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Paleoecological Study of Unguja: Can Past Environments be Inferred from Fossilized Corals and Mollusks?

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Abstract

A study was conducted on Unguja, an island off the eastern coast of Tanzania, to provide an overview of the paleoecology found in the cliff shelves across the island. It is known that Zanzibar was a submerged reef from the Neogene, approximately 23 million years ago (Ma). Two tests were carried out in 16 sites around the island. One test looked at coral fossils, while the other studied fossilized shells. Both tests measured biodiversity, with one specifically studying patterns of ocean currents, and the other studying nutrient levels and deposition rates. Biodiversity tests were inconclusive but coral diversity showed a decrease in trend from west to east, while mollusk diversity showed a decrease from east to west. The coral tests showed that the ocean current might have been transporting coral spores from the northeast part of the island. The mollusk test can be used to show how the depositional rates on the eastern part of the island were lower than the western, as well as that the nutrient availability was greater on the eastern side. Appendix I can be used to show what the reef may have looked like in the past, and can set a precedent for future studies of global climate change and show patterns of reef life in Unguja.

Introduction

<u>Importance of a Paleoecological View of Unguja</u>

Reef ecology studies very diverse and complex ecosystems, whose stability and balance maintenance affects not just the reef itself, but many populations who rely on it, such as migrating birds, fish and humans. “Coral reefs have become major sources of income for poor countries of the tropics that own most of the reef” (Veron et. al. 2000). Live corals have important ecosystem functions including, providing food for local communities, providing habitats and hatching sites for fish, protecting beaches from sand erosion, and creates an aesthetic draw for tourism (Richmond 2011). Ancient corals that make up the island are used as building materials in houses and roads, create oil and natural gas, as well as creating scenic attributes from mountain ranges to carved gifts for foreign guests (Veron 2009).

Zanzibar is a poor country that makes extensive use of both live and fossilized corals The island as a whole does not have a lot of research or extensive understanding of its geologic history. Paleoecology is the study of relationships of fossil organisms to past physical and biological environments, as well as the relationships of organisms to each other (Brenchley et. al. 1998). This discipline tracks “changes through time in the atmosphere, hydrosphere and lithosphere [as they] are intimately linked and related to the evolution of the biosphere” (Brenchley et. al. 1998).

This study is a paleoecological attempt to describe, reconstruct, and understand the workings of the coral reef that made up Zanzibar about 23 million years ago (Richmond 2011). This description can help to determine the environment and “spheres” in which the coral survived and functioned. *Corals of the World* claims, “the pattern of diversity at a species level is primarily the outcome of ocean circulation patterns and resulting geographic and evolutionary changes from Plio-Pleisteocene to present” (Veron et. al. 2000). Making estimations of these species and their environmental preferences, and life modes may help people better understand reef functions today and how quickly plants and animals adapt to new and changing conditions.

Along with coral studies, it is necessary to study the species that have past inhabited the coral, compared to species that currently inhabit it. Studying the fossil mollusk species found in fossil corals allows for the geologic environment to be further reconstructed. The fossil mollusks can allow you to identify unknown corals based on which species inhabit which corals. They also can give clues as to the temperature of water, and availability of nutrients that are required for optimal shell growth (Valentine 2006). By studying a combination of fossil coral and mollusk species, it is possible to reconstruct a geologic environment that may be difficult to otherwise interpret.

Mollusk Biology

Phylum Mollusca encompasses a variety of types of organisms, for example bivalves, gastropods, and cephalopods. There are certain classifications for each class in the phylum. The three classes that are most prevalent in this study are Bivalvia, Gastropoda, and Polyplacophora.

Class Bivalvia contain is characterized by species with two valves that are connected at the umbo, a feature on the dorsal end (Richmond 2011). Bivalves are benthic, and burrow in the substrate or attach to a surface within the substrate (Richmond 2011). The valves are connected at the dorsal end by an elastic ligament that has been partially calcified, as well as adductor muscles. The number and size of adductor muscles varies between species (Giribet and Wheeler 2002). Based on the number and type of adductor muscle, when a bivalve species dies, the muscles will relax and cause the shell to open, allowing for easier disarticulation, or the muscles will remain contracted and keep closed, which will often lead to the shell remaining articulated as it is fossilized. Bivalves also have an extensible foot, which can be used for burrowing, for infaunal bivalves, or can be used for mobility, for epifaunal bivalves (Giribet and Wheeler 2002). Infaunal bivalves extend siphon canals through the sediment for intake of nutrients from the seawater, and excretion (Richmond 2011). There are over 700 species in the Western Indian Ocean region (Richmond 2011).

Class Gastropoda represents organisms that have one-pieced shells which are usually in a coiled shape (Dance 1992). Gastropod shells generally look the same at every age in their development, but add on to the opening of their shell. Essentially, they coil around themselves to add more mass (Dance 1992). During growth, the body goes through a process called torsion, in which the visceral mass and shell are twisted and take on a spiral shape. The twisting causes one member of each pair of organs to be reduced to one, for example, two kidneys to one (Macdonald 1979). The Gastropoda class can be further subdivided based on biological characteristics including gill presence and placement, and strucure of the neurological system.

Class Polyplacophora represents the chiton species. These species are very distinctive in their morphology. They have eight calcareous plates on the dorsal side of their body, which are surrounded by a tough muscular girdle (Richmond 2011). The girdle contains hair, spines, or scales depending on the species (Richmond 2011). The radula contains 17 teeth per row, which are used for scraping and biting, and are covered with magnetite (Ernisse 2003). There are about 40 species in the Western Indian Ocean area (Richmond 2011).

Coral Biology

Coral reefs are made from individual polyps, which are animals of the Coelenterta, or Cnidaria, Tribe. It is names so because of the large body cavity, called a coelenteron with a wall made of cells, connective tissue and muscle fibers, which all members of the tribe have. Other relatives of coral in this family are jellyfish, anemone, and hydroids (Erhardt et. al. 2005).

Each polyp is an individual animal with a cup, or tube-like wall, and a foot, which attaches the polyp to the substrate. The upper end of the body, and opening acts as both a mouth and an anus, using pressure changes within the body and tentacles that extend to draw in passing plankton (Erhardt et. al. 2005). Scleractinia and other stony corals use indigestible material (calcium ions) to build a calcite or aragonite skeleton around their body wall for further stability and protection (Veron et. al. 2000).

Colonies form when similar polyps grow and attach to each other, and a lot of nutrients are gathered because of the coral polyps' unique symbiosis with zooxanthellae, photosynthetic protists which live in the polyp's body wall, which provide oxygen and glucose for the corals whilst getting protection from the elements and stable location where sunlight and co2 may be obtained (Erhardt et. al. 2005).

Each polyp is made of a vertical tube structure called a “corallite”, with radiating, vertical plates, separated and joined by horizontal sheets. (Veron et. al. 2000). The layout of a polyp is comprised of five main parts. The proportion of these parts, the spacing of polyps, growth patterns of colonies, and the individual polyps' regulation of shape and size determines the species of coral, generally (Veron et. al. 2000). The five distinguishing elements are: Septo-costae (the vertical radiating plates), synapticulae (horizontal sheets between the septa), coenosteum (sponge-like porous material in between corallites), sterome (non-porous layer within the body wall) and the epitheca (the this nonporous layer outside the body wall) (Veron et. al. Vol. 1, p. 49). The last three of these elements (coenosteum, sterome and epitheca) as well as the dissupiment (a blister-like thin membrane/ skeleton in between corallites) are used to describe corals. The coesteum and sterome are the two parts that fossilize the most and therefore are helpful in determining fossilized coral types (Veron et. al. Vol. 1, p. 50).

Three quarters of corals are hermaphroditic and use spawning as a passive dispersal technique. This method of reproduction relies heavily on ocean currents, and suitable, stable environments; the polyps only regulate the time of release and the time afloat of the planulae and gametes they release (Veron et. al. 2000).

Many corals create a stable structure that provides habitats for many fish, invertebrates, and provides nesting grounds for migrating fish. It is a symbiosis of many organisms, like all complex ecosystems (Erhardt et. al. 2005). Stony corals, whose polyps secrete calcium ions and aragonite skeletons, provide a reef structure that remains after the polyps themselves die, becoming geologic structures (Erhardt et. al. 2005). The formation of these geologic reefs was affected by factors that affect very diverse ecological systems (Veron et. al. 2000). As such, reefs are subject to global environmental changes, such as tectonic plate movements, temperature, sea level, or ocean circulation changes (Veron et. al. 2000).

<u>Reef History</u>

Reefs have been found to exist for more than two thousand million years, as the calcium skeletons break down to limestone and retain coral structures (Erhardt et.al. 2005). Reef-like structures have been identified from stromatolites in the Proterozoic Era with simple blue-green algae. Animal polyps then were found secreting calcareous coral reefs in the Cambrian, and the Devonian era was a distinctly successful era for coral to expand and diversify, with many fishes and invertebrates as well (Veron et. al. 2000). The rugose and tabulate corals are especially well preserved due to their calcite secretions, but became extinct at the end of the Proterozoic. Starting from the Triassic Period, Scleractinian corals are more common, although they don't preserve as well because they secrete aragonite as opposed to the longer lasting calcite skeletons (Veron et. al. 2000). Coral families such as Astrocoeniidae are especially well documented in the fossil record because of their form, collumnae and neatly arranged solid septa, and are easily identified (Veron et. al. 2000).

As Charles Darwin described, there are three types of reefs: fringing reefs, barrier reefs and atolls (Veron et. al. 2000). Reefs are usually located in areas with water temperatures between 20 and 30 degrees Celsius, and the zooxanthellae which help the polyps survive become stressed and leave the corals if the water temperature is increased or decreased by just 1 or 2 degrees outside of its comfort zone. The earth's average sea temperatures have been increasing at a rate of 1-2 degrees per century (Vernon et al. 2000), which makes our understanding of coral ecosystems more important in order to help preserve these natural resources.

Zooxanthellae need sunlight to produce nutrient and chemicals for the polyps to exist by helping the coral polyps' metabolism and calcification, and recycling nutrients (Veron et. al. 2000). Reef locations are therefore highly predictable since the environmental factors that the zooxanthellae require are so specific. Reefs are usually in shallow water, keeping them near land with clear water and ample sunlight. Because of their drifting mode of reproduction, coral reef species are found at points where an incoming current first hits land (Veron et. al. 2000), as well as the fact that current brings open ocean plankton to feed the coral polyps at this point (Erhadt et. al 2005). Reef growth is inversely related to the amount of sediment runoff from the land it surrounds (Erhardt et. al. 2005).

Geologic History of Unguja

The geomorphology of Unguja is characterized based on specific events in geologic history. Unguja is part of an inner coastal shelf that was uplifted during Tertiary Times (Nyandwi and Kangwe 2006). The actual development of the island occurred in the Neogene, in which the sea levels across the planet were changing drastically (Arthurton et al. 1999). Between Miocene and Holocene, there was a global rise in sea level caused by glacier melting (Muzuka et al.). This rise in sea level submerged the channel between the mainland and Unguja (Nyandwi and Kangwe 2006). The oldest rocks found on the island are of lower Miocene age, and are known as Masingini beds (Nyandwi and Kangwe 2006). These beds are marly sands with limestone, and reddish-brown sandstone (Nyandwi and

Kangwe 2006). The other common rocks found on the island are of Pleistocene-Holocene age. These consist most of coral and molluscan remains and rest upon the Miocene age rocks (Nywandi and Kangwe 2006). These Pleistocene limestones formed the cliff shelves that are seen today (Arthurton et al. 1999). The patterns of erosion on the lower portion of the cliff shelves also exhibit how the sea level was higher during the formation of the island.

Knowing the factors that affect the health of reefs will allow this study to approximate the conditions and location of the reef that is now and its prehistoric environment.

According to *Corals of the World* (Veron et. al. 2000) the East African coast has extant zooxanthellae genera about 40 million years old, dating to the Oligocene. Unguja along with Mafia, as a fossilized reef, is alive and teeming with biodiversity as an inshore coral reef system that was created during the Pleistocene epoch and separated from the mainland by shallow water channels (Richmond 2011). While today Unguja is located south of the equator and has mainly strong northwestern winds and currents passing by it, in the Oligocene it was subject to a southwest-heading ocean current (coming from the northeast) due to the tropical circum-global circulation of warm ocean water (Veron et. al. 2000). This current was conducive to the widening of coral and reef environments because of the Tethys sea and the Central American Seaway, which would eventually cut off this global current, resulting in later diversification of coral (Veron et. al. 2000).

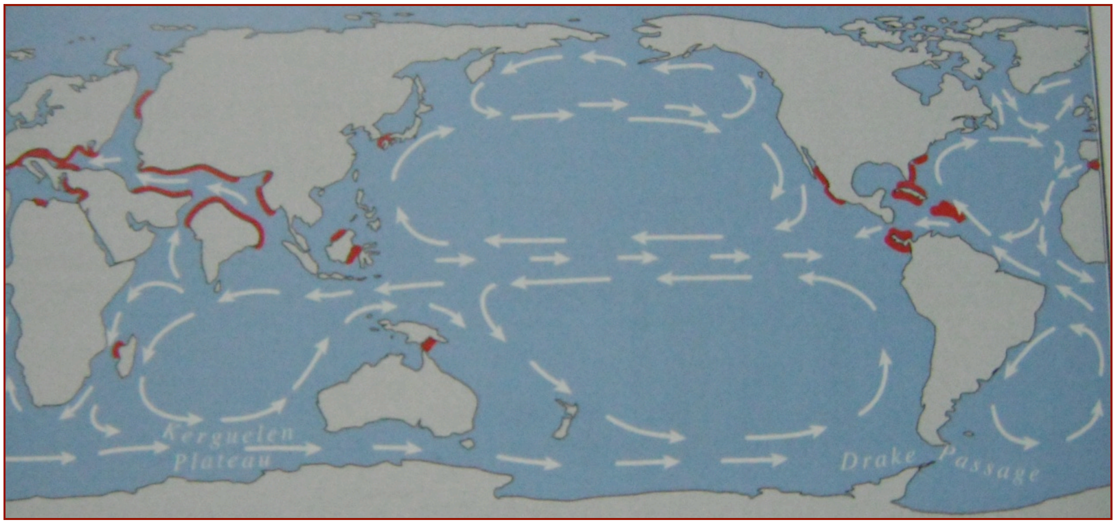

Figure 1. Prehistoric Eocene Ocean currents at the time period before Unguja reef's formation, currents going southwest along the East African Coast stay consistent throughout the Pleisteocene/Neogene (Veron et. al. Vol. 1, p. 64).

Reefs are started by an ocean current bringing spores from corals, which first attach themselves to the sediment. The reef of Unguja lived and grew in one time period, before it was in inhospitable environments due to change in ocean temperature due to global fluctuations or other factors. The size and zonation of the Unguja reef is something that can be studied however:

> "As reefs everywhere are planed off at the same level, their thickness is determined by the depth of the water in which they grow, not by the amount of time they spend growing. Minor flexures of the continental shelf have no doubt altered details of this depth pattern many times, but such movements have no relevance to the [reef's] age" (Vernon 2009).

This indicates that the exposed reef edges on the beach cliffs in Unguja are from the same reef, and formed during the same time period. Therefore, fossils from these cliffs around Unguja are comparable as living within the same environment.

Learning about the zonation of the reef can tell us the conditions that it lived in. Considering the global ocean circulation during the reef's formation, of the tropic-ocean current heading SW the NE of Unguja and coral reproduction and spreading techniques, it may be hypothesized that there should be more coral found on the NE side of the island and more turbid-withstanding corals and less sandy substrate as compared to the SW side of Unguja. Using this logic, it has been claimed that in the West Indian Ocean, because of reef spreading and ocean currents from the east, creates patterns where biodiversity falls in geographical areas from East to West (McClanahan et. al.2000).

Study Area

The study was conducted on Unguja, a small island off the eastern coast of Tanzania. Eight sites were sampled across the north, south, east, and western coasts of the island. The sites included Chumbe Island, Chwaka, Jambiani, Kendwa, Kiwengwa, Mangapwani, Mbweni, and Paje. These sites were chosen because of their proximity to the coast, as well as the abundance of cliff shelves in the area. Two sample areas were taken at each site (See Figure 1).

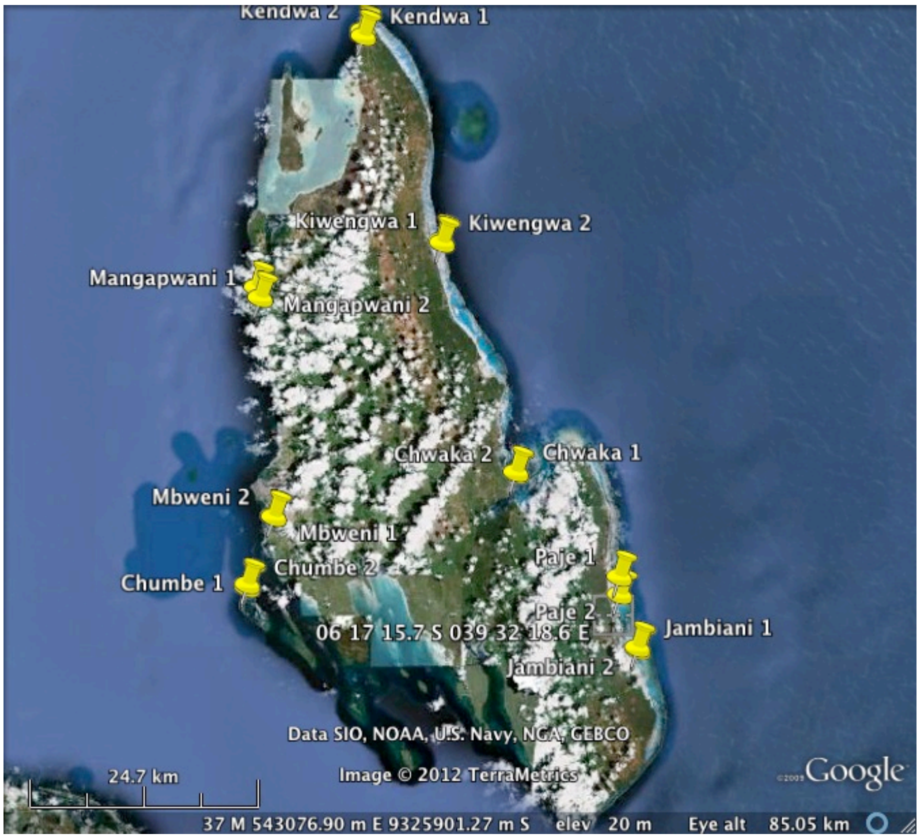

Figure 2. 16 sites across Unguja. 16 sites in total, two from each area.

Methodology

At each of the eight sites, two different sample areas were chosen. Sample areas were chosen based on accessibility, but were otherwise generated randomly. At each area, a 30 meter transect was established using a tape measurer. Horizons were made at 1.5 meters height from the ground at each site. At Jambiani the cliffs were very low, covered in vegetation, and plant roots disturbed the bedrock. Therefore, the transect was made at 0.5 m height.

For the fossil mollusk study, at 0, 10, 20, and 30 meters on the transect line, a half meter by half meter plot was taken. In each plot, all the fossils found were recorded. If possible, the width in centimeters, number of age lines, and species of each fossil were recorded. Pictures were taken of each fossil to help later determine unknown species. General observations of the site, including algae cover, and number of live organisms were also recorded.

After initial sampling, shell identification books were used to name various shell fossils found. Species type was estimated based on available observations, and was confirmed from outside sources. Site, shell species, number of species seen, and size (if available) were recorded. After each species was determined, the average size of the fossils for each site was determined. If sites contained the same species, the differences in species size were also recorded. Species diversity was then calculated using the Shannon Diversity Index.

For the coral survey, substrate was observed in a continuous horizontal stratigraphic zone (Sunderlin et. al., p.336), as a 30-meter transect line. Two factors were being observed in two different forms. One test was to look at coral types existing at the time of Unguja's formation. Substrate type and other identifiable forms were noted every 10 centimeters. Reefs grow are the same horizontal levels, with thickness unaffected by age but by the depth of the water in which it grows in. Sea level change cycles result in new reefs growth horizontally from the "core" of the reef (antecedent erosion theory) and have a horizontal towards the middle of the island showing differences in time, not a vertical time scale (Veron, p. 171). Therefore a lateral view can be more useful in looking at the diversity in the reef, as different corals would not have been deposited on top of each other through time.

Substrates and forms were then quantified and identified as likely corals. Fossils are identified as being in the same genus and the nearest living relative is found to estimate the preferred environmental conditions. Relatives of old corals may be found and observed for environment preference, but rarely are the same species of coral present today as they are in Australian Reefs (Duncan. p 406). A description of the coral is given but the closest living relatives (CLR) of the fossilized corals are used to estimate the environment preferences of the corals found in this study (Sunderlin et. al., p. 337). Species type was asserted as a best estimate, and sent for confirmation to coral expert Dr. Muhando, a researcher and lecturer at the Institute of Marine Sciences- Zanzibar/ University of Dar Es Salaam.

Calculations were done to quantify the distinct coral types and to locate their abundance in locations around Unguja. Using the environmental preferences of the different coral geneses and species, environments in which the corals grew and survived could then be estimated and compared from different sites around Unguja.

Results

Mollusk Fossils Found:

59 different species of fossilized mollusk organisms were recorded from the eight sites. The species found all belonged to Phylum Mollusca, in either the Polyplacophora, Gastropoda, or Bivalvia classes. Appendix A illustrates the full list of species found, including scientific name, common name, size, and number of each species. The life modes and habitats for each species were acquired from the Paleobiology Database.

Chumbe site 1 was dominated by *Saccostrea cucullata*, commonly known as the Hooded Oyster, a member of the class Bivalvia These shells covered the meter directly above the substrate, and ranged from a 2.4 to 8.6 centimeter width. The fossil was identified by its dark purple color, and it's cup shape (Richmond 2011). Hooded Oysters are normally found on rock shores cemented to rocks, like the specimens observed. They are epifaunal suspension feeders. The other species found at this site was *Conus Spectrum*, the Spectral Cone, a member of class Gastropoda. The brown and orange color helped to identify the fossil, as well as the convex whorl (Dance 1992). The Spectral Cone is found mostly in sandy offshore, shallow infaunal habitats (Dance 1992).

Chumbe site 2 was also dominated by *Saccostrea cucullata*. There were 32 Hooded Oyster specimens found in the four plots, ranging from 1.6 to 6.7 centimeters. *Eunaticina papilla*, Papilla Moon, was also found at this site. Papilla Moon is from Class Gastropoda, and many fossil shells were found, along with many live gastropods. Papilla Moon gastropods reside in shallow infaunal habitats, and are carnivores. *Serpulorbic imbricata*, or Scaly Worm Shell was found in two of the plots. This species normally resides on hard surfaces, such as the coral rag that they were found on. Both specimens were small, measuring 1.6 and 1.3 centimeters. The species is an epifunal suspension feeder, and is attached to the substrate. The final species found at this plot was *Tridacna squamosa*, or the Fluted Giant Clam. There are many of these fossils across the island, but most are on the flat surface above the cliff shelf. This specimen measured in at 43 centimeters. The species was identified by the thickness of the valves, as well as the scalloped edge of the scales (Dance 1992). Fluted Giant Clams are a member of the bivalvia class, and have an epifaunal life mode. They are stationary, suspension feeders.

Chwaka site 1 contained 7 different species. *Eunaticina papilla* was observed in three of the plots, and had the largest number of same species specimens in the site, with 5 specimens. There were two 'nassa' species, *Nassarius reticulatus*, or Netted Nassa, and *Nassarius coronatus*, commonly the Crowned Nassa. These species both belong to the Nassariidae family, of class Gastropoda, and are found in intertidal sand or offshore sand habitats. The Crowned Nassa has a low-level epifaunal life mode, and is a carnivore feeder, while the Netted Nassa is an infaunal species. One *Tonna galea*, or Giant Tun specimen, was observed in the cliff close to the substrate. The Giant Tun is an epifaunal carnivore, and actively hunts for prey on the substrate. The Giant Tun is a member of the gastropoda class. A *Trapezium oblongum*, or Oblong Trapezium was observed. This member of class bivalvia is an infaunal organism that obtains its nutrients through suspension feeding. *Sinistralia gallagheri*, Gallagher's Spindle, was found fossilized, as well as live in the plot. This species is a member of class Gastropoda, and inhabits coral and rocky areas. The last species found is similar to Papilla moon, as it is a moon shell. *Neverita albumen*, the Egg-White Moon, is a member of class Gastropoda, and inhabits sandy offshore areas.

Chwaka site 2 introduced a new dominating species, *Certhidia cingulata*, or Girdled Horn Shell. There were three Girlded Horn Shell specimens found, ranging from 3.2 to 4.1 centimeters in length. A new nassa species, *Nassarius papillosus* was also introduced. The Pimpled Nassa was found in two plots. This species main habitat is the sand under coral, explaining its sandy to brown coloring. *Chicoreus ramosus*, the Branched Murex, is a member of the gastropoda class, and was observed in one of the plots. This species is epifaunal, and actively feeds on other mollusks. The last species found was *Pinctada radiata*, or the Rayed Pearl Wyster. This member of the bivalvia class normal inhabits coastal, shelf environments, and has a stationary, attached life mode in which it uses suspension feeding to obtain nutrients.

Jambiani site 1 only contained two species. A new species, *Mytilus Edulis*, or Mediterranean Mussel was found. There were also live specimens of this species around the plot, but the specimens within the plot were fossilized. This species of class bivalvia is stationary, attached to the substrate, and is a suspension feeder. One Papilla Moon shell was also found in the plot.

Jambiani site 2 contained many more fossils than the first site. One Papilla Moon shell was also observed in this plot. A new species from class bivalvia, *Corbula gibba*, or Common Basket-shell, was found. This species is attached in an infaunal habitat, using suspension feeding to obtain nutrients. A Strawberry Cockle bivalve, *Fragum unedo*, was found under a layer of sand atop of the shelf. This species is an infaunal suspension feeder. Another 'cockle' species, *Plagiocardium psuedolima*, the Giant Cockle, was observed close to the Strawberry Cockle. This species was defined by it's marked growth stages, and usually inhabits sandy offshore areas. *Turbinella pyrum*, or Indian Chank, is a member of class gastropoda, and lives on the surface of the substrate, actively hunting for food. One *Cittarium pica*, or West Indian Top shell, was observed, though all of the shell besides the umbo was broken off. This species is actively mobile, and lives atop the substrate. One *Ficus subintermedia*, or Underlined Fig shell was observed. This species lives above the substrate, and is an actively moving carnivore. *Volema paradisiaca*, or Pear Melongena, is a member of class Gastropoda. The species inhabits eulittoral sand and seagrass beds. The species was identified by the notable varices (Richmond 2011). The Pitted Lucine, *Codakia punctata*, resides in sandy bottoms around the base of the reef. This species was defined using its interior purple ring around the margins. One species that appeared in many sites, but was often disarticulated and broken was *Amusium pleuronectes*, the Asian Moon Scallop. This species was found articulated in the plot. The Asian Moon Scallop usually inhabits offshore areas, and occurs frequently in the Indo-Pacific waters. A large Bivalvia species, *Atrina Vexillum*, the Flag Pen shell, was found with the interior valve visable. The specimen was covered by coral rock and sediment, so it could not be measured. This species, however, can reach a length up to 25 centimeters, and inhabits sandy offshore areas. The Mediterranean Mussel was also observed in the same plot.

Kendwa site 1 showed many species found in other areas. The Hooded Oyster was very dominant in this site, as 40 specimens were found between the four plots. The length of these specimens ranged from 1.5 to 6.3 centimeters. The other prominent species, Papilla Moon, was also found at this site with a total of five specimens. The Crowned Nassa was observed, though much of the shell had been broken and removed. Two Strawberry Cockle specimens were found. A new species, *Cypraea moneta*, the Money Cowrie, is a member of class Gastropoda. This species inhabits coral reef areas, and was identified by the strong short teeth on the under side. The final species found is a member of class Bivalvia, *Pecten maximus*, or Great Scallop. This species was identified by the strong curve in the right valve, and inhabits sandy or gravel offshore areas.

Kendwa site 2 introduced many new gastropoda and bivalvia species. The Hooded Oyster was observed, and 72 specimens were recorded. *Thatcheria mirabilis*, or Japanese Wonder shell, is a member of class gastropoda, and two specimens were observed in one of the plots. The specimens were recorded within two centimeters of one another. This species is an actively mobile carnivore that resides atop on the substrate. Papilla Moon specimens were observed in the site, recorded at 1.6 and 5.4 centimeters in length. *Strombus urceus*, or Little Bear Conch, is of the class gastropoda. This species is actively mobile, residing above the substrate. The species is an omnivore predator, but also grazes on the substrate as a mean of obtaining nutrients. The Propellor Ark, *Trisidos tortuosa*, is of the bivalvia class. Its fan shape as well as the presence of brown periostracum identified this species across the external side of the shell. The Propellor Ark is a stationary suspension feeder that normal resides in coastal, inner shelf habitats. *Strombus mutabilis*, the Changeable Conch, was observed in the same plot as the Little Bear Conch. This species inhabits sandy places inshore. The Corded Rock shell, *Trochia cingulata*, was also found with both conch species. Its very large, distinct ribs with curled edges helped to identify the species. It attaches to low rocks at low tide in oceanic areas. The final species, *Staphylea cassiaui*, Cassiau's Cowrie, was found with the Hooded Oyster specimens. This species is a member of class Gastropoda, and lives in shallow waters in the infralittoral zone.

Kiwengwa site 1 was dominated by the Common Basket-shell, with 14 specimens ranging from 0.3 to 3.4 centimeters. One Propellor Ark and one Papilla Moon shell were observed in close proximity. Three different 'lucine' species were observed in the plots. *Codakia tigerina*, the Pacific Tiger Lucine, had two large specimens in one site. This species is infaunal, and has a chemosymbiotic diet. *Codakia punctata*, the Pitted Lucine, was seen in one of the plots. *Cypraea caputserpentis*, the Snake's Head Cowrie, was found between two small pieces of eroded coral. This species lives on top of the substrate, and is an actively mobile omnivore. The Pitted Lucine was found in one of the sites. Another lucine clam, *Lucina pectinata*, the Thick Lucine, was identified by its front muscle scar on the interior of the shell. This species inhabits shallow water areas.

Kiwengwa site 2 introduced many new species not found in site 1. The Rayed Pearl Oyster was the first specimen found. It was identified by the iridescent coloring on the internal part of the shell valve. *Anadara uropygimelana*, the Burnt-End Ark was found twice at this site. The species is a member of the bivalvia class, and normally inhabits lagoonal or coastal environments. They have a semi-infaunal life mode, and are suspension feeders. *Anadara granosa*, the Granular Ark, is also a member of the bivalvia class. The species is a semi-infaunal suspension feeder that is attached to the substrate. The Marlinspike, *Terebra maculata*, was observed in close proximity with the *Conus spectrum*. This species was identified by its long, slender shape, and overlapping whorls. Marlinspikes are actively mobile carnivores that live above the substrate. A West Indian Top shell was found, but was oriented in a way that measurements were impossible to take. *Tellina virgata*, the Striped Tellin, was found covered by loose sand. This species is normally found in shallow-sandy substrates, and was identified by it's creamy orange color.

Mangapwani site 1 had few species, but many specimens in the plots. Six Papilla Moon specimens were recorded, with sizes ranging from 2.2 to 2.9 centimeters. *Natilla stellata*, the Starry Moon, was found with the Papilla Moon. The species is an actively mobile carnivore, and lives within the substrate. The Hooded Oyster had 16 specimens within the plots, ranging from 1.2 to 3.6 centimeters. There was one editerranean mussel shell that was partially buried within the cliff, and could only be measured up to 1.7 centimeters. One Underlined Fig Shell was found with a length of 5.2 centimeters. A new species was observed in the third plot. A *Chiton marmoratus*, or Marbled Chiton fossil was found in a small hole within the cliff shelf. This species is a member of the Polypolyplachophora class. There were many chitons found in other plots, but there were still living.

Mangapwani site 2 showed many different species throughout the four plots, with few repeating species between the plots. Eight Hooded Oyster specimens were observed, ranging form 1.1 to 4.2 centimeters. Four Papilla Moon specimens were observed, three of which were all grouped together in a crevice in the cliff shelf. One Propellor Ark was observed, but only 2.2 centimeters was visible. Another member in the 'ark' group, *Barbatia Foliata*, or Leafy Ark, was found with its internal valve exposed. This species lives under rocks inshore, and was defined by its deeply grooved ligamental area. There were also two Money Cowrie species, and one Burnt-End Ark and Pitted Lucine. A Black-Mouth Moon, or *Mammilla melanostoma*, was observed. This species is a member of class Gastropoda, and lives within the shallow substrate, and is a carnivore. There was one Giant Tun, *Tonna galea*, a member of the Gastropoda class. This species lives atop the substrate and is an actively mobile carnivore. Another tun, *Tonna sulcosa*, the Banded Tun, was observed in close proximity with the giant tun. This species is also a member of class Gastropoda, and has the same life mode as the Giant Tun.

Mbweni site 1 was dominated by the presence of Hooded Oysters across the lower portion of the cliff shelf. There were ten Hooded Oyster specimens observed in the four plots. One Strawberry Cockle, and one Underlined Fig shell were found in the thirty-meter plot. *Plagiocardium psuedolima*, the Giant Cockle, was found close to the Strawberry Cockle. This species inhabits shallow sand areas. Two Leafy Ark specimens were found in two plots within the transect.

Mbweni site 2 did not have many specimens in all four plots, but had a variety of new species. Seven Hooded Oyster specimens were observed throughout the four plots. There were also three different 'ark' species within the plots. The Burnt-End Ark and Propellor Ark were observed in the 30 and 10 meter plots. A new 'ark' species, *Barbatia amygdalumtostum*, the Burnt-Almost Ark, was observed with these two specimens. This species is a member of class Bivalvia, and lives under rocks and coral in shallow oceanic areas. The Papilla Moon species was found in one of the plots, but was partially covered, allowing for only 2.2 centimeters to be measured. One large specimen of class Gastropoda, *Pleuroploca trapezium*, or the Trapezium Horse Conch, was observed in the final plot of the site. This species can grow up to 13 centimeters, and inhabits shallow waters near coral.

Paje site 1 had many of the same species within the different plots. Two Crowned Nassa were found in one plot, with 1.3 and 2.1 centimeter lengths. Two Common Basket-shells were also found in the same plot, but not in close proximity. The Papilla Moon specimens were found in different plots, but were relatively the same size, and were at the same height in the cliff shelf. One Rayed Pearl Oyster and one Asian Moon Scallop were also observed in the first and final plots.

Paje site 2 also had species repetitions between the plots. The Papilla Moon, and *Amusium pleuronectes* were both found in the 30 and 10-meter plots. A new species, *Strombus canarium*, or Dog Conch was found in the plot at 0 meters. This species is a member of class Gastropoda, and lives atop the substrate and grazes. The Propellor Ark was identified alongside a new species, *Lyria Delessertiana*, Delessert's Lyria. This species is a member of class Gastropoda, and inhabits offshore areas.

Coral Types Found and Environment Preferences

Evidence of coral fossils were noted and described. In Appendix G their Identification codes are given with a description and expected closest living relative (CLR). Using *Corals: Indo-Pacific Field Guide* and *Corals of the World* Volumes 1 through 3. Identification codes have three parts: the first letter belonging to a specific family, the number of that letter indicating which genus, and a number to coordinate the CLR species.

Four types of coral from the Acroporidae family were found. Of these, two of the genus *Acropora* were found. A common name for *Acropora* corals is "table corals". Table corals grow as flat plates in order to expose a large and surface area to sunlight. Table corals are usually, currently, a dull brown or green, and provide structure and habitat for a diverse number of reef fish (Coral Identification 2010).

Some *Acroporas* fall under the common name of "staghorn corals". These types of corals are branching corals. Like table corals but grow cylindrical branches ranging from a few centimeters to over 6.5 feet (2 m) in length. They demonstrate fast growth: branches may increase in length by 4-8 inches (10-20 cm) per year and has large contribution to reef growth and fish habitat (Coral Identification 2010).

One type of fossil coral found, named A1, is hypothesized to be closely related to *Acropora aculeus*, which usually is found in shallow and calm water, and another is A2, with CLR *Acropora acuminate*. This coral is usually found in turbulent zones, along upper reef walls, below shallow water zone (Veron et. al. 2000).

The genus *Anacropora* does not have axial branchlets, and follows that same branching pattern as most Acroporidae (Erhardt et. al. 2005). The fossil AA1 has a CLR *Anacropora spinosa*, with spine-like, or extended cone corralites (Erhart et. al. 2005).

The fossil AAA1 has a CLR with the genus *Astreopora* and species *myriophythalma*. This describes a hemispherical massive growth structure with small round radiating corallites. These corals avoid turbid waters and have a wide depth and reef zone (Erhardt et. al. 2005).

Nine fossils were found to be related to the Agariciidae Family. This family is formed in either massive, columnar, or leafy structures, with indistinct septa between neighboring corallites. *Leptoseris* encompasses those species which are encrusting (leaf- or cactus- like), which also only have corallites on one side (Erhardt et. al. 2005). The genus *Pavona* are the same structures with corallites on both sides (Erhardt et. al. 2005).

Three fossils have CLRs in the *Leptoseris* genus. B1 is *scabra*, B2 is *mycetoseroides*, and B3 is *solida*. Irregular surfaces characterize these three, with organized rows or corallites running parallel to the terminal ends of the surface colonies. These corals are efficient sunlight collectors and they reside in medium turbidity to calm waters, at deeper portions of reefs (Erhardt et. al. 2005).

Two fossils are in the *Pachyseris* genus, which demonstrate laminar growth in low slabs at various heights, depending on the substrate. BB1 has a CLR of *Pachyseris speciosa*, which has polyps in concentric rows on relatively circular slabs. BB2 is closely related to *rugosa*, which grows along the substrate. These species are relatively fragile and survive best with mild currents in sandy barrier reefs (Erhardt et al. 2005).

Four species in the *Pavona* genus were found, which have leaf-like growth, like *leptoseris*, but show polyps on both sides of each "leaf" (Erhardt et al. 2005). Two of these fossils (BBB1 and BBB3) seem to be related to the species *clavus*, with thick upward growth and a large proportion of sponge-like coenosteum. BBB2 is closest related to the species *duerdeni* , and BBB4 is most closely related to *maldivensis*. These tend to be in a low water zone and are shaped to withstand high turbidity (Erhardt et. al. 2005).

The family Faviidae is hemispherical small corallites. The polyps are wide and long, sometimes wedge shaped. Faviidae are one of the older coral families, with exceptionally long lifespans, up to 900 years (Coral Identification 2010). These corals usually live shallow to mid-depths (Erhardt et. al. 2005). There are three types of corals found to be in this family. C1 has a CLR of *Goniastrrea edwardsi* , and CC1's CLR is *Faviites pentagona* because of its star shaped speta. Coral CCC1 is most closely related to *Leptoria phygia*, with very regularly spaced septa with wedge shapes.

The corals that were found to be in the Fungiidae Family were shaped in plate-like discs or ovals. They were usually found solitary and with protruding radial septa. These types of coral harbor smaller organisms that fish feed on, and usually made of secreted calcite. They prefer strong sunlight and sandy substrates, as they do not attach to the substrate. High amounts of suspended sediment and turbidity do not negatively affect the health of these corals (Erhardt et.al. 2005). D1 has a CLR of *Cycloseris repanda*, and DD1 is related to *Zooplius chinatus*, for its small conical forms and porous surface.

One coral, identified as E1, is thought to be in the Merulinidae family because of the evidence of surface monticules, and is probably a relative of *Hynophora micronos* or *rigida* (Veron et. al. 2000). This coral type prefers central reef slopes and changes growth patterns depending on its depth, but prefers very calm and shallow waters (Veron et. al. 2000). It does not have a firm base in sediment and therefore may turn with fossilization processes (Erhardt et. al. 2005).

A coral labeled F1 is most likely related to the species Oculindae *Galaxea fascicuaris.* It has round corallites with massive, connecting walls (Erhardt et. al. 2005). This coral does not survive well with strong currents, because of its irregular growth patterns (Veron et. al. 2000).

Corals from the family Pocillioporidae prefer to grow in grow in shallow waters, withstanding high turbulence and sunlight (Veron et. al. 2000). They are found on upper to mid- reef walls (Erhardt et. al. 2005). G1, *Psammocora digiata,* demonstrate polyps in neat rows and rounded branch ends. *Stylophora subseriata* is supposed to be the CLR of G2 (Erhardt et. al. 2005). The J1 coral may be related to *Pocillopora verrucosa* or *indiania* in the Pocillioporidae family, it is labeled differently because of its abundance and irregularity.

H1 is said to be Poritidae *Porites nodifera*, which grows with lateral lobes and no coenosteum, making a shallow reef environment. This coral harbours fish and invertebrates in very shallow sunlight water, and forms micro-atolls when in waters that are too shallow (Erhardt et. al. 2005).

A coral, I1, with weakly developed septa is found to have a CLR as Sideratreidae *Coscinacea moniile* or *crassa*. The coral I2, is most closely related to Sideratreidae *Psammocora explanulata*. Both of these corals live in both shallow and deep waters and can survive in very shallow water, biotic and abiotic environments (Erhardt et. al. 2005). I2's CLR is most commonly found in shallow water with sandy substrates (Veron et. al. 2000).

Some substrates are unidentifiable (UNID.) because of multiple, unknown reasons. The coral may have been eroded by wave action, urchin damage, or sedimentation during the fossilization process. The coral precedent may have also been soft corals, damaged coral or other organism and therefore not preserve.

Unidentifiable Substrate

Of each transect, 3.7-51.3% was UNID, with an increasing trend (of ≈9%) between the western and northeastern transects. The N/NE and S/SE have higher & UNID that the W side of Unguja. Appendix E shows the metric abundance of the UNID in each transect. Statistically, an unpaired T-test shows the difference between the UNID amounts on the Western transects (transects from sites 1,2 and 7) do not differ with the Eastern transects (transects from sites 3,4,5,6, and 8) with a two-tailed p- value of 0.2708.

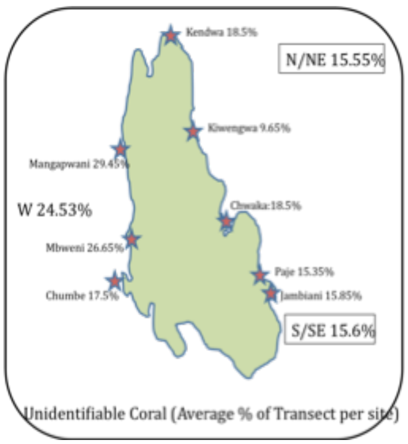

Figure 3. The proportion of UNID in each site is shown, and averages for sections of the island show a difference between the East and West sides of Unguja.

Coral Type Abundances

Appendix F shows the total meters and the percent cover of the different types of coral in each transect. Below is the summary of the most notable (highest abundance) indicator species.

West (Sites 1, 2, 7)

Mangapwani, has an abundance of BBB, or *Pavona* corals, as well as D1, J1 and G (Pocilloporidae) corals.

Mbweni has a large amount of DD1 and BBB4, as well as other corals from the Agariciidae (B) family.

Chumbe has high amounts of CCC1, DD1 and G1 species. One notable species it contains is H1.

South/Southeast (Sites 4, 8)

Jambiani most notably contains F1, CCC1, D1 and G-type corals.

Paje has D species, J1, CCC1 and H1.

North/ Northeast (Sites 3, 5, 6)

Chwaka has F1 species, and it contains evidence of D, C and G corals.

Kendwa shows a high abundance and proportion of F1 species C-type corals are also found here in abundance.

Kiwengwa transects have very high proportions of F1 species C and D species.

<u>Coral Species Diversity</u>

The number of coral species types range from six to twelve types, with a mean of 9.1 species with numbers of each site in Appendix H. The West side of the island (Sites 1, 2, and 7) had an average of 9.7 species, while the East side of the island (Sites 3,4,5,6, and 8) had an average of 8.7 species. This shows a general, but insignificant trend to a higher number of species on the West side of the island. Using a modified Simpson's Index of Diversity ($D=[\sum n(n-1)/N(N-1)]$) , by substituting percentage of cover per total identified coral area, an Index of Diversity of 0.920 was found for the transects on the West of the island, and an Index of Diversity of 0.916 was found for the East side of the Island. A paired t-test on the values of the abundances of each coral showed an insignificant difference ($p= 0.7828$) between the two populations (Appendix H).

Appendix E shows the proportion of species that is in each transect, disregarding UNID substrates, showing a clearer snapshot of what the reef may have looked like.

Discussion

Mollusk Site Comparisons:

In each of the sites, species, number of species, and shell size varied drastically. The average shell size was calculated between all of the sites based on the available sizes of shells per number of shells with recorded size (Appendix B). Chumbe site 2 had the largest shell size of all of the sites with an average of 4.96 centimeters. Paje site 1 had the smallest average shell size of 1.68 centimeters.

Throughout all of the sites, the most dominant species was *Saccostrea cucullata*, the hooded oyster. The number and size of this species varied throughout the sites, but it undoubtedly had the greatest number of specimens in the study. The lengths of the hooded oyster throughout each site are compared in Appendix C. Chumbe site 1 specimens had the greatest length, followed closely by Chumbe site 2, with average lengths of 4.51 and 4.32 centimeters. The number of hooded oyster specimens also differed between the eight sites. Chwaka site 1, both Jambiani sites, both Kiwengwa sites, and both Paje sites had no hooded oyster specimens. Between the sites that did, Kendwa site 2 had the largest number with 72 specimens. It almost doubles the site with the second largest number, which was Kendwa site 1 with 40 specimens.

Mollusk Species Diversity:

Species diversity was calculated using the Shannon Diversity Index. This index takes into account species abundance per site, and calculates the diversity of all of the species within the site. Diversity was calculated for each transect, combining all of the four plots. Appendix D compares the diversity for all 16 sites. Jambiani site 2 had the most diverse species, with a Shannon Index of 2.54, while Chumbe site 1 had the lowest diversity, with a Shannon Index of 0.13.

By calculating the diversity index, it is possible to infer about the past environment in each area. As Jambiani has the highest diversity index, we can conclude that this area was very nutrient rich, and promoted high diversity. Observing which of the other sides had high diversity, it is apparent that sites on the eastern side of the island had a higher average diversity index than the sites on the western part of the island.

Coral Environment Hypotheses

The trend of lower UNID percentages on the West side of the island supports the hypothesis that the ocean current came from the northeast. Low abundance of UNID may indicate that an ocean current made first contact with the island at that point, as hard corals are the first to settle a reef (Erhardt et. al. 2005) and are transported there by warm ocean currents from other, older reefs via spawning (Erhardt et. al. 2005). These hard corals would fossilize more frequently and therefore have a lower % UNID.

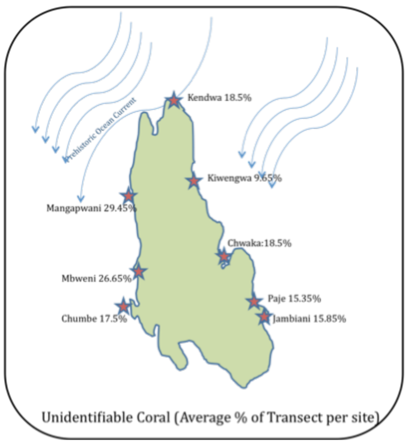

Figure 4. Using the UNID proportions of coral at each transect, the hypothesis that the ocean current of the time is coming from the NE, heading SW is supported.

Corals as Indicators of Reef Environments

Many of the fossil corals identified are able to live in many different reefs zones. Some, however, show preferences and tolerances to certain conditions. For instance, if an abundance of BBB4 corals are found in an area, it can be used to indicate strong currents because of its tolerance and preferences. J1, D1, DD1 G1 and G2 withstand turbid waters that are also shallow. I2, D1 and DD1 indicate sandy substrates. E1and F1 shows a strong preference towards calm and shallow waters (Veron et. al. 2000). H1 shows a tolerance for extreme shallows. Appendix B shows the total meters and percent cover of each type of fossil coral found in each transect.

The abundance of said indicator species indicates that the transect was hospitable to species that prefer certain conditions.

West (Sites 1,2,7)

Mangapwani, having an abundance of BBB, or *Pavona* corals, as well as D1, J1 and G (Pocilloporidae) corals is thought to be a site of turbid but shallow water.

Mbweni's high abundance of DD1 and BBB4, as well as other corals from the Agariciidae (B) family indicates a sandy, shallow environment.

Chumbe has high amounts of CCC1, DD1 and G1 species, which may point to turbid, waters with suspended sediment (land runoff). H1 is a strong indicator of very shallow environments.

South/Southeast (Sites 4, 8)

The Jambiani transect includes F1 corals, CCC1, D1 and G-type corals. F1 indicates a necessity for calm water, and CCC1 and G corals are indicators for shallow reef zonation.

Paje has D and J1 species, which withstand turbulence, and also has CCC1 and H1, which necessitate shallow waters.

North/ Northeast (Sites 3, 5, 6)

Chwaka has F1, an indicator for calm, shallow water, but also shows that it can withstand some turbidity with D, C and G corals.

Kendwa shows a high abundance and proportion of F1 species. This shows that very calm waters were here. C-type corals are also found here in abundance, which give the reef a range from shallow to mid-depth.

Kiwengwa transects have very high proportions of F1 species C and D species. These show that the reef was very shallow, with a sandy substrate and low turbidity.

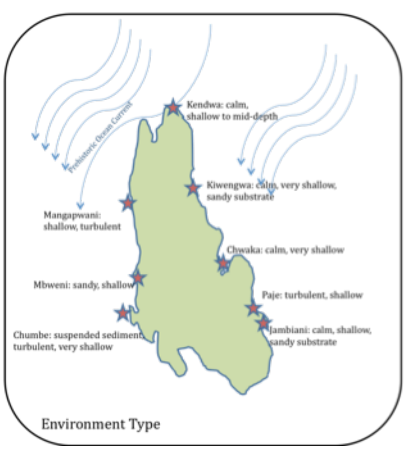

Figure 5. The environmental conditions hypothesized by each coral type is shown at the transect sites, superimposed on a map with the hypothesized prehistoric ocean current.

*The discontinuity with the phrase “turbulent” may mean that the area may withstand turbulent, but not necessarily experience it. This uncertainty may be based on either direction that each site was facing, barriers to the site area that are no longer present or identifiable, or simply differences in the environments that the coral CLR’s have with the fossil corals identified.

Coral Species Diversity

Undisrupted tropical habitats with high biodiversity indicate healthy temperatures, salinity, as well as that more nutrients, food and plankton are circulated in a particular area (McClanahan et. al. 2000). Biodiversity is measured to indicate the health of a reef (Kennedy 2010). In the West Indian Ocean, all biodiversity falls from East to West, supposedly because of “oceanic speciation”, or the reproductive patterns of corals (McClanahan et. al. 2000). The Western transects actually showed both a slightly higher average number of species and a slightly higher Simpson’s Index of Diversity than the Eastern Transects. Both of these numbers differ insignificantly, thus not disproving McClanahan et. al.’s statement.

Conclusion

The two tests that were done showed different aspects of the paleoecological environment of Unguja. Both tests measured biodiversity, one showing water environments, and the other showing nutrient levels and nature of deposition.

For biodiversity of the reef, the coral test showed more biodiversity on the west coast than the east coast, while the shell test showed more biodiversity on the east coast. The trend in the coral test is not significant in disproving the hypothesis that biodiversity falls from east to west in the Western Indian Ocean. Appendix A and Appendix I show a general overview of what the coral reef of Unguja looked like during the Pleistocene, approximately 23 Ma. The abundance of unidentifiable substrate may show that there is a higher abundance of hard coral on the northeastern side of the island. Therefore, the reef may have first started forming from the northeast side of the island, due to coral spores being carried by ocean currents around the island. Figure 5 is the hypothesized ocean current environment at the time of reef formation. Appendix B for the shell test shows the differences in shell size across the island. Through this, it is possible to infer about availability of nutrients across the island as well as depositional environments.

As studies of fossils and geologic history of Unguja is a relatively new subject, this study can provide an overview and foundation for future geological and paleoecological studies. This study can be used to look at past climates in the West Indian Ocean region, and can show how reefs react to changing environments.

Recommendations

To further knowledge about the age of the island and species on the island, research could be completed to test the age of different rocks and corals across the island. This would help to date different fossils on the island, and it would therefore be possible to develop a map of the ages of fossilized and live species in different areas.

Accounting for urchin damage and not being able to ID large portions of the transects, make the transects longer and do more in depth studies on specific types of corals, making sure they are applicable to the CLRs today. When observing fossil coral on transects note and measure specific dimensions and regularities in coral polyps in order to identify and describe more thoroughly. The coral study was meant to produce an approximation of the five main environmental patterns that affect the corals: sunlight, oxygen supply, temperature, water movement and salinity, but would have been able to do that in much greater accuracy if the coral type was more specifically known and measurable (Erhardt et. al., p. 9).

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Appendices

Appendix A: Fossil Mollusk Data

Site	Meter	Species	Common Name	# of Species	Size (cm)
Chumbe 1	30	*Saccostrea cucullata*	Hooded Oyster	24	2.4
		Saccostrea cucullata	Hooded Oyster		2.5
		Saccostrea cucullata	Hooded Oyster		6.3
		Saccostrea cucullata	Hooded Oyster		5.5
		Saccostrea cucullata	Hooded Oyster		4.9
		Saccostrea cucullata	Hooded Oyster		2.8
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		3.5
		Saccostrea cucullata	Hooded Oyster		3.9
		Saccostrea cucullata	Hooded Oyster		6.1
		Saccostrea cucullata	Hooded Oyster		5.2
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		4.4
		Saccostrea cucullata	Hooded Oyster		5.3
		Saccostrea cucullata	Hooded Oyster		2.5
		Saccostrea cucullata	Hooded Oyster		2.9
		Saccostrea cucullata	Hooded Oyster		3
		Saccostrea cucullata	Hooded Oyster		4.4
		Saccostrea cucullata	Hooded Oyster		6
		Saccostrea cucullata	Hooded Oyster		5.9
		Saccostrea cucullata	Hooded Oyster		5.9
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		3.8
		Conus Spectrum	Spectral Cone	1	2.6
	20	*Saccostrea cucullata*	Hooded Oyster	3	7.2
		Saccostrea cucullata	Hooded Oyster		8.6
		Saccostrea cucullata	Hooded Oyster		7.3
	10	*Saccostrea cucullata*	Hooded Oyster	3	4.2
		Saccostrea cucullata	Hooded Oyster		3.4
		Saccostrea cucullata	Hooded Oyster		3.6
	0	*Saccostrea cucullata*	Hooded Oyster	8	4.4
		Saccostrea cucullata	Hooded Oyster		3.9
		Saccostrea cucullata	Hooded Oyster		4.9
		Saccostrea cucullata	Hooded Oyster		5.6
		Saccostrea cucullata	Hooded Oyster		5.2
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		3.6
		Saccostrea cucullata	Hooded Oyster		3.3
Chumbe 2	30	*Saccostrea cucullata*	Hooded Oyster	20	3.3
		Saccostrea cucullata	Hooded Oyster		2.4

		Saccostrea cucullata	Hooded Oyster		6.7
		Saccostrea cucullata	Hooded Oyster		6.3
		Saccostrea cucullata	Hooded Oyster		2.9
		Saccostrea cucullata	Hooded Oyster		3.5
		Saccostrea cucullata	Hooded Oyster		4.4
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		4.9
		Saccostrea cucullata	Hooded Oyster		5.9
		Saccostrea cucullata	Hooded Oyster		5.8
		Saccostrea cucullata	Hooded Oyster		2.6
		Saccostrea cucullata	Hooded Oyster		2.9
		Saccostrea cucullata	Hooded Oyster		3
		Saccostrea cucullata	Hooded Oyster		6.2
		Saccostrea cucullata	Hooded Oyster		6.6
		Saccostrea cucullata	Hooded Oyster		5.7
		Saccostrea cucullata	Hooded Oyster		5.2
		Saccostrea cucullata	Hooded Oyster		4.4
		Saccostrea cucullata	Hooded Oyster		3.1
		Serpulorbis imbricata	Scaly Worm Shell	1	1.3
	20	*Saccostrea cucullata*	Hooded Oyster	6	4.7
		Saccostrea cucullata	Hooded Oyster		3.8
		Saccostrea cucullata	Hooded Oyster		3.6
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		2.2
		Saccostrea cucullata	Hooded Oyster		3.3
		Serpulorbis imbricata	Scaly Worm Shell	1	1.6
	10	*Eunaticina papilla*	Papilla Moon	3	1.3
		Eunaticina papilla	Papilla Moon		1
		Eunaticina papilla	Papilla Moon		2.2
	0	*Tridacna squamosa*	Fluted Giant Clam	1	43
		Saccostrea cucullata	Hooded Oyster	6	2.2
		Saccostrea cucullata	Hooded Oyster		3.4
		Saccostrea cucullata	Hooded Oyster		6.3
		Saccostrea cucullata	Hooded Oyster		5.5
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		5.7
Chwaka 1	30	*Sinistralia gallagheri*	Gallagher's Spindle	1	0.5
	20	*Tonna galea*	Giant Tun	1	7.5
		Eunaticina papilla	Papilla Moon	2	2.5
		Eunaticina papilla	Papilla Moon		
	10	*Nassarius reticulatus*	Netted Nassa	1	1.4
		Trapezium oblongum	Oblong Trapezium	1	4.3
		Nassarius coronatus	Crowned Nassa	1	1.1
		Eunaticina papilla	Papilla Moon	1	0.4
	0	*Eunaticina papilla*	Papilla Moon	3	
		Neverita albumen	Egg-White Moon	1	1.1

Chwaka 2	30	*Nassarius papillosus*	Pimpled Nassa	1	2.3
	20	*Saccostrea cucullata*	Hooded Oyster	1	4
	10	*Chicoreus ramosus*	Branched Murex	1	8.6
		Certithidia cingulata	Girdled Horn Shell	3	3.3
		Certithidia cingulata	Girdled Horn Shell		4.1
		Certithidia cingulata	Girdled Horn Shell		3.2
	0	*Nassarius papillosus*	Pimpled Nassa	1	3.3
		Pinctada radiata	Rayed Pearl Oyster	1	
Jambiani 1	30	*Mytilus edulis*	Mediterranean Mussel	8	
	20	-			
	10	*Eunaticina papilla*	Papilla Moon	1	4.8
	0	-			
Jambiani 2	30	*Eunaticina papilla*	Papilla Moon	1	2.3
		Corbula gibba	Common Basket-Shell	1	2.8
	20	*Ficus subintermedia*	Underlined Fig Shell	1	2.9
		Volema paradisiaca	Pear Melongena	1	4.7
		Fragum unedo	Strawberry Cockle	1	2.8
		Turbinella pyrum	Indian Chank	1	5.3
	10	*Corculum cardissa*	True Heart Cockle	1	
		Eunaticina papilla	Papilla Moon	1	1
		Amusium pleuronectes	Asian Moon Scallop	1	1.9
		Codakia punctata	Pitted Lucine	1	
		Atrina vexillum	Flag Pen Shell	1	
		Mytilus edulis	Common Blue Mussel	1	
	0	*Unknown 1*		1	2.2
		Cittarium pica	West Indian Top Shell	1	
Kendwa 1	30	*Saccostrea cucullata*	Hooded Oyster	22	1.5
		Saccostrea cucullata	Hooded Oyster		1.8
		Saccostrea cucullata	Hooded Oyster		1.3
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		4
		Saccostrea cucullata	Hooded Oyster		1.5
		Saccostrea cucullata	Hooded Oyster		1.2
		Saccostrea cucullata	Hooded Oyster		2.2
		Saccostrea cucullata	Hooded Oyster		2.7
		Saccostrea cucullata	Hooded Oyster		2.7
		Saccostrea cucullata	Hooded Oyster		2.4
		Saccostrea cucullata	Hooded Oyster		1.8
		Saccostrea cucullata	Hooded Oyster		1.9

		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		1.7
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		3.9
		Saccostrea cucullata	Hooded Oyster		4
		Saccostrea cucullata	Hooded Oyster		1.4
		Saccostrea cucullata	Hooded Oyster		1.9
		Cypraea moneta	Money Cowrie	1	
	20	*Codakia punctata*	Pitted Lucine	1	3.4
		Saccostrea cucullata	Hooded Oyster	5	3.3
		Saccostrea cucullata	Hooded Oyster		3.9
		Saccostrea cucullata	Hooded Oyster		2.2
		Saccostrea cucullata	Hooded Oyster		2.4
		Saccostrea cucullata	Hooded Oyster		2.9
		Nassarius coronatus	Crowned Nassa	1	0.9
	10	*Saccostrea cucullata*	Hooded Oyster	12	6.3
		Saccostrea cucullata	Hooded Oyster		5.5
		Saccostrea cucullata	Hooded Oyster		2.9
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		2.8
		Saccostrea cucullata	Hooded Oyster		4.4
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		4.9
		Saccostrea cucullata	Hooded Oyster		5.2
		Saccostrea cucullata	Hooded Oyster		6.1
		Saccostrea cucullata	Hooded Oyster		2.4
		Saccostrea cucullata	Hooded Oyster		5.5
		Codakia punctata	Pitted Lucine	1	2.3
		Fragum unedo	Strawberry Cockle	2	2.5
		Fragum unedo	Strawberry Cockle		3.4
		Nassarius coronatus	Crowned Nassa	1	0.6
		Pecten maximus		1	
	0	*Eunaticina papilla*	Papilla Moon	5	1.1
		Eunaticina papilla	Papilla Moon		1.6
		Eunaticina papilla	Papilla Moon		2.2
		Eunaticina papilla	Papilla Moon		1.4
		Eunaticina papilla	Papilla Moon		1.9
		Saccostrea cucullata	Hooded Oyster	1	1.9
Kendwa 2	30	*Saccostrea cucullata*	Hooded Oyster	40	1.2
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		3.5
		Saccostrea cucullata	Hooded Oyster		3.7
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		2.2
		Saccostrea cucullata	Hooded Oyster		1.8
		Saccostrea cucullata	Hooded Oyster		1.9
		Saccostrea cucullata	Hooded Oyster		1.2

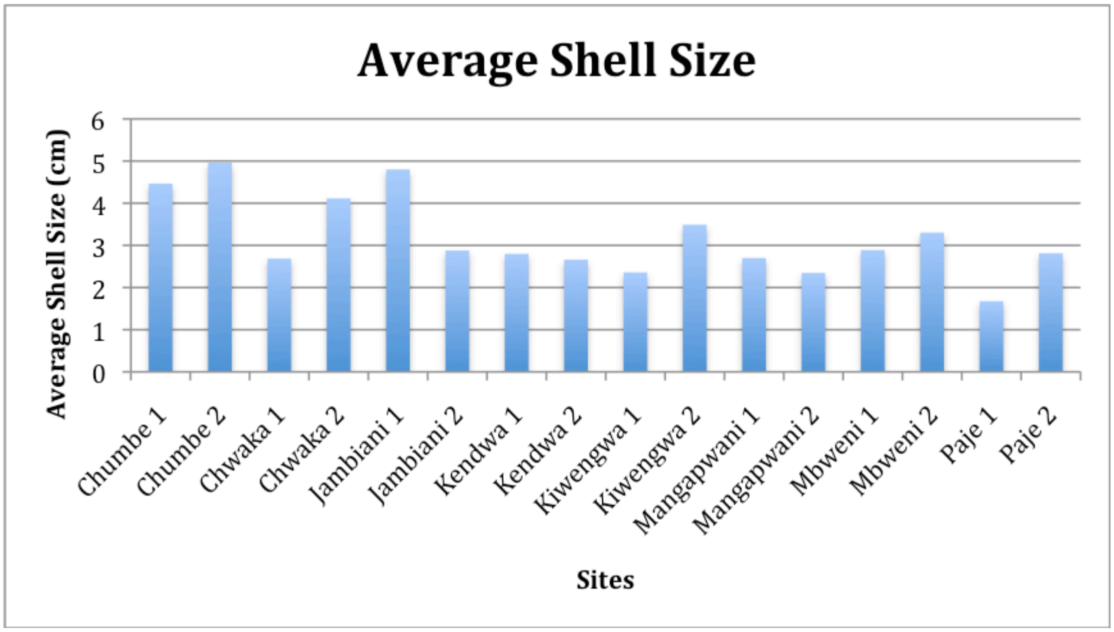
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		1.8
		Saccostrea cucullata	Hooded Oyster		4.2
		Saccostrea cucullata	Hooded Oyster		2.9
		Saccostrea cucullata	Hooded Oyster		3.1
		Saccostrea cucullata	Hooded Oyster		2.8
		Saccostrea cucullata	Hooded Oyster		2.5
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		3
		Saccostrea cucullata	Hooded Oyster		1.8
		Saccostrea cucullata	Hooded Oyster		1.9
		Saccostrea cucullata	Hooded Oyster		1.6
		Saccostrea cucullata	Hooded Oyster		1.9
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		4
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		2.8
		Saccostrea cucullata	Hooded Oyster		2.7
		Saccostrea cucullata	Hooded Oyster		4
		Saccostrea cucullata	Hooded Oyster		1.5
		Saccostrea cucullata	Hooded Oyster		3.9
		Saccostrea cucullata	Hooded Oyster		1.3
		Saccostrea cucullata	Hooded Oyster		1.6
		Saccostrea cucullata	Hooded Oyster		2.1
		Saccostrea cucullata	Hooded Oyster		2.8
		Saccostrea cucullata	Hooded Oyster		3.8
		Saccostrea cucullata	Hooded Oyster		1.3
		Saccostrea cucullata	Hooded Oyster		4.1
		Saccostrea cucullata	Hooded Oyster		2.6
		Saccostrea cucullata	Hooded Oyster		2.9
		Staphylea cassiaui	Cassiau's Cowrie	1	2.7
	20	*Strombus mutabilis*	Changeable Conch	1	2.5
		Thatcheria mirabilis	Japanese Wonder Shell	2	2.7
		Thatcheria mirabilis	Japanese Wonder Shell		
		Eunaticina papilla	Papilla Moon	1	1.6
		Strombus urceus	Little Bear Conch	2	0.6
		Strombus urceus	Little Bear Conch		0.4
		Trochia cingulata	Corded Rock Shell	1	
	10	*Eunaticina papilla*	Papilla Moon	1	5.4
		Saccostrea cucullata	Hooded Oyster	3	
		Trisidos tortuosa	Propellor Ark	1	1
	0	*Saccostrea cucullata*	Hooded Oyster	32	
Kiwengwa 1	30	*Anadara uropygimelana*	Burnt-End Ark	1	8.2
		Codakia tigerina	Pacific Tiger Lucine	2	5.2
		Codakia tigerina	Pacific Tiger Lucine		4.6
		Mytilus edulis	Mediterranean Mussel	1	1.4
		Corbula gibba	Common Basket-Shell	13	1.9

		Corbula gibba	Common Basket-Shell		1.8
		Corbula gibba	Common Basket-Shell		0.8
		Corbula gibba	Common Basket-Shell		0.3
		Corbula gibba	Common Basket-Shell		0.5
		Corbula gibba	Common Basket-Shell		2
		Corbula gibba	Common Basket-Shell		1.5
		Corbula gibba	Common Basket-Shell		1.6
		Corbula gibba	Common Basket-Shell		2
		Corbula gibba	Common Basket-Shell		0.6
		Corbula gibba	Common Basket-Shell		0.7
		Corbula gibba	Common Basket-Shell		1.3
		Corbula gibba	Common Basket-Shell		2
	20	*Codakia punctata*	Pitted Lucine	1	3.6
		Cypraea caputserpentis	Snake's Head Cowrie	1	2.1
	10	*Eunaticina papilla*	Papilla Moon	1	2.4
		Corbula gibba	Common Basket-Shell	1	3.4
	0	*Trisidos tortuosa*	Propellor Ark	1	2.3
		Lucina pectinata	Thick Lucine	1	1.1
Kiwengwa 2	30	*Pinctada radiata*	Rayed Pearl Oyster	1	1.8
		Anadara uropygimelana	Burnt-End Ark	1	4.2
	20	*Anadara granosa*	Granular Ark	1	6.6
		Terebra maculata	Marlinspike	1	3.7
		Conus spectrum	Spectral Cone	1	2.9
	10	*Cittarium pica*	West Indian Top Shell	1	2.2
		Anadara uropygimelana	Burnt-End Ark	2	4.2
		Anadara uropygimelana	Burnt-End Ark		4.4
	0	*Tellina virgata*	Striped Tellin	1	1.4
Mangapwani 1	30	*Eunaticinia papilla*	Papilla Moon	4	2.9
		Eunaticinia papilla	Papilla Moon		2.6
		Eunaticinia papilla	Papilla Moon		3
		Eunaticinia papilla	Papilla Moon		
		Natica stellata	Starry Moon	1	3.1
	20	*Saccostrea cucullata*	Hooded Oyster	3	3.2
		Saccostrea cucullata	Hooded Oyster		2.8
		Saccostrea cucullata	Hooded Oyster		3.6
		Mytilus edulis	Mediterranean Mussel	1	1.7
	10	*Eunaticina papilla*	Papilla Moon	2	2.9
		Eunaticina papilla	Papilla Moon		2.2
		Chiton marmoratus	Marbled Chiton	1	2.2
		Saccostrea cucullata	Hooded Oyster	13	1.4
		Saccostrea cucullata	Hooded Oyster		1.2
		Saccostrea cucullata	Hooded Oyster		3.3

		Saccostrea cucullata	Hooded Oyster		3.6
		Saccostrea cucullata	Hooded Oyster		3.5
		Saccostrea cucullata	Hooded Oyster		2.2
		Saccostrea cucullata	Hooded Oyster		2.4
		Saccostrea cucullata	Hooded Oyster		2.4
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		3.7
		Saccostrea cucullata	Hooded Oyster		1.4
		Saccostrea cucullata	Hooded Oyster		1.8
		Saccostrea cucullata	Hooded Oyster		1.9
	0	*Ficus subintermedia*	Underlined Fig Shell	1	5.2
Mangapwani 2	30	*Saccostrea cucullata*	Hooded Oyster	4	1.1
		Saccostrea cucullata	Hooded Oyster		1.4
		Saccostrea cucullata	Hooded Oyster		1.9
		Saccostrea cucullata	Hooded Oyster		2.3
		Eunaticina papilla	Papilla Moon	3	1.3
		Eunaticina papilla	Papilla Moon		2.1
		Eunaticina papilla	Papilla Moon		1.6
		Trisidos tortuosa	Propellor Ark	1	2.2
	20	*Cypraea moneta*	Money Cowrie	1	2.2
		Saccostrea cucullata	Hooded Oyster	4	4.2
		Saccostrea cucullata	Hooded Oyster		3.3
		Saccostrea cucullata	Hooded Oyster		2.1
		Saccostrea cucullata	Hooded Oyster		3.6
		Eunaticina papilla	Papilla Moon	1	1.6
	10	*Anadara uropygimelana*	Burnt-End Ark	1	5.4
		Codakia punctata	Pitted Lucine	2	0.9
		Codakia punctata	Pitted Lucine		2.4
		Mammilla melanostoma	Black-Mouth Moon	1	3.3
	0	*Tonna galea*	Giant Tun	1	3.4
		Barbatia foliata	Leafy Ark	3	0.9
		Barbatia foliata	Leafy Ark		1.2
		Barbatia foliata	Leafy Ark		1.6
		Tonna sulcosa	Banded Tun	1	2.3
		Monetaria moneta	Money cowrie	1	4
Mbweni 1	30	*Plagiocardium pseudolima*	Giant Cockle	3	5.2
		Plagiocardium pseudolima	Giant Cockle		5.4
		Barbatia foliata	Leafy Ark	1	6.2
		Fragum unedo	Strawberry Cockle	1	3.3
		Ficus subintermedia	Underlined Fig Shell	1	6.3
	20	*Saccostrea cucullata*	Hooded Oyster	4	2
		Saccostrea cucullata	Hooded Oyster		1.6
		Saccostrea cucullata	Hooded Oyster		1.3

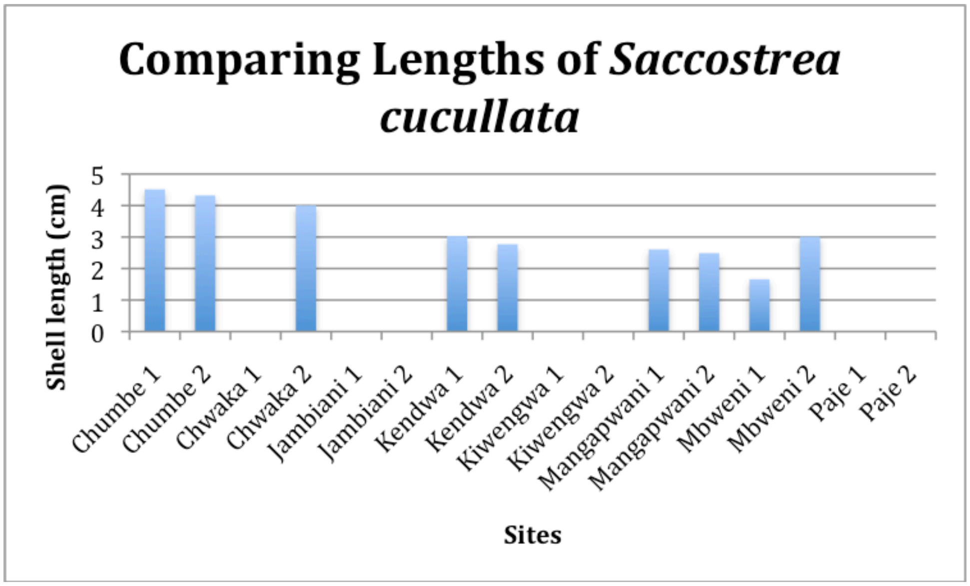
		Saccostrea cucullata	Hooded Oyster		1.2
	10	*Saccostrea cucullata*	Hooded Oyster	3	2.3
		Saccostrea cucullata	Hooded Oyster		2.1
		Saccostrea cucullata	Hooded Oyster		1.6
	0	*Saccostrea cucullata*	Hooded Oyster	3	1.5
		Saccostrea cucullata	Hooded Oyster		1.1
		Saccostrea cucullata	Hooded Oyster		1.9
		Barbatia foliata	Leafy Ark	1	3.2
Mbweni 2	30	*Saccostrea cucullata*	Hooded Oyster	3	1.1
		Saccostrea cucullata	Hooded Oyster		1.3
		Saccostrea cucullata	Hooded Oyster		1.8
		Barbatia amygdalumtostum	Burnt-Almond Ark	1	3.1
		Anadara uropygimelana	Burnt-End Ark	1	2.3
	20	*Pleuroploca trapezium*	Trapezium Horse Conch	1	6.7
		Eunaticina papilla	Papilla Moon	1	2.2
	10	*Saccostrea cucullata*	Hooded Oyster	2	5.3
		Saccostrea cucullata	Hooded Oyster		4.7
		Trisidos tortuosa	Propellor Ark	1	4.2
	0	*Saccostrea cucullata*	Hooded Oyster	2	3.2
		Saccostrea cucullata	Hooded Oyster		3.7
Paje 1	30	*Pinctada radiata*	Rayed Pearl Oyster	1	1.7
		Nassarius coronatus	Crowned Nassa	2	1.3
		Nassarius coronatus	Crowned Nassa		2.1
	20	*Corbula gibba*	Common Basket-Shell	2	0.9
		Corbula gibba	Common Basket-Shell		1.1
	10	*Eunaticina papilla*	Papilla Moon	1	1.8
	0	*Amusium pleuronectes*	Asian Moon Scallop	1	2.3
		Eunaticina papilla	Papilla Moon	1	2.2
Paje 2	30	*Eunaticina papilla*	Papilla Moon	1	1.7
		Amusium pleuronectes	Asian Moon Scallop	1	3.4
	20	*Trisidos tortuosa*	Propellor Ark	1	2.6
		Lyria delessertiana	Delessert's Lyria	1	2.2
	10	*Eunaticina papilla*	Papilla Moon	1	1.6
		Amusium pleuronectes	Asian Moon Scallop	1	3.7
		Strombus canarium	Dog Conch	1	3.2
	0	*Lyria delessertiana*	Delessert's Lyria	1	3.6
		Codakia punctata	Pitted Lucine	1	3.3

Appendix B: Site Comparisons



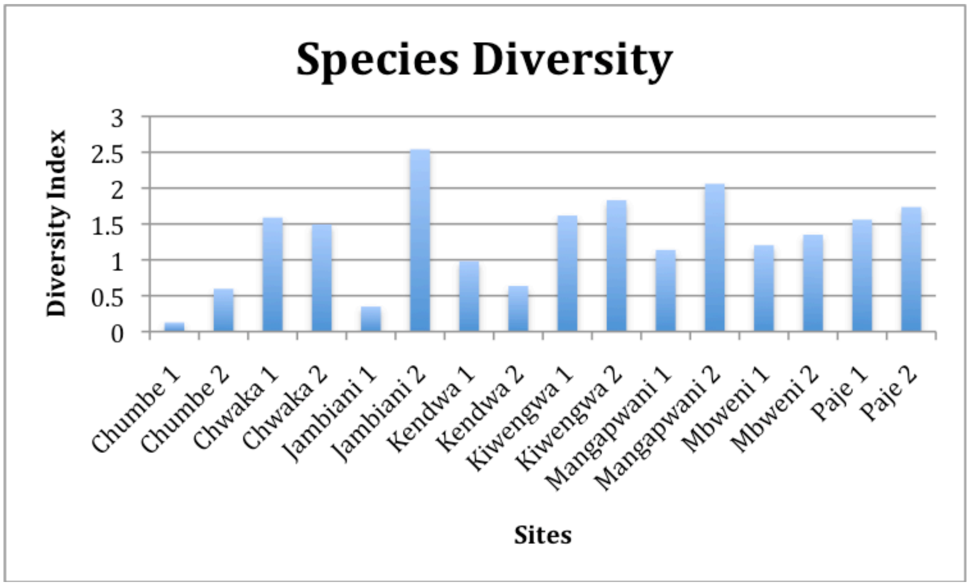
Site	**Average Shell Size**
Chumbe 1	4.464102564
Chumbe 2	4.963157895
Chwaka 1	2.685714286
Chwaka 2	4.114285714
Jambiani 1	4.8
Jambiani 2	2.877777778
Kendwa 1	2.798113208
Kendwa 2	2.660416667
Kiwengwa 1	2.358333333
Kiwengwa 2	3.488888889
Mangapwani 1	2.7
Mangapwani 2	2.345833333
Mbweni 1	2.8875
Mbweni 2	3.3
Paje 1	1.675
Paje 2	2.811111111

Appendix C: *Saccostrea cucullata* Data



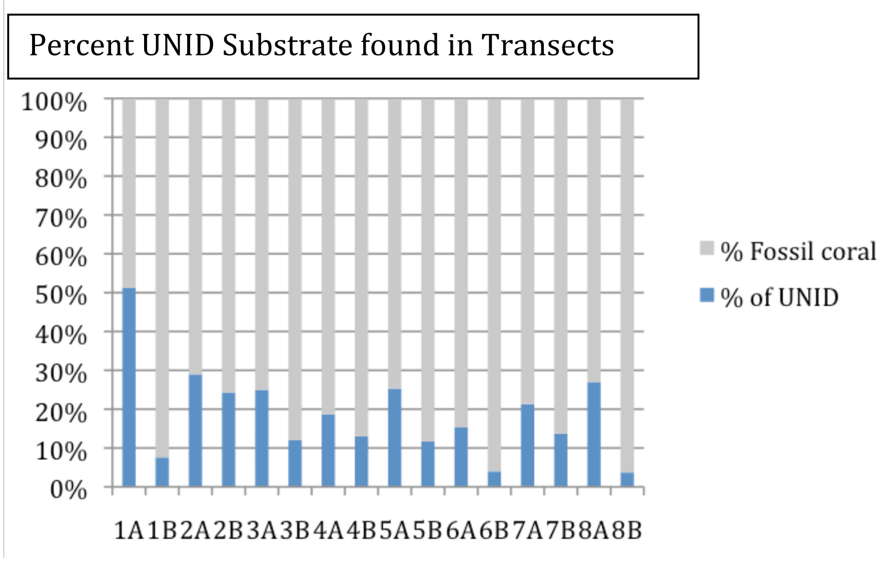
Site	Number of Species	Average Length
Chumbe 1	38	4.513157895
Chumbe 2	32	4.31875
Chwaka 1	0	0
Chwaka 2	1	4
Jambiani 1	0	0
Jambiani 2	0	0
Kendwa 1	40	3.029545455
Kendwa 2	72	2.77
Kiwengwa 1	0	0
Kiwengwa 2	0	0
Mangapwani 1	16	2.60625
Mangapwani 2	8	2.4875
Mbweni 1	10	1.66
Mbweni 2	7	3.014285714
Paje 1	0	0
Paje 2	0	0

Appendix D: Mollusk Species Diversity



Site	Species Diversity
Chumbe 1	0.126930545
Chumbe 2	0.595857736
Chwaka 1	1.589026915
Chwaka 2	1.494175138
Jambiani 1	0.348832096
Jambiani 2	2.540036304
Kendwa 1	0.982085188
Kendwa 2	0.63644137
Kiwengwa 1	1.617159814
Kiwengwa 2	1.831020481
Mangapwani 1	1.138405139
Mangapwani 2	2.058768788
Mbweni 1	1.203332041
Mbweni 2	1.349792396
Paje 1	1.559581156
Paje 2	1.735126457

Appendix E: Unidentifiable Coral Substrate



UNID Averages by Location		
Site Area	average % UNID	Sample size
W/SW (Sites 1,2,7)	24.53	6
S/SE (Sites 4,8)	15.60	4
N/NE (sites 3,5,6)	15.55	6

T-Test of UNID		
	West (Sites 1,2,7)	East (Sites 3,4,5,6,8)
Mean	24.55	17.97
SD	15.15	8.04
SEM	6.185	2.543
N	6	10

Appendix F: Coral Transect Results

Transect Data (0-30m)

Mangapwani (W)					
	1A			1B	
Species	Total M	% cover	Species	Total M	% cover
BBB1	3.3	11.0	C1	6.0	20.0
G1	3.0	10.0	B1	4.3	14.3
BBB3	2.5	8.3	F1	3.7	12.3

E1	1.7	5.7	BBB4	2.9	9.7
A1	1.5	5.0	D1	1.8	6.0
C1	1.3	4.3	J1	1.8	6.0
DD1	0.9	3.0	G2	1.4	4.7
BB2	0.4	1.3	I1	1.3	4.3
UNID	15.4	51.3	B3	1.3	4.3
			G1	1.1	3.7
			BB2	1.1	3.7
			DD1	1.0	3.3
			UNID	2.3	7.7

Mbweni (SW)					
	2A			2B	
Species	Total M	% cover	Species	Total M	% cover
DD1	10.0	33.3	A1	11.4	38.0
G2	3.6	12.0	DD1	3.5	11.7
I2	1.9	6.3	H1	2.2	7.3
B3	1.7	5.7	BBB3	1.5	5.0
A1	1.7	5.7	BBB4	1.2	4.0
A2	0.9	3.0	CCC1	1.2	4.0
G1	0.8	2.7	A2	1.1	3.7
B1	0.7	2.3	AA1	0.6	2.0
UNID	8.7	29.0	UNID	7.3	24.3

Chwaka (E)					
	3A			3B	
Species	Total M	% cover	Species	Total M	% cover
D1	5.3	17.7	AA1	6.4	21.3
A1	4.2	14.0	CCC1	5.3	17.7
CCC1	3.8	12.7	A2	4.8	16.0
G1	3.4	11.3	C1	4.3	14.3
G2	2.6	8.7	BB1	2.2	7.3
DD1	2.2	7.3	F1	1.8	6.0
F1	0.6	2.0	D1	1.2	4.0
BB1	0.4	1.3	B1	0.4	1.3
UNID	7.5	25.0	UNID	3.6	12.0

Jumbiani (SE)					
	4A			4B	
Species	Total M	% cover	Species	Total M	% cover
CCC1	8.5	28.3	G1	7.4	24.7

D1	8.3	27.7	D1	6.8	22.7
G2	2.3	7.7	CCC1	4.4	14.7
A2	2.2	7.3	F1	3.0	10.0
A1	1.8	6.0	C1	1.9	6.3
F1	1.3	4.3	B1	1.2	4.0
UNID	5.6	18.7	BBB4	0.8	2.7
			I1	0.6	2.0
			UNID	3.9	13.0

Kendwa (N)					
	5A			5B	
Species	Total M	% cover	Species	Total M	% cover
AA1	6.1	20.3	A2	8.9	29.7
BBB3	4.3	14.3	DD1	4.9	16.3
CCC1	4.1	13.7	G1	3.9	13.0
DD1	3.2	10.7	AA1	2.4	8.0
A2	2.6	8.7	F1	1.9	6.3
G1	1.2	4.0	A1	1.7	5.7
F1	0.9	3.0	B3	1.5	5.0
UNID	7.6	25.3	B2	1.3	4.3
			UNID	3.5	11.7

Kiwengwa (NE)					
	6A			6B	
Species	Total M	% cover	Species	Total M	% cover
F1	8.0	26.7	C1	6.5	21.7
D1	4.7	15.7	F1	5.2	17.3
A1	3.9	13.0	B1	4.6	15.3
CCC1	3.1	10.3	AA1	4.1	13.7
B1	1.3	4.3	D1	3.6	12.0
AA1	1.2	4.0	DD1	1.7	5.7
G1	1.2	4.0	CCC1	1.6	5.3
I1	1.2	4.0	I2	1.1	3.7
B2	0.8	2.7	G1	0.4	1.3
UNID	4.6	15.3	UNID	1.2	4.0

Chumbe (SW)					
	7A			7B	
Species	Total M	% cover	Species	Total M	% cover
A1	6.6	22.0	DD1	5.2	17.3

DD1	4.6	15.3	F1	4.9	16.3
G1	3.0	10.0	G1	3.2	10.7
CCC1	2.8	9.3	CCC1	2.9	9.7
CC1	2.0	6.7	A1	2.6	8.7
A2	2.0	6.7	D1	1.8	6.0
BBB2	1.9	6.3	B2	1.3	4.3
BBB3	0.7	2.3	A2	1.3	4.3
UNID	6.4	21.3	H1	1.2	4.0
			CC1	0.6	2.0
			B1	0.5	1.7
			BBB3	0.4	1.3
			UNID	4.1	13.7

Paje (SE)					
	8A			8B	
Species	Total M	% cover	Species	Total M	% cover
DD1	4.7	15.7	AA1	4	13.3
G1	4.1	13.7	F1	4	13.3
CCC1	3	10.0	CCC1	3.1	10.3
D1	2.9	9.7	DD1	2.6	8.7
A2	2.6	8.7	D1	1.8	6.0
AA1	2.3	7.7	G1	1.7	5.7
BBB2	0.8	2.7	A2	1.1	3.7
A1	0.7	2.3	B2	0.9	3.0
H1	0.6	2.0	CC1	0.8	2.7
BBB3	0.2	0.7	J1	0.8	2.7
UNID	8.1	27.0	BBB2	0.5	1.7
			AAA1	0.4	1.3
			UNID	8.3	27.7

Appendix G: Coral Type Identification

Coral Type Identification

Coral ID	Description	Expected Family	Expected Genus	Closest Living Relative/Species	Alternative CLR
A1	short branches, extended largerflattened branches	Acroporidae	*Acropora*	*aculeus*	
A2	up to 2m wide plate like structures with small conical branches on the upper side	Acroporidae	*Acropora*	*acuminata*	*Dendrophyllidae turbinaria*
AA1	spine, tube like termination, small diameter is 5 mm (d=5mm)	Acroporidae	*Anacropora*	*spinosa or hyacinthus*	

AAA1	tiny raditating polyps with distinct septa, in massive form	Acroporidae	*Astreopora*	*myriophythalma*	
B1	long waves of plate lines, with vertical conntecting plates evenly spacedas rectagles	Agariciidae	*Leptoseris*	*scabra*	
B2	shallow walls enciculing a massive form, no regular pattern, evenly spaced, fanning from center	Agariciidae	*Leptoseris*	*mycetoseriodes*	meandrinidae *Siderastreidae coscinaraea*
B3	vertical thick plateswith horizontal shallow separations/striations	Agariciidae	*Leptoseris*	*solida*	
BB1	small raised wavery tube/ circular slabs with horizontal striations/ tile-like	Agariciidae	*Pachyseris*	*speciosa*	
BB2	thin layers of long shallow plates, wavy pattern, evenly spaced	Agariciidae	*Pachyseris*	*rugosa*	*Trachyphylliidae geoffroyi*
BBB1	long branches (d=5-7cm) vertically stretching before a cave (indicated territorial mechanism? Or soft corals surrounding?)	Agariciidae	*Pavona*	*clavus*	
BBB2	vertical light colored tubes (d=4cm) with porous body, in front of caves suggesting territorial stingers or soft corals surrounding	Agariciidae	*Pavona*	*duerdeni*	
BBB3	tubes, dark, no directionality, flat terminations, porous	Agariciidae	*Pavona*	*clavus*	
BBB4	raised lip of polyp with radiating distinct septa. Regualrly spaced but irregulartly shaped	Agariciidae	*Pavona*	*maldivensis*	faviidae *Cyphastrea seralia*
C1	massive, smooth, rounded edges of corralite in pattern	Faviidae	*Goniastrrea*	*edwardsi*	
CC1	long horizontal layers of avg thickness 3mm, rectangle shaping septa, usually 2 rows	Faviidae	*Favites*	*pentagona*	
CCC1	vertical long shallow plates separated by short horizontal separators	Faviidae	*Leptoria*	*phrygia*	
D1	radiating septa, plate like. raised thin plates	Fungiidae	*Cycloseris*	*sinensis/repanda*	
DD1	very porous, small conical polyps	Fungiidae	*Zoopilus*	*chinatus*	
E1	porous, with larger regularly spaced holes (d=1cm)	Merulinidae	*Hynophora*	*microconos* or *rigida*	
F1	radiating septa, corallites d= from 5mm to 2cm, closely packed, regular sizing	Oculindae	*Galaxea*	d=4cm *fascicularis/* d=2cm *anomastrgea*	
G1	large tubes d=4-7cm with some shallow holes regularly spaced, porous	Pocillioporidae	*Seriatopora*	*stylophora*	siderastreidae *Psammocora digiata*
G2	d=4cm branching, small polyps	Pocilloporidae	*Stylophora*	*subseriata*	
H1	dark bulbous terminations of short tubes, d=7cm), bumpy edged, small polyps	Poritidae	*Porites*	*nodifera*	
I1	swirls of septa walls radiating from a line, regularly sized and spaced, in massive form	Sideratreidae	*Coscinacea*	*monile or crassa*	agaiciidae *Pavona venosa*
I2	directional platelets divided into two swiling around a massive form	Sideratreidae	*Psammocora*	*explanulata*	
J1	shallow raised walls in honeycomb shape. Massive shape		*Pocillopora*		
UnID	unidentifiable- smooth or rough from water or urchin damage, may be sedimentation				

Appendix H: Coral Species Diversity

Species Count			
	Distinct Species		
Site	Site A	Site B	**Average**
1. Mangapwani	9	12	10.5
2. Mbweni	9	8	8.5
3. Chwaka	8	8	8.0
4. Jumbiani	6	9	7.5
5. Kendwa	7	8	7.5
6. Kiwengwa	9	10	9.5
7. Chumbe	8	12	10.0
8. Paje	10	12	11.0

Abundance of Fossil Corals, Summation of West and East:
Modified for Use in Simpson's Index of Diversity

T-Test on Species Count

p=0.3059 Ci 95%: -0.98 to 2.92

	West	East
Mean	9.67	8.7
SD	1.86	1.7
SEM	0.76	0.54
N	6	10

West Species	sample size= 6 transects, 180m	n	n(n-1)
A1	79.4	13.23	161.89
A2	17.7	2.95	5.75
AA1	2	0.33	-0.22
AAA1	0	0.00	0.00
B1	18.3	3.05	6.25
B2	4.3	0.72	-0.20
B3	10	1.67	1.11
BB1	0	0.00	0.00
BB2	5	0.83	-0.14
BBB1	11	1.83	1.53
BBB2	6.3	1.05	0.05
BBB3	16.9	2.82	5.12
BBB4	13.7	2.28	2.93
C1	24.3	4.05	12.35
CC1	8.7	1.45	0.65
CCC1	23	3.83	10.86
D1	12	2.00	2.00
DD1	83.9	13.98	181.55
E1	5.7	0.95	-0.05
F1	28.6	4.77	17.95
G1	37.1	6.18	32.05
G2	16.7	2.78	4.96
H1	11.3	1.88	1.66
I1	10.6	1.77	1.35
I2	0	0.00	0.00
J1	6	1.00	0.00

	Totals	75.42	449.42
	Simpson's Index	0.08	
	Simpson's Index of Diversity	0.92	

East Species	sample size= 10 transects, 300m	n	n(n-1)
A1	31.2	3.12	6.6144
A2	74.1	7.41	47.4981
AA1	88.3	8.83	69.1389
AAA1	1.3	0.13	-0.1131
B1	24.9	2.49	3.7101
B2	10	1.00	0
B3	5	0.50	-0.25
BB1	8.6	0.86	-0.1204
BB2	0	0.00	0
BBB1	0	0.00	0
BBB2	4.4	0.44	-0.2464
BBB3	15	1.50	0.75
BBB4	2.7	0.27	-0.1971
C1	42.3	4.23	13.6629
CC1	2.7	0.27	-0.1971
CCC1	123	12.30	138.99
D1	97.8	9.78	85.8684
DD1	82.1	8.21	59.1941
E1	0	0.00	0
F1	88.9	8.89	70.1421
G1	77.7	7.77	52.6029
G2	16.4	1.64	1.0496
H1	2	0.20	-0.16
I1	6	0.60	-0.24
I2	3.7	0.37	-0.2331
J1	2.7	0.27	-0.1971
	Totals	81.08	547.2672
	Simpson's Index	0.0842872	
	Simpson's Index of Diversity	0.9157128	

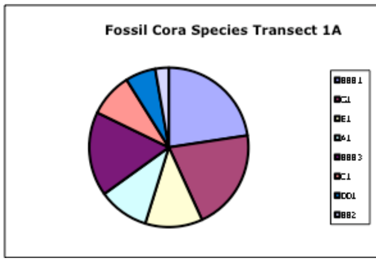
Paired T-Test on Abundance (n)

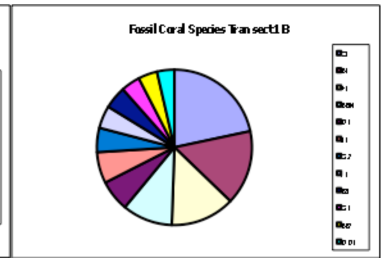
p=0.7828 CI 95%: -1.8328 to 1.3959

	West	East
Mean	2.9	3.1185
SD	3.4982	3.8756
SEM	0.6861	0.7601
N	26	26

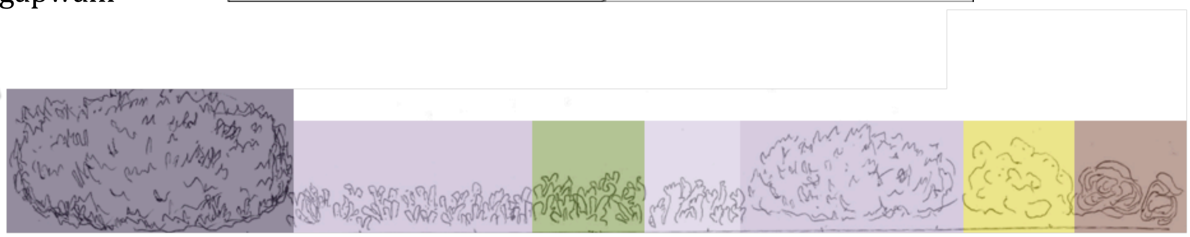
Appendix I: Proportions of Identifiable Species In Each Transect with Visual Representations

Mangapwani

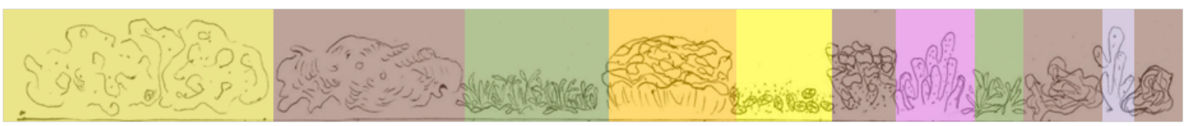




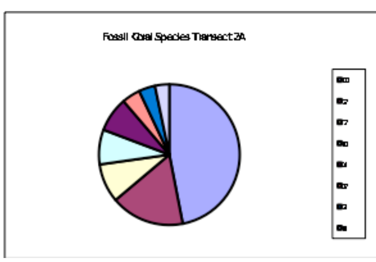
1A

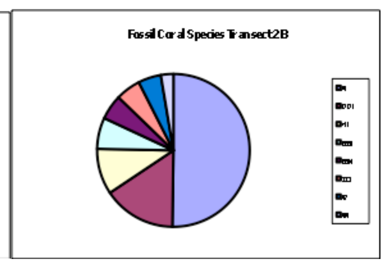


1B



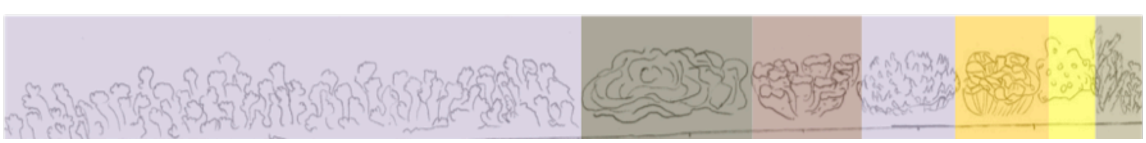
Mbweni

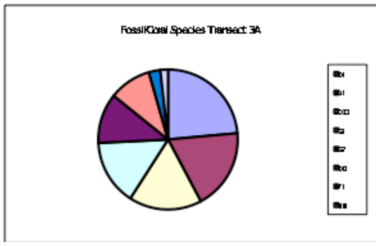


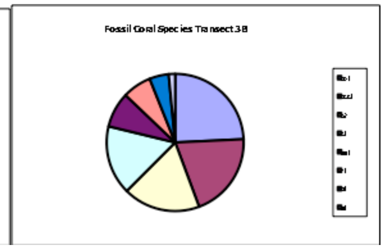


2A

2B

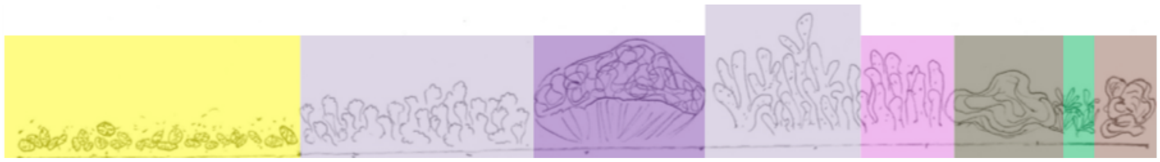




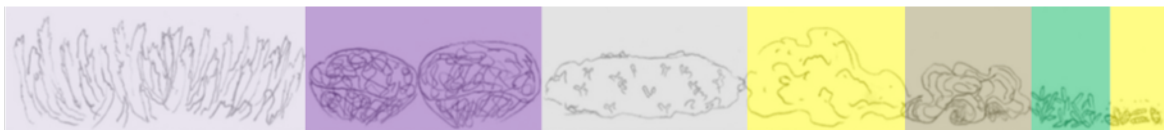


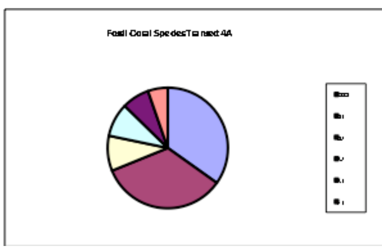
Chwaka

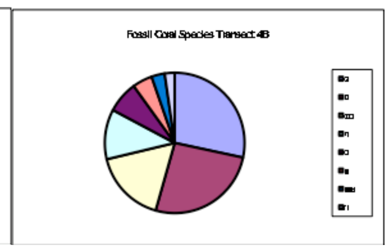
3A



3B





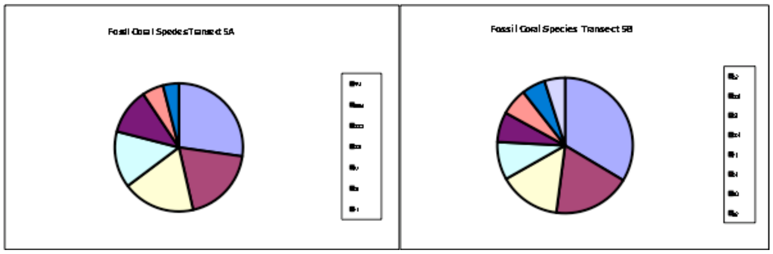


Jambiani

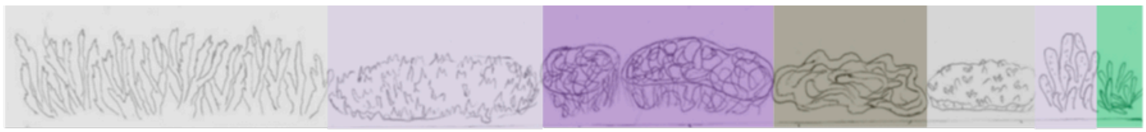
4A

4B

Kendwa

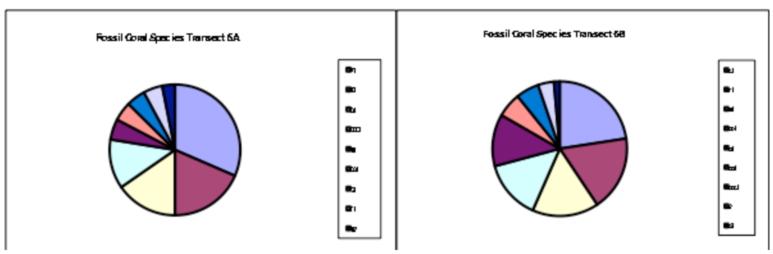


5A



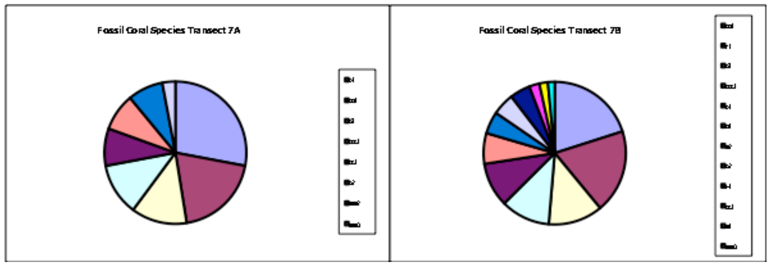
5B

Kiwengwa



6A

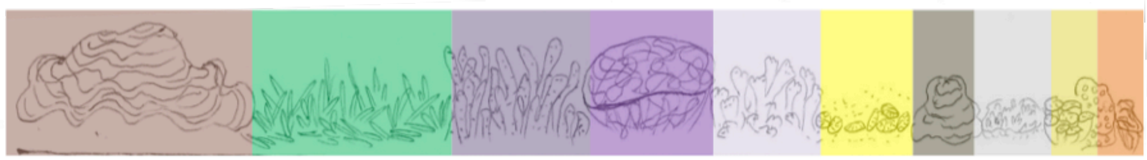
6B

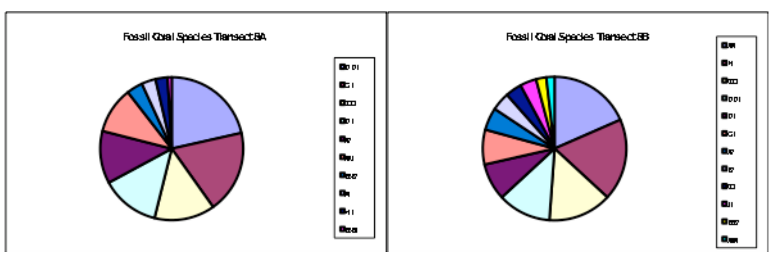


Chumbe

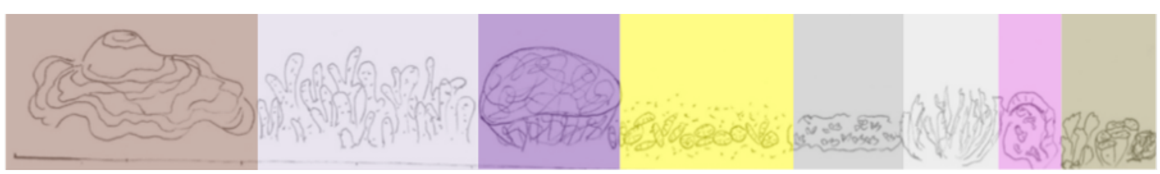
7A

7B





Paje



8A

8B