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Bioremediation Mariculture in Zanzibar, Tanzania: A Viability Assessment of Using Bath Sponge and Pearl Oyster Farms to Filter Highly olluted Waters in the Zanzibar Channel

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Abstract

Bioremediation of polluted water off the coastline of the urban center of Zanzibar—Stone Town, Unguja—was assessed for implementation feasibility through bath sponge and pearl oyster mariculture. A vast research base of the city's coastal area exists, including the pollution concentrations at various locations, the ramifications of this pollution on the fringing ecosystems, and the relevant water circulation system of eddies and passageways produced by the north flowing East African Counter Current. In following the experimental examples of bioremediation projects around the world, this study tested facets of the filtration abilities of marine sponges and oysters. Both organisms suggested strong pollution filtration abilities. Phosphate concentrations decreased from an average of 3.93 ug/L (micrograms per liter) to 1.33 and 1.73 ug/L for sponges and oysters, respectively. Unique capabilities of each organism were displayed in the experiments. The marine sponges visibly eliminated the turbidity level in the 36-hour study period. The marine oysters were suggested to chemically convert the dissolved nitrates through the tested increase in ammonium concentration from an average of 4.01 ug/L in the contaminated water to and average replicate concentration of 21.5 ug/L. The respective mariculture techniques were examined along with management logistics to assess the viability of implementing the mariculture for the pollution remediation. It was concluded that the mariculture techniques could be feasibly established by carefully collaborating with the nature of the pollution distribution, the consultation and aid of private and governmental organizations and further background scientific research.

I. Introduction

Polluted seawater is an undeniable and indisputable situation for active ports around the world. Stone Town, Zanzibar is further desecrated by the outflow of raw sewage pipelines and wastewater runoff directly into the waterfront. Numerous previous studies have shown that the sewage and wastewater runoff in the city of Stone Town have directly increased the concentrations of harmful nutrients and biological macromolecules on the town's coastline (Van Bruggen 1990, Anderson 1994, Shunula and Ngoile 1995, Mmochi 1996, Moynihan 2011,) However, little has been done in the way of mitigating these effects other than suggesting that they be researched and alleviated. Unfortunately, most of this pollution comes from the stress of the ever-increasing population size of the urban center of Zanzibar. As a cultural and political issue, population control and family planning is too sensitive to address directly. If the cause of pollution cannot be currently managed at its source, the outcomes must in the very least be mitigated to prevent any further damage to the health of both the ecosystems and the surrounding communities. The ecosystems in question involve the coral reefs and mangroves off of Stone Town, two of the epicenters of ocean health, which also provide significant socioeconomic means for local Zanzibaris.

Stone Town is an established World Heritage site where visitors from around the world come to see the history, culture and biodiversity so concentrated in one place. These visitors and the local citizens would be mutually horrified to know the extent of the pollution present in the 'pristine' waters they observe, utilize and come specifically for. Not only would they not want to know for aesthetic reasons, but health reasons as well. The sewage in the water has the potential to carry such diseases as dengue and cholera, among many other dangerous water-born afflictions. The water must some how be filtered to make the coastal environment safer and more habitable for both the humans and the species involved and affected.

The issue of how to filter this pollution is then presented. An extremely small proportion of industries and individual households are even connected to the sewage line, making runoff a substantial issue, especially in the rainy seasons (during which this study takes place.) This conveys that there has to be a way to treat the sewage not only maltreated through the lines, but the inevitable runoff from the growing population not on the lines. Effluents and other pollutants discharge into the seawater along the entire coast, simply more highly concentrated at the outflows (Mmochi 1996.) This comes across as an unsolvable task: controlling a disseminated source; but this can be managed with an ecosystem-based and integrated coastal zone management approach to filtering the harmful water present right off shore.

It is critical to act before this problem becomes accelerated. Luckily, there is still life in the ecosystems off of Stone Town, but with the continuance of such a prominent and unrelenting stressor, that life is not likely to remain (Moynihan 2012.) Given the dependence on this ecosystem both directly and indirectly, it is vital that a management process be implemented before the keystone environments are lost permanently. These keystone environments involve the coral reef and mangrove ecosystems surrounding the island, which act as both natural attractions and livelihood for humans, but also critical nurseries for the species that keep the biosphere we are a part of intact.

Ecosystem-based and integrated management takes into account the whole ecosystem affected and looks for a solution not just to dampen some of the problems, but to try to solve the entirety of the issue for the entire system (Mohammad, personal communication; *Progress in Integrated Coastal Management* 2000.) In the case of this study, it also employs natural means of solving the problem, rather than through machines or chemicals. The proposed action for the mitigation of sewage-ridden water off of Stone Town, Zanzibar is zooremediation through bivalve molluscs and sponge porifera. Zooremediation is progressively utilized as a solution to polluted waters all over the world, both marine and fresh, by employing species from various evolutionarily advanced positions to utilize their natural biological processes to treat contaminated water. Such species range from algae to fish, vertebrates and invertebrates, with varying abilities to filter, oxygenate and decontaminate the surrounding water column (Gifford et al 2006.) Though sponges and oysters may seem a strange combination and that it may be preferable to simply focus on one group, the goal is to come at the problem with a holistic ecosystem approach, meaning both that one species should not be overloaded and that the two can work together with their unique individual abilities to aid humans in remediation of the damage continually done to the marine ecosystem.

The concededly strange combination of these invertebrates actually comes from an expansive research base that has proven these seemingly evolutionarily simple creatures to be remarkable filter feeders, thriving off of what other species, including our own, process as biotoxins (Gifford et al 2005, Longo et al 2010, Rittschof and McClellan-Green 2005.) These biotoxins consist both of the direct effluents and nutrients dissolved in the mixing of seawater and sewage (such as nitrates, phosphate and ammonium,) but also organisms in the water column that exist naturally to a certain extent but become over-populated and invasive with the introduction of high concentrations of these nutrients. Phytoplankton, zooplankton and bacteria feed off of or process the introduced nutrients and proliferate. In the case of the plankton, higher populations increase the turbidity of the water (amount of dissolved particles affecting the water's transparency), which prevents keystone-photosynthesizing organisms such as seagrass and algae (including the zooxanthallae algae in coral) from accessing the essential sunlight source. The bacteria bloom causes anoxic conditions in the water given that the bacteria use the dissolved oxygen in the water when metabolizing the accumulating nutrients. Consequentially, the seawater affected becomes highly virulent to the ecosystems contained, leading to entire 'dead zones,' such as the unfortunate cases in large areas of the Caribbean and Mediterranean Seas (*NOAA* 2013.) The particular fauna in question for the remediation of these issues are bath sponges and pearl oysters, two members of the group of phyla and species who naturally maintain the ocean's biochemical stability through filter feeding.

Sponges and oysters similarly get their sustenance by sucking in ocean water, taking out bacteria and microorganisms present, and spewing back out seawater rid of these components. Sponges, in the phylum porifera, have a specialized pore called the ostia that is able to draw in water through the action of many choanocytes, custom cells that pump water, analogous to cilium on certain cells, creating a current in the surrounding fluid (Milanese et al 2003.) The water current created pulls in the seawater surrounding the sponge containing bacteria, phytoplankton and zooplankton food sources, in addition to suspended particles, which is indiscriminately filtered through the animals' mesohyl matrices. Therefore the seawater that is pushed back out into the surrounding water column through the sponges' oscule is rid of the particles taken in.

Similarly, oysters are in the class of molluscs called bivalves, which draw in water through the 'in' valve, filter it through their stomachs and gills, and propel it back out through the 'out' valve. This process, analogous to the sponges' choanocytes, is generated by cilium on the oysters' gills (Raj 2008.) Their food source comes from microalgal nanoplankton, though studies have suggested that they are indiscriminate in filtering all particulate matter (Gifford et al

2005.) In addition, they are proven to be excellent bioaccumulators of heavy metals such as zinc and cadmium (Raj 2008.) Though they do take nutrients from the water column through their consumption of phytoplankton, they do release some as well in the processing of the heavy metals (Saito 2012.) In this way, another bioaccumulator must be near to the oyster beds to have holistic biopollutant filter-feeding success.

Sponges and oysters are effective together because of their ability to collaborate in the filtration of most pollutants, but also to uniquely filter what the other cannot. Dr. Scott Lindell, director of the Marine Biological Laboratory's scientific aquaculture program, which uses oysters for zooremediation in Brewster, Massachusetts said, "The oysters themselves do produce ammonia…as they're capturing phytoplankton and they do store some in their tissue but the seaweed is more efficient at removing nitrogen." (Saito 2012.) Where Lindell cultivates seaweed for the secondary filtration source, sponges are proposed as the nitrogen repository here because it is too big an issue to introduce edible seaweed to filter sewage pollution (though that is what Lindell does in his study, though the sewage is more highly treated in his locality.)

In this way, sponges are proven to be highly effective at bioaccumulation of nitrogen and ammonia, creating a perfect coexistence with oysters. Sponges also have an unparalled ability to retain particles, including bacteria and nutrients, given their accelerated filtration and accumulation rates. Many studies have shown these abilities through studies of water column qualities before and after exposure to sponge populations (Gifford et al 2006, Longo et al 2010.) The organisms are therefore ideal candidates for pollution treatment, especially in conjunction with the accumulation power of oysters, in their impartial filtration.

Neither animal can tolerate overexposure nor to be overwhelmed by pollutants and therefore a careful placement must be assessed to ensure adequate filtration of the pollutants without harming the animals involved. Variability in pollution concentrations can affect the abilities of the organisms to effectively filter (Souza et al 2013.) The current system in the Zanzibar Channel off of Stone Town provides that the water flows northward through the channel as an extremity of the East African Counter Current (EACC.) The near shore water is deflected off of Ras Shanghani point and flows northwest between the boundary islands of Bawe and Changuu (see Appendix I, figure 4 map,) a system locally named the 'Great Pass.' (Nyandwi, personal communication.) This system was thought, in the original decision to dump the sewage in this manner, to carry the harmful water into the powerful EACC current, allowing enough mixing to dilute the pollutants. However, because of these peripheral islands, much of the polluted waters from the city are deflected in either direction in an eddy formation back toward Stone Town and the coral islands (Appendix I, figure 4 diagram.) Additionally, because of the nature of Zanzibar Channel's shallow depth, the EACC is greatly slowed, especially along the near-shore perimeter of Unguja. These confounding variables greatly affect the ability of the seawater quality to manage the introduction of the nutrients and other pollution by the growing city's wastewater. In this way, a filtration system to intercept the deflected water before it returns to the town and amplifies the problem is the best approach for an integrated and ecosystem-based management plan.

The introduction of a 'predator' to manage a 'pest' (typically on a more macro level than this situation,) must be considered very lightly to avoid predator overpopulation. For instance, the bacteria and phytoplankton feeding on the introduced effluents ('pests') represent the 'predators,' which have become invasive and overpopulated. In this way, the suggestion to introduce 'predators' to the proliferating invasive species must be managed carefully. That is a main point of a study campaigning to use animals to remediate aquatic environments; that the animals should not hold the possibility of becoming invasive on the environment in question (Gifford et al 2006.) However, this situation has a natural solution to that issue.

These species are not only particularly proficient in filtering biologically active wastewater, but also have the ability to be commercially harvested as another means of economic development, and in this way their populations will stay monitored and controlled. Furthermore, it is unrealistic to implement a project purely out of environmental soundness without the necessity of an economic incentive for local communities, no matter where the project in question is needed. However, particularly in a developing nation in need of income and employment, it is critical to think of how a project idea will directly benefit the adjacent communities. Although it is arguable that the direct benefit is sustaining the ecosystems that the community continually relies on for sustenance and income-generating activities, the communities need more tangibility, such as concrete economic benefits.

Advantageously, these two incredible zooremediators are currently experimentally farmed on Zanzibar, so the mariculture is not new here. In fact, in the 15th century, the Portuguese settlers on the island discovered that there was an abundance of pearl oysters surrounding the island and used the pearls to trade for gold (Duchi, personal communication.) Since then the oysters have been sought after, both in Zanzibar and around the world. Although sea sponges are not as valuable, they have long been harvested in the Mediterranean Sea for cosmetic and medical uses. When the wild populations began to noticeably decimate from over harvesting and disease, the mariculture cultivation of sponges was started. While the farming practices are still in the developing stages of mariculture on Zanzibar, they have great potential to become as successful as the island's seaweed mariculture business, even offering an alternative and/or supplement to the people already involved in that growing trade. Jambiani, Unguja hosts sponge farming started by a Swiss company, *Marine Cultures* (Vauterlaus, personal communication marinecultures.org) while the pearl oyster farming project was started in Fumba, Unguja. These organizations' methods of farming are analyzed and suggested as council for the project suggested.

The Revolutionary Government of Zanzibar has its own Department of Environment, separate from Tanzania's, which creates the environmental policy. The Department was created in 1990 and has been evolving the strategies and governmental involvement since. This organization works with local institutions to evolve their practices or support projects to improve environmental conditions. In this way, the institution holds the potential to support the proposed project of bioremediation by bath sponges and pearl oysters off of Stone Town, Zanzibar.

II. Study Area

Farming methods are observed in the villages of Jambiani and Fumba, Unguja. Intertidal quadrants are performed in Jambiani and biodiversity observations are performed at each location: Jambiani, Fumba and Maruhubi. In Jambiani, the intertidal quadrants are completed at coordinates S 06°18'01.49" E 039°32'52.86". The shallow-water farm is located at coordinates S 06°19'15.04" E 039°33'12.58". In Fumba, the biodiversity and farming observations are completed at coordinates S 06º08’03.2” E 039º12’46.3”.

The contaminated sample water is collected from Maruhubi, Unguja (S 06°08’00.3” E 039°12’44.10”) and the water off of the Institute of Marine Science (S 06° 9'28.72" E 39°11'30.77".) The ‘clean’ seawater is collected from Fumba, Unguja (S 06°19’19.63” E 039°18’1.16”.)

The filtration techniques experiments and all water analyses were completed at the Institute of Marine Science, University of Dar Es Salaam, Zanzibar (see above coordinates) in Stone Town, Unguja.

These locations can be found on the map of Unguja Island, Zanzibar in Appendix I, figure 3.

III. Methods

The assessment of the viability and potential success of marine sponge and oyster farming for pollution filtration off of Stone Town is initiated through the observation and analysis of the individual farming methods in the respective locations they are practiced, observing the explants (the portion of harvested organism transferred to a new medium for growth) and biofouling organisms (organisms which grow on the explants or structure, possibly hindering production.) Then, the ability of the bath sponge and pearl oyster species are experimentally analyzed at the Institute of Marine Science laboratories. Finally, the logistical aspect of implementation is evaluated through managerial interviews.

3.1 Biodiversity and Farming Surveys

The tide table dictates that the intertidal surveys, collections and farming observations will be completed during the spring tides of the study: the first week and the third of April 2013.

a. Jambiani

i. Biodiversity Survey/Observation

The nature of the Jambiani intertidal layout in correlation with the habitat niche of the sponges dictates that quadrants for exact biodiversity numbers is not the most accurate method. Four 10x10 meter quadrants are completed, recording the percent substrate cover, the total number of sponges bodies and total number of species of sponges within the quadrant. In addition to the quadrants, the sponge species seen outside the quadrants are recorded as an overall observation analysis. For the entire study, coexisting species are observed and noted.

ii. Farming Observation

The shallow-water sponge farm is visited at a low spring tide by foot and snorkel gear. The apparatus type and technique, the way the sponges are attached and the coexisting species and habitats to the apparatus are observed and noted. Regular maintenance methods performed by the *Marine Cultures* employee are observed. Local community members are surveyed on their opinions of the organization and the mariculture potential.

iii. Employee Interviews

A *Marine Cultures* employee and representative for JAMBECO and Jambiani fishermen is interviewed. He is asked about the start of the organization, how often the farms require maintenance, and the success of the various methods practiced and farms cultivated. An assistant employed as both a boat captain for the deep-water farm (when SCUBA is required) and a maintenance assistant is questioned about his experience with the organization, the community's view of the organization, and the specifics of his duties for the farms. [Employees remain anonymous.]

b. Fumba

i. Biodiversity, Farm Observation, and Employee Interview

Biodiversity of pearl oysters in the area is assessed through the interview of the farmer and observation of the farm, (given the lack of ability to use SCUBA to observe the depth of the populations.) Coexisting organisms and adjacent habitats are observed and recorded.

The oyster farm is observed by boat, using snorkel and free diving with the farmer. Regular maintenance and cultivation processes are observed. The farmer is asked how he collects explants[1], the age of the explants, about the process of growth and cultivation, and about the market and sale process. The entire interview is completed in Swahili. Local community members are surveyed on their opinions of the mariculture practice.

3.2 Collection

a. Animal Collection Process

i. Sponges

An extremely sharp knife (requiring minimal harm to the animal) is used to harvest one third of the animal's body volume. A study of sponge aquaculture states that taking two thirds of the body size is the amount that allows the animal and explant to fully recover and survive the harvest (Duckworth et al 2007.) However this study requires a small volume, so only one third is to be taken. Four species most commonly occurring on the Jambiani intertidal are collected: the 'grey', 'green', 'red branching', and 'black' species. The sponges are not squeezed during harvest, transport or testing given that this may be harmful or even fatal to the animal and its functions. The collected explants are transported in a storage container, always covered in seawater, and then immediately transferred to an oxygenated storage tank upon arrival at the laboratory.

ii) Oysters

Pearl oysters are collected at a morning spring low tide in Fumba, Unguja. The animals are collected by gently pulling them off the hard surface to which they are attached. A minimum of thirty oysters is needed for the six sample buckets with five oysters each, (but more are collected in the case of the necessity of replicates.) The oysters are transported in a mesh bag out of water, but immediately transferred to six oxygenated storage buckets.

b. Water Collection Process

'Control' seawater is collected from Fumba, Unguja using a large 20-liter bottle. Contaminated seawater is collected from the beach in front of Marahubi ruins (Marahubi is due north of Malindi port and south of the latitude Chapwani and Chunguu Islands, a focal location as ascribed by the Zanzibar Channel current discussion.) The water samples from Fumba and Maruhubi are collected by wading deep enough to fill the respective buckets.

3.3 Filtration Abilities

a. Sample set-up

i. Sponges

The filtration abilities of the sponges are assessed using the collected sponges from the Jambiani intertidal. Sponge populations are able to filter their entire surrounding water column in 24 hours or one sponge up to 14 liters per hour (Longo et al, Gifford et al.) Therefore, the sample specimens are given 36 hours to filter the experimental water column, nothing added or taken out during the experiment period except oxygenation. The four sponges are placed in a 20-liter bucket filled with 15 liters of contaminated water. During the experiment period, turbidity and particle observations are made at initiation, six hours into the study, 24 hours into the study and at the end of the study (36 hours.) After the study period is complete, three 0.5-liter sample bottles (labeled “Sponges-Date-Initials”) are filled with the sample seawater and tested for phosphates as described in section 3.3b.

ii. Oysters

Oysters are individually able to filter 2 gallons, or about 8 liters of water per hour (Raj 2008,) providing that five oysters should effectively filter 2 liters in one hour. The pollutant filtration abilities of the oysters are assessed using the collected oysters from Fumba, Unguja. Five oysters are placed in each of six 15-liter buckets containing 2 liters of seawater each (therefore studying the total 30 sampled oysters.) Two liters of the contaminated test water is measured and placed into the sampling bucket. A 0.5-liter new water bottle (cleaned with distilled water) is labeled “Oysters-Trial #-Date-Initials.” The first five sample oysters are then placed in the sample bucket and a one-hour timer is started. Three sample buckets are run at the same time using this method, therefore repeating the above method two times (for six samples.) Observations of the filtration and other activities of the oysters are taken during the sampling period, including the turbidity and movement of the water. After the one-hour trial, the oysters are placed back in their oxygenated holding buckets and the sample water is poured into the respective labeled water bottles.

b. UV Spectrophotometer Water Analysis

A 0.5-liter sample of each of the ‘contaminated’ seawater from Maruhubi and the ‘clean’ seawater from Fumba are taken and labeled appropriately (sample name, date, initials.) These samples and the trials described above are stored in their collection bottles in a $-20^{\circ C}$ freezer until they are tested for phosphates and ammonia using a spectrophotometer. These methods are dictated in Parsons et al in the Manual for Seawater Analysis (using the ‘alternative’ method for ammonium) and can be found in Appendix III.

3.4 Management Logistics

a. Marine Cultures Study

The implementation of *Marine Cultures*, a non-governmental organization (NGO) started in Switzerland, on Unguja by resident Christian Vauterlaus is analyzed. The logistics of implementation and why he chose Jambiani as a location are inquired. The market for the sponges and economic details are investigated. Finally, the rapport with the local community, how it is kept and what the steps are for future correlation are explored. Specific questions and responses are located in Appendix II.

b. Department of Environment Interview

Hamza Rijaal is the representative respondent for the Zanzibar Department of Environment. The zonation of Stone Town in terms of the plans for the sewage and drainage systems is investigated. The pollution situation is addressed along with the options for Department of Environment aid processes. Specific questions and responses are located in Appendix II.

IV. Results

4.1 Farming Techniques and Biodiversity

a. Sponges

The experimental shallow-water sponge farming project in Jambiani, Unguja was analyzed and observed for 4 days. Interviews of the employees and local community members displayed a great interest in the new form of mariculture recently introduced (2008-9) to the small community. The shallow-water farm itself (one of three currently operated by *Marine Cultures* in the area) was exposed at about 1 meter at low tide (between a spring and neap low tides.) It consisted of a 6x6 meter rope system with rows of sponge explants (diagram in Appendix I, figure 6.) *Marine Cultures* grows two types of explants at the shallow farm, called the 'grey' and 'black' species by the employee giving the farm tour. Materials for observation, harvest and maintenance include a mask and snorkel (possibly SCUBA for deeper water than the farm observed,) fins, a knife and a mesh bag. Materials for the apparatus include ropes, polyethylene line, buoys and cement blocks. The employees interviewed indicated that the farming was relatively easy and low-maintenance (given the accessibility and tools described above.)

There were more than twenty total species observed in the Jambiani intertidal, indicating a healthy biodiversity (Richmond 2011.) The substrate consisted of some coral rag or small coral growth, but mainly sand and seagrass (average 60:40 ratio, respectively.) Sponges were found growing within the seagrass, on a rock in the middle of sand, or burrowed in the sand (attached to rocky substrate under the sand.) Local interviews indicated an appreciation for an interest in the farms. A higher diversity of species was found in the vicinity of the farm than in the surrounding area.

Table 1. Sponge Intertidal Survey

Quadrant	Sponge Species	Total Sponge Bodies	Substrate %*
1	7	9	15 S, 75 SG, 10 CR
2	6	10	40 S, 55 SG, 5 CR
3	13	18	35 S, 65 SG
4	8	17	20 S, 75 SG, 5 CR

*S=sand only, SG=seagrass on sand, CR=coral rag with some sand

b. Oysters

A pearl oyster farm at Fumba, Unguja was visited. The farm belongs to a single man who created, cultivates and monitors the farm independently (with the aid of IMS—Jiddawi, personal communication.) The farm was accessed by dugout canoe and coordinates for the farm were taken at S 06º08’03.2” E 039º12’46.3”. At a neap low tide, the farm was at a depth of 4 meters, reaching 6 meters at a spring high tide. The maintenance of the farm involves checking small pieces of wood or plastic, designed for growing new explants, attached to the main T-shaped line (sketch of farm in Appendix I, figure 7); looking for new explants growing along the main line and transferring them to the mesh baskets; and taking the mesh baskets to the surface to clean off the biofouling, clean out the basket of any trapped or biofouling organisms, check on the growth of young oysters, and clean each oyster. A dull knife was used to scrape biofouling, a scrub brush to clear sedimentation, and a stick to beat the baskets clear of biofouling. A metal prying tool was used to slightly open the shell without damaging the animal to check on the status of the pearls. High biodiversity of coexisting organisms was evident surrounding the farm.

When asked about the cultivation process, the farmer explained that he gets the oyster explants from a deep reef (points to a location southwest of the farm’s location) about 1 km away from the farm and about 15 meters in depth. He explained that there are many oysters at the reef of different species; displaying the two types he grows, which were later identified as *Pinctada fucata* and *Pinctada radiata*, the former being more abundant and common in Zanzibar. In response to oyster growth, the farmer explained that it takes a year and a half to grow to maturity and to propagate all four pearls. Displaying two oysters of different sizes, both of *Pinctada fucata* species, he described that the smaller one (about a 10 cm radius) is about 5-6 months old and the larger one (about 30 cm long, 15 cm wide) is about a year old and will be harvested in four months.

At the farmer's place of residence he displayed his tools for pearl cultivation. He has a shell polisher, which also performs the function of cutting out the pearls for jewelry making. The jewelry is displayed and a pair of earrings are said to be 30,000 Tanzanian shillings. The pearl market is said to be to mostly tourists at the House of Wonder museum in Stone Town, however he indicates that there is some local market as well. When asked about what he does with the animal meat, the farmer says his family consumes it. [Farmer's name omitted.] In the local village, anonymous community members responded that they appreciate the income source of pearl farming and the ease of using the employment as a supplement in the local economy.

4.2 Collection Logistics

a. Seawater Collection

The collection of the seawater samples was partially restricted by the access to transportation and resources for water transport. Containers for seawater collection were small and previously used, possibly leading to partial contamination (changing the chemical components) of the samples.

b. Specimen Collection

Both species of sample specimens were collected at a significant distance from Stone Town (the testing and storage site.) The sponges were transported in a relatively small container and the oysters were transported out of water. However, both animals were easily collected at the respective sites, minimally disturbed in the collection process and stored in spacious, oxygenated conditions at the lab.

4.3 Filtration Abilities

a. Experimental Observations

i. Sponges

The tank containing the sponges was significantly turbid prior to sponge implementation and was completely transparent by the end of the study. The water in the experimental bucket appeared to be flowing, based on the visible movement of the particles towards the sponges, but not discernibly circulating.

ii. Oysters

The water surrounding the oysters became less turbid over the hour-long filtration period. After 5-7 minutes, all oysters in all trials had opened their shells and were actively filtering. The seawater in the buckets began to swirl in a counterclockwise rotation by 30 minutes into the study period, as indicated by the movement of visible particles in the water. The size of the oysters varied between 5 to 10 cm in diameter and the degree of shell opening and valve exposure varied between 0.2 to 1.5 cm.

b. Seawater Analysis

All experimental replicate data is presented in Appendix III; table 2-3 and figure 8 for phosphate and table 4-5 and figure 9 for ammonium.

The spectrophotometer tests displayed that for both the sponges and the oysters, the concentration of phosphates decreased significantly (see figure 1.) The average concentration of the contaminated water replicates was 3.93 ug/L phosphate (before filtration.) After the sponge filtration period, the average phosphate concentration of the sample seawater was 1.33 ug/L.

Similarly, the oysters decreased the concentration to an average of 1.73 ug/L phosphate. The control seawater sample from Fumba contained 1.86 ug/L phosphate.

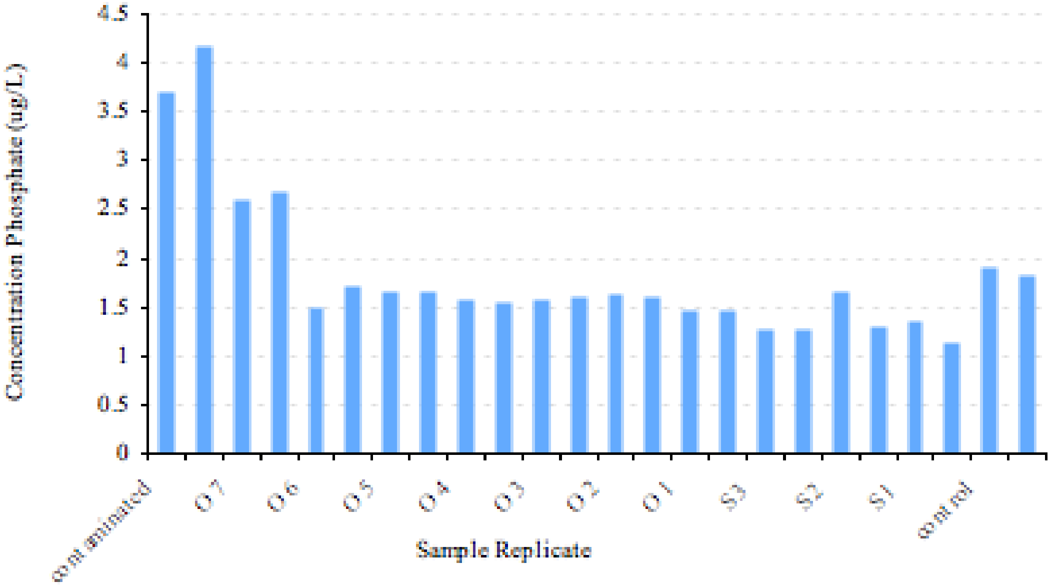

Figure 1. Experimental Phosphate Filtration Results (O=oyster; S=sponge.)

For the ammonium test, only completed for the oyster samples, the concentration of ammonium increased during the filtration period (see Figure 2.) The average ammonium concentration of the contaminated water was 4.01 ug/L and went up to an average of 21.5 ug/L after the sample filtration period.

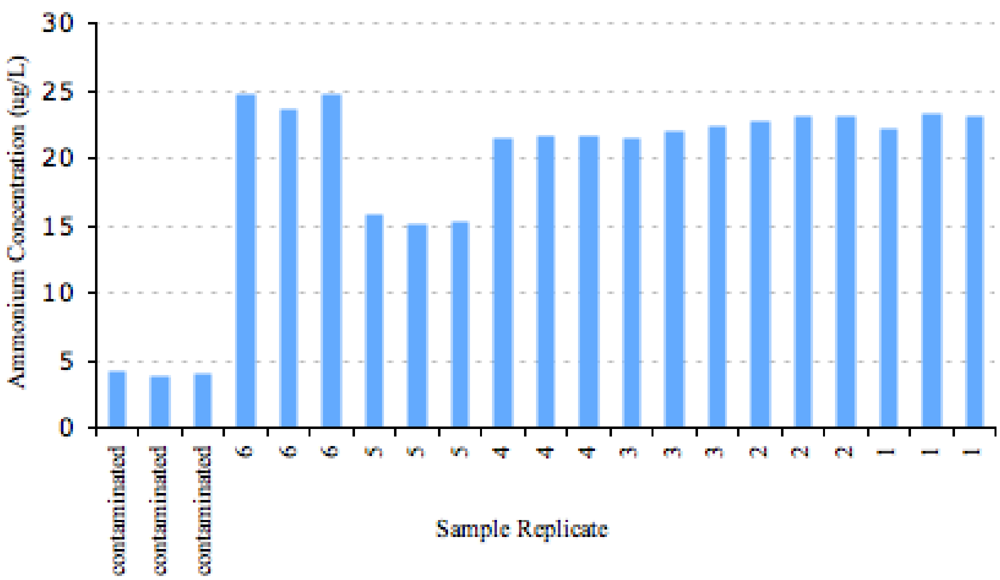

Figure 2. Experimental Oyster Ammonium Filtration Results

4.4 Management Interviews

a. Marine Cultures Organization

Christian Vauterlaus, founder of the Zanzibar branch of *Marine Cultures* (Vauterlaus, personal communication,) a Swiss NGO, was the respondent in the inquiries surrounding sponge-farming logistics. He explained that the idea for *Marine Cultures'* Zanzibar sponge project was started after he and his wife moved to Jambiani in 2006 and saw the difficulties associated with the seaweed farming. After a six-month research trip to countries and islands in the South Pacific to study alternative tropical mariculture options, they found a sponge farming project in Micronesia that had been successful for a highly impoverished place (in a similar situation as Zanzibar.) He explains that the farming is relatively easy to implement, manage, and sell on a rising world market. The fact that the sponges are for cosmetic purposes, and not for consumption, rids the trade of the liability of other mariculture activities.

After studying the techniques in Micronesia, Vauterlaus came back to Jambiani, Unguja and established *Marine Cultures* as an official NGO in April of 2009. He started correlation with the founder of Jambiani Marine and Beach Conservation Organization (JAMABECO—employee to remain anonymous.) Together they used SCUBA and snorkel methods to gather sponges and practice the farming techniques, identifying some of the numerous species around Unguja's east coast. Both the mesh basket and fixed line method have been implemented for successful analysis by *Marine Cultures*, and both have their pros and cons, depending on the species in question. A softer species may survive better in the basket and the fixed line can cause malformation. However, the line method works well for most and is the cheapest and easiest method for the cultivation.

In terms of local rapport, *Marine Cultures* started early in involving the local community in the mariculture process. Vauterlaus immediately created local meetings to inform the community, particularly the local fishermen and seaweed farmers, about what was going on with the mariculture and its future prospects. The organization currently employs six community members for various jobs such as collection, cleaning, and captaining the boats. *Marine Cultures* and the community are in full understanding that the mariculture is still in its developing stages here and Vauterlaus explains that the community is highly interested in involvement, but waiting for the logistics to be worked out by *Marine Cultures*. Ultimately, they feel they have a connected and successful relationship with the local community. In terms of future prospects, Vauterlaus indicates that *Marine Cultures* "would be open to help wherever we can" and that after their logistics are figured out, they plan to aid locals, other organizations, and government institutions in starting the mariculture where it is wanted and needed, in addition to continuing research on controlling and regulating the growth.

b. Department of Environment

Hamza Rijaal was the respondent for the interview of the Zanzibar Department of Environment position on remediation efforts. He explained that the Department was started in 1990 with little local knowledge or support. He referred to the Zanzibar Environmental Policy created in 1996, which dictates that the Department's role is to identify an environmental issue and suggest solutions or alternatives.

In explaining the current sewage situation it was revealed that only the originally defined perimeter of Stone Town, (northern border Malindi, eastern Benjamin Mkapa Road, southern Kilimani, and western coastline—see Appendix I, figure 5 map, Van Bruggen 1990) is a part of the sewage pipe system. This system consists of pipes to septic tanks, salt pits and then directly into the seawater. He explained that the outflow pipes used to go only 10-50 meters off shore, then changed to 150-200 meters with the discovery of high effluent concentrations. The original decision for this system was described to have come from the idea that the Eastern Africa Counter Current (EACC) is strong enough to take the polluted water away from human habitation, also in the hopes of being strong enough to create mixing, and therefore not to harm the marine environment to a great extent. He disclosed that this system is not working to keep the harmful effluents from the coast and effects are evident at the offshore reefs. Rijaal disclosed that the system often fails when—particularly in the rainy season, such as the season of this study—sewage overflows into the streets and becomes runoff. Similarly, the areas of Stone Town that are constantly expanding outside of the original perimeter are not on this system but have individual tanks or simply bury the waste. Both of these methods routinely overflow and leak raw sewage and effluents into the runoff onto Stone Town's coastline.

When asked about the Department's role in environmental remediation, he mentioned the Van Bruggen study completed in 1990, which was one of the Department's first actions. Finland was aiding in developing their first environmental policy in 1996 and the Department asked for an EIA of the wastewater from Stone Town. He emphasized that although they expected the high effluent levels that were found, the unexpected discovery of high heavy metal concentrations was sourced to wastewater from local industry. Upon further prompting, Rijaal indicated that the Department is open to aid new projects for remediation of environmental issues.

V. Discussion

5.1 Pollution Situation

The growing human population in Stone Town, Unguja undeniably affects the surrounding coastal waters destructively. A large population places significant pressure on the adjacent ecosystems not only through resource use and extraction, but also considerably from the waste associated with resource use. This involves industrial and chemical runoff/leakage, storm water runoff and sewage outfalls. Stone Town's leading issue, both for the health of the ecosystems and the human population, is the effluent pollution leaking straight from sewage and runoff outfalls. A majority of the population is not a part of the sewage system and therefore either has their own tanks or no system at all (Rijaal, personal communication.) These systems leak into the groundwater and overflow with flooding. The sewage treatment that is present in the city only involves the originally defined area of Stone Town (west of Mkapa Road.) This system directs wastewater into a septic tank, through a salt pit and then through out-flowing pipes straight into the coastal water. Unconventional systems are usually just dug pits, which seep the nutrients directly into the groundwater. Even connected to the sewage lines, all of these systems described cause leakage of raw sewage effluents into the watershed, which on a small island is directly into the seawater.

Stone Town's population is constantly growing as people come for the opportunities associated with the city. A larger population both demands and facilitates the increasing trade business of which Zanzibar is historically famous for. The issue with this mass influx is the lack of city planning and management of the waste that this multiplying population creates, such as garbage and sewage. When the waste water system was first implemented, the outflows only protruded 10-50 meters into the water. When reassessed with the growing population and pressure, especially with the visible effects on the surrounding ecosystems, the pipes were simply extended 150-200 meters off the coastline (Hamza Rijaal, personal communication.) While the mixing is more effective farther away from the coast, the problem is not solved. Sewage outflows and overflowing storm runoff leak into the coastal waters and bring with them harmful nutrients and particles, which dissolved in the water column are hazardous.

The initial decision to allow raw sewage and wastewater to flow directly into the coastal seawater came from the belief that the EACC is strong enough to both take the dangerous water away from the human habitation and to mix it effectively enough not to harm the coastal ecosystems. However, the shallow nature of the Zanzibar Channel greatly slows down the strength of the EACC, nullifying its power in transferring and mixing the seawater (Nyandwi, personal communication.) The outward jut of Stone Town toward the west creates a slight deflection of the current to the northwest. This detail would perhaps effectively take the hazardous water directly to the deeper portion of the Channel, allowing for adequate mixing, but the fringing islands off Unguja's southwest coast complicate the matter. While there is a flow of the current directly northwest, the destination is directly between two of the fringing islands, funneling much of the seawater through the opening (called the 'Great Pass' locally,) but deflecting much of the seawater back to Stone Town and the adjacent coastline (see Appendix I, figure 4 schematic, Anderson 1994.) Subsequently, the contaminated seawater that is not sufficiently mixed carries harmful nutrients to the coral reef ecosystems of these fringing islands, not to mention back to the human population of the coastline.

The harmful nutrients and effluents include nitrates and phosphates, which facilitate the growth of bacteria and phytoplankton algae. These organisms are already in the water column to a limited extent, but with the introduction of these effluents, which they feed off of, they become invasive and overwhelming to the environment. Particularly nitrogen facilitates bacterial growth, which live in the sediment and water column, acting as natural nitrogen fixation processes for the soil and atmosphere. This is evident in the success of the mangrove plot directly down current from (north of) the outflows of Stone Town. Mangrove systems contain a high concentration of nitrogen-fixing bacteria in the correlating soil, part of what make the ecosystems keystone to the environment (Shunula and Whittick 1996.) These bacteria thrive off of the nitrogen released directly into their habitat and proliferate. The process of nitrogen fixation they perform turns the nitrate (NO_3) released into the water to ammonium (NH_4), dominating the oxygen in the water for their metabolic processes and causing eutrophication (*ScienceDaily* 2013.) Although this allows for the growth of the mangrove trees, which obtain their oxygen source from the atmosphere, it creates anoxic conditions in the surrounding seawater, prohibiting the inhabitance of marine organisms that need oxygen for survival. Similarly, phytoplankton thrive off of the phosphate source for growth. The experimental value of 3.93 ug/L phosphate is high in comparison to the naturally occurring concentration in seawater (Intergovernmental Oceanographic Commission 1993.) The higher concentration is an indication that these nutrients are introduced from an outside source (Parsons et al 1985.) This yields an increase in the phytoplankton population and sequentially the zooplankton population, increasing the turbidity of the water (called a ‘bloom’) and decreasing light access to keystone photosynthesizing organisms, such as the zooxanthallae algae of coral. Consequentially, the upsurge in bacteria and phytoplankton from the excess concentration of nitrates and phosphates (respectively) in the seawater is deleterious to the corresponding ecosystems.

Polluted seawater carries the dissolved nutrients discussed, increasing populations of marine microorganisms, and also the effluents associated with sewage, such as fecal bacteria.

These bacteria include fecal coliforms (*Enterococci* and *E. coli I*), which dissolved in seawater can be both an indication of sewage runoff presence (Hanes and Fragala 1967) and can be extremely dangerous to the health of the human population and the ecosystems. A study completed in 2011 to test indications of sewage in the coastal seawater off of Stone Town suggested that there were high concentrations of the bacteria in the water. What was particularly pivotal was the discovery that the concentrations were highest near the outfalls, but were also found on the fringing reefs of Stone Town, such as Bawe and Chapwani (Moynihan 2011.) The study additionally shows that the bacteria present are correlated with early stages of eutrophication. It is therefore evident that the sewage runoff is not only reaching the surrounding ecosystems, but starting to damage them as well.

The turbidity of the seawater observed throughout the study is a suggested indication of these microorganisms and effluent particles present. In the collection of contaminated seawater at Maruhubi, the seawater was highly turbid with a sight distance of less than 1 meter. As reported in the results, this sample water was still distinctly turbid prior to the filtration experiment, indicating that the turbidity of the water in the collection site was not simply due to sediment, as may have been asserted given the collection time at low tide. Suspended particles were observably filtered throughout the experimental interval, however a total suspended organic carbon analysis could not be completed because of the observation of suspended organisms that would not be filtered and would skew the results, such as barnacle bodies. Nonetheless, the observation of the filtration of the turbidity of the water was deemed viable in suggesting that most of the suspended material was microorganisms, such as the bacteria and plankton discussed.

A final noxious element of wastewater runoff is the heavy metals associated with sewage piping and industrial runoff. The Environmental Impact Assessment completed by Van Bruggen in 1990 displayed that many artisan industries in Stone Town and around Zanzibar released heavy metals such as aluminum, cadmium, zinc and others. These elements, like the others discussed, are present in seawater naturally to a small degree, but in high concentrations from runoff can have such actions as corroding, inhibiting calcifying organisms and impacting some marine organisms' reproductive mechanisms (Shunula and Ngoile 1995.) Therefore, heavy metals, along with the other runoff pollutants discussed, need to be controlled to prevent their probable destructive effects. Particularly given the circulation pattern of the bordering seawater, the present and potential damage is threatening the continuance of the area's biodiversity and health.

The majority of the studies referenced have been completed to display the effects of the runoff situation in Stone Town and Zanzibar as a whole. These various studies have all emphasized the importance of addressing and treating the distressed environmental conditions, but little has been done in the way of actual remediation efforts. The Zanzibar branch of the Institute of Marine Science, located in the heart of the area in question, is constantly working to research both the progressing effects on the environment and the potential solutions. However, the previous bioremediation solutions (sea cucumber and algae) have had little success, assumedly because of the traffic in the area and the strong concentration of pollutants (Jiddawi, personal communication.) Perhaps adjusting the placement of the experimental remediation would aid in its success, such as a location far enough down-current from the pollution source to prevent overloading the filtration system, but before the water can reach the vital coral and mangrove ecosystems or the feedback eddy system. Optimizing the location in this way aids in both the protection of the physical structure of the system and the survival of the filtration organisms involved.

5.2 Filter Feeding Capabilities

The abilities of oyster bivalves and sponge porifera, powerful filter feeding animals, have been analyzed and explored.

a. Sponges

Sponges are evolutionarily simple organisms of the porifera phylum. This phylum is suitably named for the pores covering the living tissue, which draw in and funnel out the surrounding water column with the purpose of attaining nourishment. These organisms greatly contribute to their ecosystems because of the side effects of this feeding process, which involves the filtration of the entire water column. According to a study completed for *Biomolecular Engineering*, a dense population can filter an adjacent water column within 24 hours (Milanese et al 2003.) This is possible because the ostia pores throughout the body have the ability to filter all particles between 0.1 and 50 micrometers, which provides them the nutrition of phytoplankton and bacteria (Friday 2011.) Through this process they accumulate the water's nutrients that these lower-trophic-level microorganisms concentrate in their cells. A particularly important note about the filtration abilities of the sponges is their retention rates of the particles they are feeding on. In the above-mentioned study, the sponges were shown to retain up to 80% of the particles they filter (Milanese et al 2003.) This presents how incredibly essential sponges are to their ecosystems in retaining the harmful particles to other species as sustenance for their own growth.

Through the study performed, the collected sponges proved to be effective filtration systems for the experimental water column. The analysis of phosphate displayed a decrease in the concentration over the study period by comparing the phosphate level of the contaminated sample seawater (3.93 ug/L average concentration) to the water after the sponges' filtration period (1.33 ug/L average concentration—see figure 1 in section *4.3 b*.) This demonstrates that the sponges are successfully accumulating the phosphate source in the seawater, most likely from the thriving phytoplankton populations. In a study comparing the phosphorus and nitrogen levels with the phytoplankton and bacterioplankton present, a correlation between phosphorus and phytoplankton levels was evident, and a further relationship between phytoplankton and bacterioplankton was present as well (as the bacterioplankton consume the phytoplankton,) indicating that an increase in phosphorus levels increases phytoplankton and bacterioplankton correspondingly (Kisand et al 2001.) As discussed in section *5.1*, an increase in these microorganisms can be incredibly harmful to the coinciding habitat and marine environment.

A perhaps even more pivotal observation in the study is the elimination of water turbidity and particle evidence. This suggests that the organisms are not only taking the harmful chemicals out of the water, but also the harmful bacteria and plankton that are thriving off of the chemicals. Tropical Demosponges such as the proposed species feed off of microorganisms, organic particulates and bacterioplankton (Holmes 2000.) These microorganisms cause turbidity in the water, threatening the ability of the photosynthesizing organisms such as seagrass and coralline algae to photosynthesize and oxygenate the seawater, which is an imperative ecosystem service. When the sponges and oysters filter the water of these destructive microbes, they are thereby indirectly assisting marine photosynthesis. A European study completed in 2006 concluded that in one hour a 1-m^2 patch of sponges could retain up to 7×10^{10} *E. coli* cells through a filtration of 14 liters of seawater (Gifford et al 2006.) *E. coli* are bacteria cells that are contained directly in the effluent runoff and can be deadly to humans if ingested, not to mention the damage done to other engulfed species. It has been found that, in some places, benthic sponges may even thrive closer to an enrichment source (Holmes 2000.) The idea that sponges can filter and retain these cells proves them to be vital to a remediation process for both humans and the surrounding impacted ecosystems.

Marine sponges have the advantageous ability to degrade organic pollutants in effluents. This is suggested in studies displaying their ability to break down PCBs (polychlorinated biphenols) and surfactant molecules more rapidly than bacteria or oysters given their ability to concentrate halogenated biomolecules in their cell (Gifford et al 2006.) This is pivotal in preventing these molecules from reaching the coral and mangrove ecosystems housing the majority of the local marine organisms. As discussed, these biomolecules can have such deleterious effects as interrupting reproduction and inhibiting growth. The filtration by the sponges is therefore a significant ecosystem service and recommended.

Fortunately, marine sponges are abundant and highly diverse around Zanzibar, as represented by the biodiversity observations performed in Jambiani. In East Africa alone, there are hundreds of species, just a portion of the 7000 species (fresh and marine) worldwide (Richmond 2011.) This involves various morphologies such as encrusting, burrowing, digitate (finger-like), branching and globular (Friday 2011.) In this study globular sponges, in the class Demospongiae, are the focus given their optimum proportion of spongin protein and calcium carbonate skeleton for commercial cultivation (Duckworth et al 2007.) This class is also highly adaptable, proven through the observation of their ability to regenerate their pinacocyte tissue after explantation and continue to expand their mass and volume of each explant, all from the same original organism. This was evident in both the observations of the farmed sponges and the collected sponges of Jambiani, Unguja. Two rows of ‘black’ species and two rows of ‘grey’ species sponges at *Marine Cultures'* farm had been implemented two weeks prior to observation and the places of cutting on each sponge was barely evident and only visible upon close inspection. (Sponges are identified by color because of the lack of knowledge about the widespread diversity of demosponge in the area (Vauterlaus, personal communication.)) Additionally, the sponges collected for the filtration experiment had covered the spongocoels and choanocytes (visible after cutting) with pinacocytes by the second day of study. These examples display their adaptability to morphological manipulation and therefore their ability to successfully survive and grow throughout explantation.

b. Oysters

Similarly to sponges, oysters provide an ecosystem service to their benthic habitats through filtering the surrounding water column. Oysters are in the class bivalves, members of mollusc invertebrates that possess two siphons to enable the flow and filtration of seawater through their bodies. The purpose of this flow for the oysters is to both obtain nutrition and to deliver oxygenated seawater to their gills. It is suggested that both *P. fuctada* and *P. radiata* species feed nonselectively, meaning through the filtration of seawater for a microalgal food source, the species filter the entire surrounding water column of particulate matter (Gervis and Sims 1992.) In a study performed in Australia on *P. imbricata*, it was exhibited that one ton of oysters could filter 7.5 kg of nitrogen and 0.55 kg phosphorus (Gifford et al 2005.) These findings are strong representations of the power oysters have in seawater nutrient remediation, particularly in large populations.

The filtration experiment supports this data in showing the significant decrease in phosphate concentration of the seawater samples after the filtration periods. In comparison to the 3.93 ug/L phosphate concentration of the contaminated water, the average concentration after oyster filtration of the seven replicates was 1.73 ug/L (see figure 1 in section *4.3 b*.) Similarly to the sponge, this indicates the effective uptake of the destructive phytoplankton population in the seawater, and therefore the pivotal ecosystem service the oysters provide.

As indicated in the Australian study, the oysters are also distinguished accumulators and curators of nitrogen levels. The sharp increase in the concentration of the ammonium dissolved in the seawater is an indication of dissolved nitrate remediation and eutrophication prevention. The average ammonium concentration in the contaminated seawater is 4.01 ug/L while the average concentration after the filtration experiment is 21.5 ug/L. This sharp increase is suggested to be caused by the remediation of nitrates given that dissolved nitrogen exists in seawater in one of the two forms. With the acute increase in ammonium concentration across replicates (see figure 2, section *4.3 b*,) the oysters are evidently accumulating the nitrates in the seawater and releasing the source back out as ammonium to a dominant degree. Oysters contain symbiotic bacteria in their gills that perform this denitrification, providing the oysters with the oxygen gas byproduct (Raj 2008.) Accordingly, the oysters actually need a certain concentration of nitrates in the water and therefore it is advantageous to the organisms to out compete the sediment bacteria for the nitrogen source, thereby indirectly preventing that anoxic process. While the surge in ammonium concentrations are admittedly not much more ideal for the aquatic environment, the substance can at least be treated by a simpler organism. The project by Lindell in the United States utilizes the high concentrations of ammonium to grow seaweed near the oyster farms (Saito 2012.) Thus it could be advantageous to continue this study by including seaweed as a tertiary remediation source, which would contribute further to the idea of a holistic ecosystem-based management approach. Ultimately, oysters are suggested as uniquely effective nitrate remediation for polluted seawater filtration.

It is therefore analyzed that oysters provide unique nitrate remediation abilities, while sponges provide the unique particle filtration and retention capacity. However, similarly to the sponge experiment, the turbidity of the water also appreciably decreased over the study period. The study completed in 2006 for the journal *Trends in Biotechnology* supports these findings, showing both that oysters reduced effluent presence of nitrogen and phosphorus (by 72% and 86% respectively,) but also the turbidity due to chlorophyll a concentrations (Gifford et al 2006.) Chlorophyll a is what accumulates when microalgae and bacteria overpopulate, disallowing photosynthesizing organisms to use the compound for energetic processes.

The turbidity remediation by both the sponges and the oysters studied could have been more effectively quantified with a total dissolved organic carbon test. However, due to lack of time and lab resources, the test could not be completed in the study period. This obstacle was prevailed over using simple visual observation, permitted because of the incredible filtration abilities of the two organism groups.

5.3 Farming Feasibility

The filtration abilities of both the sponges and the oysters are clear and indispensable, but what truly assist in the argument to implement these organisms are the benefits they provide to the local community economically.

The mariculture farming techniques of both bath sponges and pearl oysters require regular maintenance and monitoring. When local communities provide the employment for these necessities, both farming techniques clearly contribute a great economic aid to the human population. As evident from the observation of the techniques, maintenance includes removal of biofouling and diseased or dead organisms, and structural adjustments or damage repair. For the sponge farming, this is completed four to eight times monthly, which depends on farmer's experience, going more times if new at the process. In the case of the oyster farming, the maintenance can be completed one to three times monthly, depending on the growth stage of the organisms.

Additionally, the sponge and the oyster farms require employees for the actual cultivation of the organisms. This involves collection, cleaning and preparation for sale. In the case of the sponges, *Marine Cultures* followed the guidelines of cultivation given by the Micronesian farm they studied in 2008 before coming to Zanzibar (Ellis et al 2008.) Both the employee interviews and the instructions reveal that the growth process takes about 1.5 to 3 years. The cultivation then begins with collecting the ready sponges, which is indicated by growth to a full size of between 10-15 cm radius of the spherical shape and a rounding out of their structure. As indicated by the employee interview, if a sponge grows in an unfavorable shape for sale, that organism will be used for more explants (*Marine Cultures* employee, personal communication.) This idea is another indication of how sustainable the mariculture can be through the ability to recycle explants. Additionally, the Micronesian instructions dictate that at least 25% of the explants should be left. After collection, the sponges are dried out (much like the seaweed mariculture process) and then squeezed out in fresh water and soap, and finally just fresh water, to clear out the tissue of the animal, leaving just the spongin skeleton and a shape that bounces back after squeezing. After all of the cleaning, they are dried again and placed into attractive and protective packaging for shipment and sale (Ellis et al 2008.)

For the oyster cultivation, the growth and pearl development process is complete after 1.5 years. After this period, the oysters are taken from the baskets, cleaned and processed. In the case of the Fumba pearl oyster farm, the farmer and his family consumed the oyster meat, but in the suggested plan that would not be a part of cultivation. After the meat is disposed of, the shells begin to be processed. This involves polishing the shells with the buffing machine. If the shell is kept whole, the buffing and cleaning of the shell is the end of the process, but if the pearl and/or shell are to be processed further into jewelry, they are cut, polished, and packaged for sale. All of this requires little equipment past the buffing machine, a small engine that costs 30,000 Tanzanian shillings ($18.75 USD) according to the farmer studied.

All other supplies for the respective farming techniques are comparatively inexpensive, uncomplicated and low-maintenance. Advantageously, both methods require similar supplies, such as cement blocks for anchoring, rope for attachment, and buoys for flotation and marking. Similarly, that is the main extent of the supplies that each method needs and that equipment can all be made and sold locally, adding even more of an economic stimulus from the two mariculture implementations. For example, when *Marine Cultures* started work in Jambiani, they sought out local producers to make their deep-water farm baskets (an alternative sponge farming medium) and have since obtained all of their farming material from the local community. However, these supplies are inexpensive and simple, so even providing an economic stimulus to the community, it is not overly expensive for the farmer attempting to start the farms.

The requisite locations of the proposed farming techniques are further advantageous aspects of the cultivation pursuits. Both farms visited were easily accessed by their proximity to the coastline and their shallow depths, which allowed for simple snorkeling techniques to maintain and cultivate. A simple boat such as a dugout canoe or walking/swimming to the farming locations is possible, making them both easily accessible to the local populations. This is an important factor in the implementation of these techniques because it offers a viable market to the local community (as opposed to a beneficial, but expensive and complicated idea, such as deep-water fishing.)

In the same way, the market for the products must be accessible to the local populations for the farming techniques to be practical. While the two products are still in the process of finding consistency in a market, they are well on their way, especially in the fact that sponge and pearl products have a long history of economic success on the global market. Although the products are for cosmetic purposes, which could be thought of as nonessential and inconsistent, they both have great potential. Zanzibar attracts thousands of ecotourists year-round, who find more allure in the authentic and sustainable souvenirs, which they can both get use out of and feel good about. The House of Wonder museum in downtown Stone Town displays numerous local products and crafts, including the pearls of the farmer visited in this study. This provides not only a market, but also access for tourists to the products (publicity) and another form of employment from the process (sales.) The farmer interviewed also explained that there is some Zanzibari market for pearls (Fumba pearl oyster fisherman, personal communication,) so the entire market would not entirely rely on tourists.

Similarly, the sponges could begin to be used by locals in supplement to the Bombax tree (‘Silk-Cotton tree,’ common name—Juma, personal communication) or imported synthetic sponge typically used for sponge material locally. This would not only yield more self-sufficiency from the currently substantial trade market, but also would provide a market for the sponge farmers. *Marine Cultures* is currently in the process of finding an investor for the sale, and until then, Vauterlaus explained, they will not advertise it further to the local community (Vauterlaus, personal communication.) However, through the survey of local community members, the interest in the mariculture methods was high and the practices revered. The organization is adamant to create a viable local income source, but they don’t want to encourage large-scale participation until they find a consistent investment source. While this is vital to the widespread growth of the mariculture on Zanzibar, until that economic niche is discovered the sponges can be marketed locally analogously to the pearl market discussed. Furthermore, the pearl market can act along the lines of *Marine Cultures* and seek out foreign investors. Both natural commercial products discussed are already established on the global market, but are simply in the preliminary stages on Zanzibar, so the investment should not be difficult to acquire.

The organisms of this study were not only chosen because of their premier filtering skills with an economic incentive provided to local communities, but also decisively because they are not cultivated for consumption purposes. In spite of this precaution, the organisms must be prudently processed to prevent reintroducing the same pollutants they filtered in the first place. While some of the pollutants may be caught in the structure being utilized, many of the pollutants may be in the living tissue of the organisms that is called for disposal in the harvesting process. For instance, the marketable part of the sponges is the protein spongin skeleton, and proteins use nitrogen for synthesis, but on the same token, most of the disposed oyster is protein. Similarly, as discussed, the oysters accumulate heavy metals in their system, so the disposal of the living tissue after cultivation must be carefully completed and further studied. In a Japanese bivalve farm, a process for removing cadmium from the mollusc meat was created where the cadmium is recycled and reused by a car battery plant to make fertilizer (Gifford et al 2006.) This progressive innovation for the waste material is a representation of the further research that is needed into the proper disposal or further remediation of the polluted waste from these proposed cultivation techniques. With further study, if the edible portion of the oysters were tested safe for consumption, it could be yet another aspect of economic stimulus this remediation system brings to Zanzibar.

In the end, both farming techniques provide a significant economic stimulant to the local community on multiple levels, and that is an extremely important aspect in the consideration of implementing a new project in Zanzibar. It is particularly important that—given that the reason for implementing these methods is pollution—the products are for cosmetic purposes as opposed to consumption. The disposal of the excess material from the organisms involved in the farming may admittedly contain some of the nutrients and toxins that they filtered out of the water in the first place, so it is important to continue with this study to pursue these confounding variables. Still, the benefits of these remediation techniques are noteworthy both for the environment and the economy.

5.4 Implementation Logistics

With progressing pollution issues, immediate action is necessary to prevent any further damage to the human habitation and marine life of Zanzibar's coastline. Through the study of the pollution situation, the proposed organisms' filtration abilities, and the cultivation logistics it is evident that the implementation of these systems could actually be possible with proper management and organization. The proposed techniques are supported by the definitions of ecosystem-based management and integrated coastal zone management, which are both viable strategies for environmental planning and policy.

Managerial positions were studied from the perspectives of the mariculture creation and implementation and the supervision of environmental issues themselves, which indicated the feasibility of implementing the proposed techniques on Zanzibar. From the study of *Marine Cultures* and the interview with Christian Vauterlaus it is apparent that the experimental sponge mariculture is progressing successfully and has great potential for the village of Jambiani. Although the cultivation of the marine sponges was not enacted with the purpose of remediation, the practice is a quality example of the potential success of the mariculture at providing employment and income to the local community. Vauterlaus explained that the village has a large populous that participates in seaweed farming, but are making little income from the trade, and that introducing a similar and straightforward alternative could greatly aid the residents of Jambiani. With respect to relational management, *Marine Cultures* is active in public outreach about the potential of the farming, including education about the techniques, market situation, and ecosystem services provided (such as the increase in biodiversity in the area.) The organization is an advantageous example for the proposed farming techniques given their ability to perform background research, ensure prosperity and aid in education and implementation.

The study of the Department of Environment's involvement with pollution remediation efforts provided an insight into the steps for the proposed implementation. In conjunction with the environmental policy of 1996, it is found that the Department is not particularly involved in the creation of policy, but is active in identifying environmental stressors and proposing solutions. In section 3b of the policy it is stated that Integrated Coastal Zone Management should be used as a framework and that efforts should pay particular attention to the progression of "coral reef degradation by… or mangrove destruction by…pollution." In section 9 the policy emphasizes the "participation in the environmental programme by the community." Finally, in section 22, the policy asserts that environmental legislation should be drafted in support of "control of pollution [and]…environmental health management." (*National Environmental Policy for Zanzibar* 1996.) By these standards, the proposed project is the ideal primary solution to the pollution situation given that it is taking an integrated approach through a holistic ecosystem viewpoint and involving and benefiting the local community. The last consideration the policy provides is in promoting legislation to control environmental health, which makes the incentive palpable for the enactment of the proposed techniques. Integrated coastal zone management is a policy framework catered to the development of the human population, which dictates that the coastline should be zoned in the most sustainable and advantageous way both for the multiple uses it serves and for the health of the environment, a concept of sustainable development (*Progress in Integrated Coastal Management* 2000.) Implementing bath sponge and pearl oyster farming for the remediation of polluted waters could be promoted and aided by the Department of Environment through further community outreach and education, legislation enactment, and funding opportunities.

Remediation mariculture management involves both the mobilization of the local communities and the integration into the respective environment. Ecosystem-based management is a format for handling environmental issues which calls attention to the entire system: what is taken out, what is put in and the indirect services the system provides (Mohammad, personal communication.) This method is appropriate for the implementation of the bath sponge and pearl oyster filtration mariculture given the fact that the proposed remediation techniques treat the pollution using a natural member of the ecosystem. Both farming operations observed displayed a high level of biodiversity within and surrounding the respective farms. Additionally, the mariculture solutions employ the local communities in manpower and expertise and can be cultivated as an economic stimulus to the adjacent population. EBM highlights the connectivity within ecosystems, between ecosystems and with the human population. A key aspect of the proposed project that falls into the category of ecosystem-based management is that the techniques holistically benefit the ecosystems' sustainability and services, filtration organisms and human populations simultaneously.

With a hypothetical implementation of the proposed techniques, the location is a pivotal aspect. The nominated location is off the shores of Maruhubi and/or Mtoni because this area is a prime location for remediation. Seawater at this location is far enough away from both the traffic of Stone Town and the intensity of the concentration at the sewage outflows (see figure 5, Van Bruggen map, of Appendix I.) The formation of this coastline is also ideal because its shallow depth allows access to the community to the potential locations of the mariculture farms. The seawater deflected off the Stone Town peninsula would pass through these actively filtering waters before reaching the fringing reefs or the feedback water circulation system (see diagram in figure 4 of Appendix I.)

The management logistics analyzed are vital considerations in the implementation of the mariculture for pollution remediation. Creation and implementation efforts of the farms themselves can be modeled after and aided by the progressively successful *Marine Cultures* organization. The Department of the Environment can facilitate the zonation and legislation efforts needed for the new sector to be implemented.

VI. Conclusion

Bath sponge and pearl oyster farms are suggested as feasible natural pollution filtration systems for the remediation of the seawater off the coast of Stone Town, Unguja. Coastal waters off of Stone Town have displayed a high concentration of pollution since the investigation began in the 1990s. Since the Department of Environment was created and began performing Environmental Impact Assessments through the Institute of Marine Science and other outside organizations, the pollution impact has tested to be decidedly concentrated and perceptibly negatively affecting the surrounding ecosystems. The effects are not only harmful to the marine environment, but also dangerous to the human population who uses the marine resource for sustenance and threatening the reputation of the pristine biodiversity Zanzibar is known for. With a lack of background research into the proper planning and engineering of the sewage and runoff system in the urban center, raw effluents have been consistently discharging into the coastal seawater since the city's emergence, gaining strength with the surge in population in recent decades, and noticeably impacting the fringing keystone coral reef and mangrove ecosystems. Raw effluents carry dissolved nutrients, such as nitrates and phosphates; toxic microorganisms, such as fecal coliform bacteria, and dissolved organic compounds. The nutrients cause eutrophication and overpopulation of naturally occurring microorganisms in the water column, which creates inhabitable conditions for other organisms. The fecal bacteria can carry deadly diseases to the human populations such as dengue fever and cholera and in high populations can be toxic and deleterious to the species in the affected ecosystems. Dissolved organic components can inhibit the growth, reproduction and ultimately survival of the marine life.

Detrimental affects of pollution strongly advocate for the establishment of techniques to decelerate the environmental degradation. This study displayed a glimpse into the unique filter feeding abilities of the powerful marine sponges and oysters. It showed that both organisms accumulate phosphates to a high degree, suggesting that they are also filtering the water of phytoplankton overpopulation. Marine sponges exhibited a unique ability to retain suspended particulate matter through the turbidity observations. The literature on the organisms reinforces these findings and provides the details of their distinct filtration rate. The oyster analysis suggested a unique ability to remediate nitrate levels through chemical transformation, which is supported by literature along with their distinct ability to accumulate heavy metals.

In conjunction with the filtration abilities of the organisms, the research on the farming accessibility on the island of Zanzibar suggests that implementing the mariculture as a pollution filtration system could be highly effective. The sea farming techniques are simple, inexpensive and require an accessible location. Collaboration between the participants could initiate the essential process of remediation. This collaboration would involve the consultation by the organizations that are already experimentally practicing the farming techniques around the island, the management and aid of the applicable governmental sectors, the education and participation of local communities, and the continuance of scientific research by the Institute of Marine Science.

Implementing ecosystem-based filtration techniques for the remediation of polluted seawater off the coast of Stone Town is a prudent action in protecting the health of the human population and the environment. The techniques would not only benefit the ecosystem by catching the toxic water before it enters the ecosystems, but also before it enters the feedback water circulation eddies, bringing the pollution back to the surrounding coastal inhabitance. With further research, the proposed project has the ability to benefit the environment and the human population simultaneously, while slowing the harmful effects of the pollution inputs.

VII. Future Recommendations

This proposal is in extremely theoretical and experimental stages. For the responsible and effective implementation of the proposed techniques, further research needs to be completed.

In terms of the filtration abilities of the organisms studied, nitrate and dissolved oxygen analyses would further support the data on their ability to effectively filter the pollution. Additionally, varying concentrations of the contaminated seawater in relation to the organism replicate filtration rate/quality would indicate the organisms' tolerance to pollution and better suggest where an optimal location would be for the proposed mariculture structures.

The farming process could be further analyzed with the integration of other organisms such as algae or polychaetes (filter feeding sea worms (Harlan 2008.)) A key study would be the contaminant level of the living tissue that is disposed of after cultivation and techniques to recycle or neutralize these potential waste products. The market for the commercial products could also be explored further.

Managerial studies could be continued by evolving community meetings education topics and locations. The involvement of potential shehas and organization heads, in coordination with the further seawater analysis suggested above, could provide further information into the realistic potential location of the proposed mariculture techniques.

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Appendix I. Maps and Diagrams

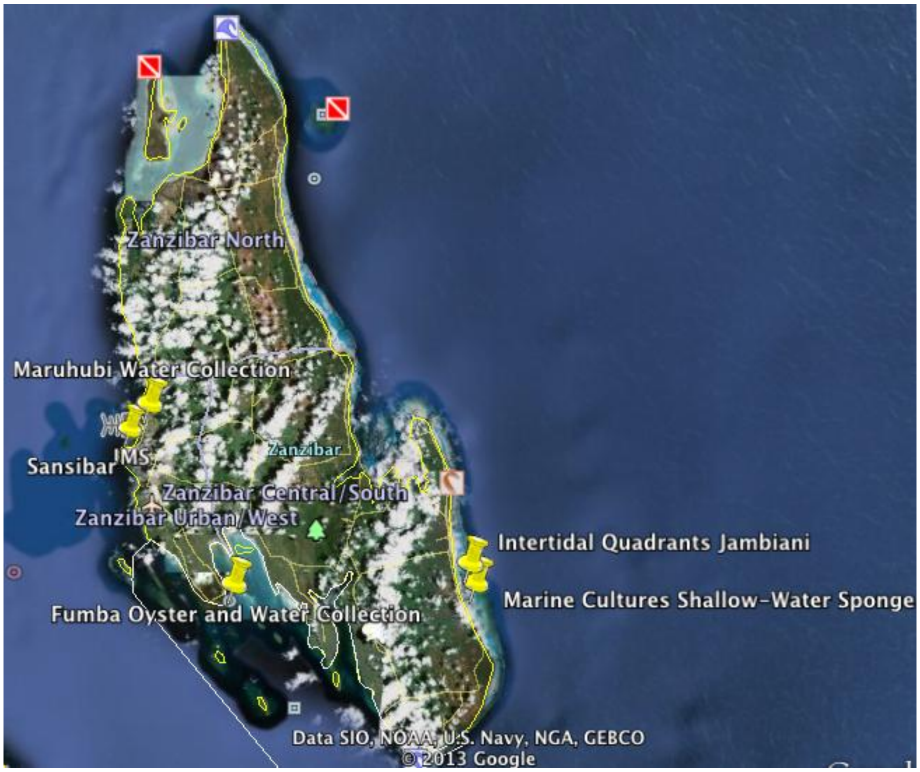

Figure 3. Zanzibar, Unguja Island with study area markers. (GoogleEarth 2013)

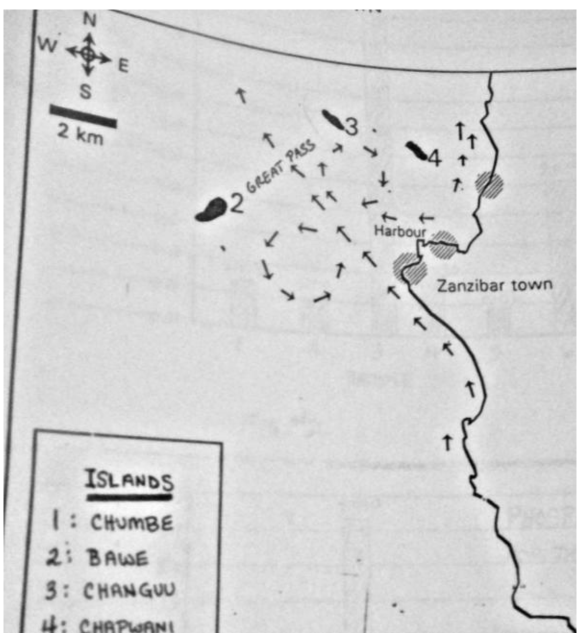

Figure 4. Urban Zanzibar seawater current system. (Anderson 1994.)

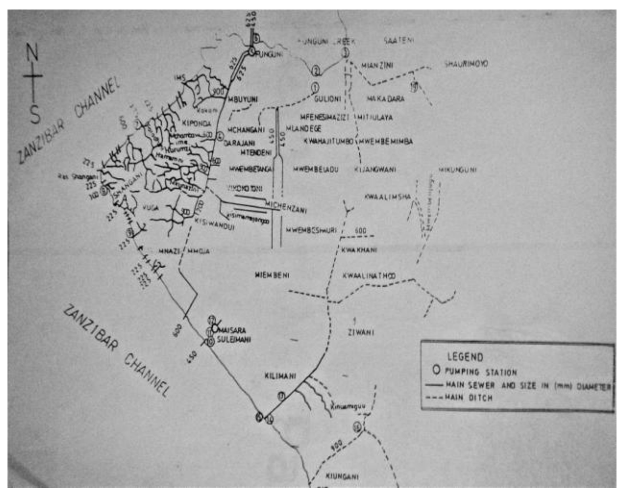

Figure 5. Stone Town runoff system. (Van Bruggen 1990.)

Farming Structure Diagrams

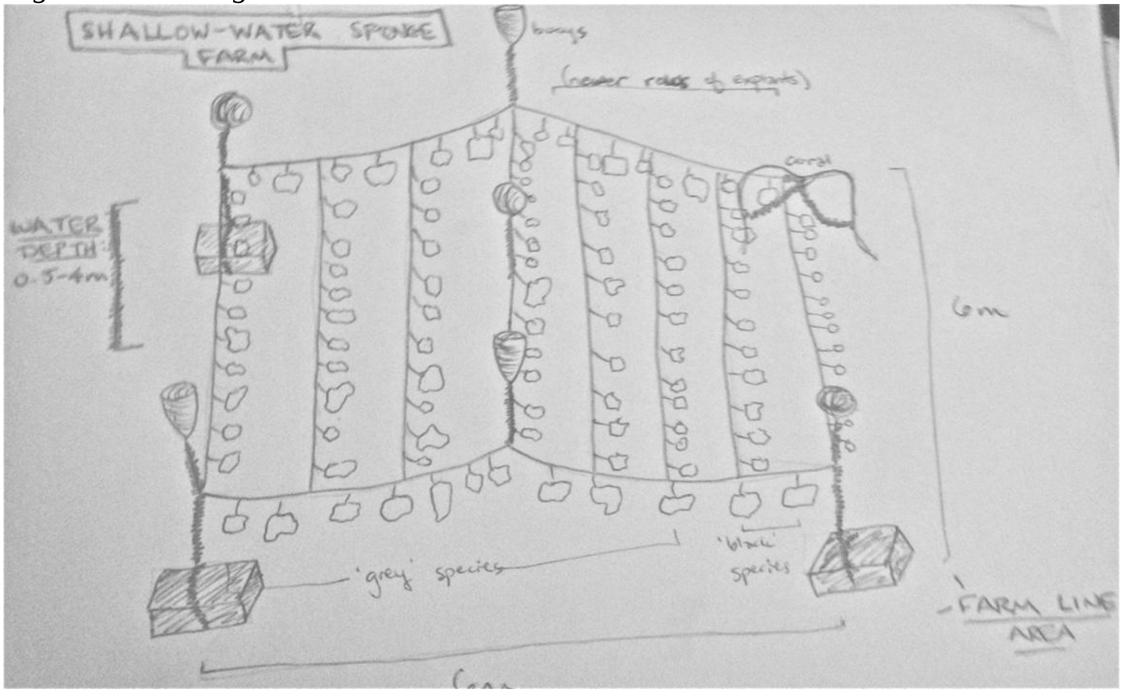

Figure 6. *Marine Cultures* Shallow-Water Experimental Sponge Farm Diagram. (Observation period 2:00-4:00 pm, 3rd of April, 2013.)

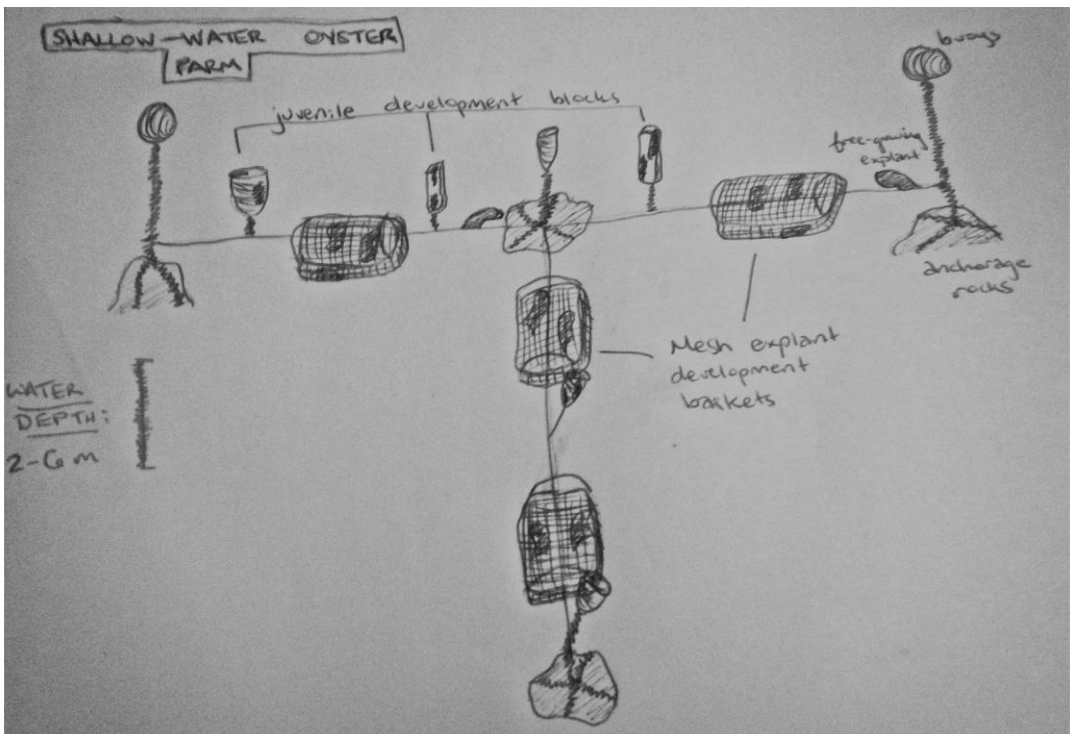

Figure 7. Pearl Oyster Farm Diagram. (Observation period 9:00-11:30 am, 18th of April, 2013.)

Appendix II. Interviews.
Marine Cultures, Christian Vauterlaus, 3:30-5:00 pm, 15th of April, 2013

-When and why did you start *Marine Cultures'* sponge farms in Unguja? (How did you decide on Zanzibar Island? Jambiani?)

2006 we built a house in Jambiani and have been impressed by the seaweed farming but soon we found out that the women did not get a salary they deserve. We thought that there must be marine products that have a better return. In 2008 we made a six month research trip to Thailand, India, Vietnam, Cambodia, Micronesia and Indonesia to check out what kind of aquaculture forms are successful and auspicious for Zanzibar. In Pohnpei, Micronesia (http://www.meripmicronesia.org/sponges/) we found an interesting project and decided to try that. Sponge farming does not need so much investment like pearl farming for example nor is there a security issue. And there are no permission needed like e.g. for the export/import of farmed corals for the aquarium trade. No storage or transport problems for food products like farmed shell or fish because of the lack of secure cooling. Sponge farming is very simple and in contrary to pearls the prices of sponges are going up and up and there are not enough sustainably cultured sponges on the marked. We think it is an interesting niche and we knew that Zanzibar is rich of sponges. In April 2009 we registered marinecultures.org in Zanzibar and started with our research.

-How did you meet Okala and/or learn about the Jambiani Marine and Beach Conservation Organization (JAMABECO)?

We knew Okala since 1999 and because he is an entrepreneur and a very active person we asked him if he joins our operation.

-Which species of sponge do you grow?

At the moment we try to farm two different species. As far as we know they are
Agelas Mauritania var. oxeata and Callyspongiidae – Haplosclerida
But we have some doubts about the results of the University of Genova that identified our samples. We actually are waiting for a new identification round and a confirmation.

-Do you find the line or the mesh basket sponge cultivation method more effective? Why?

If you cultivate a sponge with a high fixedness the line method is very good because it is the cheapest method and as well the sponges are not touched by anything or blessed by any material. Some very soft sponges or sponges that you cannot put on a line are better in a basket. The problem of the line method is that a lot of sponges grow in a donut shape (Farming Sponges to Supply Bioactive Metabolites and Bath Sponges: A Review / 2009 Alan Duckworth)

-What is the market like for the sponges? Is it hard to find?

No. We made a small research and many wholesalers are interested in cultivated sponges. But some although do not know cultivated sponges so they say " We will see..) Fact is that demand and supply on the world market are not balanced. There are not enough natural sponges and the prices are going up an up and the oceans are more and more empty. At the moment the Caribbean Sea is poached. The bath sponges of the Mediterranean Sea are nearly exterminated like in many other parts of the world. So it's high time to start to cultivate sponges.

-Have the local Zanibaris expressed an interest in doing this cultivation themselves?

Yes but they don't have any know how so they wait on our results. But the interest is high.

-What topics do you discuss/present in the local meetings? Do you plan to continue these? How often?

No we only do local meetings if we work in new areas to inform the local communities and as soon as we have something new to say we will present them to the locals of Jambiani.
We think a lot of NGO's make a lot of blabla before they really have something achieved and have a rollout. We still are in a research phase yet and we do not want to generate high expectations that we later cannot comply. As soon as we start with a commercial production and can really scale the sponge farming we will promote it for sure. To the locals but as well to other organizations and even the governmental institutions. Probably it will be necessary to install some regulations too therefor there is no uncontrolled growth of sponge farming with negative impacts on the environment.

-Would *Marine Cultures* be open to a sponsorship in efforts to clean up pollution off Stone Town, Unguja through sponge zooremediation (using their filter-feeding abilities)?
Yes I think we would be open to help wherever we can with our know how and our manpower. There are interesting sponge filtering systems under fish farms in the Mediterranean Sea by the specie Dysidea avara (see Osinga et al. 2010 and Robert Prozato, *Sponge-fishing, disease and farming in the Mediterranean Sea*, 1999

Department of Environment, Hamza Rijaal, 9:30-10:30 am, 17th of April, 2013
How is the coast of Stone Town zoned? (Are there certain zones for certain activities?)
Who manages the use of the coastal zone?
What is the plan of the sewage system? How does it work?
What do you see as the pollution issues in Stone Town? Are they being treated (how?)
Would the port/town be open to filtration systems for pollution?
Who would/could be in charge of monitoring these systems?
What is the state of the coastal employment (ie fishermen, etc)? Are there other employment opportunities sought after?
Response:
-The Department oversees the environmental issues: monitors, intervenes, suggests alternatives and solutions
-Sewage system is tank to salt pit directly to outflow
- -Used to be 10-50 m off the coast until harmful effects evident—moved to 150-200 m
- -Proven that the harmful material is getting to the reefs (Changuu, Bawe, etc)
- -Stone Town is only technically Darajani to coast (east-west) and ndege to malinndi (south-north)—this is the only area on the sewage system—the rest freely flows or comes in runoff

-Department sponsors/helps solutions to environmental issues
- -Not the sole creator of policy but consults on the environmental aspects
- -Created in 1990 with the help of Finland, then 1996 Zanzibar Environmental Policy
- -1990 Van Bruggen study completed as an EIA (requested by Department)
    - -Proves presence of effluents but also heavy metals (lead—source found in artisan industry)
- -Not very much support (minimal awareness and environment not thought of as an issue)
- -Seeks donors (US, Finland, Sweden aid)

Appendix III. Seawater Chemical Analysis—UV Spectrophotometer

Laboratory Testing Procedures

All seawater analysis procedures are followed from the Manual for Seawater Analysis (Parsons et al.) Filter samples through vacuum filtration with "4.5 cm Whatman GFC glass filter papers and standard Millipore filtration equipment. Wash the sample bottle with small portion of the filtered water (twice) and replace the seawater into the sample bottle. Repeat for all samples. Pipette 10 milliliters (mL) of each sample twice into two separate, labeled 40-mL plastic sample-mixing bottles. Pipette 10 mL of distilled water into two 'blank' labeled sample-mixing bottles.

Phosphate

The reagent needs a 100:250:100:50 mL ratio of ammonium molybdate:sulfuric acid:ascorbic acid:potassium antimonyl-tartrate, so in order to get 1 mL reagent per sample (100:10 ratio needed of sample:reagent,) 25 mL of the reagent is needed (one for each of 22 samples.) Therefore, the respective reagents are added 5:10:5:2.5 mL. One mL is pipetted into each sample cuvette, which is shaken to mix. The absorbance is measured and recorded at 885 nm in a UV spectrophotometer. Calibration methods are followed from section 1.6 of the Manual for Seawater Analysis. (Parsons et al.)

Ammonium

Each sample requires 5 mL of the reagent solution, half the suggested amount in the Manual procedure. The reagent therefore needs a ratio of 1.5:1.5:3.25 mL in order to get 5 mL of the reagent per sample (2:2:5 ratio needed of phenol solution:nitroprusside:oxidizing solution.) Five mL of the reagent is added to each sample cuvette, which is shaken to mix. The absorbance is measured and recorded in a UV spectrophotometer at 640 nm. The calibration method is followed from section 1.3 of the Manual for Seawater Analysis (Parsons et al.)

Phosphate Analysis Data Results

Table 2. Standard Phosphate Concentration Calibration

Phosphate Concentration (ug/L)	Absorbance at 885 nm
0	0.0012
0	0.0033
0.5	0.0117
0.5	0.0112
1	0.0215
1	0.0212
2	0.0452
2	0.0446
4	0.093
4	0.093
5	0.1193
5	0.1135

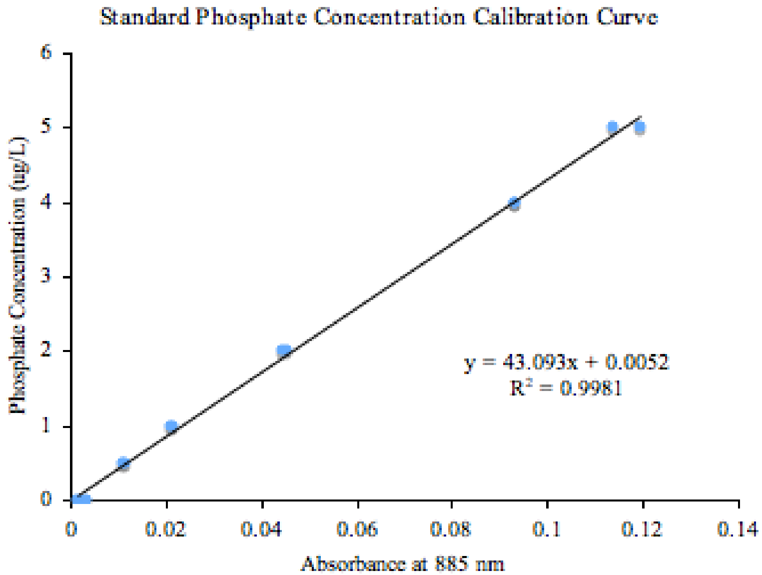

Figure 8. Standard calibration curve of phosphate concentration (ug/L)

Table 3. Sponge and Oyster Phosphate Filtration Results

Sample	Absorbance at 885 nm	Concentration (ug/L)
Contaminated	0.0858	3.7025794
Contaminated	0.0963	4.1550559
Control	0.0441	1.9056013
Control	0.042	1.815106
O1	0.0336	1.4531248
O1	0.0336	1.4531248
O2	0.038	1.642734
O2	0.037	1.599641
O3	0.0366	1.5824038
O3	0.0371	1.6039503
O4	0.0364	1.5737852
O4	0.0359	1.5522387
O5	0.0381	1.6470433
O5	0.038	1.642734
O6	0.0342	1.4789806
O6	0.0393	1.6987549
O7	0.0602	2.5993986
O7	0.0618	2.6683474
S1	0.0259	1.1213087
S1	0.0314	1.3583202
S2	0.0303	1.3109179
S2	0.0384	1.6599712
S3	0.0294	1.2721342
S3	0.0291	1.2592063

*O=oyster replicate sample; S=sponge replicate sample; contaminated=Maruhubi, Control=Fumba

Ammonium Analysis Data Results

Table 4. Standard Ammonium Concentration Calibration

Ammonium Concentration (ug/L)	Absorbance at 640 nm
0	0.0251
0	0.0208
1.5	0.0466
1.5	0.0444
1.5	0.0554
1.5	0.0559
1.5	0.0554
1.5	0.0559
1.5	0.0552
2.25	0.0609
2.25	0.068
2.25	0.0693
2.25	0.0651
2.25	0.0665
4.5	0.1128
4.5	0.1107
4.5	0.1118
9	0.1943
9	0.2001
9	0.202
9	0.1935

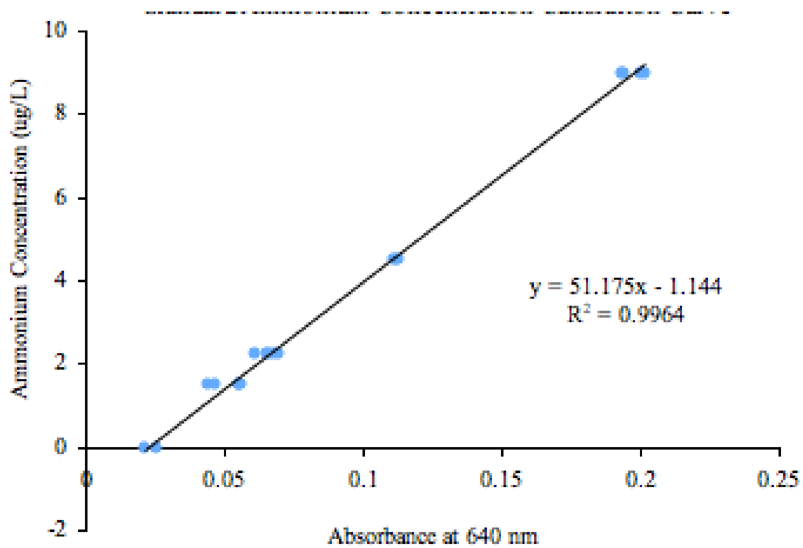

Figure 9. Standard Ammonium Concentration Calibration Curve

Table 5. Oyster Ammonium Filtration Results

Sample	Absorbance at 635 nm	Ammonium Concentration (ug/L)
Contaminated	0.1042	4.188435
Contaminated	0.0981	3.8762675
Contaminated	0.1	3.9735
1	0.4564	22.21227
1	0.4763	23.2306525
1	0.4719	23.0054825
2	0.4684	22.82637
2	0.472	23.0106
2	0.4727	23.0464225
3	0.442	21.47535
3	0.4512	21.94616
3	0.4584	22.31462
4	0.4397	21.3576475
4	0.4447	21.6135225
4	0.4467	21.7158725
5	0.3314	15.815395
5	0.3186	15.160355
5	0.3208	15.27294
6	0.5057	24.7351975
6	0.4849	23.6707575
6	0.5073	24.8170775
7	1.1917	59.8412475
7	1.2152	61.04386
7	1.2161	61.0899175