use of artificial reef is mainly aimed to restore a disturbed system; in my opinion aggregation of new resident species could promote that goal. However, to optimize the use of the system more aspects should be taken in the consideration. The inconsistency in reporting artificial reefs functionality could be due to the inconsistency in the approaches each of the development and site selection process followed on the deployment of these reefs. Community structure and productivity are one of the missing points in the artificial reefs programs since they are usually underestimated, even though it forms one of the main indicators of artificial reef success. However, to enhance our understanding in how these artificial reefs function, a supervised model could be developed (Smith et al. 2016). Mathematical and computational methods could be used to assess the knowledge of the types of ecological processes (Simpson et al. 2013) partially leading to the increase of the productivity in newly deployed artificial reefs. Our results suggest indeed that biomass, beside diversity, has been stimulated through the deployment of the studied artificial reefs, mainly inferred through the size distribution of the assessed fish communities. An increase in productivity should trigger a larger fish to be present in the site and this was fairly demonstrated here.

REFERENCES

Agudo-Adriani Esteban A., Cappelletto José, Cavada-Blanco Francoise, Cróquer Aldo. 2019. Structural Complexity and Benthic Cover Explain Reef-Scale Variability of Fish Assemblages in Los Roques National Park, Venezuela. Frontiers in Marine Science 6: 690. DOI=10.3389/fmars.2019.00690

Al-Abdulrazzak Dalal, Dirk Zeller, Dyhia Belhabib, Dawit Tesfamichael, Daniel Pauly. 2015. Total marine fisheries catches in the Persian/Arabian Gulf from 1950 to 2010. Regional Studies in Marine Science 2: 28-34. doi.org/10.1016/j.rsma.2015.08.003.

Al-Ghadban, A. N., and A. R. G. Price. 2002. "Dredging and Infilling." *The Gulf Ecosystem, Health and Sustainability* 207–18.

Al-Oufi, Hamed, Andrew Palfreman, and Ewen McLean. 2000. "Observations upon the Al-Batinah Artisinal Fishery, the Sultanate of Oman." *Marine Policy* 24(5):423–29. doi: 10.1016/S0308-597X(00)00017-8.

Arney, Rachel N., Catheline Y. M. Froehlich, and Richard J. Kline. 2017. "Recruitment Patterns of Juvenile Fish at an Artificial Reef Area in the Gulf of Mexico." *Marine and Coastal Fisheries* 9(1):79–92. doi: 10.1080/19425120.2016.1265031.

Artim, J. M., and P. C. Sikkel. 2013. "Live Coral Repels a Common Reef Fish Ectoparasite." *Coral Reefs* 32(2):487–94. doi: 10.1007/s00338-012-0995-8.

Ateweberhan M., Tim R. McClanahan. 2010. Relationship between historical sea-surface temperature variability and climate change-induced coral mortality in the western Indian Ocean. Marine Pollution Bulletin 60(7): 964-970. doi.org/10.1016/j.marpolbul.2010.03.033.

Baine, Mark. 2001. "Artificial Reefs: A Review of Their Design, Application, Management and Performance." *Ocean and Coastal Management* 44(3–4):241–

59. doi: 10.1016/S0964-5691(01)00048-5.

Bell, JO, and R. Galzin. 1984. "Influence of Live Coral Cover on Coral-Reef Fish Communities." *Marine Ecology Progress Series* 15:265–74. doi: 10.3354/meps015265.

Bohnsack, James a., and Scott P. Bannerot. 1986. "A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes." *NOAA Technical Report NMFS* 41(July):21 pp.

Bohnsack, James A., Douglas E. Harper, David B. McClellan And, and Mark Hulsbeck. 1994. "(PDF) Effects of Reef Size on Colonization and Assemblage Structure of Fishes at Artificial Reefs Off Southeastern Florida, U.S.A." *Bulletin of Marine Science* 796–823. Retrieved January 9, 2021 (https://www.researchgate.net/publication/233497940_Effects_of_Reef_Size_on_Colonization_and_Assemblage_Structure_of_Fishes_at_Artificial_Reefs_Off_Southeastern_Florida_USA).

Brock, Richard E. 1982. "A CRITIQUE OF THE VISUAL CENSUS METHOD FOR ASSESSING CORAL REEF FISH POPULATIONS Visual Recognition and Tallying of Species and Numbers Underwater Is One of the Few Non-Destructive Methods Presently Available to Assess Coral Reef Fish Com- Munities . Sinc." 32(1):269–76.

Brock, Vernon E. 1954. *A Preliminary Report on a Method of Estimating Reef Fish Populations*. Vol. 18.

Burt, J., A. Bartholomew, P. Usseglio, A. Bauman, and P. F. Sale. 2009. "Are Artificial Reefs Surrogates of Natural Habitats for Corals and Fish in Dubai, United Arab Emirates?" *Coral Reefs* 28(3):663–75. doi: 10.1007/s00338-009-0500-1.

Burt, John A., Khalifa Al-Khalifa, Ebtesam Khalaf, Bassem AlShuwaikh, and Ahmed

Abdulwahab. 2013. "The Continuing Decline of Coral Reefs in Bahrain." *Marine Pollution Bulletin* 72(2):357–63. doi: 10.1016/j.marpolbul.2012.08.022.

Burt, John A., Aaron Bartholomew, and David A. Feary. 2012. "Man-Made Structures as Artificial Reefs in the Gulf." Pp. 171–86 in. Springer, Dordrecht.

Burt, John A., Radhouane Ben-Hamadou, Mohamed A. R. Abdel-Moati, Lucia Fanning, Simeon Kaitibie, Fahad Al-Jamali, Pedro Range, Suhur Saeed, and Christopher S. Warren. 2017. "Improving Management of Future Coastal Development in Qatar through Ecosystem-Based Management Approaches." *Ocean & Coastal Management* 148:171–81. doi: 10.1016/j.ocecoaman.2017.08.006.

Caldwell, Zachary R., Brian J. Zgliczynski, Gareth J. Williams, and Stuart A. Sandin. 2016. "Reef Fish Survey Techniques: Assessing the Potential for Standardizing Methodologies." *PLoS ONE* 11(4):1–14. doi: 10.1371/journal.pone.0153066.

Carr, Mark H., Todd W. Anderson, and Mark A. Hixon. 2002. "Biodiversity, Population Regulation, and the Stability of Coral-Reef Fish Communities." *Proceedings of the National Academy of Sciences of the United States of America* 99(17):11241–45. doi: 10.1073/pnas.162653499.

Chabanet, P., H. Ralambondrainy, M. Amanieu, G. Faure, and R. Galzin. 1997. "Relationships between Coral Reef Substrata and Fish." *Coral Reefs* 16(2):93–102. doi: 10.1007/s003380050063.

Chancerelle, Yannick, Robert Maurin, Sébastien Poujade, and Caroline Vieux. 2008. "Photo Tow: A New Method for Estimating Coral Reef Status and Changes at Large Spatial Scale. A Coral Bleaching Event Case Study." *Journal de La Société Des Océanistes* (126–127):67–74. doi: 10.4000/jso.3312.

Colvocoresses, James, and Alejandro Acosta. 2007. "A Large-Scale Field Comparison of Strip Transect and Stationary Point Count Methods for Conducting Length-Based Underwater Visual Surveys of Reef Fish Populations." *Fisheries Research* 85(1–2):130–41. doi: 10.1016/j.fishres.2007.01.012.

le Cren, E. D. 1951. *The Length-Weight Relationship and Seasonal Cycle in Gonad Weight and Condition in the Perch (Perca Fluviatilis)*. Vol. 20.

Darling, E.S., Graham, N.A.J., Januchowski-Hartley, F.A. et al. Relationships between structural complexity, coral traits, and reef fish assemblages. Coral Reefs 36, 561–575 (2017). https://doi.org/10.1007/s00338-017-1539-z

Fabi, Gianna, Alessandra Spagnolo, Denise Bellan-Santini, Eric Charbonnel, Burak Ali Çiçek, Juan J. Goutayer García, Antony C. Jensen, Argiris Kallianiotis, and Miguel Neves dos Santos. 2011. "Overview on Artificial Reefs in Europe." *Brazilian Journal of Oceanography* 59(SPEC. ISSUE 1):155–66. doi: 10.1590/s1679-87592011000500017.

Feary, David A., Glenn R. Almany, Geoffrey P. Jones, and Mark I. McCormick. 2007. "Coral Degradation and the Structure of Tropical Reef Fish Communities." *Marine Ecology Progress Series* 333(Hughes 1994):243–48. doi: 10.3354/meps333243.

Feary, David A., John A. Burt, and Aaron Bartholomew. 2011. "Artificial Marine Habitats in the Arabian Gulf: Review of Current Use, Benefits and Management Implications." *Ocean & Coastal Management* 54(10):742–49. doi: 10.1016/J.OCECOAMAN.2011.07.008.

Ferrari, R., Malcolm, H.A., Byrne, M., Friedman, A., Williams, S.B., Schultz, A., Jordan, A.R. and Figueira, W.F. (2018), Habitat structural complexity metrics improve predictions of fish abundance and distribution. Ecography, 41: 1077-1091. https://doi.org/10.1111/ecog.02580

Galzin, Rene, and Pierre Legendre. 1987. *The Fish Communities of a Coral Reef Transect!* Vol. 41.

Garpe, Kajsa C., Saleh A. S. Yahya, Ulf Lindahl, and Marcus C. Öhman. 2006. "Long-Term Effects of the 1998 Coral Bleaching Event on Reef Fish Assemblages." *Marine Ecology Progress Series* 315:237–47. doi: 10.3354/meps315237.

Gladstone, William, Steven Lindfield, Melinda Coleman, and Brendan Kelaher. 2012. "Optimisation of Baited Remote Underwater Video Sampling Designs for Estuarine Fish Assemblages." *Journal of Experimental Marine Biology and Ecology* 429:28–35. doi: 10.1016/j.jembe.2012.06.013.

Glenn, Hilary D., James H. Cowan, and Joseph E. Powers. 2017. "A Comparison of Red Snapper Reproductive Potential in the Northwestern Gulf of Mexico: Natural versus Artificial Habitats." *Marine and Coastal Fisheries* 9(1):139–48. doi: 10.1080/19425120.2017.1282896.

Goetze, Jordan S., Todd. Bond, Dianne L. McLean, Benjamin J. Saunders, Tim J. Langlois, Steve Lindfield, Laura. A. F. Fullwood, Damon Driessen, George Shedrawi, and Euan S. Harvey. 2019. "A Field and Video Analysis Guide for Diver Operated Stereo-video" edited by J. McPherson. *Methods in Ecology and Evolution* 10(7):1083–90. doi: 10.1111/2041-210X.13189.

Grandcourt, Edwin. 2012. "Reef Fish and Fisheries in the Gulf." Pp. 127–61 in. Springer, Dordrecht.

Granneman, Jennifer E., and Mark A. Steele. 2015. "Effects of Reef Attributes on Fish Assemblage Similarity between Artificial and Natural Reefs." *ICES Journal of Marine Science: Journal Du Conseil* 72(8):2385–97. doi: 10.1093/icesjms/fsv094.

Grossman, Gary D., Geoff P. Jones, and William J. Seaman. 1997. "Do Artificial Reefs Increase Regional Fish Production? A Review of Existing Data." *Fisheries*

22(4):17–23. doi: 10.1577/1548-8446(1997)022<0017:DARIRF>2.0.CO;2.

Hammond, M., T. Bond, J. Prince, R. K. Hovey, and D. L. McLean. 2020. “An Assessment of Change to Fish and Benthic Communities Following Installation of an Artificial Reef.” *Regional Studies in Marine Science* 39:101408. doi: 10.1016/j.rsma.2020.101408.

Hopkins, Christopher C. E. 2007. *Dubai Pilot Project: Test Report for ‘Reef Systems’ at the Palm Jumeirah*.

Komyakova, Valeriya, Philip L. Munday, and Geoffrey P. Jones. 2013. “Relative Importance of Coral Cover, Habitat Complexity and Diversity in Determining the Structure of Reef Fish Communities.” *PLoS ONE* 8(12). doi: 10.1371/journal.pone.0083178.

Leujak, W., and R. F. G. Ormond. 2007. “Comparative Accuracy and Efficiency of Six Coral Community Survey Methods.” *Journal of Experimental Marine Biology and Ecology* 351(1–2):168–87. doi: 10.1016/j.jembe.2007.06.028.

Lindahl, Ulf, Marcus C. Öhman, and Christiane K. Schelten. 2001. “The 1997/1998 Mass Mortality of Corals: Effects on Fish Communities on a Tanzanian Coral Reef.” *Marine Pollution Bulletin* 42(2):127–31. doi: 10.1016/S0025-326X(00)00167-3.

Lowry, Michael, Heath Folpp, Marcus Gregson, and Iain Suthers. 2012. “Comparison of Baited Remote Underwater Video (BRUV) and Underwater Visual Census (UVC) for Assessment of Artificial Reefs in Estuaries.” *Journal of Experimental Marine Biology and Ecology* 416–417:243–53. doi: 10.1016/j.jembe.2012.01.013.

Malcolm, Hamish A., William Gladstone, Steven Lindfield, James Wraith, and Tim P. Lynch. 2007. “Spatial and Temporal Variation in Reef Fish Assemblages of Marine Parks in New South Wales, Australia - Baited Video Observations.”

Marine Ecology Progress Series 350:277–90. doi: 10.3354/meps07195.

McManus, John W., R. I. Miclat, and V. P. Palaganas. 1981. "Coral and Fish Community Structure of Sombrero Island, Batangas, Philippines Agent-Based Modelling for Broad Application View Project Spratly Islands and Scarborough Reef Peace Parks. View Project." *Proceedings of the Fourth Coral Reef Symposium* 2:271–80.

Minte-Vera, Carolina v., Rodrigo Leão de Moura, and Ronaldo B. Francini-Filho. 2008. "Nested Sampling: An Improved Visual-Census Technique for Studying Reef Fish Assemblages." *Marine Ecology Progress Series* 367(September):283–93. doi: 10.3354/meps07511.

Moati, Mohamed Abdel, Ahmad al Mansoori, Ashraf al Cibahy, Suaad al Harthi, Kristi Foster, Sam Purkis, Wendy Wood, Bernard Reigl, Christophe Tourenq, Fred Launay, and Razan al Mubarak. 2008. "Conservation and Management Plan For Abu Dhabi and Eastern Qatar Coral Reefs." (April).

N. Downing, R. A. Tubb, C. R. EI-Zahr and R. E. McClure. 1985. "ARTIFICIAL REEFS IN KUWAIT, NORTHERN ARABIAN GULF." *BULLETIN OF MARINE SCIENCE* 37(1):157–78.

Nay, Tiffany J., Jacob L. Johansen, Jodie L. Rummer, John F. Steffensen, Morgan S. Pratchett, and Andrew S. Hoey. 2020. "Habitat Complexity Influences Selection of Thermal Environment in a Common Coral Reef Fish" edited by G. Raby. *Conservation Physiology* 8(1). doi: 10.1093/conphys/coaa070.

Perkol-Finkel, S., N. Shashar, and Y. Benayahu. 2006. "Can Artificial Reefs Mimic Natural Reef Communities? The Roles of Structural Features and Age." *Marine Environmental Research* 61(2):121–35. doi: 10.1016/J.MARENVRES.2005.08.001.

Polovina, Jeffrey J. 1989. *ARTIFICIAL REEFS: NOTHING MORE THAN BENTHIC FISH AGGREGATORS*. Vol. 30.

Richards, Benjamin L., Ivor D. Williams, Marc O. Nadon, and Brian J. Zgliczynski. 2011. “A Towed-Diver Survey Method for Mesoscale Fishery-Independent Assessment of Large-Bodied Reef Fishes.” *Bulletin of Marine Science* 87(1):55–74. doi: 10.5343/bms.2010.1019.

Richer, Renee. 2008. *Conservation in Qatar: Impacts of Increasing Industrialization*.

Riegl, Bernhard M., and Sam J. Purkis. 2012a. “Coral Reefs of the Gulf: Adaptation to Climatic Extremes in the World’s Hottest Sea.” Pp. 1–4 in. Springer, Dordrecht.

Riegl, Bernhard M., and Sam J. Purkis. 2012b. *Coral Reefs of the Gulf: Adaptation to Climatic Extremes in the World’s Hottest Sea*.

Riegl, Bernhard M., and Sam J. Purkis. 2012c. “Dynamics of Gulf Coral Communities: Observations and Models from the World’s Hottest Coral Sea.” Pp. 71–93 in. Springer, Dordrecht.

Robbins, William D., Mizue Hisano, Sean R. Connolly, and J. Howard Choat. 2006. “Ongoing Collapse of Coral-Reef Shark Populations.” *Current Biology* 16(23):2314–19. doi: 10.1016/j.cub.2006.09.044.

da Rocha, Diogo Fonseca, Marcos Alberto Lima Franco, Pedro Vianna Gatts, and Ilana Rosental Zalmon. 2015. “The Effect of an Artificial Reef System on the Transient Fish Assemblages - South-Eastern Coast of Brazil.” *Journal of the Marine Biological Association of the United Kingdom* 95(3):635–46. doi: 10.1017/S0025315414001519.

Rooker, J. R., Q. R. Dokken, C. v. Pattengill, and G. J. Holt. 1997. “Fish Assemblages on Artificial and Natural Reefs in the Flower Garden Banks National Marine Sanctuary, USA.” *Coral Reefs* 16(2):83–92. doi: 10.1007/s003380050062.

Samoilys, Melita A., and Gary Carlos. 2000. “Determining Methods of Underwater Visual Census for Estimating the Abundance of Coral Reef Fishes.” *Environmental Biology of Fishes* 57(3):289–304. doi: 10.1023/A:1007679109359.

Schwartzkopf, Brittany D., and James H. Cowan. 2017. “Seasonal and Sex Differences in Energy Reserves of Red Snapper Lutjanus Campechanus on Natural and Artificial Reefs in the Northwestern Gulf of Mexico.” *Fisheries Science* 83(1):13–22. doi: 10.1007/s12562-016-1037-1.

Seaman, William. 2002. “Unifying Trends and Opportunities in Global Artificial Reef Research, Including Evaluation.” *ICES Journal of Marine Science* 59:14–16. doi: 10.1006/jmsc.2002.1277.

Sheppard, Charles, Mohsen Al-Husiani, F. Al-Jamali, Faiza Al-Yamani, Rob Baldwin, James Bishop, Francesca Benzoni, Eric Dutrieux, Nicholas K. Dulvy, Subba Rao v. Durvasula, David A. Jones, Ron Loughland, David Medio, M. Nithyanandan, Graham M. Pilling, Igor Polikarpov, Andrew R. G. Price, Sam Purkis, Bernhard Riegl, Maria Saburova, Kaveh Samimi Namin, Oliver Taylor, Simon Wilson, and Khadija Zainal. 2010. “The Gulf: A Young Sea in Decline.” *Marine Pollution Bulletin* 60(1):13–38. doi: 10.1016/J.MARPOLBUL.2009.10.017.

Sheppard, Charles, and Ronald Loughland. 2002. “Coral Mortality and Recovery in Response to Increasing Temperature in the Southern Arabian Gulf.” *Aquatic Ecosystem Health & Management* 5(4):395–402. doi: 10.1080/14634980290002020.

Sheppard, Charles, Andrew. Price, and Callum. Roberts. 1992. *Marine Ecology of the Arabian Region : Patterns and Processes in Extreme Tropical Environments*. Academic Press.

Simonsen, Kirsten A., James H. Cowan, and Kevin M. Boswell. 2015. “Habitat

Differences in the Feeding Ecology of Red Snapper (Lutjanus Campechanus, Poey 1860): A Comparison between Artificial and Natural Reefs in the Northern Gulf of Mexico.” *Environmental Biology of Fishes* 98(3):811–24. doi: 10.1007/s10641-014-0317-9.

Smith, James A., Michael B. Lowry, Curtis Champion, and Iain M. Suthers. 2016. “A Designed Artificial Reef Is among the Most Productive Marine Fish Habitats: New Metrics to Address ‘Production versus Attraction.’” *Marine Biology* 163(9):1–8. doi: 10.1007/s00227-016-2967-y.

Szedlmayer, Stephen T. 2007. “An Evaluation of the Benefits of Artificial Habitats for Red Snapper, Lutjanus Campechanus, in the Northeast Gulf of Mexico.” *Proceedings of the Gulf and Caribbean Research Institute* 59(Camber 1955):229–30.

Vaughan, Grace O., Holly A. Shiels, and John A. Burt. 2021. “Seasonal Variation in Reef Fish Assemblages in the Environmentally Extreme Southern Persian/Arabian Gulf.” *Coral Reefs* 1–12. doi: 10.1007/s00338-020-02041-2.

Wetz, Jennifer J., Matthew J. Ajemian, Brooke Shipley, and Gregory W. Stunz. 2020. “An Assessment of Two Visual Survey Methods for Documenting Fish Community Structure on Artificial Platform Reefs in the Gulf of Mexico.” *Fisheries Research* 225(May 2019):105492. doi: 10.1016/j.fishres.2020.105492.

Williams, DMcB. 1986. “Temporal Variation in the Structure of Reef Slope Fish Communities (Central Great Barrier Reef): Short-Term Effects of Acanthaster Planci Infestation.” *Marine Ecology Progress Series* 28:157–64. doi: 10.3354/meps028157.

APPENDIX

Appendix A: Species List

Table 8 List Including Both Methods (UVC, BRUV) Records, Family, Genus and Species.

#	Genus species	Family	BRUV	UVC	IUCN status
1.	*Abudefduf vaigiensis*	**Pomacentridae**	■		NT
2.	*Acanthopagrus bifasciatus*	**Sparidae**	■	■	LC
3.	*Carangoides bajad*	**Carangidae**	■	■	LC
4.	*Cephalopholis hemistiktos*	**Serranidae**	■	■	NT
5.	*Chaetodon nigropunctatus*	**Chaetodontidae**	■	■	VU
6.	*Cheilodipterus novemstriatus*	**Apogonidae**	■	■	LC
7.	*Cryptocentrus lutheri*	**Gobiidae**		■	LC
8.	*Diplodus sargus kotschyi*	**Sparidae**	■	■	LC
9.	*Ecsenius pulcher*	**Gobiidae**	■		LC
10.	*Epinephelus coioides*	**Serranidae**	■	■	VU
11.	*Gerres oyena*	**Gerreidae**	■		LC
12.	*Gerres longirostris*	**Gerreidae**	■		LC
13.	*Gnathanodon speciosus*	**Carangidae**	■		LC
14.	*Heniochus acuminatus*	**Chaetodontidae**	■	■	VU
15.	*Lethrinus sp.*	**Lethrinidae**	■	■	
16.	*Lutjanus sp.*	**Lutjanidae**	■	■	
17.	*Parupeneus margaritatus*	**Mullidae**	■	■	LC
18.	*Platax teira*	**Ephippidae**	■		LC
19.	*Plectorhinchus sordidus*	**Haemulidae**	■	■	LC
20.	*Pomacanthus maculosus*	**Pomacanthidae**	■	■	LC
21.	*Rhabdosargus sp.*	**Sparidae**	■	■	
22.	*Scolopsis ghanam*	**Nemipteridae**	■	■	LC

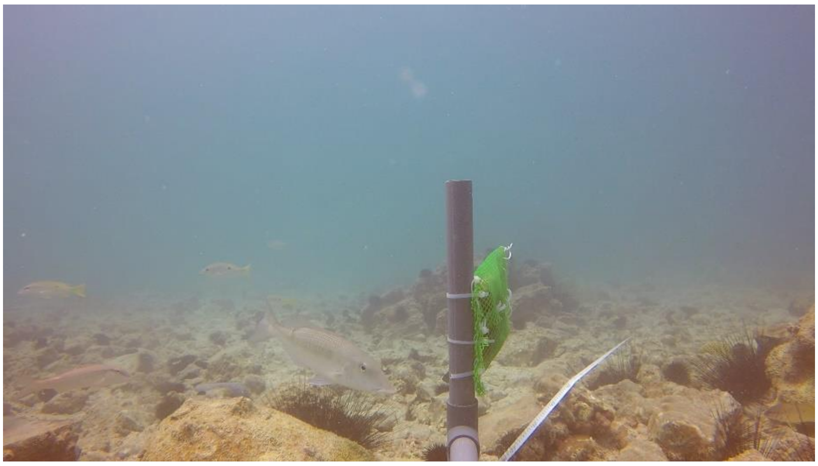
#	Genus species	Family	BRUV	UVC	IUCN status
23.	*Scolopsis taeniatus*	**Nemipteridae**	■	■	LC
24.	*Scomberoides sp.*	**Scombridae**	■		

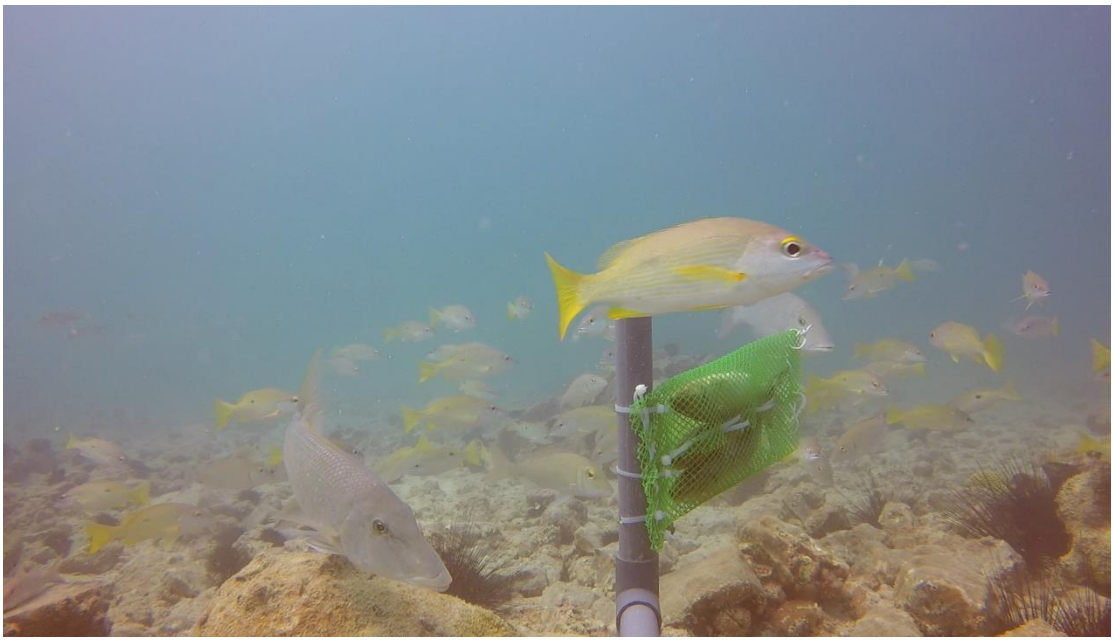
Appendix B: Diversity Indices

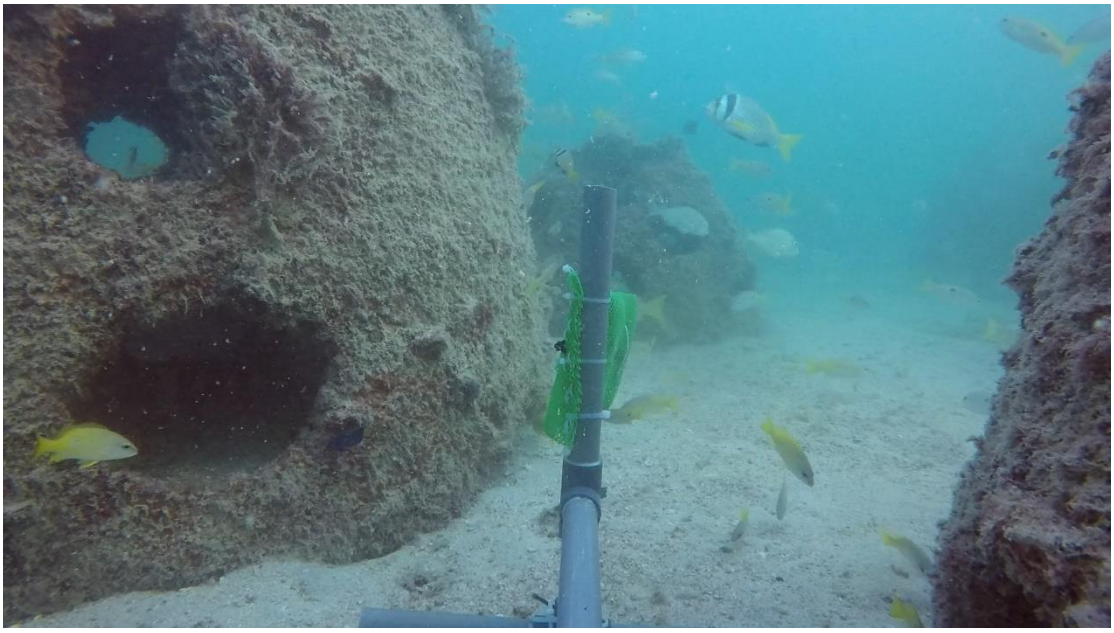
	S	N	d	J'	H'(loge)	1-Lambda'	Method	Site	Sampling Time	Replicate
S1	3	7	1.027797	0.914101	1.004242	0.714286	BRUVS	DS	March	1
S2	6	51	1.271674	0.341938	0.61267	0.256471	BRUVS	DS	March	2
S3	8	37	1.938565	0.556608	1.157433	0.504505	BRUVS	DS	March	3
S4	6	28	1.500508	0.828071	1.483704	0.748677	BRUVS	DS	October	1
S5	5	21	1.313835	0.857914	1.380759	0.747619	BRUVS	DS	October	2
S6	8	29	2.078819	0.87294	1.815227	0.832512	BRUVS	DS	October	3
S7	9	11	3.336259	0.954966	2.098274	0.945455	BRUVS	LS	March	1
S8	11	36	2.790553	0.918332	2.202065	0.892063	BRUVS	LS	March	2
S9	12	59	2.697707	0.769291	1.911616	0.784921	BRUVS	LS	March	3
S13	7	53	1.511224	0.565097	1.099628	0.532656	BRUVS	LS	October	1
S14	8	35	1.968865	0.757228	1.57461	0.741176	BRUVS	LS	October	2
S15	10	47	2.337573	0.666136	1.533834	0.698427	BRUVS	LS	October	3
S16	7	33	1.715998	0.810372	1.576911	0.765152	BRUVS	RB	March	1
S17	9	34	2.268628	0.860968	1.89174	0.827094	BRUVS	RB	March	2
S18	8	18	2.421834	0.940629	1.955984	0.895425	BRUVS	RB	March	3
S19	8	56	1.738978	0.535487	1.113513	0.501948	BRUVS	RB	October	1
S20	7	43	1.595236	0.574635	1.118188	0.506091	BRUVS	RB	October	2
S21	8	51	1.780343	0.521497	1.084422	0.46902	BRUVS	RB	October	3
S22	6	78	1.147655	0.84734	1.51823	0.758575	UVC	DS	March	1
S23	7	51	1.526009	0.812858	1.581748	0.746667	UVC	DS	March	2
S24	6	37	1.384689	0.756925	1.356228	0.66967	UVC	DS	March	3
S25	4	49	0.770848	0.407026	0.564258	0.263605	UVC	DS	October	1
S26	4	32	0.865617	0.806597	1.118181	0.647177	UVC	DS	October	2
S27	3	33	0.571999	0.707538	0.77731	0.515152	UVC	DS	October	3
S28	6	63	1.206816	0.806186	1.444491	0.72043	UVC	LS	March	1
S29	9	36	2.232443	0.859677	1.888904	0.838095	UVC	LS	March	2
S30	6	116	1.051837	0.887017	1.589322	0.782909	UVC	LS	March	3
S31	7	40	1.62651	0.906775	1.764502	0.833333	UVC	LS	October	1
S32	6	45	1.313487	0.614841	1.101647	0.534343	UVC	LS	October	2
S33	5	20	1.335233	0.679994	1.094409	0.568421	UVC	LS	October	3
S34	7	64	1.442695	0.675001	1.313491	0.684028	UVC	RB	March	1
S35	10	42	2.407917	0.850258	1.957792	0.843206	UVC	RB	March	2
S36	6	28	1.500508	0.933564	1.672722	0.830688	UVC	RB	March	3
S37	4	231	0.551226	0.369898	0.512787	0.242725	UVC	RB	October	1
S38	7	398	1.002263	0.275564	0.536222	0.222802	UVC	RB	October	2
S39	6	113	1.057667	0.587571	1.052786	0.493679	UVC	RB	October	3

Appendix C: Selected BRUV's MaxN Snapshots

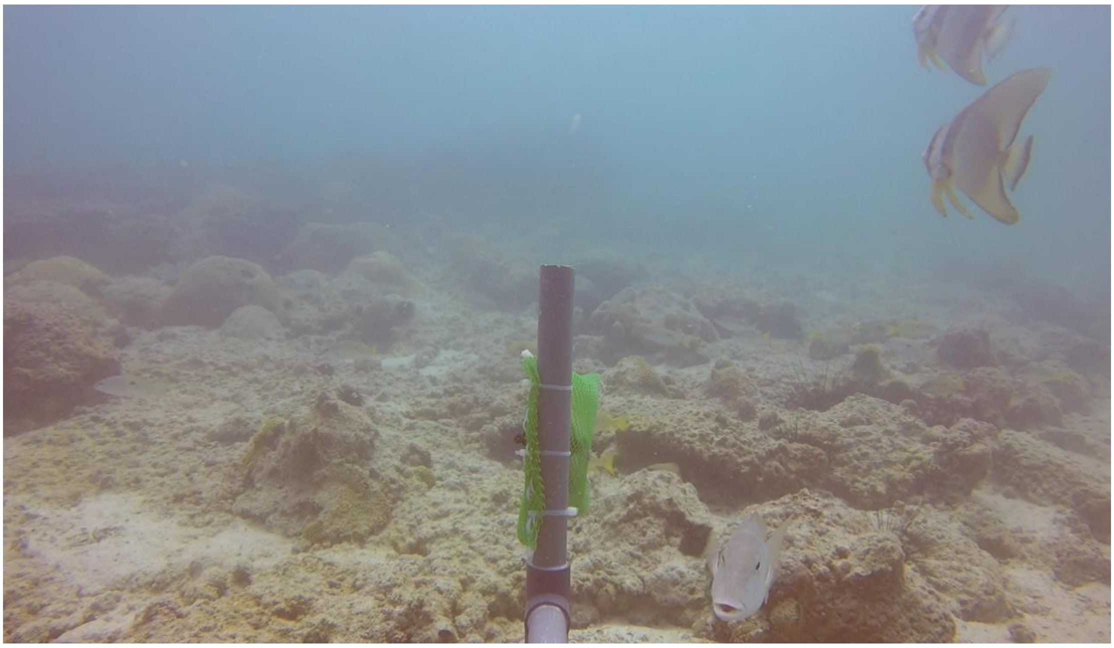
Mixed Schools of fish



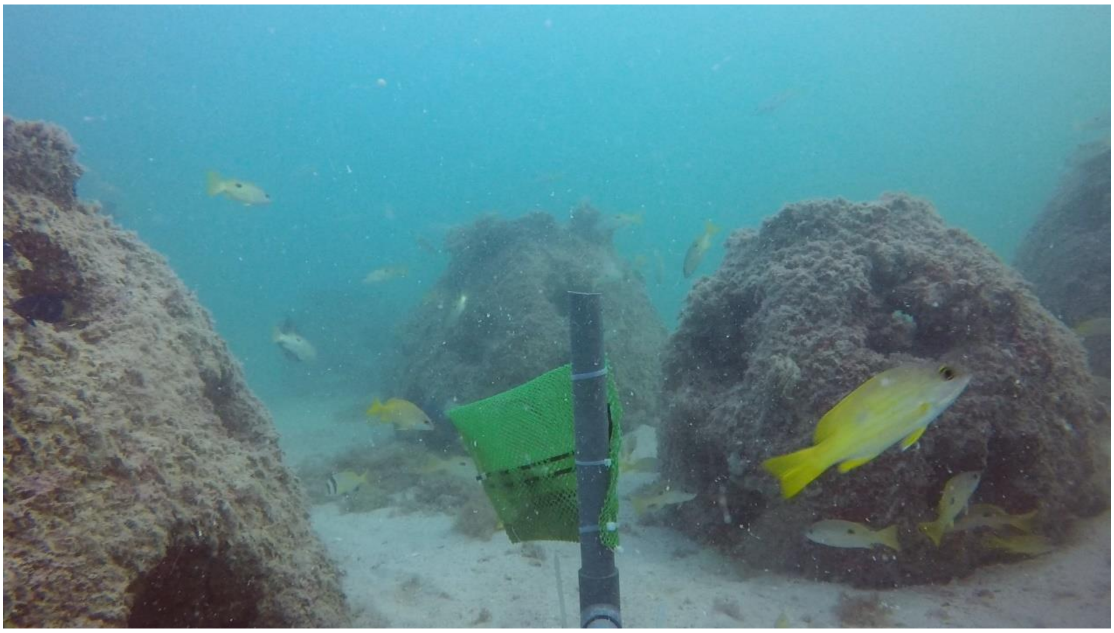


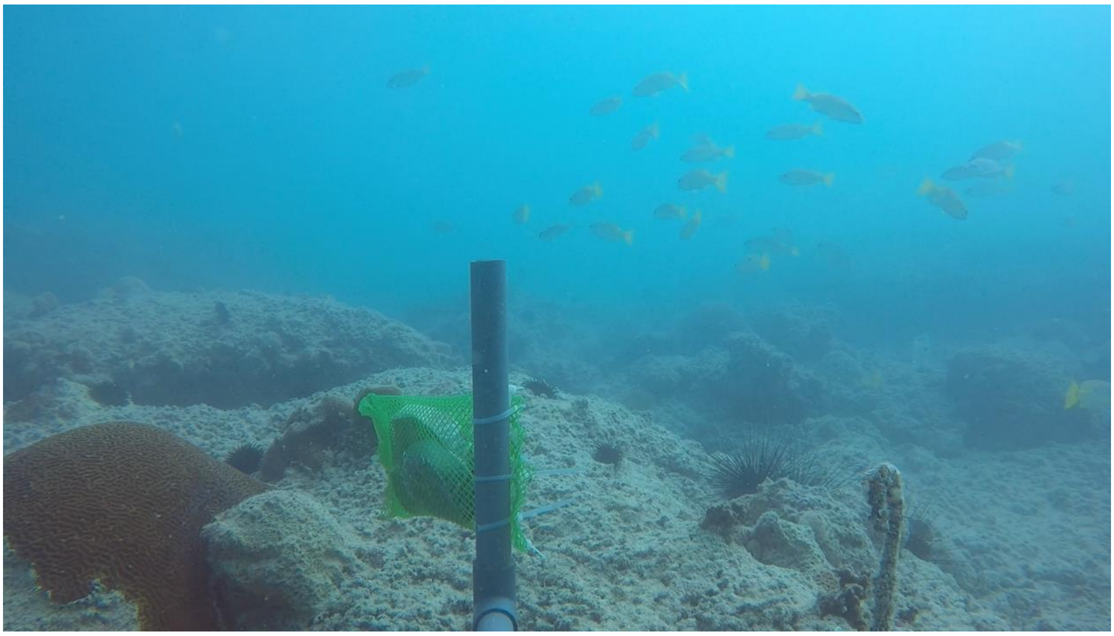


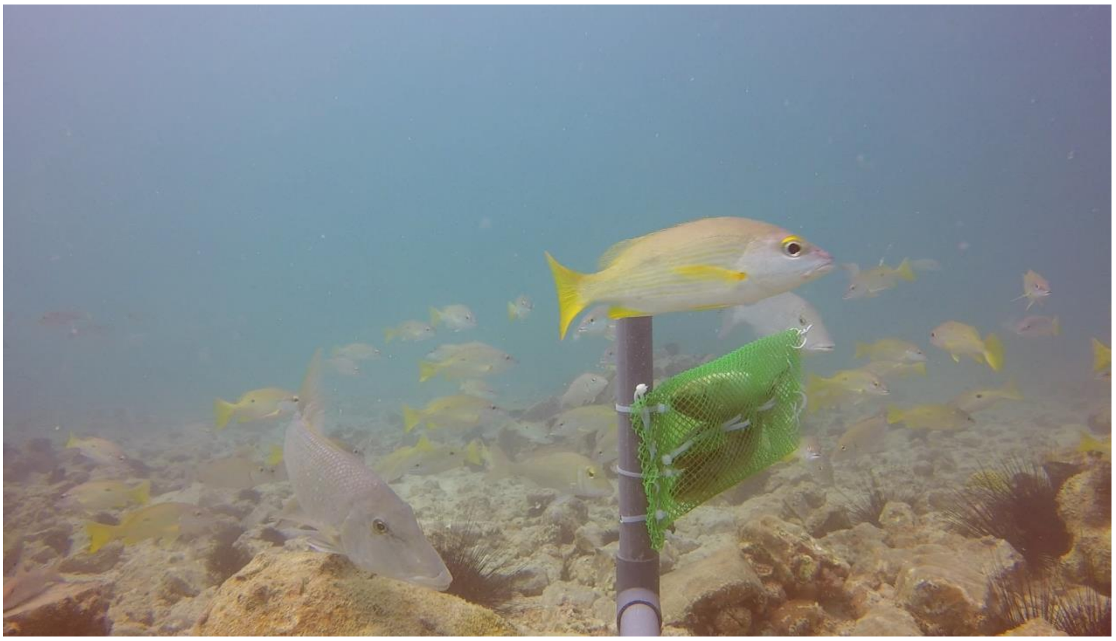
Platax teira



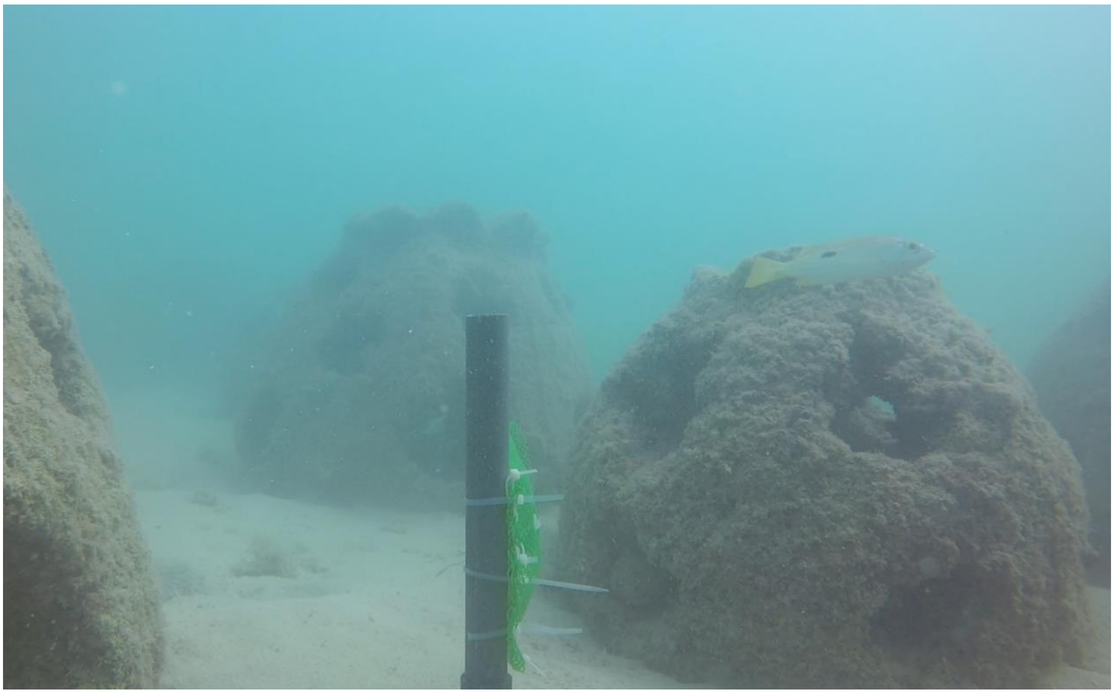
Lutjanus fulviflamma



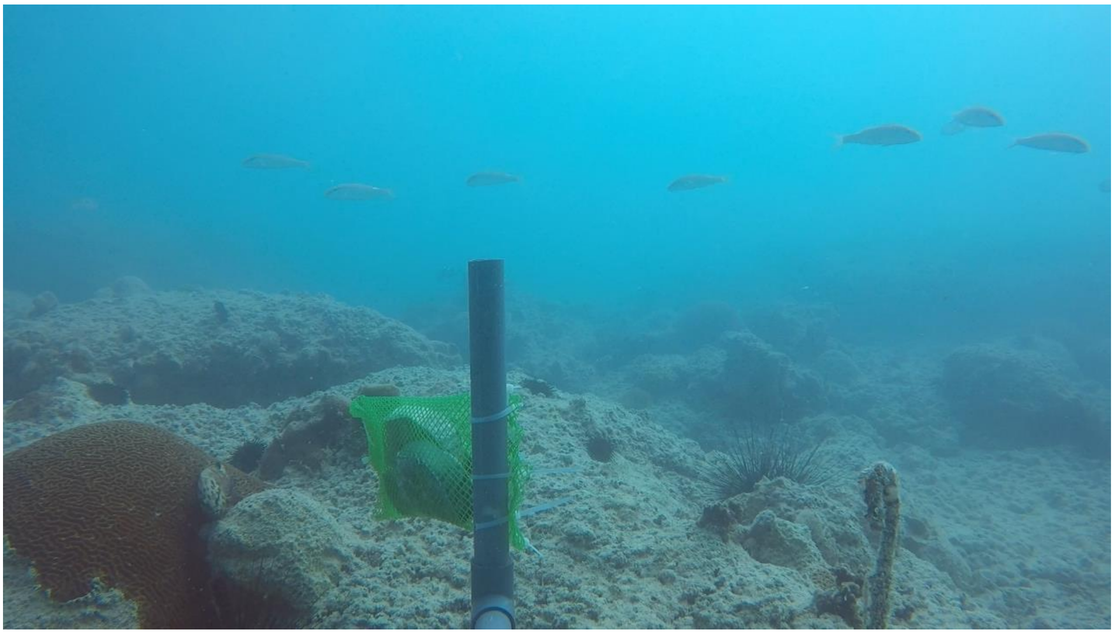




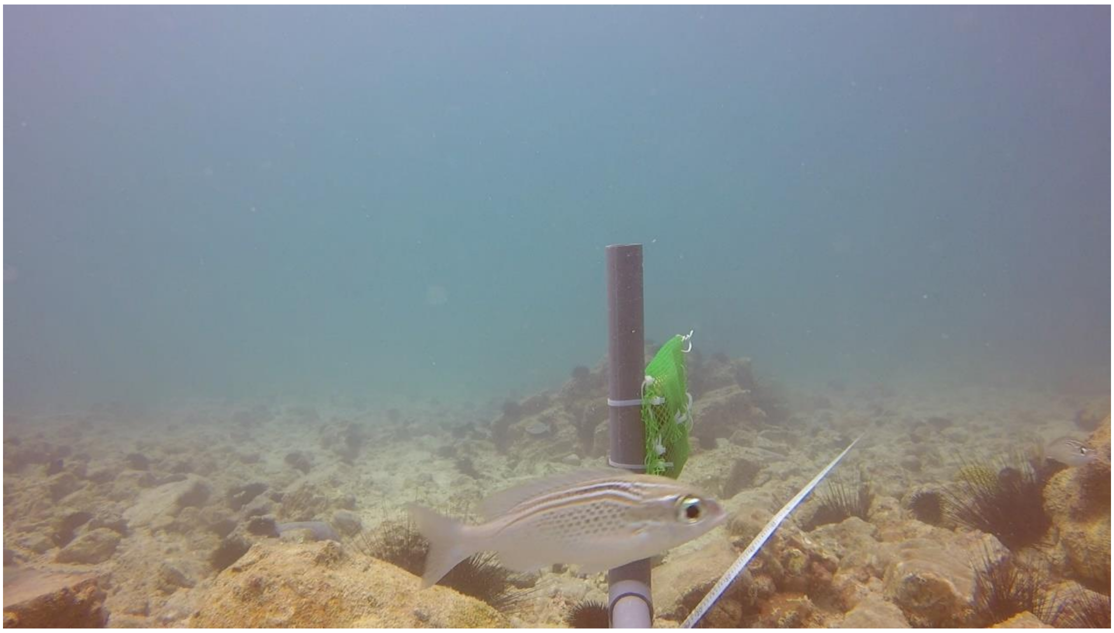
Lutjanus ehrenbergii



Parupeneus margaritatus

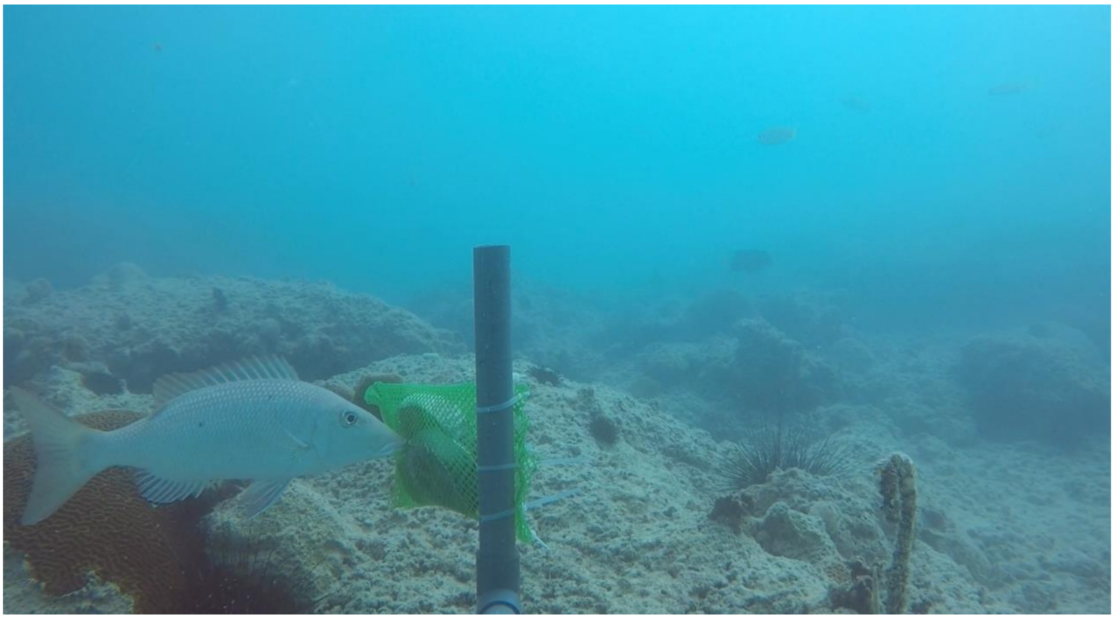


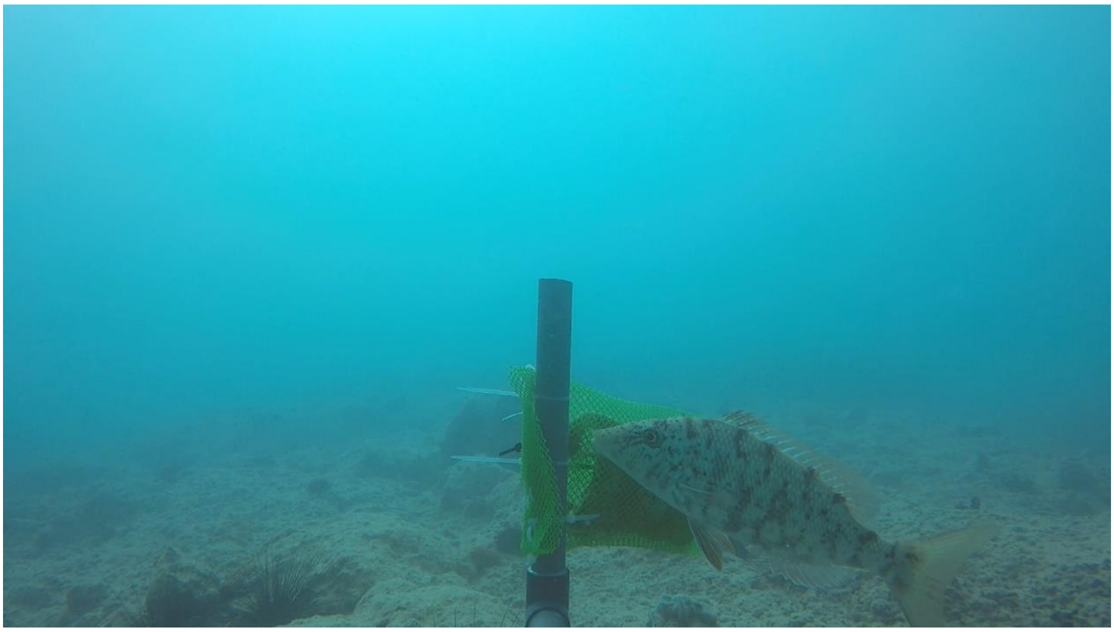
Scolopsis ghanam

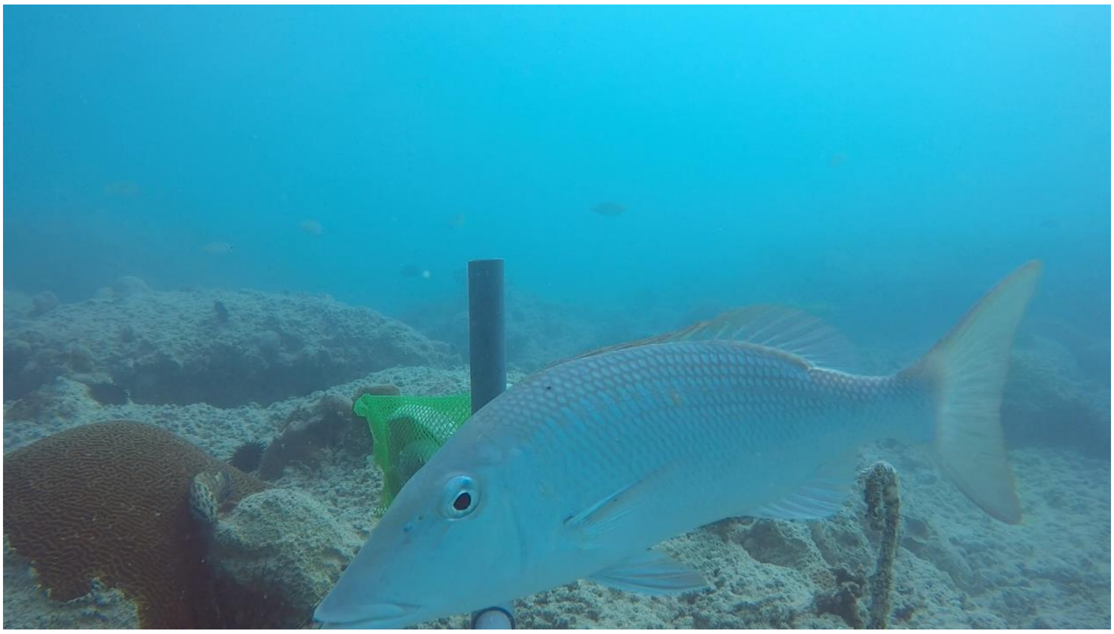


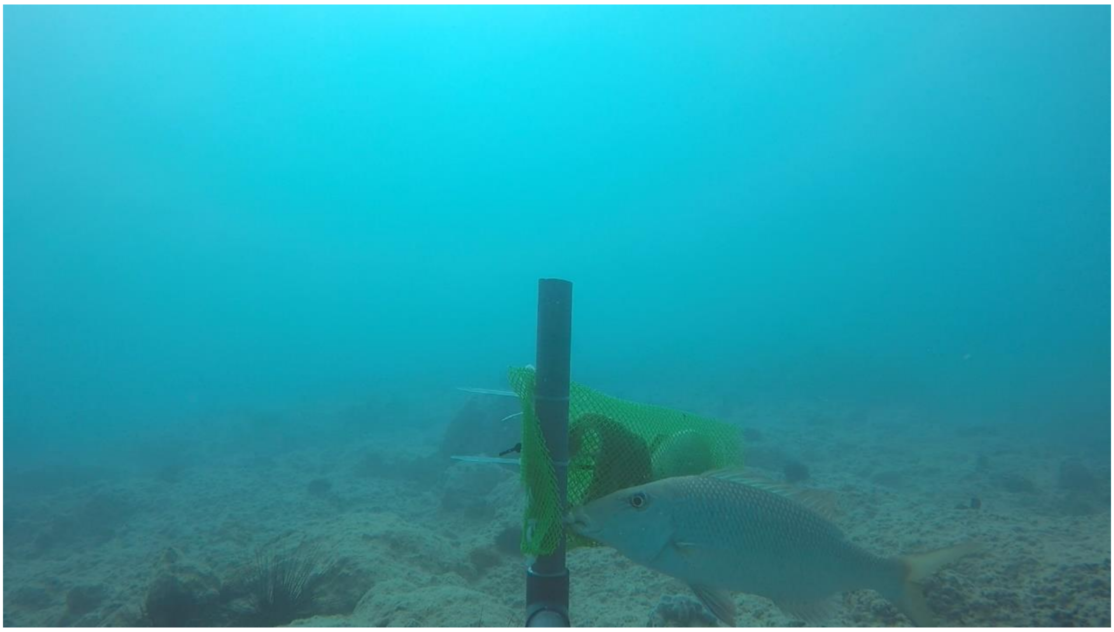
Acanthopagrus bifasciatus

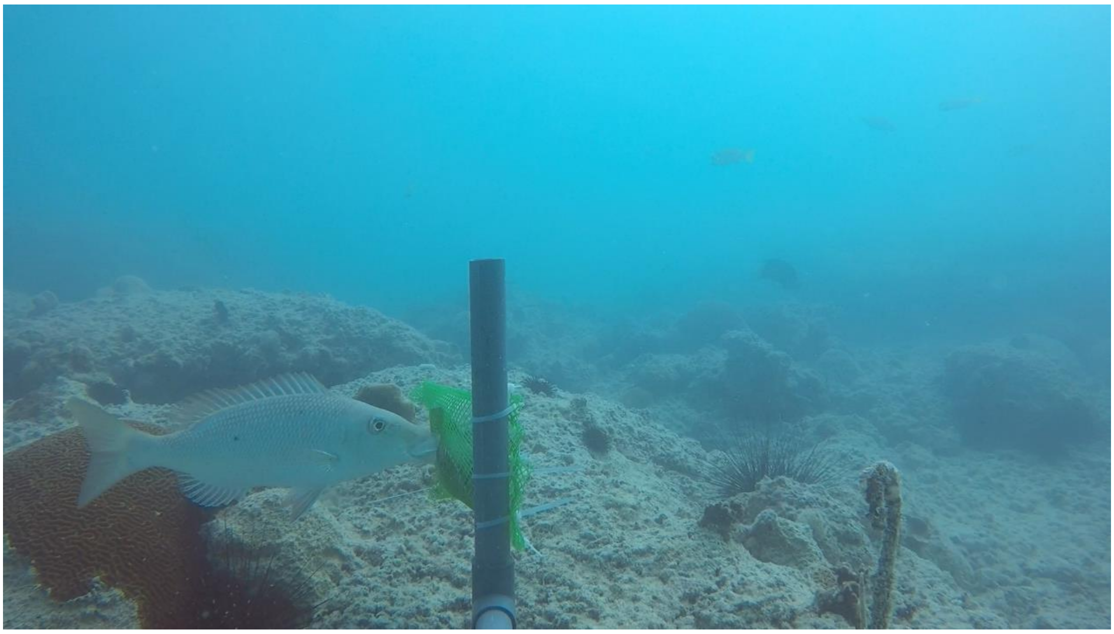
Lethrinus microdon



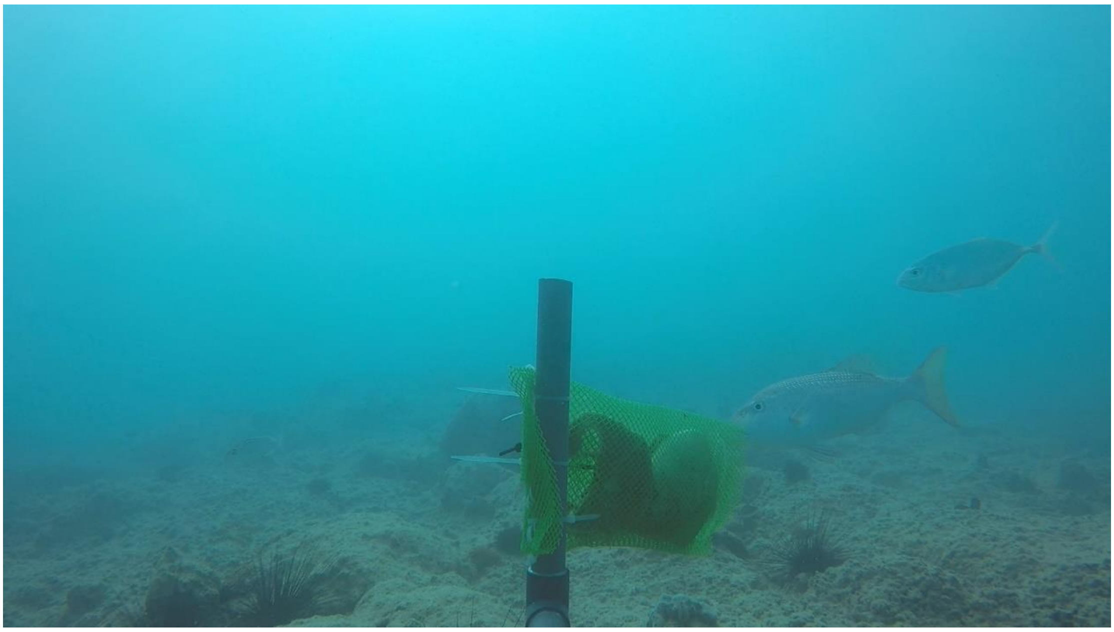


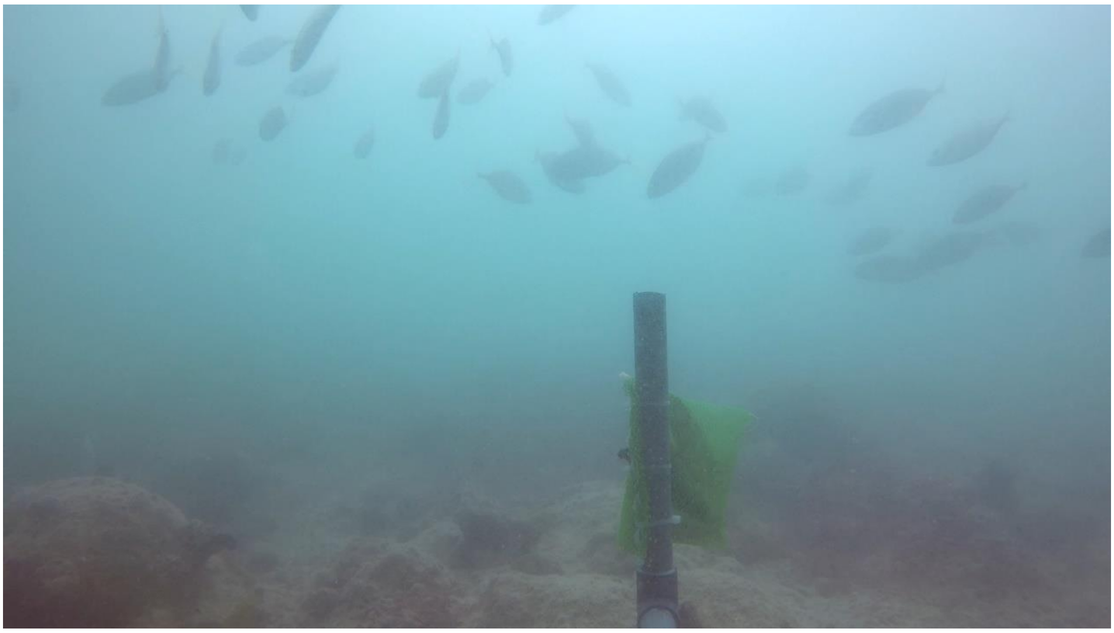






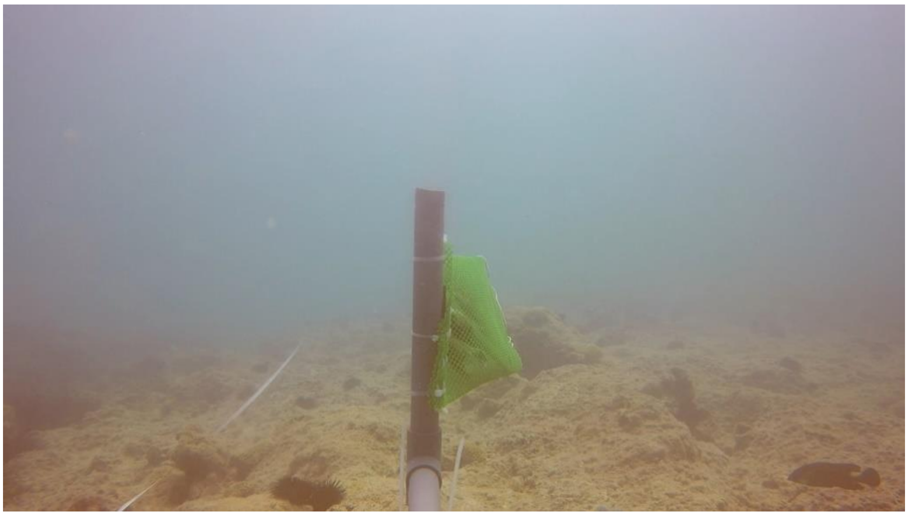
Carangoides bajad



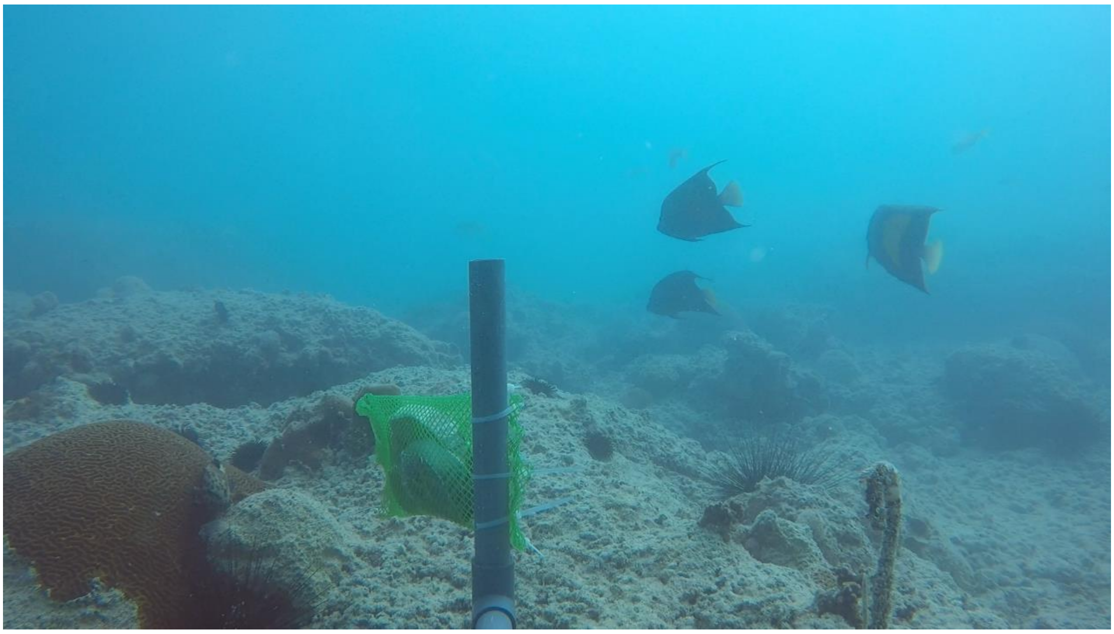


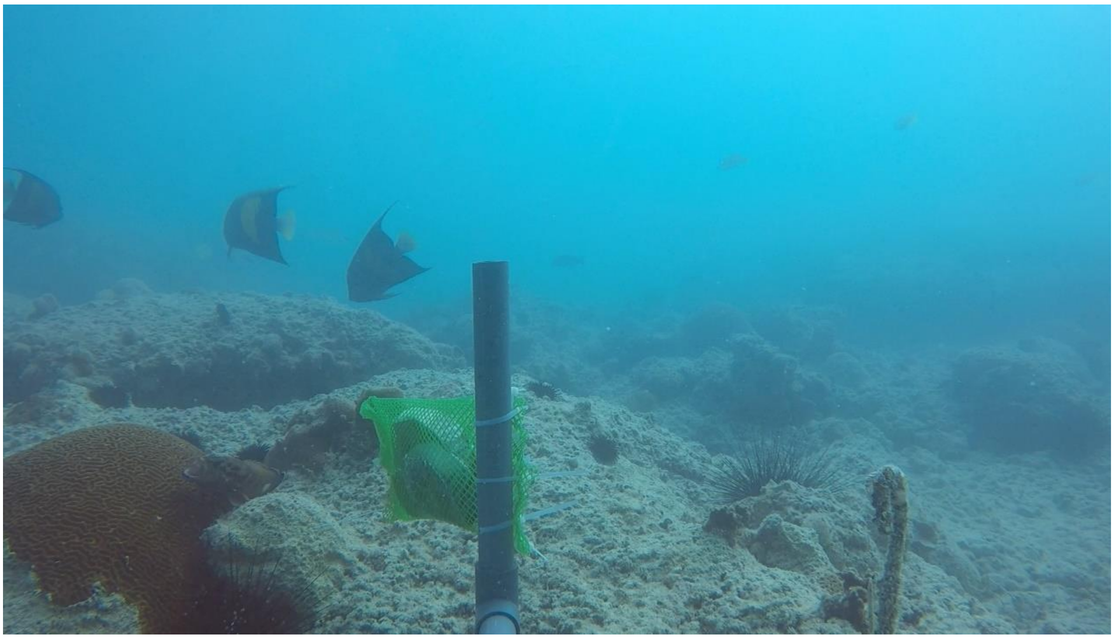
Cheilodipterus novemstriatus

Cephalopholis hemistiktos



Pomacanthus maculosus

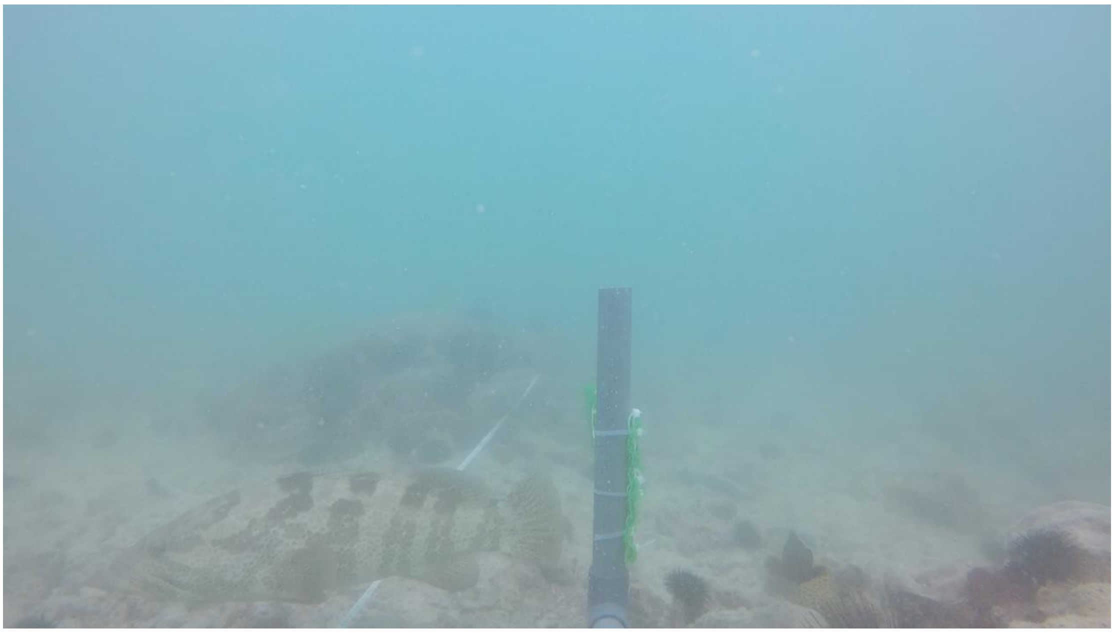




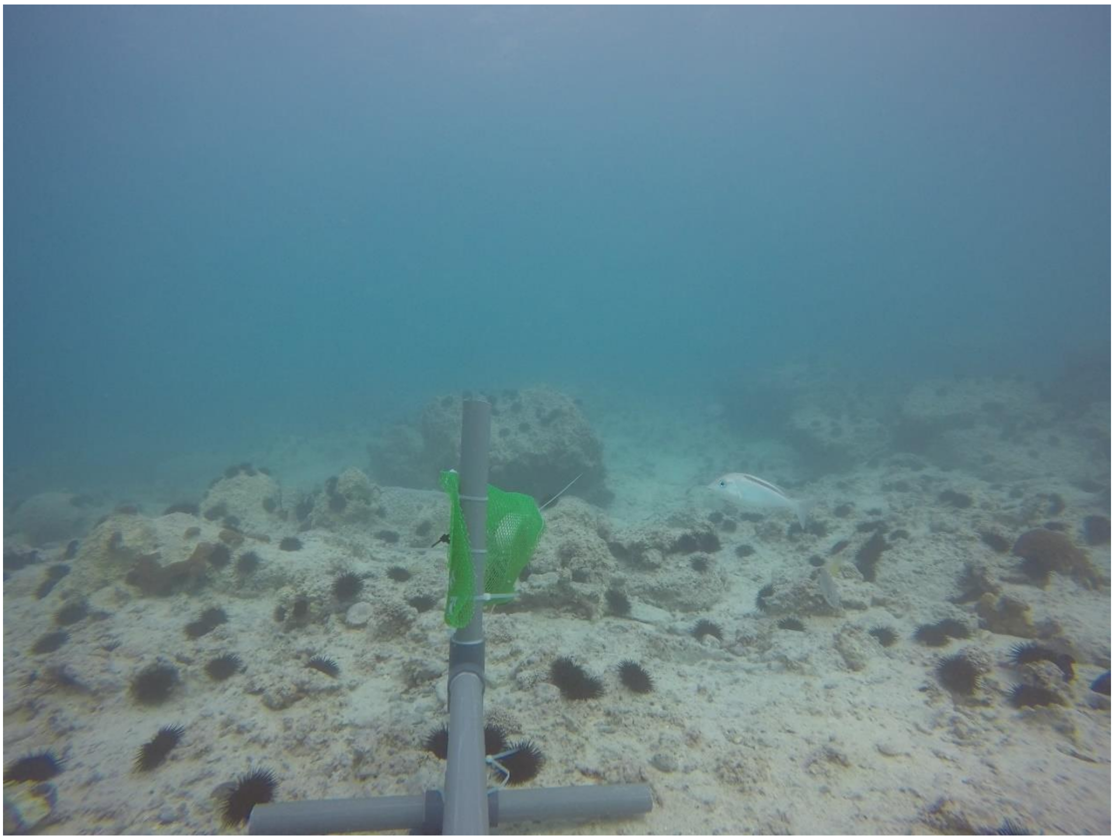
Heniochus acuminatus

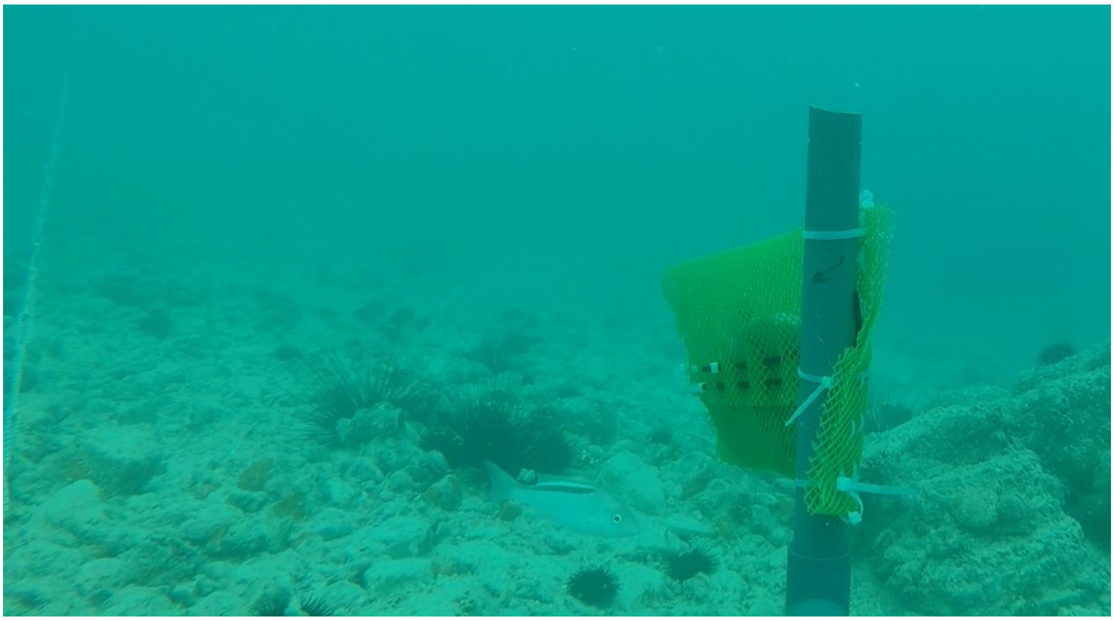
Scomberoides tol

Epinephelus coioides



Scolopsis taeniatus

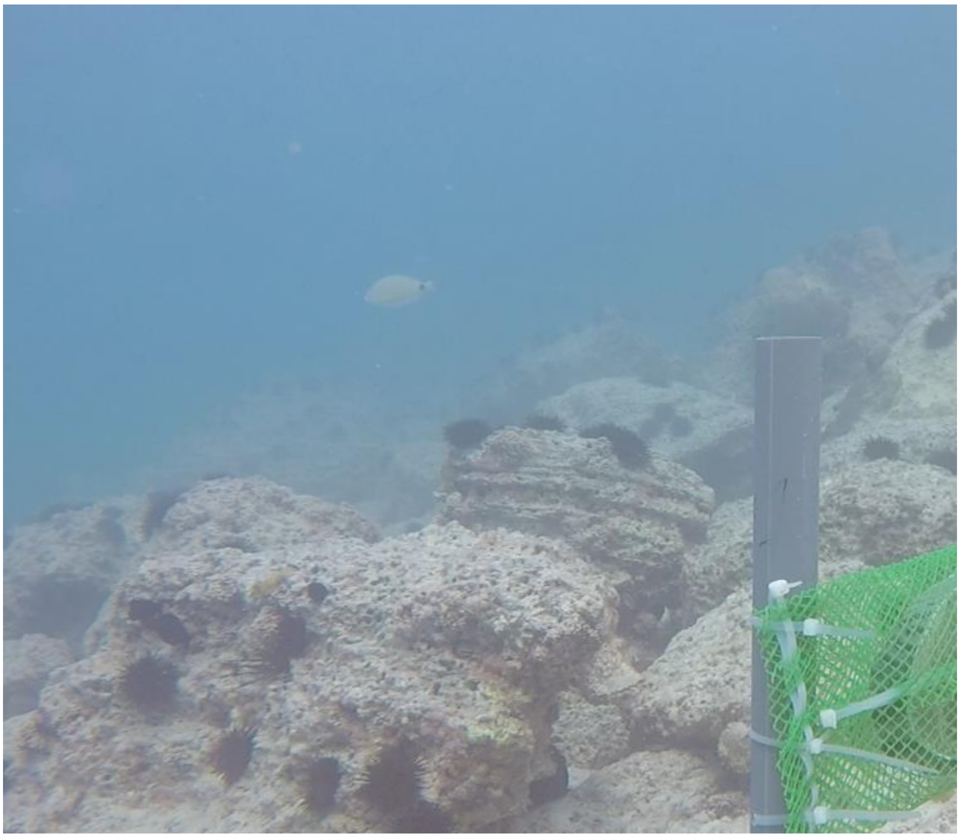




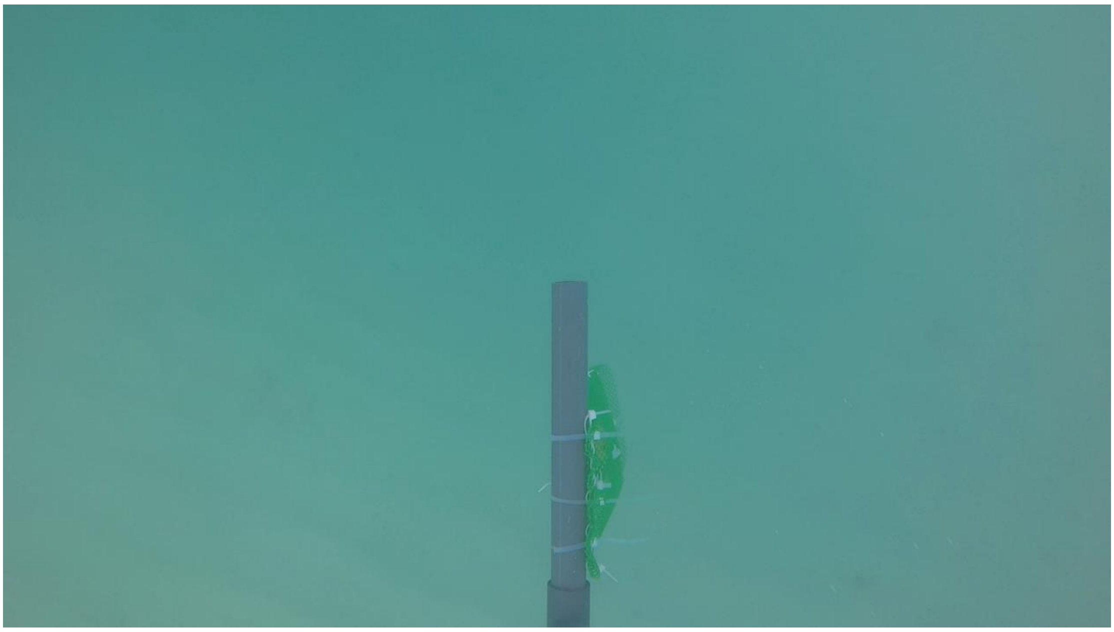
Gnathanodon speciosus

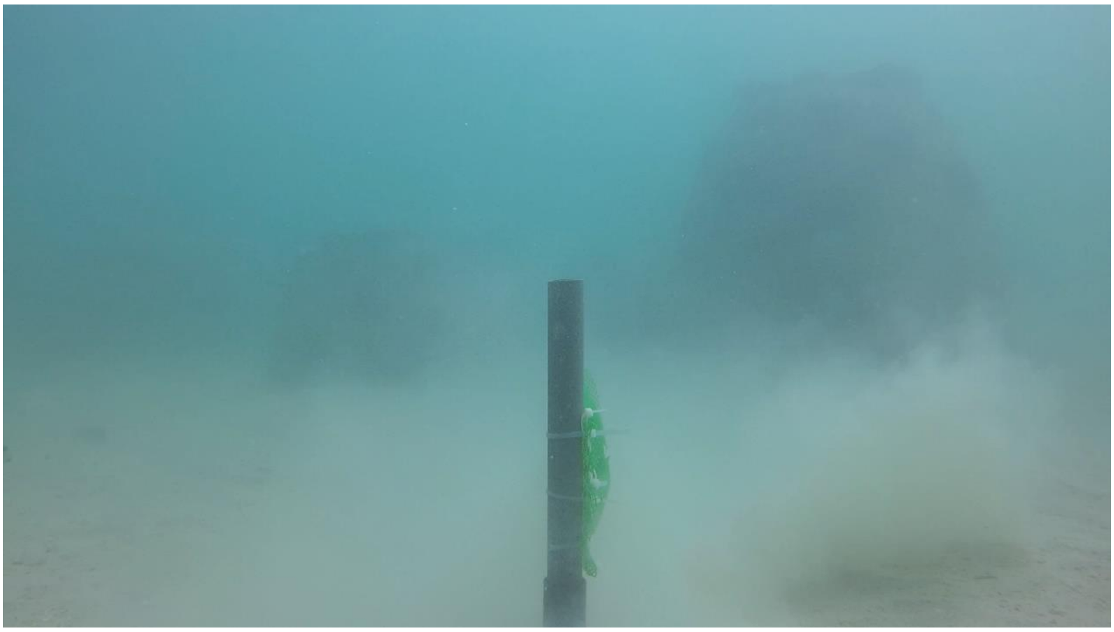
Abudefduf vaigiensis

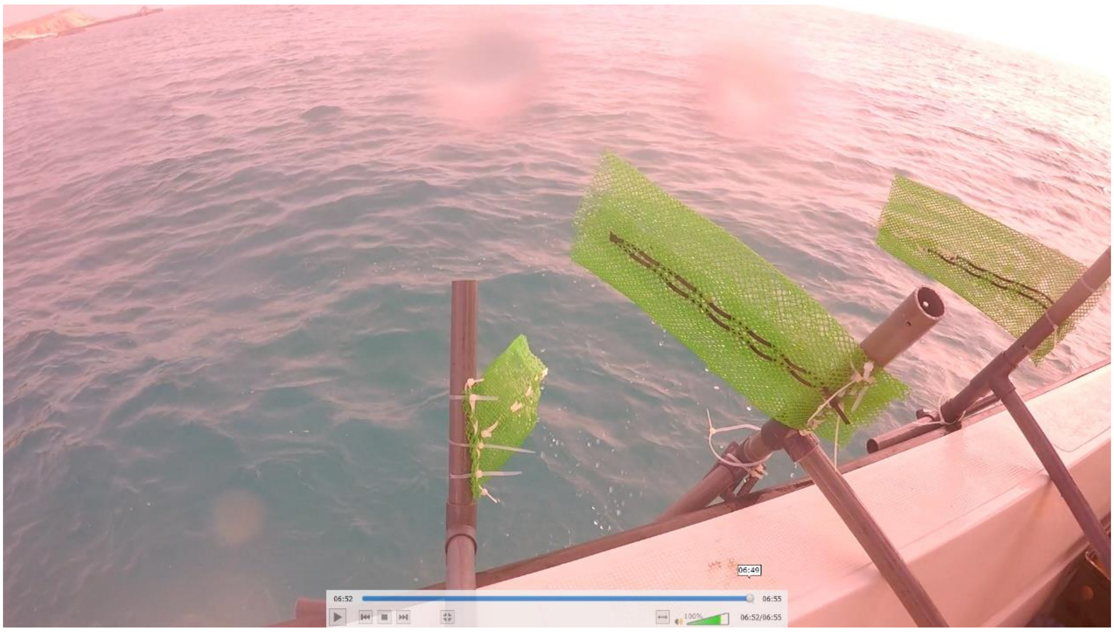
Diplodus sargus kotschyi



Deployment





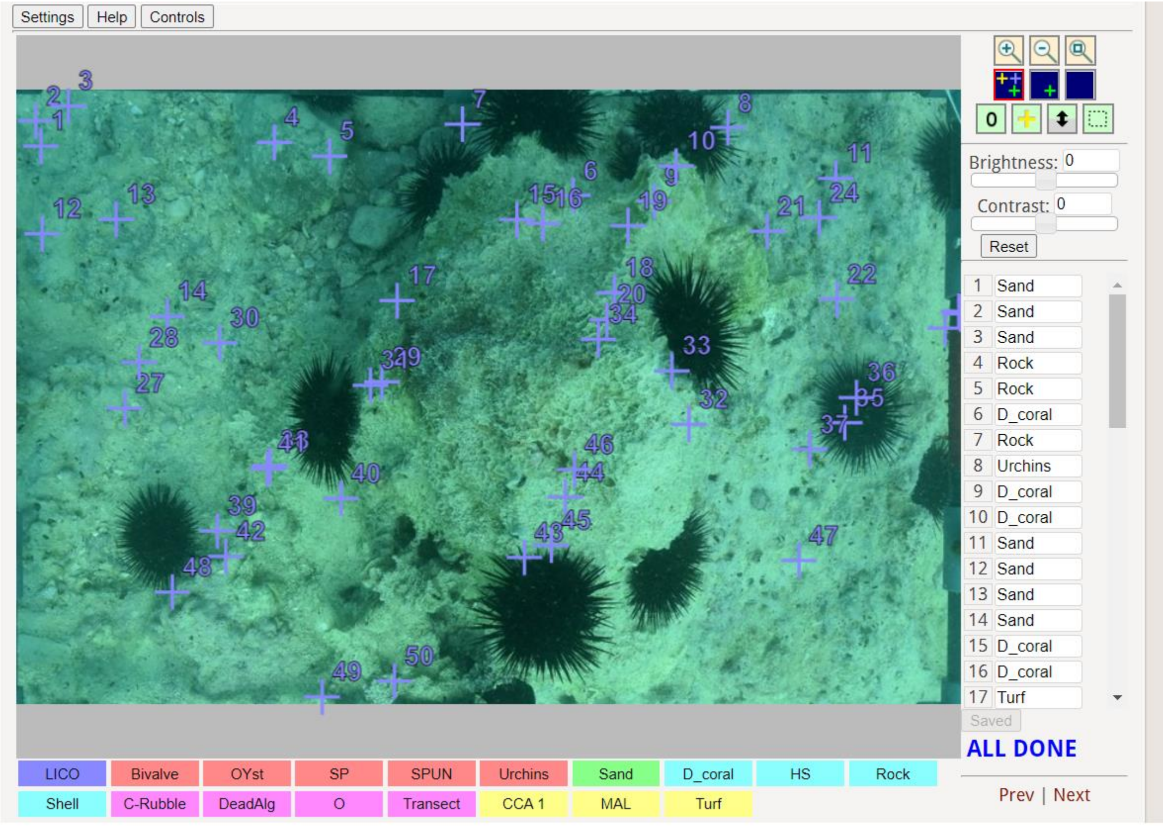


06:49
06:52
06:55
100%
06:52/06:55

Appendix D: Field Data Sheets

<table>
<tr><td colspan="2">Location:</td><td colspan="6" rowspan="6">Site description:</td></tr>
<tr><td colspan="2">Date:</td></tr>
<tr><td colspan="2">Visibility:</td></tr>
<tr><td colspan="2">Temperature:</td></tr>
<tr><td colspan="2">Time Started:</td></tr>
<tr><td colspan="2">Time Ended:</td></tr>
<tr><td colspan="2">DI:</td><td colspan="4">max/min Depth:</td><td>RN:</td><td></td></tr>
<tr><td rowspan="2">Code/ Name</td><td colspan="2" rowspan="2">N
5mins</td><td colspan="3">Length in cm</td><td colspan="2" rowspan="2">Comments/ Notes</td></tr>
<tr><td>Min</td><td>Max</td><td>Av
g.</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td><td colspan="2" rowspan="8"></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
</table>

Appendix E: Coral net platform



Appendix F: Statistic Test

Snapshots from the data analysis through primer 6 software

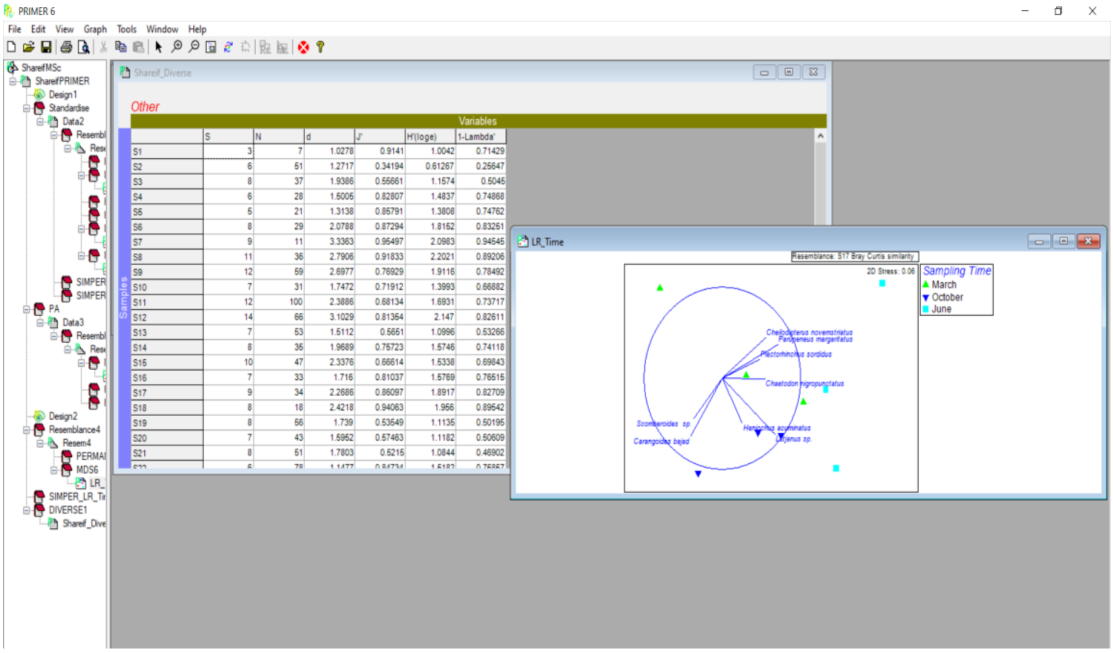


Table 9 ANOVA TABLE FOR DIVERSITY BETWEEN STUDY SITES

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
DS	12	14.36999	1.197499	0.157965
LS	12	19.3033	1.608608	0.145561
RB	12	15.78656	1.315547	0.254957

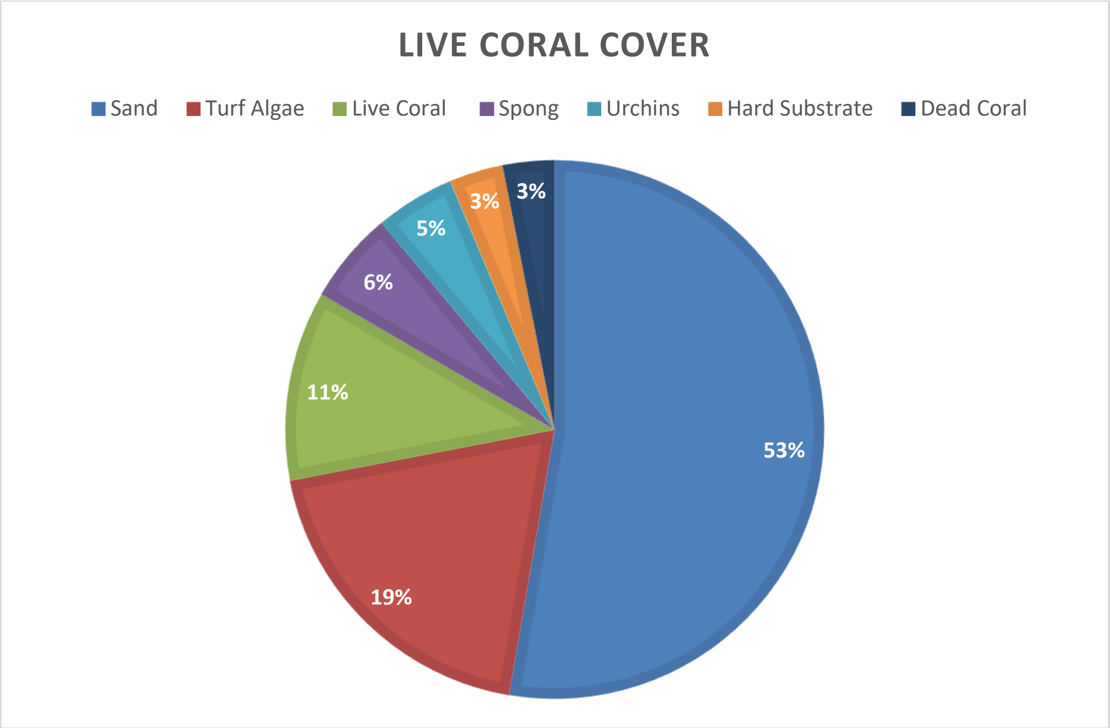
ANOVA

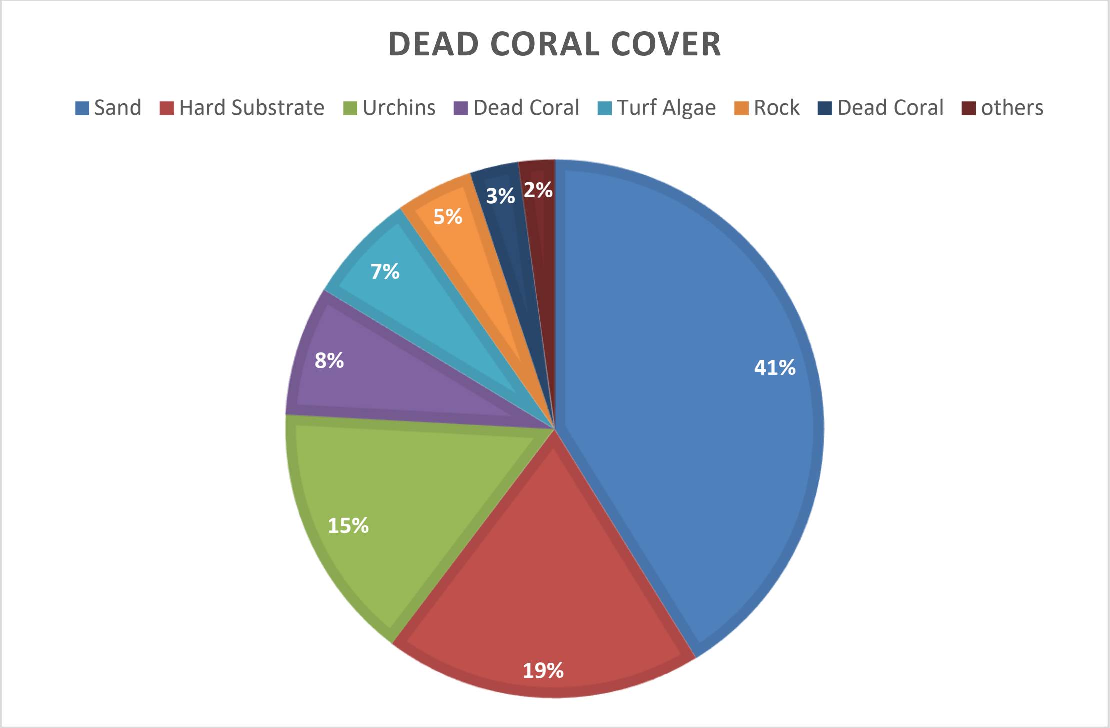
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.075325	2	0.537663	2.888158	0.069844	3.284918
Within Groups	6.143316	33	0.186161			
Total	7.218641	35				

Method means through comparison.

t-Test: Paired Two Sample for Means

	BRUVS	*UVC*
Mean	7.777778	6.055556
Variance	4.418301	2.996732
Observations	18	18
Pearson Correlation	0.262247	
Hypothesized Mean Difference	0	
df	17	
t Stat	3.113768	
P(T<=t) one-tail	0.003158	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.006315	
t Critical two-tail	2.109816	




DEAD CORAL COVER
Sand
Hard Substrate
Urchins
Dead Coral
Turf Algae
Rock
Dead Coral
others
41%
19%
15%
8%
7%
5%
3%
2%

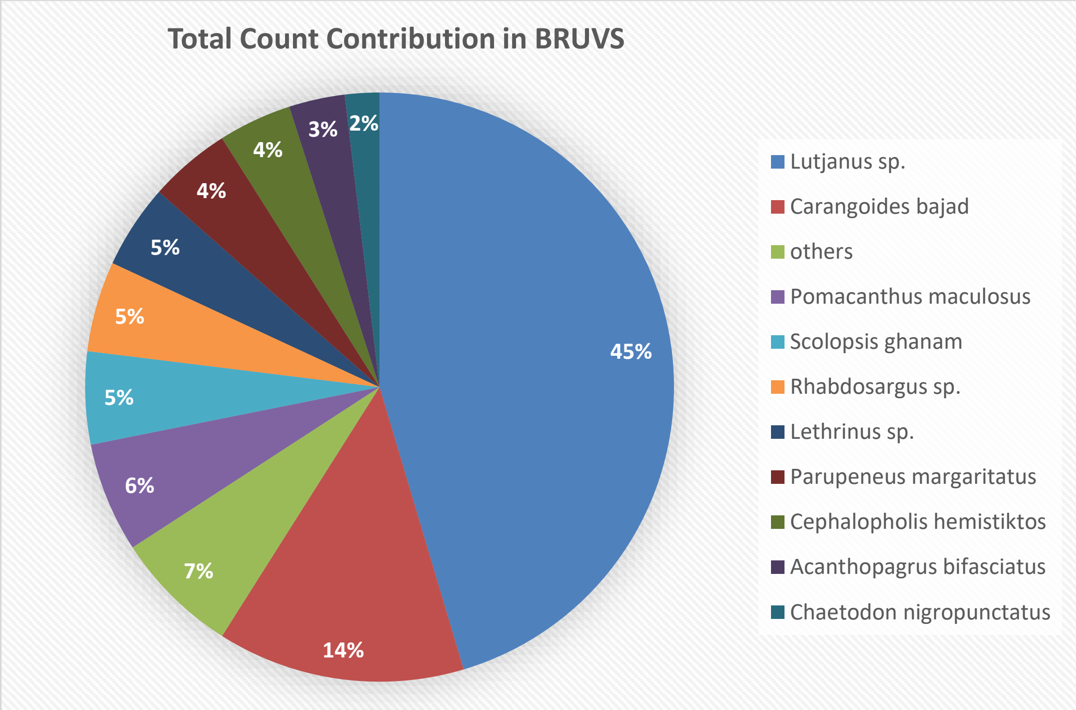


Figure 26 Percentage of contribution of the 24 species in the total species count by BRUVs

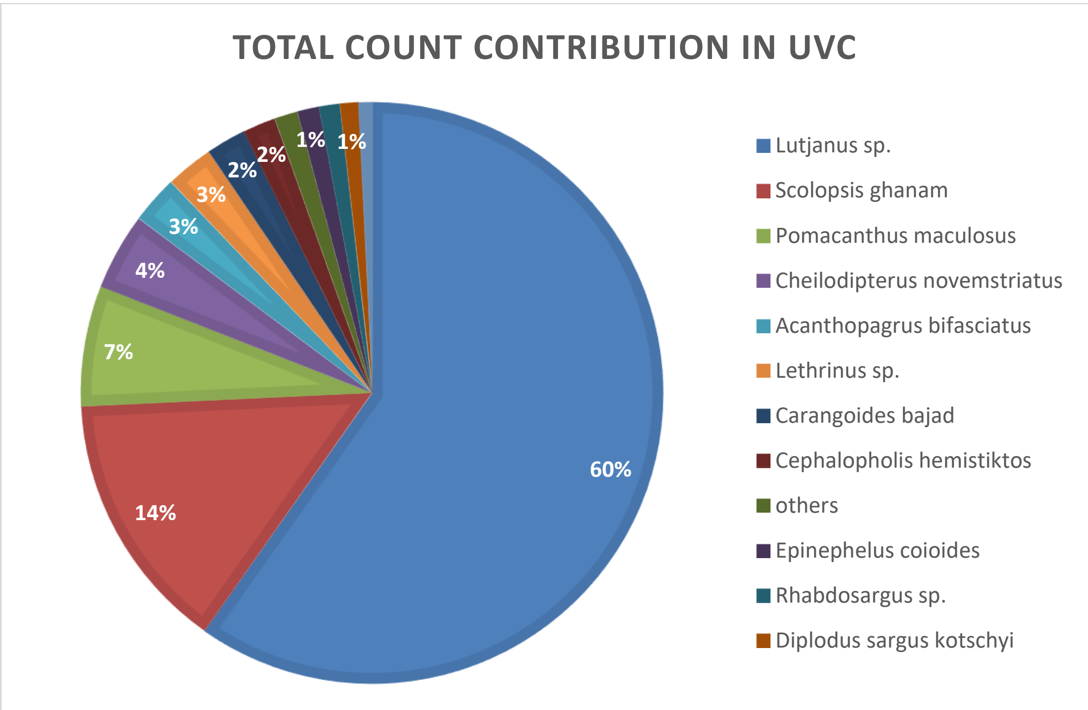


Figure 27 percentage of contribution of the 24 species in the total species count by UVC

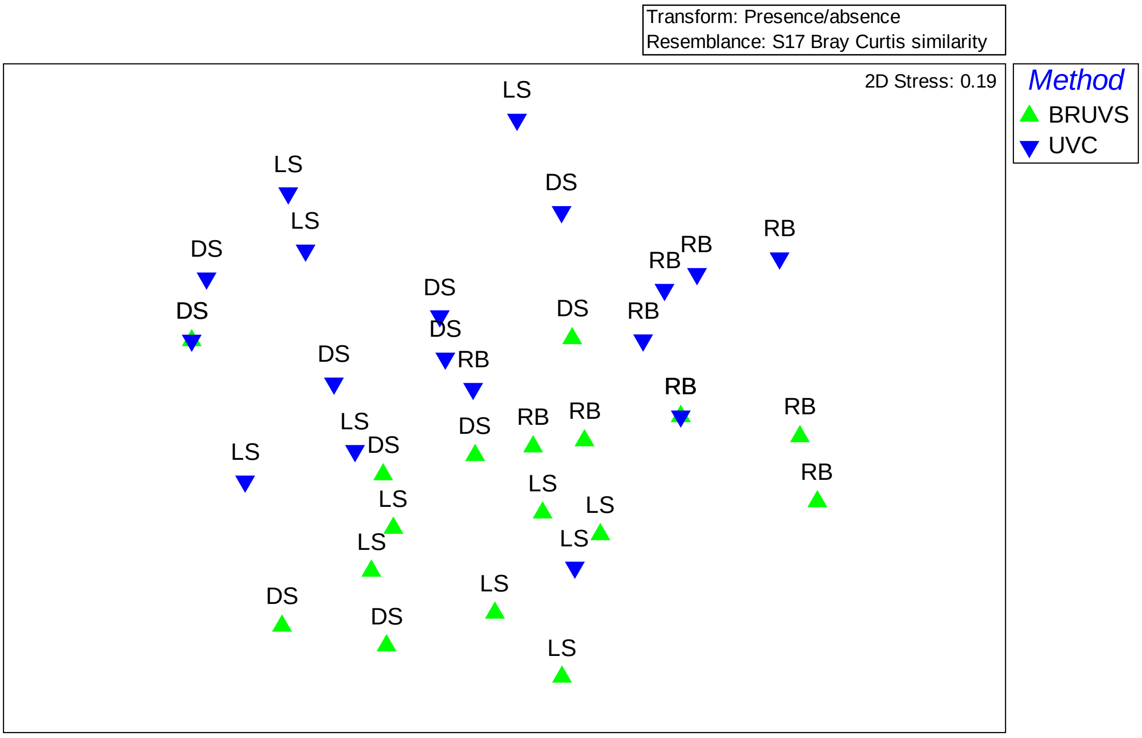


Figure 28 nMDS plot, base on Presence/abcence data

Live site the species count changed (species richness) from the first season.

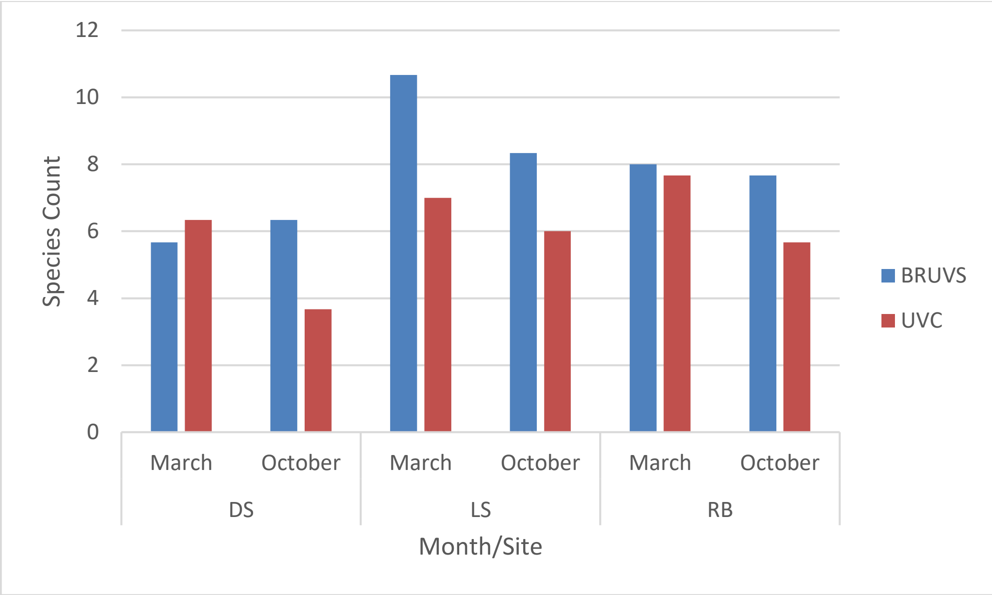


Figure 29 Means of Species Richness Each of The Study Sites by different methods in Different Seasons. The temporal variation of each fish count at each in live coral site coral

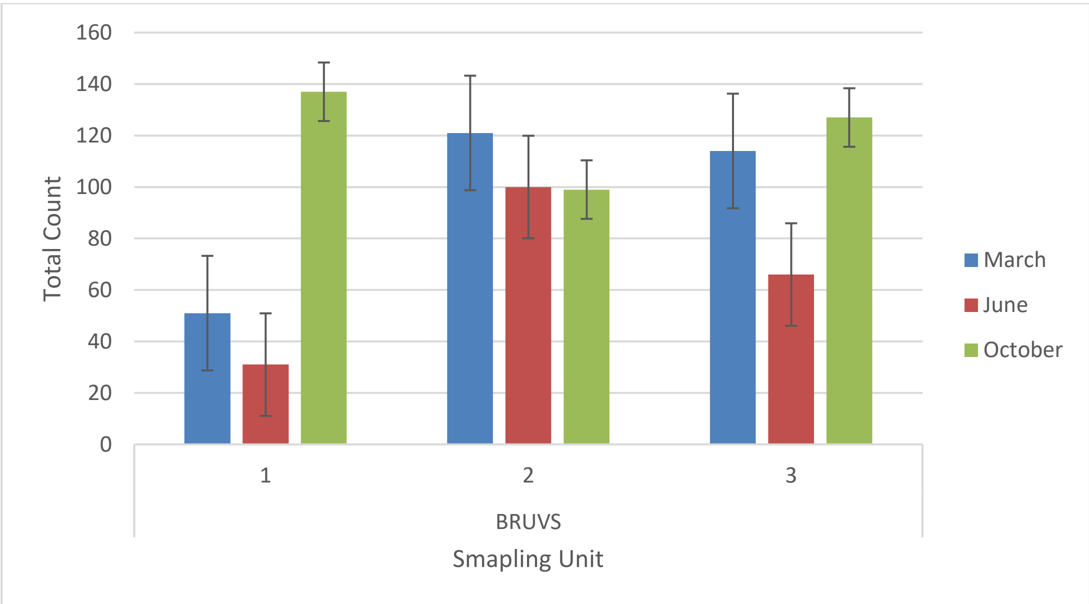


Figure 30 Live Site Seasonal variation considering only BRUVs data

Table 10 Permanova Table of Biomass

PERMANOVA table of results biomass						
						Unique
Source	df	SS	MS	Pseudo-F	P(perm)	perms
Si	2	7633.7	3816.8	1.8049	0.057	998
Mo	1	3988.4	3988.4	1.8861	0.083	998
SixMo	2	6312.3	3156.2	1.4925	0.137	998
Res	12	25376	2114.7			
Total	17	43310				

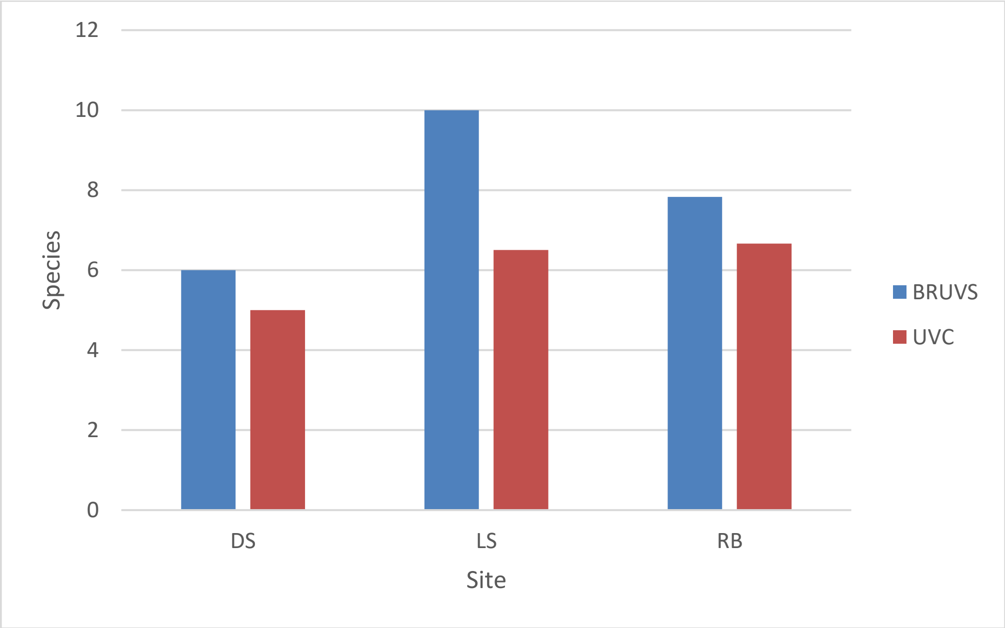


Figure 31 Mean number of species (±SE) identified by BRUV and UVC at each site

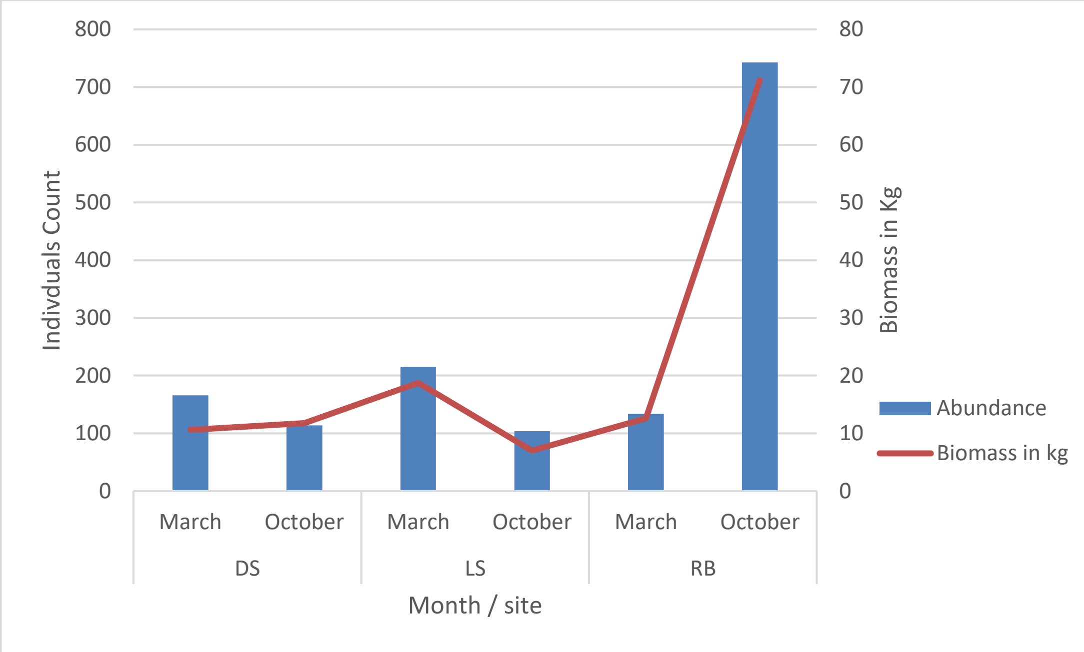
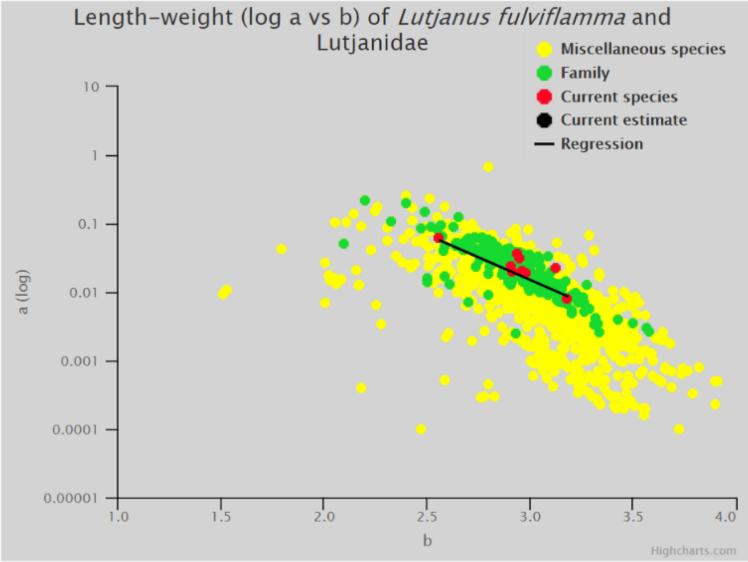
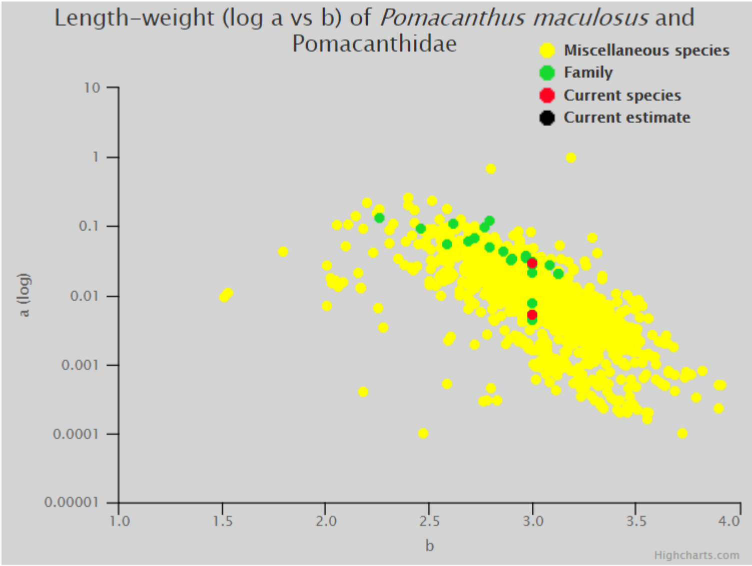


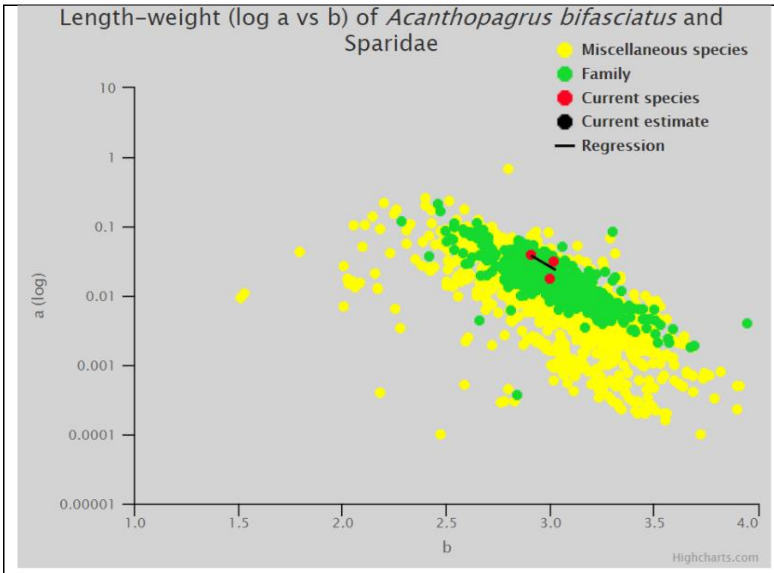
Figure 32 Gross abundance and biomass of fish between the sites during different months

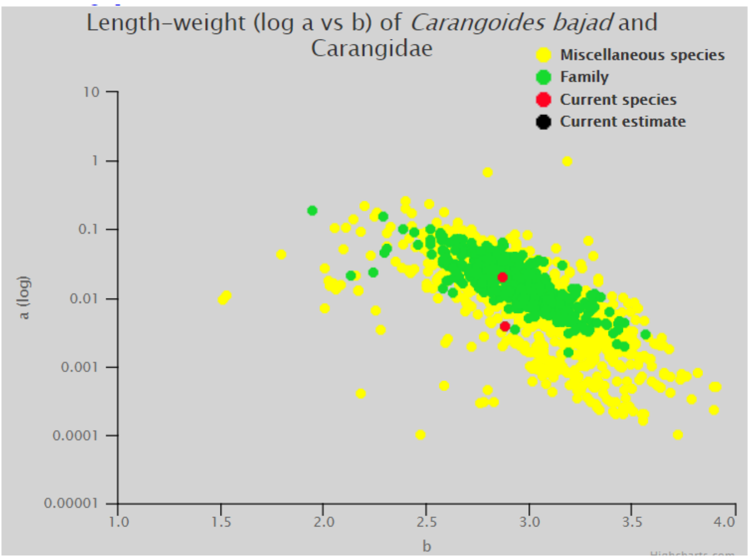
Appendix G: Length-Weight relation Graph from fishbase.org platform

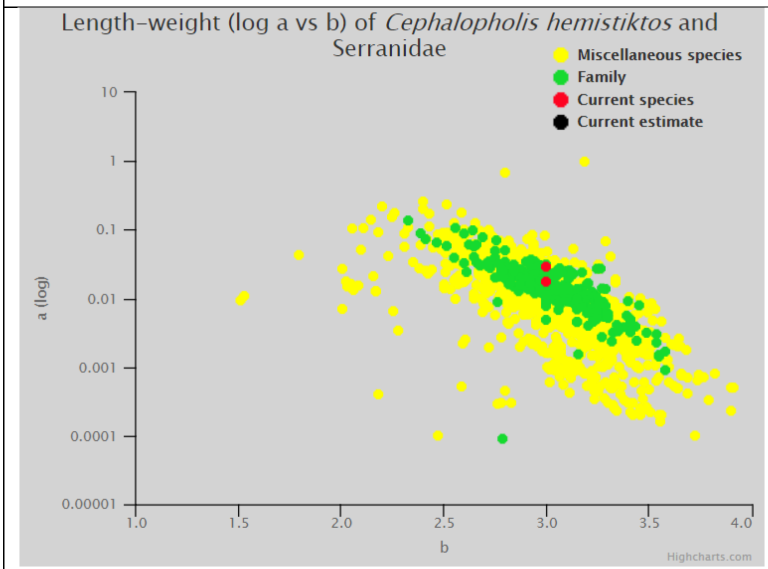


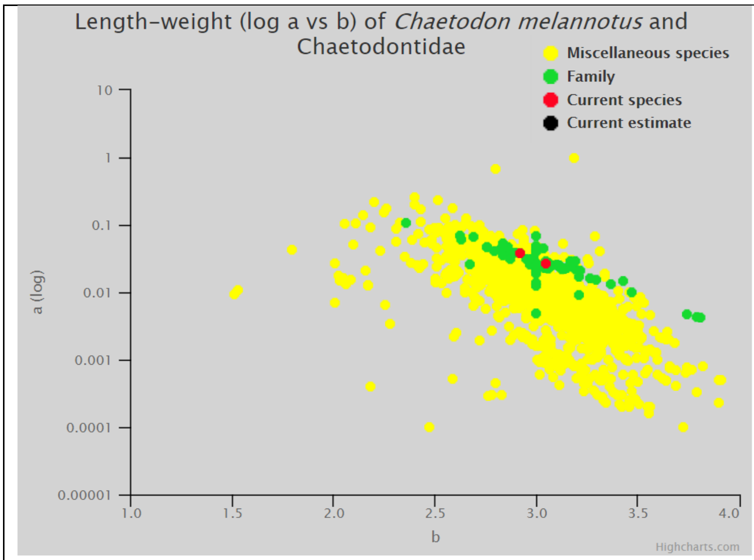


[n = 2 studies ; mean a = 0.0123, b = 3]

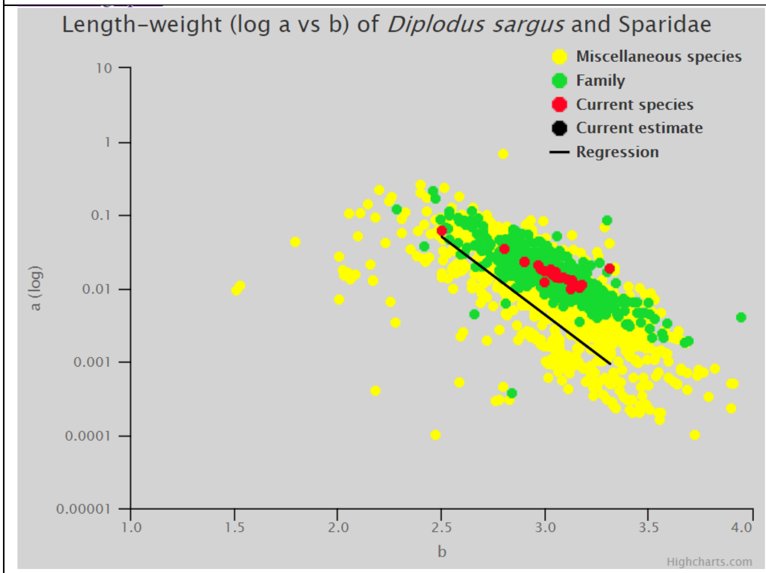

Length-weight (log a vs b) of *Acanthopagrus bifasciatus* and Sparidae
Miscellaneous species
Family
Current species
Current estimate
Regression
10
1
0.1
0.01
0.001
0.0001
0.00001
a (log)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com


Length-weight (log a vs b) of *Carangoides bajad* and Carangidae
Miscellaneous species
Family
Current species
Current estimate
10
1
0.1
0.01
0.001
0.0001
0.00001
a (log)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b

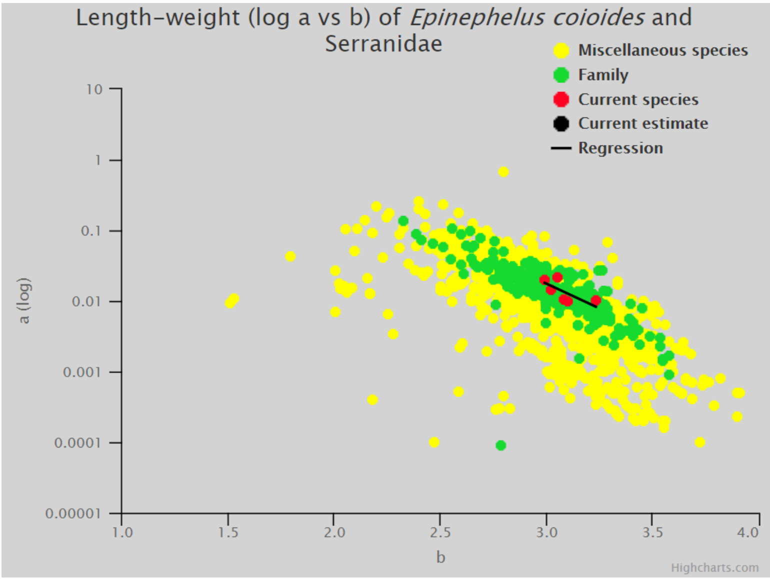

Length-weight (log a vs b) of *Cephalopholis hemistiktos* and Serranidae
Miscellaneous species
Family
Current species
Current estimate
10
1
0.1
0.01
0.001
0.0001
0.00001
a (log)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com



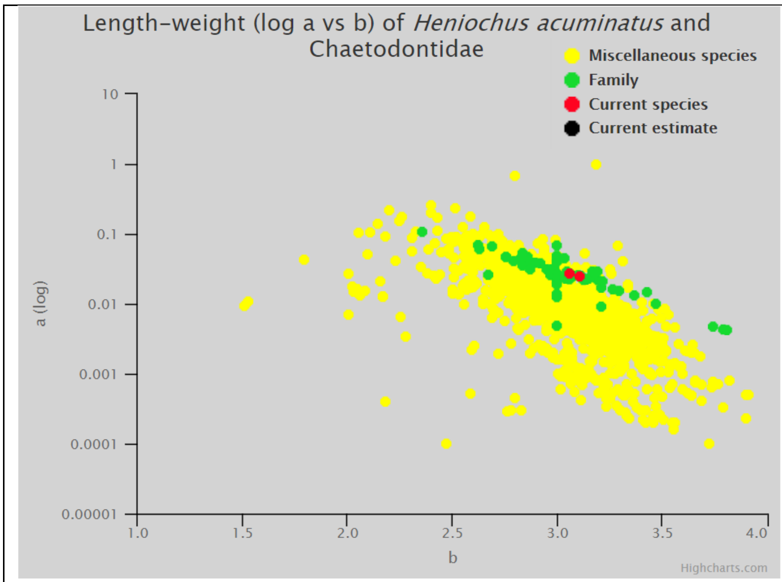
Length-weight (log a vs b) of *Chaetodon melannotus* and Chaetodontidae
Miscellaneous species
Family
Current species
Current estimate
a (log)
10
1
0.1
0.01
0.001
0.0001
0.00001
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com

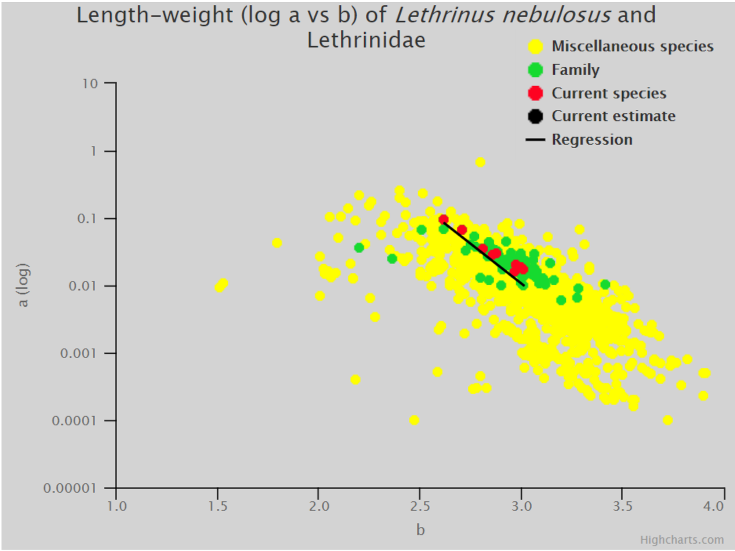


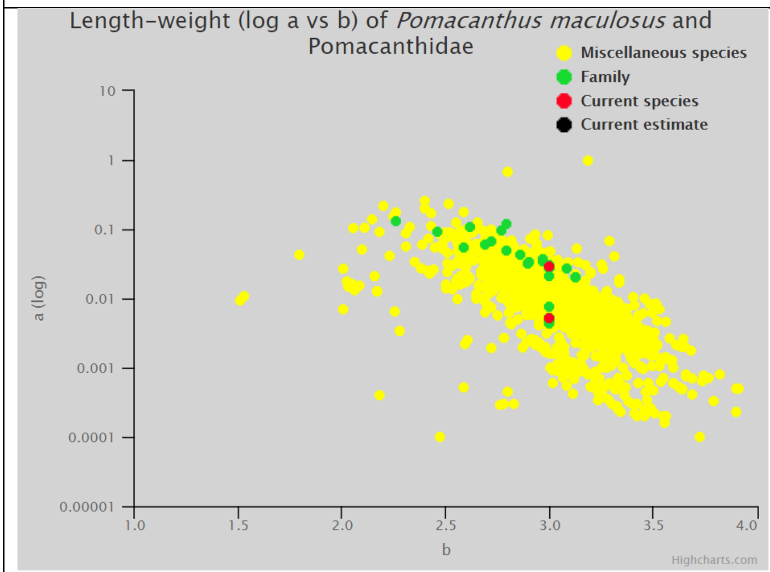
Length-weight (log a vs b) of *Diplodus sargus* and Sparidae
Miscellaneous species
Family
Current species
Current estimate
Regression
a (log)
10
1
0.1
0.01
0.001
0.0001
0.00001
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com



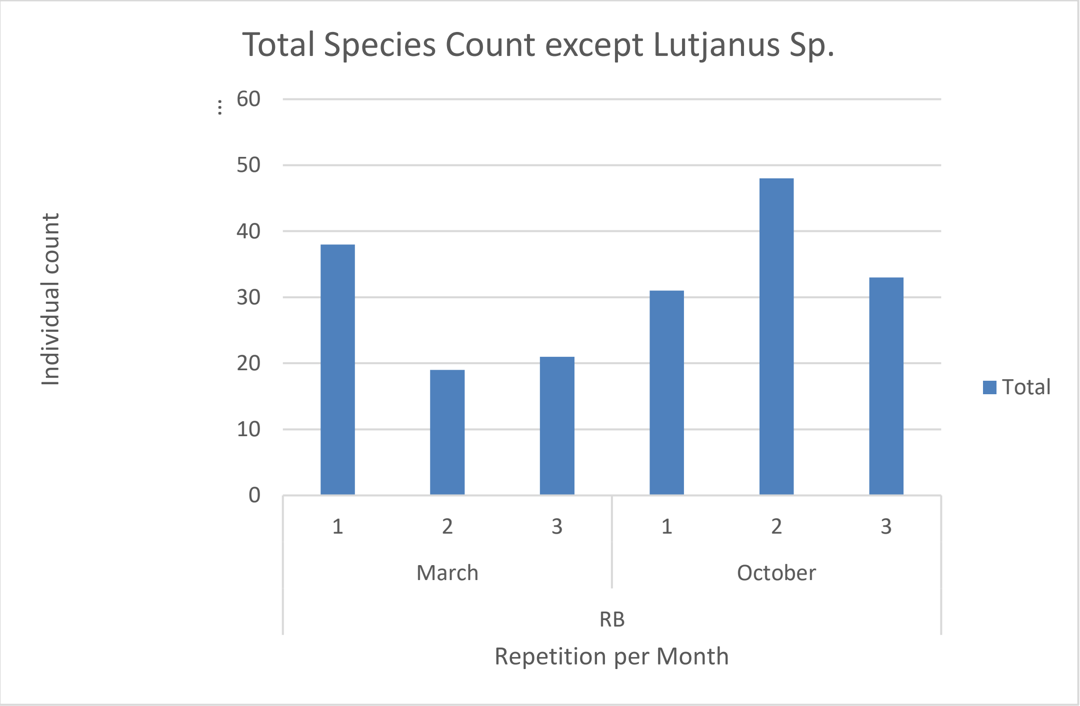
Length-weight (log a vs b) of *Epinephelus coioides* and Serranidae
Miscellaneous species
Family
Current species
Current estimate
Regression
a (log)
10
1
0.1
0.01
0.001
0.0001
0.00001
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com


Length-weight (log a vs b) of *Heniochus acuminatus* and Chaetodontidae
Miscellaneous species
Family
Current species
Current estimate
10
1
0.1
0.01
0.001
0.0001
0.00001
a (log)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com

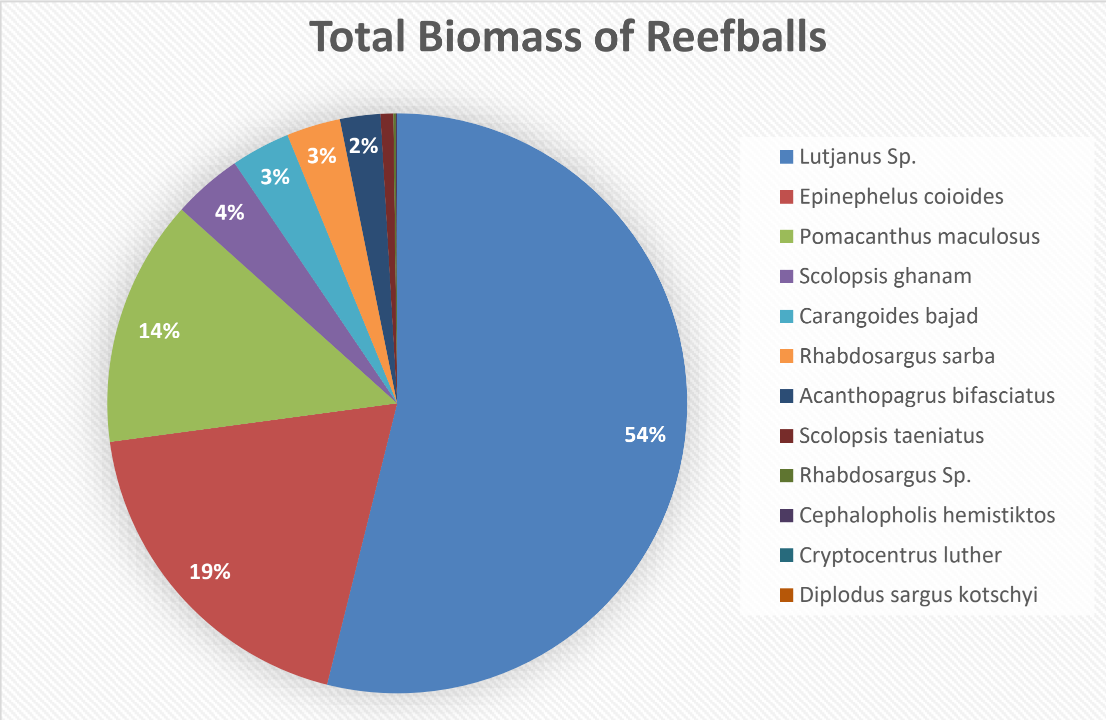

Length-weight (log a vs b) of *Lethrinus nebulosus* and Lethrinidae
Miscellaneous species
Family
Current species
Current estimate
Regression
10
1
0.1
0.01
0.001
0.0001
0.00001
a (log)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com

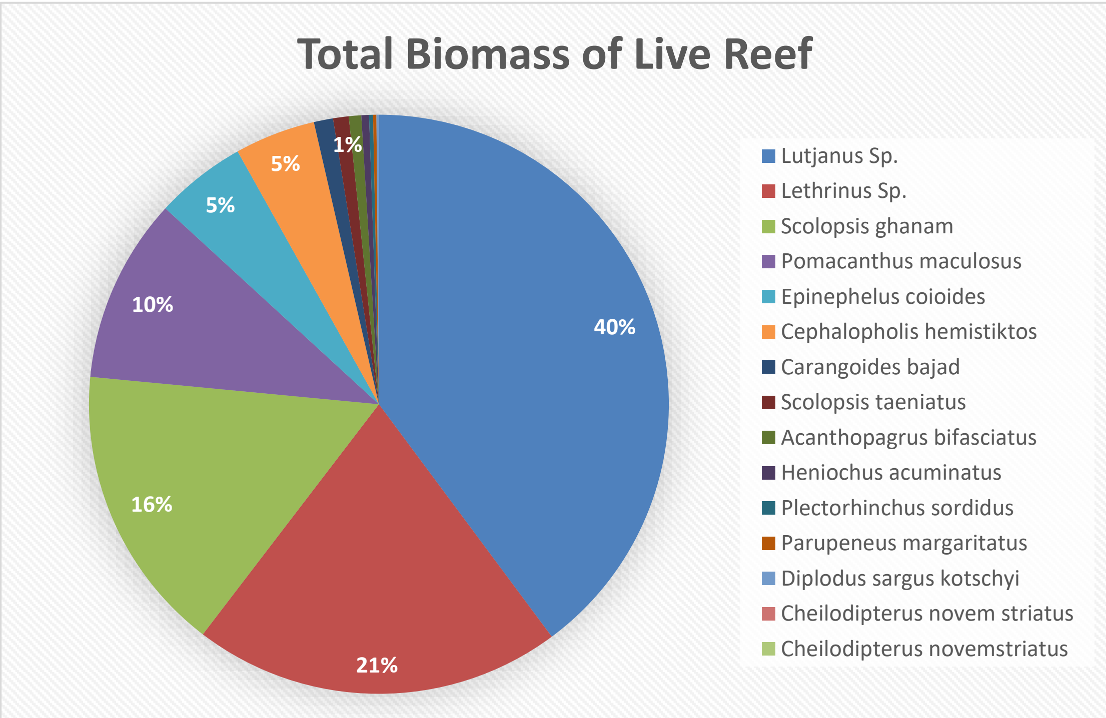

Length-weight (log a vs b) of *Pomacanthus maculosus* and Pomacanthidae
Miscellaneous species
Family
Current species
Current estimate
10
1
0.1
0.01
0.001
0.0001
0.00001
a (log)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
b
Highcharts.com

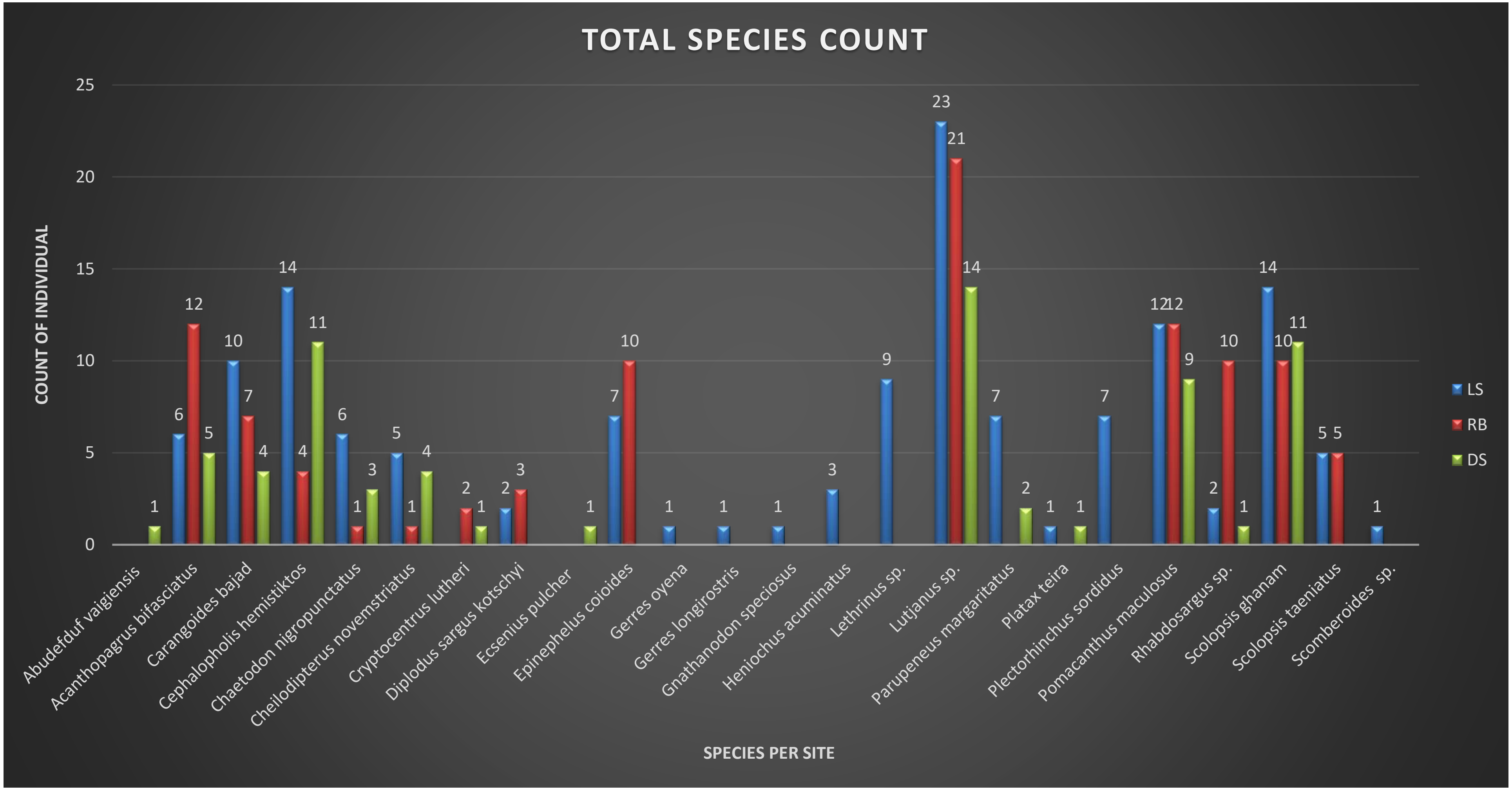
Appendix H: Sublimintray Graphs



Fish Biomass






TOTAL SPECIES COUNT
COUNT OF INDIVIDUAL
0
5
10
15
20
25
1
6
12
5
10
7
4
14
4
11
6
1
3
5
1
4
2
1
2
3
1
7
10
1
1
1
3
9
23
21
14
7
2
1
1
7
12
12
9
2
10
1
14
10
11
5
5
1
Abudefduf vaigiensis
Acanthopagrus bifasciatus
Carangoides bajad
Cephalopholis hemistiktos
Chaetodon nigropunctatus
Cheilodipterus novemstriatus
Cryptocentrus lutheri
Diplodus sargus kotschyi
Ecsenius pulcher
Epinephelus coioides
Gerres oyena
Gerres longirostris
Gnathanodon speciosus
Heniochus acuminatus
Lethrinus sp.
Lutjanus sp.
Parupeneus margaritatus
Platax teira
Plectorhinchus sordidus
Pomacanthus maculosus
Rhabdosargus sp.
Scolopsis ghanam
Scolopsis taeniatus
Scomberoides sp.
SPECIES PER SITE
LS
RB
DS