critters@lembeh

LEMBEH STRAIT | INDONESIA

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Introduction:
The following document details my time volunteering in Lembeh, including the projects I worked on, recommendations for future researchers, an outline and explanation of my research paper on the House Reef and the research paper itself.

Projects:
My initial time at Lembeh was spent working on my independent research for the University of Colorado at Boulder. The first goal of my independent research was to use the data recorded by Gen Heffernan (a volunteer researcher from October to November of 2009) in order to survey and analyze changes in population, family and species numbers at each of the six artificial reef structures on the resort House Reef. The second goal of my independent research was to use the data recorded by Olga Bondarenko (a volunteer researcher from July to August of 2008) to analyze growth rates of coral transplants on the Biorock and the Fish Houses. Due to project complications (which are detailed in my research paper), this portion of my research was altered in order to create baseline measurements of coral growth rates on the Biorock. My time at Lembeh was also spent doing coral transplantation, removing the invasive purple sponge from the Biorock structures, cleaning the marker buoys, removing trash from the House Reef, creating a House Reef Restoration Booklet for educational purposes, creating a Volunteer Guide to help inform future volunteers about ongoing and potential future projects, attempts to place a second shipwreck on the House Reef, and editing information about the origin of the names of the dive sites and biological information on the countless critters that can be found in the Lembeh Straight.

Future Recommendations:
The volunteer guide details ongoing and potential future projects for volunteers and researchers. Ongoing projects include coral transplantation, buoy maintenance, purple sponge removal, trash cleanup and coral growth measurements. In addition to these, there are countless potential projects for the House Reef, including follow up studies on the coral growth rates, changes in numbers of population, species and families on each of the six artificial structures, the implementation of new structures on the House Reef, and the

implementation of artificial reef structures on surrounding reefs that are damaged and in need of restoration. Another interesting project would be to chart and compare growth rates over time of the same species of coral when transplanted onto the six different artificial structures. Raising money to help continue and improve the House Reef Project is essential, and creating some sort of educational understanding with local villages about the importance of not polluting the Straight will be essential to the future success and health of all of the reefs in Lembeh.

Research Paper:
The following research paper was done as a part of my Independent Research study for the University of Colorado at Boulder. The paper is broken down as follows:

Abstract & Background: This section gives an abstract of the paper and background information drawn from scholastic journal articles about the question of the relationship between diversity and productivity on coral reefs.

Purpose: This section details the reasoning behind my particular project and the goals it set out to achieve.

Methods: This section details the methodology used for my particular experiment, which would be especially important to any researcher who intends to do a follow up experiment on the data collected by myself and Gen Heffernan.

Results: This section details both the results of the number of population, species and families found on each of the artificial structures as well as percentage and volumetric data on each. It also holds the baseline measurements taken on the corals that were transplanted onto the Biorock.

Discussion: This section details the conclusions made about the differences in diversity at each of the structures. ***This is especially important information for any future volunteers who intend to implement additional structures, as it details observations about what might make some structures more successful than others.***

The Following is my Official Independent Research Paper:

Population, Species and Family Analysis of Artificial Reef Structures

EBIO 4870: Independent Research Paper

Lindsey Dougherty

8/6/2010

Abstract

The relationship between diversity and ecosystem productivity of coral reefs is poorly understood and often debated. However, artificial reef structures are one alternative that increasing numbers of coastal nations are using in an attempt to both counteract the declining number and diversity of organisms on damaged coral reefs and improve the productivity and overall health of the reefs. The following experiment conducted a population, species and family data analysis for six alternative artificial reef structures in Lembeh Straight, Indonesia over an 8 month period in order to analyze the relative effectiveness of each type of structure. It was found that Fish Houses and Biorock structures were the most advantageous to maintenance or improvement of the above, with proximity to natural coral reefs, high interior volume, ample entry access to internal volume and the material of the structure being important characteristics. Baseline coral measurements were also taken in order for growth to be charted in the future and utilized as comparative data, both locally and globally.

1. Background

Indonesia is famed for incredible marine biodiversity. National Geographic named the islands of Raja Ampat as having the greatest coral reef biodiversity for their size in the world, with over 450 species of reef-building coral. The entire Caribbean, by comparison, has fewer than 70 species (Doubilet, 2007). These incredibly high numbers of coral species can be explained by the findings of Vollmer and Palumbi in 2002, which state that although coral should theoretically exhibit stifled species diversification and hybridization due to mass-spawning, the opposite is actually true, as many mass-spawning coral groups have rapidly diversified as exhibited by laboratory crosses from a number of genera (Vollmer ad Palumbi 2002). However, the International Union for the Conservation of Nature (IUCN) has listed 27% of 850 reef-building coral species in Indonesia as threatened (endangered and vulnerable) and 21% as near threatened (Polidoro *et. al*. 2008). The IUCN classifies the coral triangle region of the Indonesian-Malaysian-Philippine archipelago as the epicenter of marine biodiversity, with the highest coral species richness in the world. Unfortunately, the region also has the highest number of reef-building coral species in the threatened categories. Threats to the reef-building corals in these regions include bleaching and disease events from increases in sea temperatures, coastal development, coral extraction, sedimentation, pollution, and ocean acidification from increasing levels of atmospheric carbon dioxide (Polidoro *et. al.* 2008). The maintenance of diversity is important to reefs from a tourism perspective, as resorts strive to keep diverse reefs in order to bring in customers, and hence, bring revenue to the local economy. The effect diversity has on the health of the reef itself, however, is questionable.

For example, Johnson *et. al*. found in 2008 that although coral diversity on the Indo-Pacific reefs is roughly ten times higher than on Caribbean reefs, the rates of carbonate production and reef growth are similar on both, suggesting coral diversity is unimportant to overall reef growth rates. By studying the distribution of Caribbean fossil coral reefs through the seven intervals of the Late Oligocene to Late Pleistocene, they found that not only is coral diversity unrelated to reef development, but also that the most extensive Caribbean coral reef development period in the past 28 million years, the Late Pleistocene, was characterized by exceptionally low species diversity of reef-building corals, as this development period occurred after the number of coral species plummeted when half of the Late Pliocene species became extinct. Their research hypothesized that because the symbiotic relationship between the coral and the algae functions most effectively within a limited range of nutrient and temperature conditions, optimal environmental conditions can result in high production of carbonate by either low or high diversity coral communities, and that the characteristics of dominant coral species are therefore more important to reef growth than the number of species present. (Johnson *et. al*. 2008) Although high coral species diversity may not alter the rates of carbonate production by reefs, it was found by Kiessling in 2005 that coral species diversity can promote ecological stability in biogenic reefs on million-year timescales. The study found that the higher the mean reef coral diversity in a particular time interval, the smaller the change in skeletal density, style of reef building and biotic reef types in the subsequent time interval (Kiessling 2005). Therefore, coral diversity may have the potential to stabilize or minimize changes that reefs experience in future generations.

Although the diversity of coral species themselves may not impact the rate of carbonate production, the existence of coral may be an essential component to both the attraction and maintenance of other organisms in and near the reef. Bracken *et. al.* found in 2007 when studying fisheries' yields and their relationship to marine ecosystem function that areas with a higher number of species resulted in higher catch levels, deducing that increased species numbers led to an increased yield and increased productivity. They also found that the catch abundances were highest where there was coral present, suggesting that coral is a keystone element contributing to higher levels of species present. Finally, they found that when marine foundation species such as coral, kelp or sea grass was present, catch diversity increased one and a half times and catch abundances increased three and a half times. (Bracken *et. al.* 2007) This data all suggests that the presence of coral reefs is positively correlated with both the amount and diversity of fish species present. Expanding on the importance of reefs to organisms, Leis found in 2002 that in contrast to the historical notion that larvae are distributed passively at the mercy of currents, larvae are actually not passive at all. In fact, late-stage larvae of coral reef fish can swim faster than currents, sense where coral reefs may be from some distance, and actively seek out those reefs. (Leis 2002) Since coral reefs provide an amount of protection to larvae, their importance is paramount in this sense.

The loss of a keystone or habitat-modifying species through range shift can also have drastic effects on reefs, further supporting the need to maintain biodiversity in current or historical conditions. In 2008, Ling studied the pole-ward range expansion of the sea urchin *Centrostephanus rodgersii* and found that when the sea urchin moved into a new area due to increasing temperatures in their past habitat, there was a minimum net loss of approximately 150 taxa typically associated with the region. (Ling 2008) This stunning loss of biodiversity due to range-expansion of habitat-modifying organisms is drastic, and range expansion of these species can occur for any number of reasons, including changes in temperature, destruction, degradation, or changes in the physical or chemical nature of the environment. Current changes in ocean temperature are often cited as a major worry and destructive force on the diversity of coral reefs, but surprisingly, it was found by Pandolfi *et. al.* in 2003 that most of the reef ecosystems throughout the world were substantially degraded before the year 1900. They concluded that the chronic and severe historical decline of reef ecosystems had been occurring long before the first observations of mass mortality resulting from coral bleaching and outbreaks of disease were noted. (Pandolfi *et. al.* 2003) However, pollution is still a concern for species diversity, as it was found by McClanahan *et. al.* in 2007 when studying algal succession on coral reefs that diversity declined with an imbalance of excess nutrients (either nitrogen or phosphorus), was intermediate with the addition of both nutrients in sync, but was highest within the controls. (McClanahan *et. al*. 2007) The delicate balance needed to maintain species diversity is undoubtedly threatened by numerous factors.

One surprising characteristic of reefs that was found by Bellwood and Hughes in 2001 was that the area of suitable habitat within 600km of a study site was the most important predictor of fish diversity along with coral diversity for a measured area, rather than latitude, longitude or reef type (offshore versus continental). Furthermore, all of the areas they measured exhibited remarkably similar proportions of total diversity based on families, which may reflect the importance of different families in various feeding guilds. However, the areas that were classified as extremely species-poor reef sites did not show a similar proportion based on families. The significance of this finding is that areas with low diversity might be especially vulnerable to destruction or damage because they lack one or multiple families that might be able to help the reef recover (Bellwood and Hughes, 2001). This is yet another finding that highlights the necessity of maintaining species or family diversity.

Overall, there have been countless studies dealing with species diversity, especially in Indonesia, but there are far fewer studies assessing the relative success of various artificial structures used to rehabilitate reefs and increase species diversity. The methods of rehabilitation on artificial reefs are important to note, as understanding these methods can help researchers pinpoint what behavioral patterns are important. In 1985, Bohnsack and Sutherland found during a comprehensive analysis of studies done on artificial reefs that the increases in biomass from attraction to artificial reefs were due to adult immigration, as well as larval and juvenile recruitment. Increases in biomass from growth were due to food resources on artificial reefs, benthic food resources around artificial reefs, and plankton food resources. Decreases in biomass from losses occurred due to emigration, pollution, predation, and mortality. The study confirms the fact that the importance of attracting new fish biomass versus producing new fish biomass was unproven, but attracting new fish biomass seemed to be more important to the success of the reef (Bohnsack and Sutherland, 1985). Therefore, the measured changes in population numbers as well as species and family diversity (hence the attraction of new fish biomass) could be a useful tool in assessing the health of newly developed artificial reefs as a means to rehabilitating damaged reefs.

2. Purpose

Lembeh Resort in Northeast Sulawesi initiated a House Reef Project in March of 2003 to help regenerate the reef around the resort (the "house reef"), which has been damaged by anchoring, storms, pollution, sedimentation, fishing, sewage, runoff, and human/diver damage. The goal of their project is to evaluate methods of artificial reefs and expand the project to the reefs in front of the three villages in the closest vicinity to the resort. The house reef projects will be community protected areas where fishing is not allowed. The first purpose of this research will be the continuation of the project started in 2009 by a researcher from James Cook University in Australia, Genevieve Heffernan.

Genevieve observed species on each of the six artificial reef structures surrounding the house reef during October 10th to November 22nd of 2009 and created histogram data of population, species and family abundance. The goal in repeating her data collection is to evaluate the changes in population, species and family diversity on each of the six various artificial reef structures. The information gained through this research will serve to asses the changes in population and diversity of each of the artificial structures on the reef and will be relayed to Lembeh Resort. Based on the measured changes, the resort will have information about which structures are maintaining higher population, species and family numbers than others. Although other factors affect the health of a reef including the depth of the structure and time allowed to develop, analyzing changes in population and diversity is one way in which the success of the structures can be assessed. The changes will also be assessed based on volume in order to standardize results between structures that differ significantly in size. This information can guide Lembeh and other resorts in their future efforts to restore other damaged reefs.

The second purpose of this study was to follow up on information gathered by Olga Bondarenko during July - August of 2008. Olga was also a researcher from James Cook University in Australia. She compared the survival rate and growth of coral transplants on the Biorocks (with electrical current) and those on the Fish Houses (without electrical current). Twenty four colonies were planted on the Biorock and twenty six colonies were transplanted on the Fish Houses, all numbered using colored plastic tags and photographed. Unfortunately, of the fifty coral transplants that were catalogued, only five remain, and of those five, only three appear to be the original coral transplants. This high loss of transplants might have occurred either due to death, detachment, or movement/loss of the plastic markers. In addition, the coral fragments used were relatively small (most under 10cm) which may have contributed to the low attachment rate. Furthermore, the electricity to the Biorock stopped working during October of 2009, making the comparison between the affect of the electrical current versus a lack of electrical current on the coral growth rates impossible. The plastic markers used to numerically identify each transplant were covered with growth and for the most part unreadable, further hindering the follow up study. The three remaining fragments were unsuitable and statistically insignificant from which to draw general conclusions about coral growth rates, and were hence not included as a part of the study.

Therefore, as an addition to this experiment, ten coral transplants that were significantly larger and sturdier than those used for measurement in the past were tagged and measured for both width and height. A map of the placement of the corals was also created and pictures taken of each in order to simplify the process of data collection for future researchers. The Biorock was chosen as the site for the coral measurements because it is the easiest to navigate and will create the least confusion for follow up studies.

3. Methods

3.1 Study Site: Population, Species and Family Diversity

There are six artificial reef structures whose population, species and family numbers were analyzed, including the Biorock, Fish Houses, Reef Balls, Concrete Blocks, Fishnet, and Wreck. The

Structure	Date of Installation
Biorock	Dec 2007
Fish Houses	Jan 2006 – June 2007
Reef Balls	May 2003
Concrete Blocks	Oct 2009
Fish Net	Jul 2009
Wreck	Dec 2007

3.1a: Dates of Installation

three Biorock structures, which include “Tunnel”, “Pagoda” and “Dome”, are within 5.5m to 7.5m.The 23 Fish Houses are grouped as “Shallow” which are above 12m and “Deep” which are below 12m. The 18 Reef Balls are grouped as “Shallow” which are 16m-17.5m and “Deep” which are 17.5m-19m. The Concrete Blocks are at approximately 22m. The Fish Net is at approximately 17m and the Wreck is at approximately 25m. Figure 3.1a shows the list of installation dates for each structure and Figure 3.1b shows a detailed map of these artificial reef structures within the house reef. Photos of the structures can be found in Appendix A.

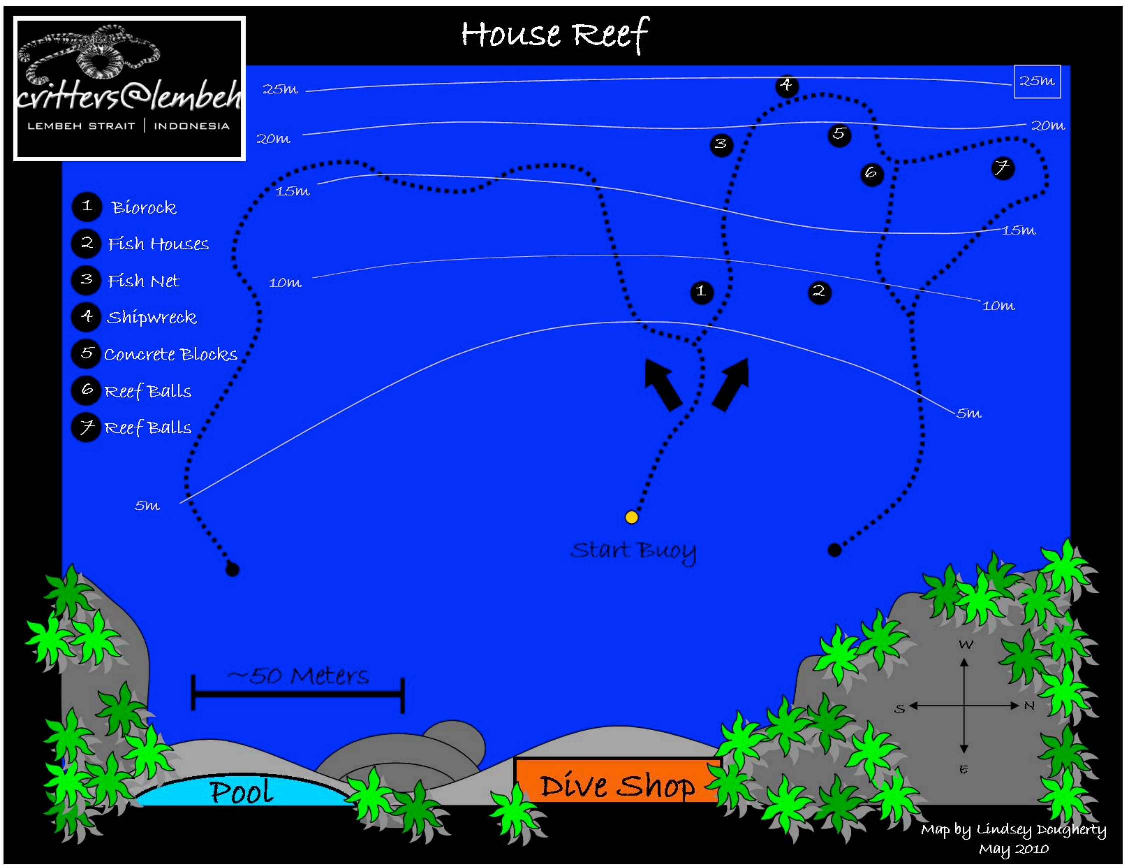


Figure 3.1b: Map of the house reef and the locations of the artificial structures.

3.2 Data Collection: Population, Species and Family Diversity

Attempting to mimic the previous researcher’s methods as closely as possible, the same techniques were used in dividing the structures for analysis. This included sectioning the six artificial reef structures into ten sub-structures, including separating the Biorock into the three separate structures of “Tunnel”, “Pagoda” and “Dome”, as well as separating the Fish Houses and Reef Balls into “Shallow” and “Deep” sections for analysis. Further following previous techniques, only organisms that were associating with the structure being assessed were recorded. For example, the count included organisms who were feeding from the structure, using the structure for protection, or actively involved with the structure in some way, rather than those who simply drifted past, either alone or in schools. Complete data is in Appendix B. In order to standardize results with the previous researcher, one official organism count was taken at each structure for 20-30 minutes, depending on the size and the depth of the structure. An underwater camera was used to document unknown species, which were later identified using *Reef Fish Identification: Tropical Pacific* (Allen et. al., 2003). Underwater slates were used to keep organism counts and take additional notes when necessary.

In order to compare the structures based on volume, approximate measurements were taken using fin kicks or arm lengths to obtain the lengths, widths, radii or height of the various structures. Only the volume within the structures was taken into consideration. For example, the area under the half-cylinders of the Biorock tunnel was measured and the area of each fish house was taken and then multiplied by the total number of fish houses.

3.3 Data Collection: Coral Growth Rates

Ten coral transplants were measured and marked on the three Biorock structures, including six on the Tunnel, two on the Pagoda, and two on the Dome. Each coral transplant was marked with bright red plastic straps, which will need to be cleaned periodically in order for them to be easily recognizable to future researchers. Measurements were first taken for the maximum width of the coral, and then for the maximum height of the coral. Measurements were taken in centimeters using a standard ruler. If the coral was situated vertically on the structure, the width measurement was taken horizontally across the front, and the height measurement was taken at 90 degree angle from the structure, keeping the data consistent for corals situated in different positions. Care was taken while measuring not to harm either the coral being measured or surrounding corals or organisms. Figure 3.3 shows a map of the location of the corals, which was created in order to eliminate confusion for follow up data measurements. Descriptions of the corals were noted (Figure 4.5a) using the *Indo-Pacific Coral Reef Field Guide* (Allen and Steene, 2002). This was done in order for future researchers to have a reference guide of which species of coral they are measuring, as well as a comparative tool to make sure the corals being measured are the same corals that were previously measured.

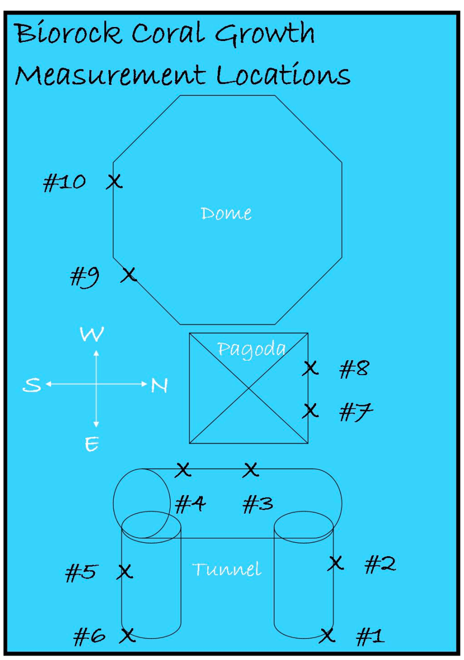
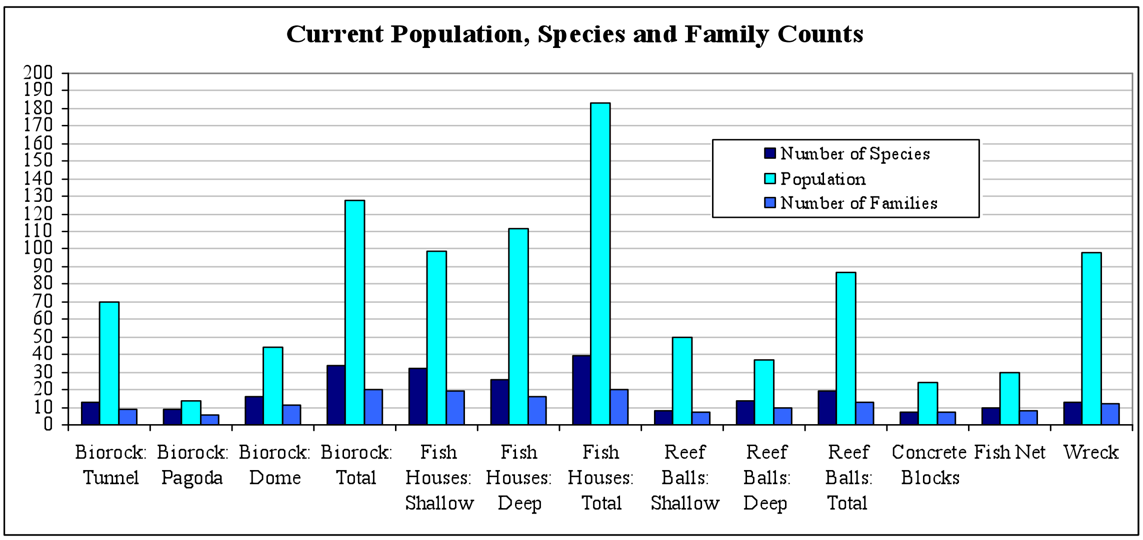


Figure 3.3: Map of Coral Measurement Locations

4. Results

4.1 Current Population, Species and Family Counts

Figure 4.1 shows the current counts of population, species and family numbers. These are the observations that were noted during May and June of 2010 and then later compared with the past data from October and November of 2009. Total current count changes are also noted for the structures that were divided, including the Biorock, the Fish Houses, and the Reef Balls.



4.2 Numerical Changes in Observed Count

Figure 4.2a details the increases or decreases in the population, number of species and number of families for each of the ten divided structures since the previous count in 2009. Total count changes are also noted for the structures that were divided, including the Biorock, the Fish Houses, and the Reef Balls. The wreck data was put in a separate graph due to a massive drop in population with the absence of a large school of fish, because including it in the cumulative graph made the other data points unreadable. It is shown below the cumulative graph as Figure 4.2b.

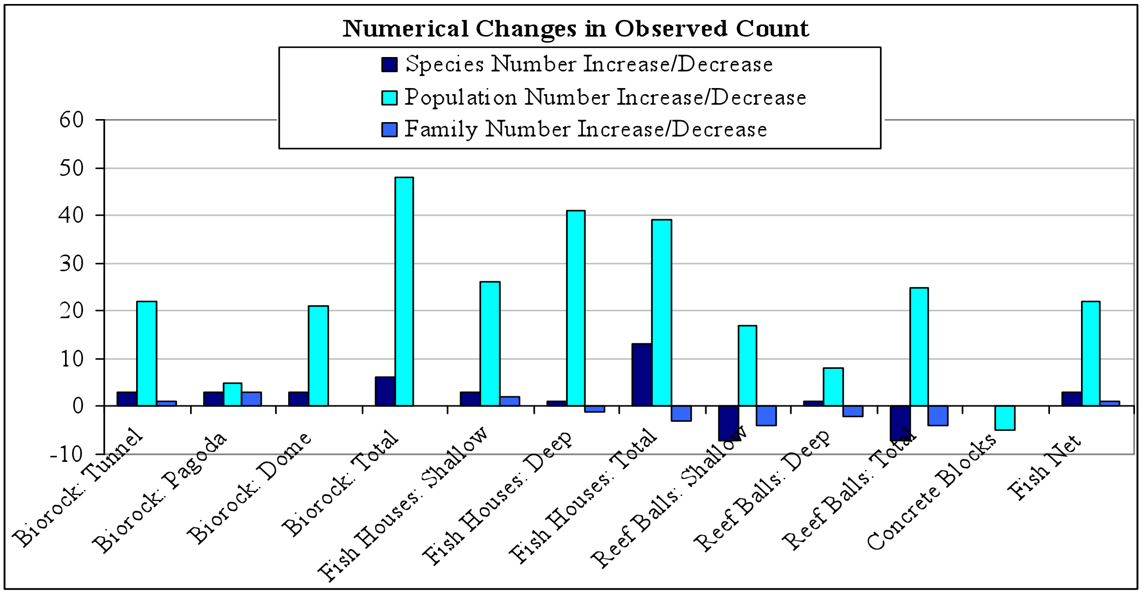


Figure 4.2a: Numerical Changes in Observed Count

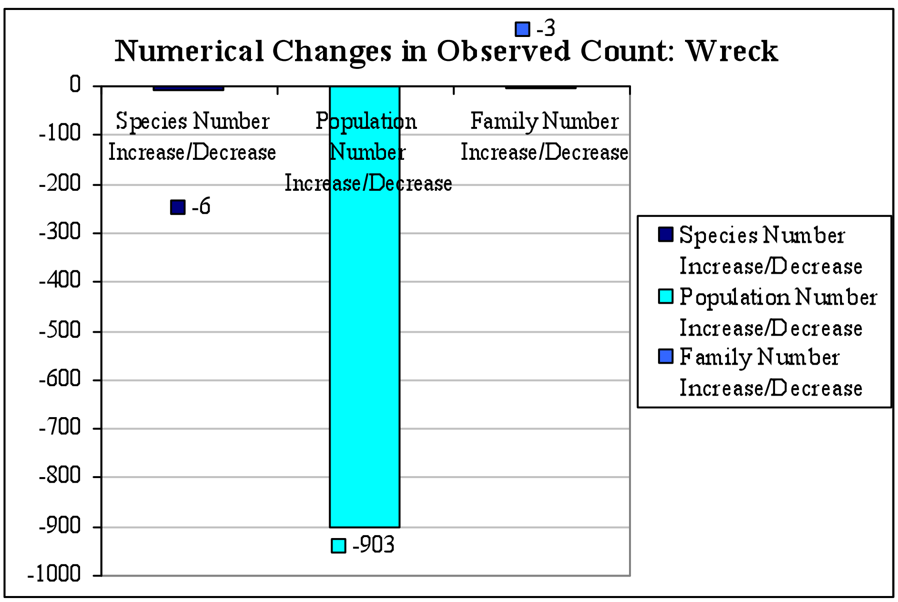


Figure 4.2b: Numerical Changes in Observed Count: Wreck

4.3 Percentage Changes in Observed Count

Figure 4.3a details the percentage increase or decrease in the population, number of species and number of families for each of the ten divided structures based on the numerical changes observed that are shown in Figure 4.2a. Total percentage changes are also noted for the structures that were divided, including the Biorock, the Fish Houses, and the Reef Balls. Again, the percentage changes for the wreck data were put in a separate graph due to a massive drop in population with the absence of a large school of fish, because including it in the cumulative graph made the other data points unreadable. It is shown below the cumulative graph as Figure 4.3b.

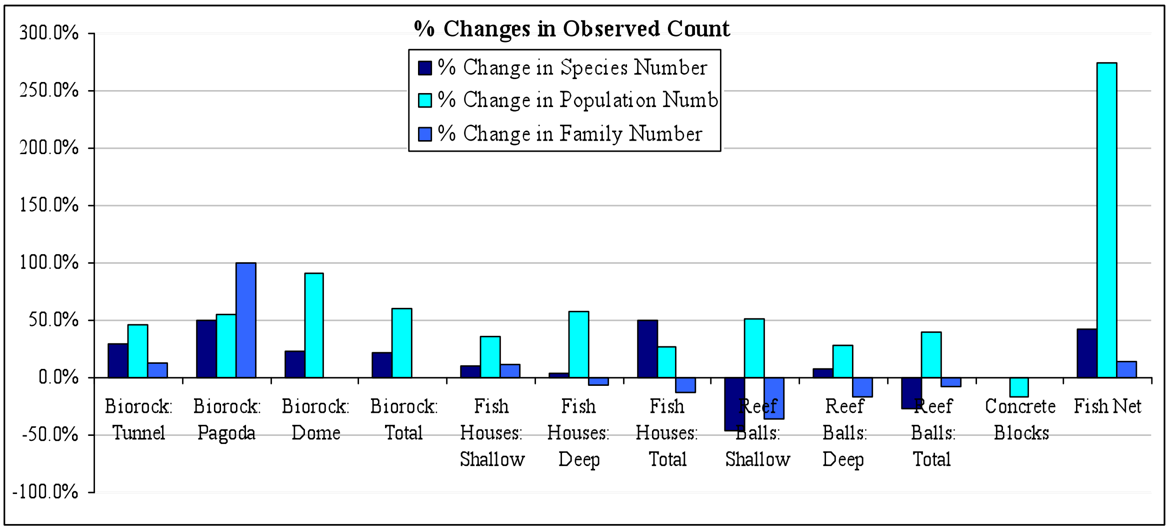


Figure 4.3a: Percentage Changes in Observed Count

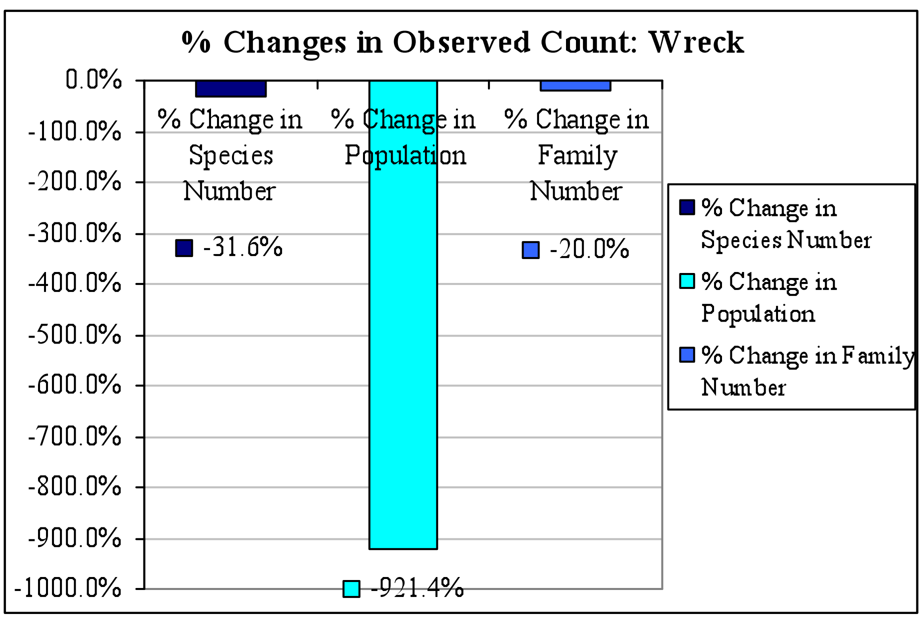


Figure 4.3b: Percentage Changes in Observed Count: Wreck

4.4 Population, Species Diversity and Family Diversity by Structure Volume

The volume of each structure was first measured (Figure 4.4a) and then the changes in population, species number and family number were compared on a per-volume basis (Figure 4.4b). The volume data from the wreck was not included in the graph due to the aforementioned problem. The numerical changes in observed count based on volume for the wreck were -0.21, -32.30 and –0.11 for species, population and family number increase/decrease per m^3 respectively.

Structure	Volume (m^3)
Biorock: Tunnel	28.7
Biorock: Pagoda	4.5
Biorock: Dome	33.5
Biorock: Total	66.7
Fish Houses: Shallow	16
Fish Houses: Deep	12
Fish Houses: Total	28
Reef Balls: Shallow	19
Reef Balls: Deep	17
Reef Balls: Total	36
Concrete Blocks	16
Fish Net	25
Wreck	28

Figure 4.4a: Volume of each Structure.

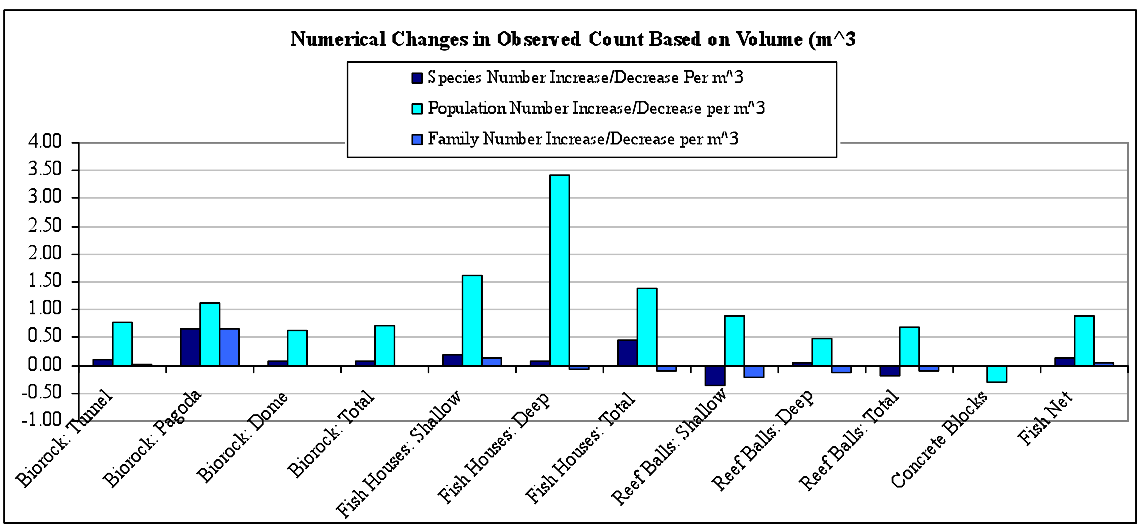


Figure 4.4b: Numerical Changes in Observed Count Based on Volume (m^3)

4.5 Coral Growth Rates Baseline Measurements: Biorock Structures

Figure 4.5a shows the data relating to the ten coral structures, including maximum width, maximum height, their location, and a description of their genus, species and family.

Number	Location	Max Width (cm)	Max Height (cm)	Direction When Facing	Description	Family
1	Tunnel	26	7	S	*Acropora secale*	Acroporidae
2	Tunnel	19	16	S	*Acropora valenciennesi*	Acroporidae
3	Tunnel	20	17	E	*Alveopora sp.*	Poritidae
4	Tunnel	20	14	E	*Porites nigrescens*	Poritidae
5	Tunnel	21	7	N	*Acropora digitifera*	Acroporidae
6	Tunnel	21	8	N	*Acropora cerealis*	Acroporidae
7	Pagoda	20	7	S	*Alveopora sp.*	Poritidae
8	Pagoda	16	13	S	*Acropora valenciennesi*	Acroporidae
9	Dome	21	18	N	*Acropora valenciennesi*	Acroporidae
10	Dome	23	14	N	*Tubastraea micrantha*	Dendrophylliidae

Figure 4.5a: Baseline Coral Measurements

5. Discussion

5.1 Biorock

Biorock is the application of a low voltage current to a conductive structure (any non-aluminum metal), where current causes dissolved minerals in seawater to precipitate and adhere to the structure. The current is harmless to swimmers and marine life. Biorock was developed by Professor Wolf H. Hilbertz in 1979. Hilbertz demonstrated that by establishing a direct electrical current between electrodes in sea water, which is an electrolyte, the anode will produce oxygen and chlorine, while the cathode creates a precipitate of calcium carbonates (the basic structure of coral), magnesium hydroxides, and hydrogen (Hilbertz, 1979). The electrodeposited minerals have recently been used for the construction of artificial coral reefs, as wild corals settle on the surfaces. Biorock has been found in studies to increase the survival of transplanted coral fragments in addition to attracting wild corals (Sabater and Yap, 2002). Therefore, the success and productivity of Biorock has potential for damaged reef restoration.

Unfortunately, the electrical current feeding into the Biorock at Lembeh resort has not been functioning since October of 2009. Regardless of this fact, the Biorock structures were the second most successful of all the artificial reef structures on the house reef, especially considering their short development time, as they were installed along with the wreck in December of 2007. The current counts of total population, number of species and number of families that the Biorock exhibit (128, 34 and 20, respectively) rival that of the Fish Houses (183, 39 and 20, respectively), which had the highest numbers of all the structures. That the Biorock structures were able to attract similar numbers to Fish Houses despite being installed up to a year later is noteworthy. Based on volume, the Biorock structures were not as successful as the Fish Houses, as the Fish Houses experienced a larger increase in species per m^3 and population per m^3 (0.46 versus 0.09 and 1.39 versus 0.63, respectively). However, the Fish Houses experienced a drop in families per m^3 while the Biorock maintained their family numbers at the same level as the previous experiment per m^3 (0.00 versus -0.11, respectively). From the measurements taken in 2009, the Biorock structures maintained family diversity, and exhibited increased population numbers and species diversity, (0.00%, 60.0% and 21.4% increases, respectively) whereas the Fish Houses experienced a drop in family numbers, a smaller gain in population but a larger gain in species numbers (-13.0% decrease, 27.1% and 50.0% increases, respectively).

In addition, the biorock seems to act as a nursery, as there were several schools of juvenile fish seeking protection from corals attached to the structures. One hypothesis about the success of the Biorock is the large volume of area through which fish can pass. Higher numbers of fish as well as fish that were larger in size were sighted inside the structure than in Fish Houses or the Reef Balls, which have smaller internal volumes. A combination of the structure of the Fish Houses and the Biorock might be beneficial to the design of future artificial structures, as the internal volume of the Biorock, the surface area of the concrete of the Fish Houses, and the strategic interspersed placement between natural coral reefs all seem to be factors that contribute to higher numbers of population, species and families.

5.2 Fish Houses

The Fish houses were perhaps the most successful artificial structure on the house reef. Although they have had a longer period to develop than the Biorock, as they were installed during January 2006 – June 2007, they exhibited increases in population and diversity numbers, with only a slight drop in the number of families present (27.1%, 50.0% and -13.0%, respectively). Regardless of the decrease in families present from the previous measurements, they exhibited the highest number of current families present along with the Biorock (20 total families each, with the next closest structure being the Reef Balls with 13 families), the highest number of species present (39 total species, with the next closest structure being the Biorock with 34 total species), and had by far the highest population numbers (183 total organisms, with the next closest structure being the Biorock with 128 total organisms). These high numbers are even more impressive considering that the Fish Houses have a smaller volume than any other structures except the Fish Net and the Concrete Blocks (see Figure 4.4a). The Fish Houses are placed through a wide area that is surrounded and interspersed by reefs, a fact which might result in higher traffic and hence higher numbers of species and populations. One beneficial aspect of the Fish Houses is that they seemed to serve as cleaning stations for various species of fish that rub their skin over the concrete. Although the Fish Houses have a much smaller total volume than the Biorock (28 m^3 versus 66.7 m^3, respectively), they are spread out over a much wider total area, which may account for their higher numbers of both populations and species.

5.3 Reef Balls

The Reef Balls were not as successful as either the Biorock or the Fish Houses. Installed in May of 2003, they have had four more years to develop than the Fish Houses, yet lack the high population, species and family numbers that the Fish Houses exhibit. One reason for this difference could be that the Reef Balls are located in deeper waters which don't receive as much sunlight, hindering the process of photosynthesis and decreasing the amount of production available to herbivorous fish. The internal volume of the Reef Balls might be another hindrance to their development, as they lack enough space for larger fish to use them as protection. In addition to a decrease in number of families (-8.3% decrease) the Reef Balls also experienced a substantial decrease in the number of species since the last survey (-27% decrease), suggesting that some species might have relocated to other structures. However, the population of the Reef Balls seems to be thriving (with a 40.3% increase since the previous measurements), and they showed an increase in population per m^3 of 0.69 organisms. However, this number is still not as strong as either the Biorock or the Fish Houses, which increased by 0.72 and 1.39 organisms per m^3 respectively, and the Reef Balls experienced a drop per m^3 of both the number of families and species (-0.11 and -0.19, respectively). With the extended period of time the Reef Balls have had to develop, they should be able to exhibit stronger and more competitive numbers with the other structures.

Finally, the group of shallow Reef Balls is somewhat offset from the overall grouping of the artificial structures, and is therefore not in as close of a proximity to natural coral reefs. This might have been part of the deterring effect that led to the decrease in numbers. Positioning artificial structures close by to natural coral reefs seems to be beneficial, and should be attempted in future placements.

5.4 Concrete Blocks

The Concrete Blocks were not as successful artificial structures as the nearby Fish Net, as population numbers decreased while species and family numbers stayed constant (-17.2%, 0.00% and 0.00% decreases, respectively). One reason for their lack of success could be their short time to develop, as they were the most recent addition to the house reef, installed in October of 2009. However, the Fish Net, which was installed only two months prior to the Concrete Blocks, showed increases in population, species and family numbers (275.0%, 42.9%, and 14.0% increases, respectively), and the location of the Fish Net is within ten meters of the Concrete Blocks. The reason behind this difference might be the structures used, as the Concrete Blocks are filled with several items that aren't necessarily beneficial places for fish and other organisms to live, such as a computer. These types of items should generally be avoided, rather using items that provide ample protection or areas from which to feed or seek protection, such as concrete or metal.

5.5 Fish Net

The Fish Net showed great promise for success given its short time to develop as it was installed in July of 2009. With an increase in population, species and family numbers, (275.0%, 42.9%, and 14.0% increases, respectively), it will hopefully continue to diversify in the future. The Fish Net also showed substantial increases in population, species and families per m^3 (0.88, 0.12 and 0.04, respectively, as compared to the Concrete Blocks at -0.31, 0.00 and 0.00, respectively), being the only total structure to experience positive changes in all three areas. Part of the reason behind this increase in numbers might have been due to the fact that a large number of sponges were recently transplanted onto the Fish Net in April of 2010. Since the Fish Net and Concrete Blocks are in such close proximity, this might explain some of the differences in numbers.

5.6 Wreck

The Wreck experienced a severe drop in population due to the absence of a large school of fish (900 organisms), along with a drop in species and family numbers (decreases of -921.4%, -31.6% and -20.0%, respectively). The most likely reason for this drop is due to considerable stress that has been put on the area due to the attempt to sink another boat nearby. There has been excess debris, high diver activity, structure movement, and frequently interrupted site arrangement. Another possible reason for this is the accelerated degradation of the structure. Since its placement in December of 2007, the wreck has much of its structural integrity, with both sides crumbling nearly to the seafloor. Therefore, it provides less protection, which could be part of the reason for the decrease in organisms present there. Because of the relatively small volume of the Wreck (28 m^3), it also experienced a substantial drop in population, species and families per m^3, -32.3, -0.21 and -0.11, respectively. However, wrecks are generally a beneficial place for organisms as they provide protection and shelter, and the decline in diversity on this particular wreck should only be considered when the extenuating circumstances are acknowledged.

5.7 Coral Growth Measurements

The initial coral growth measurements taken during this study can be used as a baseline for future studies on house reef growth rates. By charting the growth of the ten specific corals on the Biorock structures, rates can be compared both locally and globally to see where they lie on a broader scale of observations.

5.8 Overall Observations

Overall, the most successful structures based on changes population, species and family numbers and volumetric comparison were the Fish Houses and the Biorock. The placement of these structures suggests that locations near surrounding coral reefs in water with depths accessible to ample amounts of sunlight are preferable. High internal volume and amply-sized access to that internal volume was also a characteristic that seemed to correlate with higher levels of population, species and family diversity. The most successful materials for coral growth and retention as well as the ability to attract higher numbers of species were concrete and metal, with larger surface areas seeming to be more beneficial to sustained growth.

The Fish Net was the next most successful structure, likely due to its high internal volume and structural provisions for small fish. The recent sponge additions also seemed to have helped the Fish Net diversity, suggesting that increasing the number of transplants on the structures would be beneficial to increasing population, species and family numbers. The Reef Balls were less successful which may be due to their depth, small internal volumes, small access entries to their internal volumes, and one group’s lack of proximity to surrounding reefs.

The Concrete Blocks and the Wreck were the least successful structures. The Concrete Blocks may have been inhibited due to the fact that the structures used were not all ideal surfaces for coral attachment. The Wreck experienced abnormal stress due to external events, so its results should only be examined in light of the aforementioned circumstances. Overall, every artificial structure on the house reef, although some were more successful than others, have all managed to take on transplanted corals and experience levels of population, species and family diversity that were previously absent in the area. In that sense, every structure is a success and a representation of the potential for future reef restoration through artificial structures.

Acknowledgements

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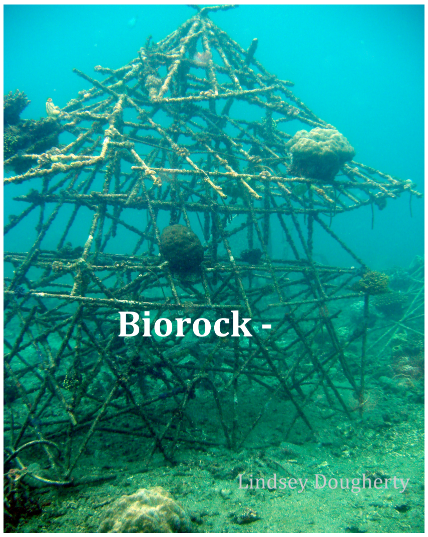
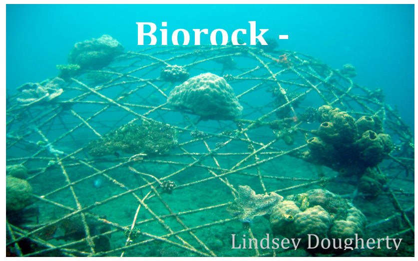
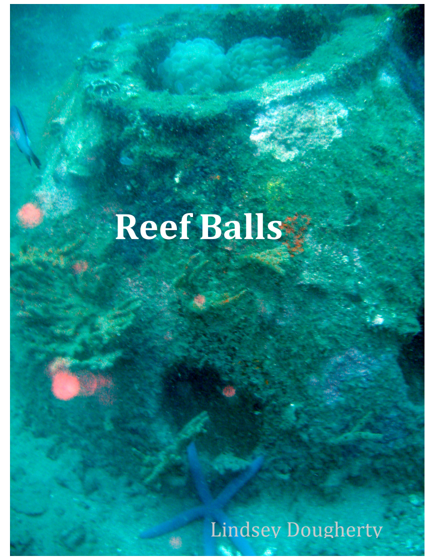
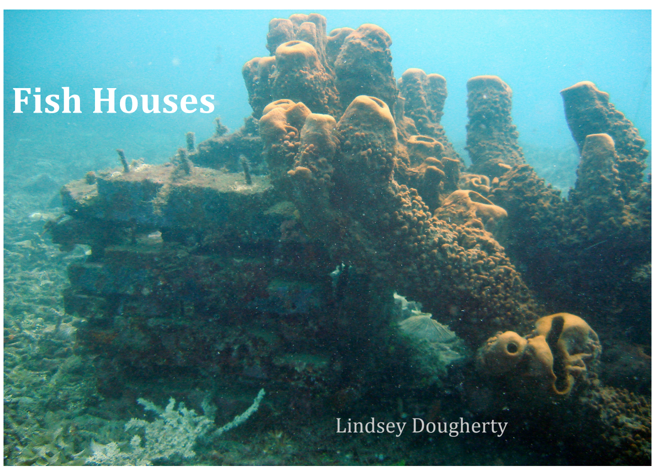
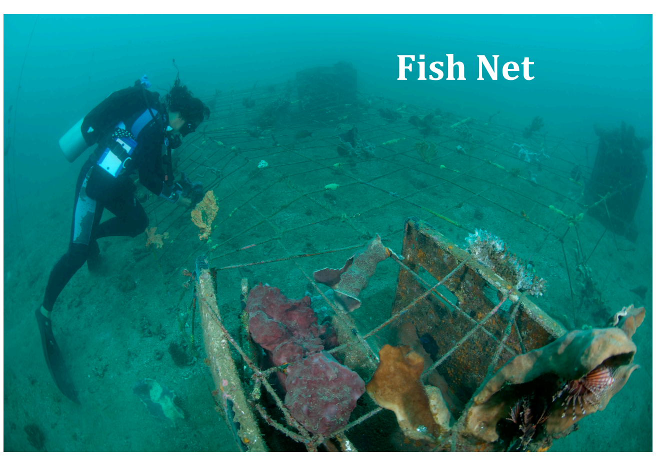
Appendix A: Photos of the Artificial Structures











Appendix B: Population, Species and Family Counts by Structure

Biorock: 3 Structures

1. Pagoda

Gen

	Common Name	Family	Genus and Species	Count
1	Parrotfish	Scaridae		2
2	Javanese Damoiselle	Pomacentridae	*Neoglyphidodon oxyodon*	2
3	Angelfish	Pomacanthidae		1
4	Eight Banded Butterfly fish	Chaetodontidae	*Chaetodon octofaciatus*	2
5	Lined Butterflyfish	Chaetodontidae	*Chaetodon lineolatus*	1
6	Hawkfish (female)	Pomacentridae	*Cirrhitchthys falco*	1
			Population	**9**
			Species	**6**
			Families	**3**

Lindsey

	Common Name	Family	Genus and Species	Count
1	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	2
2	Common Lionfish	Scorpaenidae	*Pterois volitans*	1
3	Morish Idol	Zanclidae	*Zanclus cornutus*	1
4	Javanese Damsel	Pomacentridae	*Neoglyphidodon oxiodon*	1
5	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	2
6	Spiny chromis	Pomacentridae	*Acanthochromis polyacanthus*	2
7	Yellow Chromis	Pomacentridae	*Chromis analis*	2
8	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	1
9	Blue Streak Cleaner Wrasse	Labridae	Labroides dimidiatus	1
	Species % increase	**50.0%**	**Population**	**14**
	Population % increase	**55.6%**	**Species**	**9**
	Family % increase	**100.0%**	**Families**	**6**

2. Tunnel

Gen

	Common Name	Family	Genus and Species	Count
1	Bleakers Parrotfish	Scaridae	*Chlorurus bleekeri*	8
2	Golden Spadefish	Ephippidae	*Platax boersii*	6
3	Filefish	Monocanthidae		2
4	Javanese Damoiselle	Pomacentridae	*Neoglyphidodon oxydodon*	2
5	White Patch Damoiselle	Pomacentridae	*Dischisotodus crysopecilus*	2
6	Dash lined Blenny	Blenidae	*Blenniella interupter*	2
7	Yellow Chromis	Pomacentridae	*Chromis analis*	8
8	Feather star	Crinoidea		2
9	Dark- Finger Coral Crab	Decapoda	*Decapoda Xanthidae*	6
10	Redeye Hovering Goby	Gobiidae	*Bryaniops natans*	10

			Population	**48**
			Species	**10**
			Families	**8**

Lindsey

1	Spotted Toby	Tetradontidae	*Canthigaster solandri*	2
2	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	1
3	Spiny chromis	Pomacentridae	*Acanthochromis polyacanthus*	2
4	Morish Idol	Zanclidae	*Zanclus cornutus*	1
5	Bleakers Parrotfish	Scaridae	*Chlorurus bleekeri*	1
6	Coral Demoiselle	Pomacentridae	Neopomacentrus nemurus	50
7	Wedgespot Damsel - Juvenile	Pomacentridae	Pomacentrus cuneatus	2
8	Indian Half-and-Half Chromis	Pomacentridae	Chromis dimidiata	2
9	Tiger Cardinalfish	Apogonidae	Cheilodipterus macrodon	2
10	Redbreasted Wrasse	Labridae	Cheilinus fasciatus	2
11	Chain-Lined Wrasse	Labridae	Halichoeres leucurus	1
12	Mud Goby	Gobiidae	Cryptocentrus cyanotanid	2
13	Three Striped Whiptail - Variation	Nemipteridae	*Pentapodus trivitatus*	2

Species % increase	**30.0%**	**Population**	**70**
Population % increase	**45.8%**	**Species**	**13**
Family % increase	**12.5%**	**Families**	**9**

3. Dome

Gen

1	Morish Idol	Zanclidae	*Zanclus cornutus*	3
2	Three Striped Whiptail - Variation	Nemipteridae	*Pentapodus trivitatus*	2
3	Goldback Damoiselle	Pomacentridae	*Pomacentrus Nigromanus*	5
4	Sangai Cardinalfish	Apogonidae	*Apogon Sangiensis*	1
5	Black Ribbon Eel	Muraenidae	*Rhinomuraena quaesita*	1
6	Blue Seastar	Echinodermata	*Linckia laevigata*	1
7	Redtail Parrotfish	Labridae	*Scarrus pyrrhurus*	1
8	Blue Spotted Ray	Dasyatidae	*Taeniura* sp.	1
9	Black Saddled Toby	Tetradontidae	*Canthigaster valentini*	1
10	Cardinal	Apogonidae	*Apogon* sp.	1
11	Cardinal	Apogonidae	*Apogon* sp.	3
12	Trumpet fish	Aulostomidae	*Aulostomus chinensis*	2
13	Banded Messmate Pipe fish	Doryrhamphinae	*Chorythoichthys* sp.	1

Population	**23**
Species	**13**
Families	**11**

Lindsey

1	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	2
2	Spiny chromis	Pomacentridae	*Acanthochromis polyacanthus*	2
3	Broadclub Cuttlefish	Sepiidae	Sepia latimanus	1
4	Indian Half-and-Half Chromis	Pomacentridae	Chromis dimidiata	6
5	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	3
6	Morish Idol	Zanclidae	*Zanclus cornutus*	1
7	Black-Saddled Toby	Tetradontidae	*Canthigaster valentini*	1
8	Blue barred parrotfish	Scaridae	Scarus ghobban	1

9	Eclipse Parrotfish	Scaridae	Scarus russellii	2
10	Green-Headed Wrasse	Labridae	Halichoeres chlorocephalus	2
11	Backstripe Wrasse	Labridae	Cirrhilabrus katerinae	16
12	Blue Seastar	Echinodermata	*Linckia laevigata*	1
13	Pearl Scaled Angelfish	Pomacanthidae	Centropyge vroliki	1
14	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	1
15	Pastel-green Wrasse	Labridae	Halichoeres cholropterus	2
16	Dash lined Blenny	Blenidae	*Blenniella interupter*	2

Species % increase	**23.1%**	**Population**	**44**
Population % increase	**91.3%**	**Species**	**16**
Family % increase	**0.0%**	**Families**	**11**

Total Biorock Count		**Total Biorock Changes**	
Gen:		**Species % increase**	**21.4%**
Population	**80**	**Population % increase**	**60.0%**
Species	**28**	**Family % increase**	**0.0%**
Families	**20**		
Lindsey:			
Population	**128**		
Species	**34**		
Families	**20**		

Fish Houses: 2 Structures

Fish Houses - Shallow

Gen

1	Javanese Damoiselle	Pomacentridae	*Neoglyphidodon oxyodon*	1
2	File fish	Monocanthidae		2
3	White Belly Damoiselle	Pomacentridae	*Amblyghphidodon leucogaster*	1
4	Eight Banded Butterfly fish	Chaetodontidae	*Chaetodon octofaciatus*	3
5	Parrot fish	Scaridae		2
6	Morish Idol	Zanclidae	*Zanclus cornutus*	5
7	Trumpetfish	Aulostomidae	*Aulostomus chinensis*	2
8	Violet Damoiselle	Pomacentridae	*Neopomacentrus violascens*	2
9	Filefish	Monocanthidae		1
10	Red Head Dwarf Gobie	Gobiidae	*Trimma* sp.	1
11	Nudibranch	Nudibranchia	*Chromodoris* sp.	1
12	One Spot Damsel	Pomacentridae	*Chrysiptera unimaculata*	2
13	File fish	Monocanthidae		1
14	Variegated Lizard fish	Synodontidae	*Synodus variegatus*	2
15	Javanese Damoiselle	Pomacentridae	*Neoglyphidodon oxyodon*	2
16	One Spot Damsel	Pomacentridae	*Chrysiptera unimaculata*	1
17	Golden Spadefish	Ephippidae	*Platax boersii*	2
18	Brown Damselle	Pomacentridae		2
19	Pacific Double Saddled Butterflyfish	Chaetodontidae	*Chaetodon ulietensis*	1
20	Orange Anenomy fish	Pomacentridae	*Amphiprion sandaracinos*	8
21	Banggai Cardinal fish	Apogonidae	*Pterapogon kauderni*	16
22	Variegated Lizard fish	Synodontidae	*Synodus variegatus*	1
23	Wrasse	Labridae		4

24	Trigger	Balistidae		1
25	Eight Banded Butterflyfish	Chaetodontidae	*Chaetodon octofaciatus*	4
26	Orange Lined Triggerfish	Balistidae	*Balistapus undulatus*	1
27	Spotted Coral Grouper	Serranidae	*Plectropomus maculatus*	1
28	Dwarfgobie	Gobiidae	*Trima* sp.	2
29	White-Belly Damsel	Pomacentridae	*Amblyglyphidodon leucogaster*	1
			Population	73
			Species	29
			Families	17

Lindsey

1	Javanese Damsel	Pomacentridae	*Neoglyphidodon oxiodon*	7
2	Titan Triggerfish	Pemperidae	Parapriacantus ransonneti	*2*
3	Spiny chromis	Pomacentridae	*Acanthochromis polyacanthus*	24
4	Eight-Banded Butterflyfish	Chaetodontidae	*Chaetodon octofaciatus*	3
5	Morish Idol	Zanclidae	*Zanclus cornutus*	3
6	Orange Anemonefish	Pomacentridae	*Amphiprion sandaracinos*	5
7	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	2
8	Six-Banded Angelfish	Pomacanthidae	*Pomacanthus sexstriatus*	1
9	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	2
10	Redbreasted Wrasse	Labridae	Cheilinus fasciatus	2
11	Variegated Lizard fish	Synodontidae	*Synodus variegatus*	1
12	Goby	Gobiidae	Cryptocentrus cyanotanid	7
13	Orange Lined Triggerfish	Balistidae	*Balistapus undulatus*	3
14	Spotted Toby	Tetradontidae	*Canthigaster solandri*	1
15	Blue Seastar - White Version	Echinoderm	*Linckia laevigata*	1
16	Wedgespot Damsel - Juvenile	Pomacentridae	*Pomacentrus cuneatus*	3
17	Eclipse Parrotfish	Scaridae	Scarus russellii	1
18	Bullethead Parrotfish	Scaridae	Clorus sordidus	1
19	Spiny chromis - Variation	Pomacentridae	*Acanthochromis polyacanthus*	4
20	Blue Seastar	Echinodermata	*Linckia laevigata*	*3*
21	Indian Half-and-Half Chromis	Pomacentridae	Chromis dimidiata	2
22	Broadclub Cuttlefish	Sepiidae	Sepia latimanus	1
23	Three Striped Whiptail - Variation	Nemipteridae	*Pentapodus trivitatus*	1
24	Double Banded Soapfish	Serranidae	*Diploprion bifasciatum*	4
25	Japanese Surgeonfish	Acanthuridae	*Acanthurus japonicus*	2
26	Strapweed Filefish	Monacanthidae	*Pseudomonacanthus macrurus*	1
27	Floral Wrasse	Labridae	Cheilinus chlorourus	2
28	Barramundi	Serranidae	*Cromileptes altivelis*	1
29	Fine-Lined Surgeonfish	Acanthuridae	*Acanthurus grammoptilus*	2
30	Blue Streak Cleaner Wrasse	Labridae	Labroides dimidiatus	1
31	Redbreasted Wrasse	Labridae	Cheilinus fasciatus	3
32	Redhead Dwarf Goby	Gobiidae	Trimma species	3
	Species % increase	**10.3%**	**Population**	99
	Population % increase	**35.6%**	**Species**	32
	Family % increase	**11.8%**	**Families**	19

Fish Houses - Deep

Gen

1	Javanese Damoiselle	Pomacentridae	*Neoglyphidodon oxyodon*	3
2	Long Barbel Goatfish	Mullidae	*Parupeneus ciliatus*	1
3	Snapper	Lutjanus		20
4	Penshell Bivalve	Bivalvia	*Atrina pectineita*	4
5	Yellow Eyed Cardinal fish	Apogonidae	*Apogon monospilus*	1
6	Angelfish	Pomacanthidae		1
7	Fingerprint Toby	Tetradontidae	*Canthigaster compressa*	1
8	Reticulated Puffer	Tetradontidae	*Arothron reticularis*	1
9	Tripple Tail Wrasse	Labridae	*Chelinus trilobatus*	1
10	Crosshatch Goby	Gobiidae	*Amblygobius decussatus*	1
11	Damsel fish	Pomacentridae	*Pomacentrus coelestis*	7
12	Nudibranch	Nudibranchia	*Chromadoris magnifica*	1
13	Nudibranch	Nudibranchia	*Chromadoris elisabethina*	1
14	Goby	Gobiidae	*Cryptocentrus cyanotanid*	1
15	Nudibranch	Nudibranchia	*Phyllidia coelestis*	1
16	Trumpetfish	Aulostomidae	*Aulostomus chinensis*	2
17	Damsel	Pomacentridae		6
18	Wrasse	Labridae		4
19	Violet Damoiselle	Pomacentridae	*Neopomacentrus violascens*	7
20	Eight Banded Butterflyfish	Chaetodontidae	*Chaetodon octofaciatus*	2
21	Pearly Monacle Bream	Nemipteridae	*Scolopsis margaritifer*	1
22	Snail	Gastropoda		1
23	Sailfin waspfish	Tetarogidae	*Paracentropogon* sp.	1
24	Blue Seastar - white version	Echinodermata	*Linckia laevigata*	1
25	Reef Lizardfish	Synodontidae	*Synodus variegatus*	1
			Population	71
			Species	25
			Families	17

Lindsey

1	Eight-Banded Butterflyfish	Chaetodontidae	*Chaetodon octofaciatus*	5
2	Three Striped Whiptail - Variation	Nemipteridae	*Pentapodus trivitatus*	6
3	Six-Banded Angelfish	Pomacanthidae	*Pomacanthus sexstriatus*	**1**
4	Strapweed Filefish	Monacanthidae	*Pseudomonacanthus macrurus*	1
5	Barramundi	Serranidae	*Cromileptes altivelis*	1
6	Nudibranch	Nudibranchia	*Chromodoris sp.*	3
7	Indian Half-and-Half Chromis	Pomacentridae	*Chromis dimidiata*	5
8	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	4
9	Blue Seastar	Echinodermata	*Linckia laevigata*	3
10	Floral Wrasse	Labridae	*Cheilinus chlorourus*	1
11	Orange Lined Triggerfish	Balistidae	*Balistapus undulatus*	2
12	Blue Streak Cleaner Wrasse	Labridae	*Labroides dimidiatus*	3
13	Blue barred parrotfish	Scaridae	*Scarus ghobban*	1
14	Eclipse Parrotfish	Scaridae	*Scarus russellii*	2
15	Morish Idol	Zanclidae	*Zanclus cornutus*	4
16	Green-Headed Wrasse	Labridae	*Halichoeres chlorocephalus*	4
17	Spiny chromis	Pomacentridae	*Acanthochromis polyacanthus*	30
18	Violet Damoiselle	Pomacentridae	*Neopomacentrus violascens*	3

19	Bullethead Parrotfish	Scaridae	*Chlorurus sordidus*	1
20	Wedgespot Damsel - Juvenile	Pomacentridae	*Pomacentrus cuneatus*	9
21	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	2
22	Redbreasted Wrasse	Labridae	*Cheilinus fasciatus*	1
23	Orange-Striped Pygmy Basslet	Liopropomatinae	*Luzchichthys waitei*	8
24	Brown demoiselle	Pomacentridae	*Neopomacentrus filamentosus*	9
25	Giant Cuttlefish	Sepiidae	*Sepia latimanus*	1
26	Boxer Shrimp	Crustacea	*Stenopus hispidus*	2

Species % increase	**4.0%**	**Population**	112
Population % increase	**57.7%**	**Species**	26
Family % increase	**-5.9%**	**Families**	16

Total Fish House Count

Gen:

Population	**144**	**Species % increase**	**50.0%**
Species	**26**	**Population % increase**	**27.1%**
Families	**23**	**Family % increase**	**-13.0%**

Lindsey:

Population	**183**
Species	**39**
Families	**20**

Reef Balls: 2 Structures

Reef Balls - Deep

Gen

1	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	2
2	Blackstriped Cardinalfish	Apogonidae	*Cheilodipterus nigrotaeniatus*	1
3	Trumpetfish	Aulostomidae	*Aulostomus chinensis*	1
4	Feather star	Crinoidea		1
5	Black Saddled Toby	Tetradontidae	*Canthigaster valentini*	3
6	Common Blue Seastar- White	Echinodermata	*Linckia laevigata*	2
7	Wrasse	Labridae		3
8	Banded Messmate Pipe fish	Doryrhamphinae	*Corythoichthys* sp.	8
9	Mud Gobie	Gobiidae	*Valenciennea limicola*	1
10	Toothy Cardinalfish	Apogonidae	*Cheilodipterus isostigmus*	1
11	Common Lionfish	Scorpaenidae	*Pterois volitans*	1
12	Boxer Shrimp	Crustacea	*Stenopus hispidus*	3
13	Morish Idol	Zanclidae	*Zanclus cornutus*	2

Population	**29**
Species	**13**
Families	**12**

Lindsey

1	Burrough's Damsel - Juvenile	Pomacentridae	*Pomacentrus burroughi*	4
2	Banded Messmate Pipe fish	Doryrhamphinae	*Corythoichthys* sp.	8
3	Boxer Shrimp	Crustacea	*Stenopus hispidus*	2
4	Translucent Cleaner Shrimp	Caridae	Periclimenes sp.	1
5	Double Banded Soapfish	Serranidae	*Diploprion bifasciatum*	1

6	Three-striped Whiptail	Nemipteridae	Pentapodus trivittatus	4
7	Violet Demoiselle	Pomacentridae	Neopomacentrus violascens	2
8	Indian Half-and-Half Chromis	Pomacentridae	Chromis dimidiata	2
9	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	1
10	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	2
11	Redbreasted Wrasse	Labridae	Cheilinus fasciatus	1
12	Wedgespot Damsel - Juvenile	Pomacentridae	Pomacentrus cuneatus	5
13	Goby	Gobiidae	Cryptocentrus cyanotanid	2
14	Floral Wrasse	Labridae	Cheilinus chlorourus	2
	Species % increase	**7.7%**	**Population**	**37**
	Population % increase	**27.6%**	**Species**	**14**
	Family % increase	**-16.7%**	**Families**	**10**

Reef Balls - Shallow

Gen

1	Trumpetfish	Aulostomidae	*Aulostomus chinensis*	2
2	Bullethead Parrotfish	Scaridae	*Clorus sordidus*	2
3	Double Banded Soapfish	Serranidae	Diploprion bilfasciatum	4
4	Three-striped Whiptail - Variation	Nemipteridae	*Pentapodus trivittatus*	1
5	Blue Streak Cleaner Wrasse	Labridae	*Labroides dimidiatus*	1
6	Morish Idol	Zanclidae	*Zanclus cornutus*	2
7	Surgeon	Acanthuridae	*Acanthurus* sp.	9
8	Javanese Damoiselle	Pomacentridae	*Neoglyphidodon oxiodon*	2
9	Triggerfish	Balistidae		1
10	Finelined Surgeonfish	Acanthuridae	Acanthurus sp.	3
11	Wrasse	Labridae		1
12	Chocolate Grouper	Serranidae	*Cephalopholis boenak*	1
13	Green Sergent	Pomacentridae	*Abudefduf whitleyi*	1
14	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	2
15	Dwarf Gobie	Gobiidae	*Trimma sp.*	1
			Population	**33**
			Species	**15**
			Families	**11**

Lindsey

1	Double Banded Soapfish	Serranidae	*Diploprion bifasciatum*	3
2	Morish Idol	Zanclidae	*Zanclus cornutus*	2
3	Floral Wrasse	Labridae	Cheilinus chlorourus	3
4	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	1
5	Common Lionfish	Scorpaenidae	*Pterois volitans*	1
6	Orange Socket Surgeonfish	Acanthuridae	Acanthurus auranticavus	1
7	Chain-Lined Wrasse	Labridae	Halichoeres leucurus	22
8	Striped Catfish	Plotosidae	Plotosus lineatus	17
	Species % increase	**-46.7%**	**Population**	**50**
	Population % increase	**51.5%**	**Species**	**8**
	Family % increase	**-36.4%**	**Families**	**7**

Total Reef Ball Count

Gen:

Population	**62**	**Species % increase**	**27.0%**
Species	**26**	**Population % increase**	**40.3%**
Families	**18**	**Family % increase**	**8.3%**

Lindsey:

Population	**87**
Species	**19**
Families	**14**

Concrete Blocks

Gen

1	Tiger Cardinalfish (juv.)	Apogonidae	*Cheilodipterus macrodon*	2
2	Porcupinefish	Diodontidae	*Diodon* sp.	1
3	Reef Lizardfish	Synodontidae	*Synodus variegatus*	2
4	Common Lionfish	Scorpaenidae	*Pterois volitans*	1
5	Three-striped Whiptail - Variation	Nemipteridae	*Pentapodus trivittatus*	1
6	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	2
7	Bandspot Cardinalfish	Apogonidae	*Apogon selas*	20

Population	**29**
Species	**7**
Families	**7**

Lindsey

1	Blue Streak Cleaner Wrasse	Labridae	Labroides dimidiatus	1
2	Black-Saddled Toby	Tetradontidae	*Canthigaster valentini*	3
3	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	2
4	Balloonfish	Diodontidae	Diodon holocanthus	2
5	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	1
6	Burrough's Damsel - Juvenile	Pomacentridae	*Pomacentrus burroughi*	13
7	Dash lined Blenny	Blenidae	*Blenniella interupter*	2

Species % increase	**0.0%**	**Population**	**24**
Population % increase	**-17.2%**	**Species**	**7**
Family % increase	**0.0%**	**Families**	**7**

Fish Net

Gen

1	Batavia Spadefish- mid juvenile	Ephippidae	*Platax batavianus*	1
2	Common Lionfish	Scorpaenidae	*Pterois volitans*	1
3	Vermiculated Angelfish	Pomacanthidae	*Chaetodontoplus mesoleucus*	1
4	Black Saddled Toby	Tetradondidae	*Canthigaster valentini*	1
5	Filefish	Monocanthidae		1
6	Orangelined Triggerfish	Balistidae	*Balistapus undulatus*	1
7	Longhorn Cowfish	Ostraciidae	*Lactoria comuta*	2

Population	**8**
Species	**7**

			Families	**7**

Lindsey

1	Common Lionfish	Scorpaenidae	*Pterois volitans*	4
2	Black-Saddled Toby	Tetradontidae	*Canthigaster valentini*	3
3	Spotted Toby	Tetradontidae	*Canthigaster solandri*	2
4	Burrough's Damsel - Juvenile	Pomacentridae	*Pomacentrus burroughi*	9
5	Golden Spadefish	Ephippidae	*Platax boersii*	1
6	Longfin Spadefish	Ephippidae	*Platax teira*	1
7	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	1
8	Double Banded Soapfish	Serranidae	*Diploprion bifasciatum*	4
9	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	1
10	Blue Streak Cleaner Wrasse	Labridae	*Labroides dimidiatus*	4

Species % increase	**42.9%**	**Population**	**30**
Population % increase	**275.0%**	**Species**	**10**
Family % increase	**14.0%**	**Families**	**8**

Wreck

Gen

1	Goldspotted Sweetlip	Haemulidae	*Plectrhinchus flavomaculatus*	20
2	Triggerfish	Balistidae		2
3	Striped Catfish	Plotosidae	*Plototus lineatus*	10
4	Orange Banded Coralfish	Chaetodontidae	*Coradion chrysozonus*	1
5	Eclipse Parrotfish	Scaridae	*Scarus* sp.	1
6	Blue Seastar - white version	Echinodermata	*Linckia laevigata*	1
7	Bluesteak Cleaner Wrasse	Labridae	*Labroides dimidiatus*	3
8	Black Saddled Toby	Tetradondidae	*Canthigaster valentini*	4
9	Yellowmouth Cardinalfish	Apogonidae	*Archamia goni*	900
10	Broadclub Cuttlefish	Sepiidae	*Sepia latimanus*	1
11	Trumpetfish	Aulostomidae	*Aulostomus chinensis*	1
12	Star Puffer- Older juvenile	Tetradondidae	*Arothron stellatus*	1
13	Black Velvet Angelfish	Pomacanthidae	*Chaetodontoplus melanosoma*	2
14	Violet Soldierfish	Holocentridae	*Myripristis* sp.	1
15	Dancing Shrimp	Rhynchocinetidae	*Rhynchocinetes durbanensis*	40
16	Wrasse	Labridae		3
17	Thornback cowfish	Ostraciidae	*Lactoria fornasiri*	1
18	Five Lined Cardinalfish	Apogonidae	*Cheilodipterus quinquelineatus*	8
19	Philippine Wrasse	Labridae	*Pseudocoris* sp.	1

Population	**1001**
Species	**19**
Families	**15**

Lindsey

1	Morish Idol	Zanclidae	*Zanclus cornutus*	2
2	Black-Saddled Toby	Tetradontidae	*Canthigaster valentini*	6
3	Yellowmargin Triggerfish	Balistidae	Pseudobalistes flavimarginatus	2
4	Burrough's Damsel - Juvenile	Pomacentridae	*Pomacentrus burroughi*	3
5	Blacklip butterflyfish	Chaetodontidae	Chaetodon kleinii	2
6	Three-spot Squirrelfish	Holocentridae	Sargocentron comutum	6
7	Balloonfish	Diodontidae	Diodon holocanthus	6

8	Spotted Toby	Tetradontidae	*Canthigaster solandri*	1
9	Indonesian Sweet Lips	Haemulidae	Diagramma sp.	13
10	Double Banded Soapfish	Serranidae	*Diploprion bifasciatum*	4
11	Blue Seastar	Echinodermata	*Linckia laevigata*	1
12	Trumpetfish	Aulostomidae	*Aulostomus chinesis*	2
13	Yellowtail Tubelip	Labridae	*Diproctacanthus xanthurus*	50
	Species % increase	**-31.6%**	**Population**	**98**
	Population % increase	**-921.4%**	**Species**	**13**
	Family % increase	**-20.0%**	**Families**	**12**