AN ECOLOGICAL ENVIRONMENTAL IMPACT STATEMENT APPROACH TO ECOLOGICAL RESTORATION: THE VIABILITY OF BIOREMEDIATION MARICULTURE IN ZANZIBAR, TANZANIA.

by

HAYLEY CATHERYN OAKLAND

A THESIS

Presented to the Environmental Studies Program of the University of Oregon
In partial fulfillment of the requirements
For the degree of
Bachelor of Science
University of Oregon
June 2014

An Abstract of the Thesis of

Hayley Oakland for the degree of Bachelor of Science

In the Environmental Studies Program to be taken June 5, 2014

Title:
AN ECOLOGICAL ENVIRONMENTAL IMPACT STATEMENT APPROACH TO ECOLOGICAL RESTORATION: THE VIABILITY OF BIOREMEDIATION MARICULTURE IN ZANZIBAR, TANZANIA.

Approved: [redacted]
Cristin Hulslander

In 2013, a study was completed in Zanzibar, Tanzania to observe the viability of pearl oyster and bath sponge mariculture implementation as bioremediation of sewage effluents off of the city Stone Town, Zanzibar. This pollution threatens coral reef ecosystem adjacent to the city, which are keystone to the survival of human populations in the region. It was found in the 2013 study that the organisms studied can viably chemically remediate phosphates (both organisms) and nitrates (oysters), physically filter turbidity (and associated suspended organic matter), and socially be farmed as mariculture for economic gain. This study attempted to observe the logistics of the potential pollution mitigation through an Environmental Impact Statement (EIS)-like framework. This looked at the positive, negative, and neutral impacts of the options between 'No Action,' the proposed mitigation alone, and additions and alternatives to the proposed bioremediation mariculture. Due to already present ecosystem indicators of pollution and shifts, such as coral bleaching and echinoderm overpopulation, the combination of the previously proposed project, as well as some supplemental alternatives/additions, is recommended, (with advantageous and deliberate placement and further research into biochemical, ecological and hydrological/other physical implications).

Hayley Oakland
EnvSci Thesis Spring '14
Advisor: Cristin Hulslander

Introduction

In April of 2013, a study was completed in Stone Town, Zanzibar that evaluated the effectiveness of using bioremediation mariculture to address the sewage effluent problem in coastal waters. This project was successful in displaying the *in situ* remediation of bath sponge and pearl oysters at filtering contaminated water of phosphates and nitrates, as well as physiological proof of the filter feeders' unique abilities. It also detailed a plan for the idea's viability through discussing the idea with mariculture experts on the island as well as with a representative from the Ministry of the Environment of Zanzibar where the roles of each mariculture and funding by the ministry were discussed. Using previous water chemistry studies in the area, theoretical potential placements of the mariculture were suggested to best benefit the coral reef, though that idea was not delved into in detail. [Oakland, 2013].

For the sake of environmental sustainability and responsibility, this study will be analyzed using an "environmental impact statement" (EIS) framework from a biological and ecological perspective (as opposed to economic/social costs and benefits). The EIS demonstrated will come closer to conveying whether the 2013 study is viable; environmentally and socially responsible; and effective as an idea for pollution remediation.

Every human action, to varying degrees, impacts the environment. Environmental impact assessments or statements (EIA or EIS) have become globally common practice in modern attempts to practice sustainable development. These assessments are to ensure human impacts are the optimal balance of inherently environmentally destructive, yet necessarily provisional of natural resources for the local communities. In an ideal sustainability situation, every human action would be analyzed based on its impact on the environment in relation to its benefit to humans, and then analyzed as to whether it is necessary and realistic. This concept should not only be applied to economic development, but also to any other large-scale human action, such as recreation, establishment of residences, and even attempts to ameliorate environmental harm caused in the past present or future. In the history of human attempts at environmental repair, there have been multiple cases of remediation attempts doing more harm than good due to lack of preemptive research. For example, there have widespread preservation efforts that end up kicking native communities off of the land they have used for centuries. In this way, not only environmental restoration in itself, but also the responsibility of the restoration's techniques, should be assessed.

Environmental impact statements and assessments began to be casually used in the United States in the 1960s, but were formally initiated for analysis of development under the National Environmental Policy Act (NEPA) in 1969 (EPA, 2014). 'Assessments' (EIA) are seen as the initial step in the process, to be followed by a more in-depth 'Statement' (EIS) if the development in question is seen as particularly harmful and entrenched. After the US set the precedence in the 60s and 70s for environmental protection, many other industrialized nations, such as those in the European Union (EU), followed suit and developed the process even further than the progressive-at-the-time US policies. In the current setting of attempts at environmental soundness in development, many developing nations are also analyzing the ways in which they can develop economically without the associated destruction that has been evident in the major industrialized nations, such as the US and EU. For instance, under the Kyoto Protocol (developed in 1997 as a part of the United Nations Framework Convention on Climate Change), carbon offsets were suggested as a way that developing nations could be a 'part of the conversation' and solution to the growing issue of carbon emissions. In this way, developing nations would develop sustainably (by creating an industry out of environmental protection), while participating with industrialized nations in abating carbon emissions (Jacobsen, 2014). While the Kyoto Protocol was, for many sound reasons, seen as a failure of environmental protection policy, the idea of the importance of aiding developing nations' respectful relationship with the environment during development, (as opposed to how 'developed' nations ignored that relationship when developing), is a necessary problem to address in this day and age.

As mentioned, environmental impact statements (EISs) are valuable methods with which to evaluate the impacts of humans, including the impacts of humans' attempts at management techniques. Therefore, an environmental impact assessment is the preferred method to analyze the true effectiveness and value of ecosystem-based management and the mariculture method chosen to implement that management. A thorough biological/ecological environmental impact statement must include an assessment of the costs and benefits to the ecosystems in question. This must include an analysis of the ecosystem affected, the potential effectiveness of proposed management techniques, and the alternative possible outcomes of the management. The environmental impact statement will address corals and their needs in association with pollution stress, the potential effectiveness of introducing this type of bioremediation as a management technique, and the potential unexpected outcomes if this management were to be implemented. The purpose of this biological and ecological impact assessment is to provide a responsible realm in which to introduce environmental management. The format used throughout this analysis is adapted from the Council on Environmental Quality (under NEPA) regulations, as synthesized by the Environmental Training and Consulting International, Inc. organization (ETCI, 2006).

1.0 Purpose and Need

1.1 Purpose and Need for the Action

Zanzibar, an archipelago of islands off of Tanzania, East Africa, is a continually economically and culturally developing nation-state. As of 2012, the entire Zanzibar archipelago had a population of about 1.3 million people (NBS and OCGS, 2013). While the culture and population has long been working within the environmental range of the islands, the growing and more concentrated population, in association with the pressure of economic development, has created a situation of environmental stress. The Mjini Magharibi district contains the port of Stone Town, Zanzibar (also called Zanzibar City, which is the largest city of the archipelago), and had a population of about 593,678 alone as of 2012 (45% of the total population of the islands) with a growth rate of 4.2 between 2002 and 2012 (NBS and OCGS, 2013). Stone Town has long been an active shipping port, important in trading for all of East Africa, the Middle East and Asia. This is part of what has created such a historic and thriving culture in the area, but it is also what creates an epicenter of development and population growth that stresses the adjacent concentrated biodiversity and abundance on the island's fringing coral reefs.

Polluted seawater is an undeniable and indisputable situation for active ports around the world. Stone Town, Zanzibar 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, but is a polluted port that 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, which includes a series of fringing coral reefs (Van Bruggen 1990; Anderson 1994; Shunula and Ngoile 1995; Mmochi 1996; Moynihan 2011). However, little has been done in the way of actually mitigating this runoff. In the context of wastewater pollution, the growing and concentrated population in Stone Town is the main stressor, especially since much of the population is not on any sewer system (Mmochi, 1996; Van Bruggen, 1990, Figure 1.3)). As is true with any human culture, population growth is not an issue readily available to curb, therefore in the least the ramifications of that population growth must be managed to prevent further damage to the health of both the surrounding ecosystems and local human communities. The cleanliness of the seawater proves essential to the habitability of the entire ecosystem, adjacent ecosystems, and the biosphere as a whole, which means it must be addressed.

Ecosystem-based management (EBM) is an evolving technique with the idea that aiding the health of an entire ecosystem is more effective than focusing on a single species (Mohammad, 2013; *Progress in Integrated Coastal Management*, 2000). A study completed in 2013 in Stone Town, Zanzibar showed that using bath sponge and pearl oyster mariculture techniques may provide a viable means to 'zooremediate' (resolve the pollution through animal processes) the wastewater before it reaches the reef ecosystems through ecosystem- and community-based management techniques (Oakland, 2013).

1.2 Specific Objectives of the Project

Corals represent not only organisms in themselves, but also an ecosystem essential to the intertidal zone. Corals are autogenic ecosystem engineers, which is to say that they provide a structural habitat for other species' survival, by regulating ocean current, siltation rates, and wave action, as well as providing refuge from predation (Jones et al, 1994). In this way, a threat to the health of corals is not only to one organism, but also to a whole ecosystem. Corals are cnidarians that practice endo-symbiosis with zooxanthallae algae, which provides the organisms a supply of photosynthetic carbon and a means with which to deposit their skeleton (Work and Aeby, 2014). Through these provisions by the algae, the coral organisms gain an energy source and the organisms dependent on the reef ecosystems gain a structurally engineered habitat (Jones et al, 1994). In this way, coral reefs provide invaluable 'ecosystem services' to human populations in creating locations of biodiversity and abundance hotspots, as well as creating physical oceanic control. This is an important provision for the global biosphere, but is particularly important in tropical habitats such as Zanzibar. Tanzania is one of the developing nations where fish protein comprises 2-4 grams per capita per day and more than 20% of the total animal protein supplies (FAO, 2013). The corals attached to and around Zanzibar are heavily used for fishing resources, which means they must be protected if the livelihood of the human population is to continue healthily.

Fringing corals off of Stone Town are suffering from bleaching and overpopulation of urchins (coral-eating echinoderms). Both of these conditions are indicators of stress on the coral populations (Mumby and Steneck, 2011). The overpopulation of urchins is due to overfishing of the top-predator fish that consume urchins, thereby controlling their populations. That is an issue that could be discussed in great length, but the issue of coral bleaching will be the focus in this analysis of the health of the reefs. Coral bleaching occurs when the coral organisms reject their symbiotic zooxanthallae algae due to stress, which "bleaches" them bone white, because they no longer take the color of the associated photosynthetic organisms (Lesser, 2011). While this situation is not necessarily permanent, if the stressor remains, bleaching can lead to massive coral die-offs, and therefore the loss of the reef ecosystems.

Such stressors can include pollution and disease, both of which are associated with sewage and wastewater runoff contamination. Effluent pollution leaches high concentrations of biological macromolecules and organic nutrients into seawater, which creates a bloom of pelagic plankton (whose limiting factor for proliferation is basically only access to nutrients). As these blooms cycle from continued effluent inputs, these plankton continually die off and sink to the sediment where bacteria efficiently utilize dissolved oxygen in the decomposition process. Intense bacterial use of dissolved oxygen in the water column (from large plankton blooms from intense nutrient input) slowly depletes the sources of oxygen for other organisms, causing hypoxic (depleted oxygen) or, in extreme cases, such as some in the Gulf of Mexico, anoxic (no oxygen) conditions (Souza et al, 2013). Plankton blooms can also carry disease to the corals from harmful algal blooms (HABs) that can also result from the overloading of effluents, or eutrophication, into the water column (Folke et al, 2004; Fabricius, 2011). Similarly, pollution in general can stress the corals through pressuring the allowable nutrient thresholds of the corals' physiology, which will be expanded upon in sections 3-4 (Lesser, 2011). Marine organisms are vulnerable to the chemical and biological conditions of the water column in the same way that terrestrial organisms are vulnerable to air and water quality: healthy environmental conditions are necessary for survival.

The mariculture of filter feeding organisms, as proposed in the 2013 study, was displayed as a potentially successful technique to remediate the biochemical wastewater pollution of Stone Town's coastal waters. Sponges and oysters were specifically chosen for the study since both organisms use methods of filter feeding. Such species have varying abilities to filter, oxygenate and decontaminate the surrounding water column (Gifford et al 2006). In the study completed in 2013, these organisms were shown to effectively lower the concentration of nitrates and phosphates in contaminated water, successfully filtering out effluents associated with wastewater, as well as with environmental harm in the form of eutrophication and harmful algal blooms (HABs). Moreover, sponges and oysters naturally coexist in the intertidal zone, the shallowest and most diverse ocean habitat, making them ideal filtration partners to holistically support keystone coral ecosystems. The implementation of more than one organism as a bioremediation technique attempts to ensure that neither will be overloaded with effluent.

The choice of these invertebrates arises 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 of phyto- and zooplankton and bacteria: the organisms in the water column that exist naturally to a certain extent but become over-populated and sometimes toxic (HABs) with the introduction of high concentrations of these nutrients. High 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. Bacteria blooms cause anoxic conditions in the water by depleting the dissolved oxygen in the water when metabolizing the accumulating nutrients. Consequentially, the seawater affected becomes highly noxious to the ecosystems contained, leading to entire 'dead zones' (NOAA, 2013). The specific fauna in question for the remediation of these issues are bath sponges and pearl oysters, two organisms that naturally maintain the ocean's biochemical stability through filtering plankton and bacteria out of seawater.

1.3 List of significant issues to be resolved

Neither organism, nor the ecosystems involved can tolerate overexposure to pollutants and therefore a careful placement must be assessed to ensure adequate filtration of the pollutants without harming these animals or ecosystems. Variability in pollution concentrations can affect the abilities of the organisms to effectively filter (Souza et al, 2013). Therefore, careful placement of the proposed mariculture is necessary to allow the organisms to effectively filter without vulnerability. Similarly, these organisms cannot become invasive to the ecosystems to which they are introduced. The method proposed involves some inherent management, particularly given that these organisms are currently cultivated through constantly adapting mariculture practices around the island (Vauterlaus, personal communication; IMS, 2013)). In addition, the management of the organisms through ecological means is necessary for the responsible introduction. Supervision and investment could be provided by the Department of Environment of the Revolutionary Government of Zanzibar. In this way, the use of pearl oysters and bath sponges to filter the water off of Zanzibar could be carefully designed to effectively aid in the port's pollution situation.

It must also be analyzed how effective the bioremediation (through the advantageous placement of the mariculture of these filter feeding organisms) is on its own, and whether that is the most beneficial technique of ecosystem-based management to ameliorate the environmental stress, or whether other organisms or remediation techniques should be added.

1.4 Location map(s)

The series of fringing reefs in question are to the north and west of the Stone Town, Zanzibar peninsula. The figures below show the ocean currents pattern and locations of these reef islands.

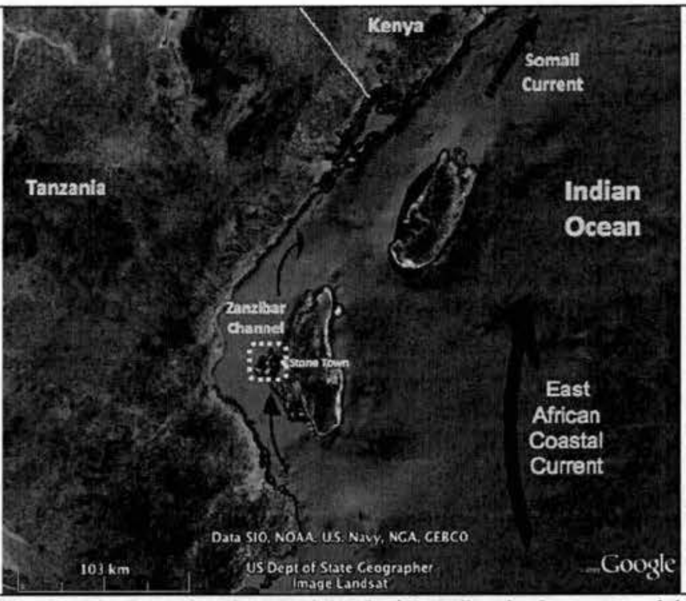

Figure 1.1. Zanzibar Archipelago showing the island of Zanzibar in the center of the image, with Stone Town bulleted and the area of interest in the yellow box. This map also shows the dynamics of the Indian Ocean East African Coastal Current becoming the Zanzibar Channel between the island and the mainland of Tanzania and leading to the Somali Current after the Zanzibar Archipelago. (Map edited from image by Google Earth, 2014; ocean current information from IMS, 2013 and Schartl et al, 2005).

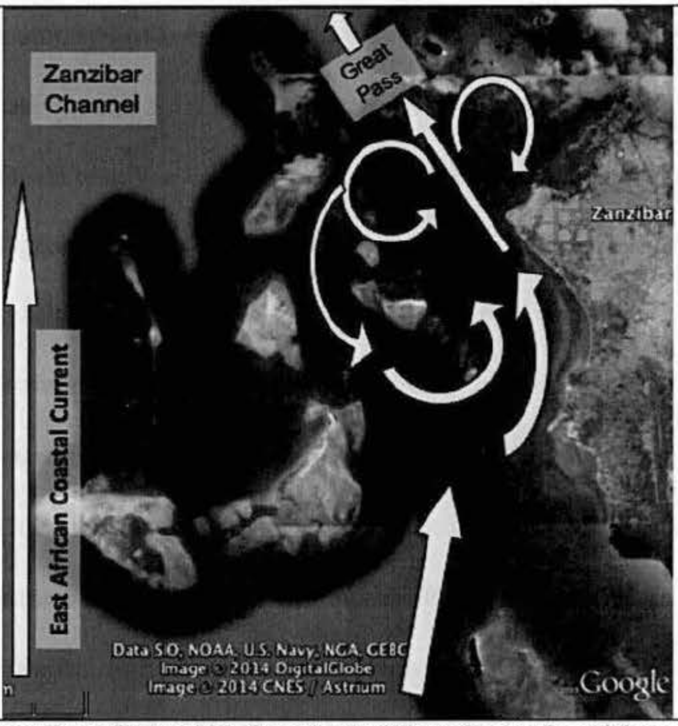

Figure 1.2. Current dynamics resulting from the EACC running northward through the Zanzibar Channel and deflecting off of the fringing islands off of Zanzibar town (Stone Town). (Image adapted from GoogleEarth, 2014; current information adapted from Andersen, 1994).

1.5 Relationship to other Department of Environment actions

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—Figure 3 below, Van Bruggen 1990) is a part of the sewage pipe system. This system consists of wastewater 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, and then changed to 150-200 meters with the discovery of high effluent concentrations near the shoreline. The original decision for this system was described to have come from the idea that Zanzibar Channel's current, driven by the large Eastern Africa Coastal Current (EACC), would be strong enough to take the polluted water away from human habitation, and 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—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.

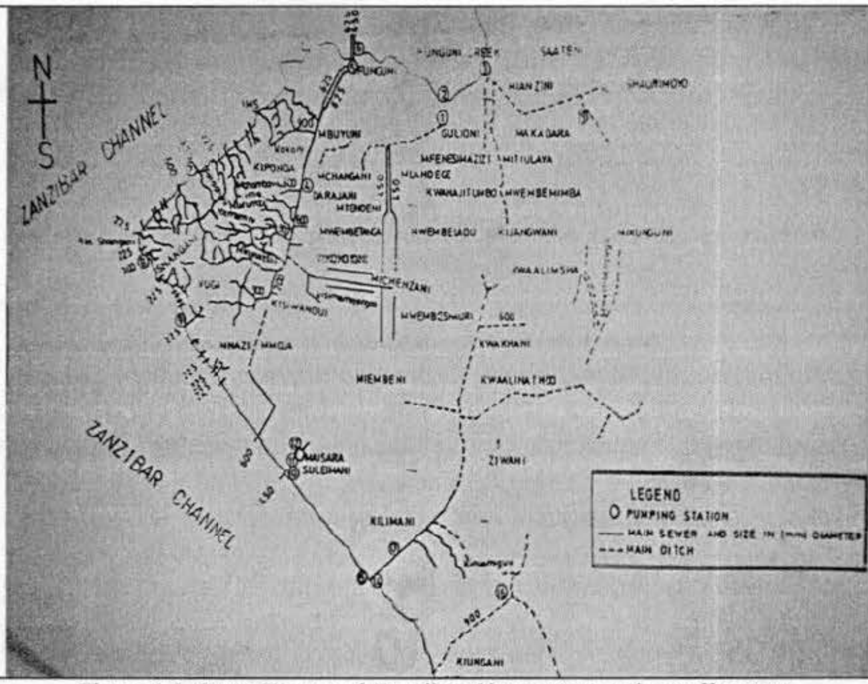

Figure 1.3. Stone Town and Zanzibar City sewage and runoff system.
(Van Bruggen 1990).

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, which has since been addressed by the Department. Upon further prompting, Rijaal indicated that the Department is open to aid new projects for remediation of environmental issues.

1.6 Department of Environment decision to be made

Zanzibar's Department of Environment will make the decision, based on this environmental impact statement and further supplemental research, whether to implement this form of pollution remediation.

Acceptance of these remediation methods, including the potential amendments suggested in this EIS, is not as important as bringing greater awareness to the Department. Pollution remediation must in some way be initiated in the area, and these suggested methods are just one of many options. Therefore, whether the methods outlined in this EIS are accepted or not, action must be taken by the Department of Environment to abate the pollution impairing the essential coral ecosystems and local human populations.

1.7 Evaluation criteria and weighting

The positive impacts of the remediation management techniques are the effective use of ecosystem- and community-based management. *Ex situ* bioremediation is an ideal form of management in that it uses natural systems to aid in the recovery of an entire ecosystem of value. Similarly, it provides a means with which the community can be involved in that remediation, which is particularly important in a developing nation in need of economic prosperity. In this way, the remediation techniques provide not only a method of pollution filtration, but also employment for the local community in the potential to sell the products of the mariculture.

However, these positive outcomes of the management techniques could also be linked to negative, unintended outcomes. Using these mariculture techniques would need to be preceded by thorough research to ensure not only that they will actually have a tangible impact, but also ensure that they will not have a negative impact. These adverse effects could include throwing off the balance of the species in the ecosystem through introducing too many of a certain type (such as the sponges and oysters), concentration of contamination, or lack of ability to create any economic incentive for the local human population (and perhaps even concentrating pollutants in forms that could be transmitted to them). Another alternative could be the fact that the sponges and oysters are already at their maximum abundances in the ecosystem, and any further introduction would not have any impact on pollution management. Each of these impacts—positive, negative, and neutral—must be assessed to ensure the most beneficial outcome of implementation.

The pollution management methods must also be realistic for responsible implementation, so an analysis of the logistics of the project is necessary. This includes not only the analysis of the impacts, as previously mentioned, but also of any additional methods that could be supplemented for the downfall of the previously studied methods of mariculture. This could include adding more organisms with other unique pollution remediation techniques, or adding other methods of management besides bioremediation, such as better management practices of terrestrial runoff.

2.0 Alternatives

2.1 Description of the proposed action(s), including maps as appropriate

Under the proposed remediation, mariculture would be a means with which to aid the pollution situation in Zanzibar's port and most populous area.

Two methods of mariculture already in practice on the island are bath sponge and pearl oyster cultivation for cosmetic products, which are ideal candidate methods given the fact that both organisms are natural filter feeders. Many studies have shown success in pollution filtration by these organisms given these physiologies, such as in the Mediterranean and Australia (Milanese et al, 2003; Gifford et al, 2005).

Sponges and oysters similarly get their sustenance by sucking in ocean water, taking out 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, creating a current in the surrounding fluid (Milanese et al 2003). This current created pulls in the seawater surrounding the sponge containing bacteria, phytoplankton and zooplankton food sources, in addition to suspended particles, which are indiscriminately filtered through the animals' mesohyl matrices. These organisms have a uniquely strong retention and accumulation ability and can filter their entire surrounding water column in 24 hours (Longo et al, Gifford et al).

Similarly, oysters are in the class of molluscs called bivalves, which draw in water to filter through their stomachs and gills. This process, analogous to the sponges' choanocytes, is generated by cilium on the oysters' gill cells (Raj 2008). Their food source comes from microalgal nanoplankton, however they are indiscriminate in filtering all particulate matter (Gifford et al 2005). Though they do take nutrients from the water column through their consumption of phytoplankton, they do release some as well (Saito 2012.) This indicates that to have a holistic bioremediation situation, perhaps another bioaccumulator must be near to the oyster, such as seaweed.

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. Sponges are proposed as the nitrogen repository here to prevent the combination of edibility and wastewater filtration. In this way, sponges are proven to be highly effective at bioaccumulation of ammonia and their ability to accumulate dissolved biological particles at a high rate (Gifford et al 2006, Longo et al 2010), creating an ideal coexistence with oysters.

This shows the potential for these organisms to act as ecosystem remediators to protect the unique biodiversity of this area, particularly the coral reefs. The suggested methods would involve the ideal placement, which would concededly require more research into the oceanography of the area using on site data.

Figure 2.1 Potential sites for proposed remediation mariculture in correlation with the coastal currents. (Image adapted from GoogleEarth, 2014 and reef location information from IMS, 2013).

By incorporating the mariculture into the affected coral ecosystems, the proposed remediation technique would be considered a type of ecosystem-based management. In taking a regional approach to marine environmental pollution, it is suggested that an effective form of ecosystem-management is to consider entire "hydrobiocoenoses," or a regional unit that includes the entirety of the interconnected hydrology, biology and ecology of the system (Patin, 1982). The proposed mariculture remediation techniques are an ideal example of accounting for these complex systems in management. The techniques would employ organisms that already exist within the ecology of the habitat, filter out the chemical and biological pollution affecting that ecology, and utilize the most effective placement within the hydrology of the system to catch the pollutants.

Within these methods of ecosystem-based management there would also be inherent community-based management. The idea of using mariculture for the remediation effort comes from the fact that environmental management is difficult to justify in the social climate of Zanzibar without economic incentive to do so. An important aspect of the mariculture is in the fact that the animals would be cultivated for cosmetic, and not consumptive, purposes. Therefore there are not only economic benefits from the mariculture, but also health-related benefits over consumptive types of mariculture, which may be inappropriate for pollution mitigation. Community members could be employed to initiate and manage the mariculture. Community involvement is an essential ingredient of successful ecosystem management through including the stakeholders affected by the pollution in its remediation. Similarly, working with a range of perspectives allows for an active adaptive management process (Meffe et al, 2002). In these ways, the use of mariculture for pollution remediation is more consequential than isolated techniques, such as reserves or species-based management, which are commonly exclusive of a local populations' influence.

Finally, this would be a method of the integrated coastal zone management (ICZM) and global international waters agreement (GIWA) frameworks, which outline responsible policies to manage coastal waters. An integrated coastal zone would take into account all human and ecological uses of the coast and manage accordingly by creating zones for the different uses (PAP/RAC, 2000). For example, in Stone Town, the zones could include areas for shipping, fishing, other boating, untouched nature, and (under the proposed actions) pollution mitigation. This would also fit into the GIWA framework by addressing the sources of the issues (such as overlapping zones) and attempting to find a solution that benefits all stakeholders in some way (Belausteguigoitia, 2004). Through the inclusion of multiple perspectives and needs, as well as the necessities of a developing society, the remediation mariculture has the potential to be a highly valuable technique.

2.2 Description of alternatives considered and eliminated, along with reasons why

One model that has been attempted in traditional environmental protection and management is endangered and/or threatened species-based management. However, this model is arguably ineffective given that it simply addresses the effects of the problem, not the cause of the problem in the first place. Even though most models of endangered species management will take efforts to protect the habitat of the threatened organisms, which is only part of the consideration of the techniques. Often these organisms are preserved in zoos, aquariums or research institutions to ensure that the biodiversity still exists. However, it is unrealistic to imagine that the biodiversity still exists if it cannot be in its natural habitat. The Global International Waters Assessment (GIWA) is a framework for protecting international waters in a way that addresses root causes rather than covering the effects of the problem (Belausteguigoitia, 2004). In this case, the GIWA framework would advocate for policy that works towards mitigating the actual sewage problem and why it is polluting the coast of Zanzibar, which addresses the problem on the scale of ecosystem- and biospheric-based management. Instead, a species-based concept would be insufficient in that it would simply dictate that the corals (if those were the species in question) were simply put in reserves while allowing continued pollution and the destruction of the reefs outside the reserves, which is, needless to say, an unsustainable solution and not effective in the long term. In contrast to this, ecosystem-based management builds resilience in the habitats for all species that are harmed by the environmental damage (Van Dyne, 1969; Folk et al, 2004). Particularly in the case of water pollution, it is reasonable to say that every species in the area of pollution is affected in some way, so an ecosystem basis for mitigation is not only more effective ecologically, but also economically and temporally.

It would seem then, in order to truly address the root of the problem as suggested by the GIWA framework, that attempting to place the entire population on a controlled, managed wastewater system would be the only real option for success in the situation with Stone Town, Zanzibar's pollution. Unfortunately, the reality in Zanzibar is that the logistics of implementing such an expensive system is unrealistic in the current economic and social circumstances.

For comparison, the system used in the US per the Clean Water Act (1972) is that each wastewater treatment plan must have at least primary (physical filtration) or secondary (solid settlement) treatment (McDowell, 2014). However, this system has been historically difficult to implement even in the affluent US, income (and therefore tax money) disparities and polarization across regions. As mentioned, there is a portion of Stone Town on primary treatment (filtration), but most of the city is a disseminated source (not treated; simply runs off). Again, in comparison to the US, this is not that different (perhaps only that a greater proportion of the population is not on the wastewater system). However, in the US, it is similar in that disseminated pollution is without a doubt the biggest issue in water pollution management, and for the CWA actions in general (McDowell, 2014; Jacobsen, 2014). More progressive cities in the US are on secondary, tertiary (biological treatment) and quaternary (chemical treatment) pollution systems. For example, in Coos Bay, Oregon, the city wastewater treatment plan is on a quaternary system, where wastewater is primarily physically filtered, secondarily solids are settled out, tertiary remediated with bacteria, and quaternary treated with chemicals, which ultimately creates potable water (City of Coos Bay, 2006). This, of course, would be the ideal for all wastewater, but unfortunately, most places in the US can't even afford that level of treatment. In comparison, the wastewater from Zanzibar either goes through only a primary level of treatment, (which is limited to downtown Stone Town), or through no treatment (most of the Zanzibar City sprawl), simply running into an unlined drainage ditch (see Figure 2.2). This means the sewage and wastewater effluents soak into the ground and/or surface water, and runoff into the surrounding keystone ecosystems (such as coral reefs and mangrove ecosystems), which provide breeding grounds and habitats to many vital organisms of Zanzibar, not only to humans, but also to the biosphere of the island in general.

As is evident in the figure displaying the wastewater system (figure 1.3 above), a very small proportion of the population is on a sewage system, while the majority of the city's population uses ditches for wastewater. This is a particularly consequential comparison given the fact that the province of Zanzibar City (the expansion of Stone Town) is growing at such an immense growth rate (as referenced above). Therefore, although controlling the sewage and wastewater at pollution at the source would be highly preferable, it is perhaps unrealistic in the present to assume that wastewater treatment plants could be readily implemented for the entire human population (not to mention the livestock population) on the island, so the critical ecosystems must, in the very least, be protected until that is possible.

2.3 Description of No Action

If the system in place were to continue with unremediated coastal pollution, the bleaching and disease of the coral reefs would continue to amplify, which would cut off the essential source of an ecosystem that protects and maintains the diversity of organisms. These organisms are not only important for the sake of biodiversity, and therefore ecosystem resilience, but also serve many invaluable ecosystem services to the local and regional human population.

The most apparent provision by coral ecosystems to human populations is in the habitat they provide to the fish and other seafood. In Zanzibar, as described above, the local and regional human population relies on this source for a large proportion of their nutrition. A less pronounced, though equally important service of the reefs is in wave detonation and storm control. In these ways, the protection of the coral reef ecosystems is not just important for the integrity of the natural environment, but also for the vital ecosystem services these ecosystems provide to the local human populations. Therefore, if human populations are to be supported and sustained in the area, 'no action' is not an option.

2.4 **Description of other reasonable courses of action that will meet the purpose and need and project objectives (i.e. alternatives)**

Other actions that could reasonably meet the needs of pollution mitigation for ecosystem protection include controlling the effluents at the outflows or employing other forms of remediation in addition to the proposed.

As pictured in Figure 1.3, there are distinct outflows from which the wastewater of Stone Town / Zanzibar City is released where there could be measures taken to filter pollution. Such measures could include physical, chemical or biological filtration (such as through bacterial pools). Although this would perhaps be more effective in terms of filtration as well as more effective under the GIWA framework (of addressing the source over the effects), this is also perhaps not as realistic. For example, one issue is that the city's coastal space is already highly utilized, both on the shore and in the water. However, a vertical physical and/or chemical filter could be a more space-effective way to, in the very least, remediate some of the pollution. In figure 1.3, the part of the city on the sewage pipe system is physically and chemically filtered through coal as primary treatment (Hamal, 2013). This system could be applied at each outflow to provide at least that level of treatment for all wastewater, which is a necessary step to take whether in addition to or instead of biological remediation.

Another alternative to the proposed remediation is to amend or build on it with other bioremediation techniques, which would not only meet the proposed objectives, but also further the concept of ecosystem- and resilience-based management. Additional forms of remediation could also be a form of keeping the proposed methods in check ecologically by creating greater balance in the species distribution. Some organisms that have been studied for bioremediation (in addition to sponges and oysters) are polychaetes and macroalgae. Polychaetes are benthic filter feeding marine worms that can tolerate relatively high amounts of seawater pollution. The worms are actually proposed as useful indicator species given this ability, which is only possible because of their ability to bioaccumulate organic enrichment pollutants (Dean, 2002). Similarly, seaweed macroalgae has the potential to aid in an ecosystem-wide remediation effort given the inherent ability of photosynthetic nutrient sequestration. A project by Woods Hole Oceanographic Institute on oyster cultivation in the United States utilizes the processes of nitrate remediation into ammonium by the oysters to grow seaweed near the oyster farms (Saito, 2012). Thus it could be advantageous to include seaweed culture to the proposed remediation mariculture, which would contribute further to the idea of a holistic ecosystem-based management approach.

2.5 **Comparison of environmental impacts and mitigation measures of each alternative, including No Action**

The environmental impacts of the alternative possible actions for the pollution of Stone Town are highly variable. First, if 'no action' is to be taken, as explained above, the continuation of ecological degradation will ultimately lead to conditions that are unsuitable for human habitation. As suggested, the mitigation measures for this are one of the outlined remediation techniques.

Controlling wastewater outflows has positive environmental impacts, but could not be sufficient in itself. Even the parts of Stone Town on the primary treatment system result in highly toxic waters from the outflows (Mmochi, 1996). A similarly insufficient mitigation technique on its own is to attempt to place the entire town on the wastewater pipe system. While this is necessary to start to implement, it cannot protect the presently threatened ecosystems. However, in the long-term this technique would be the most environmentally influential, particularly in the fact that it takes a GIWA framework. Under this framework, addressing and ultimately improving the pollution problem at the source will lead to lowering the pollution stress on the coral reefs, therefore allowing them to continue to provide essential ecosystem services to the human population, and finally that will encourage institutional reform to abet the improvements (Belausteguigoitia, 2004). In this way, the GIWA-style approach would definitely be the most effective and consequential action, however it is also the most difficult to implement.

The most effective alternative when taking into account both socioeconomic realism and environmental need would be additional remediation sources. The environmental impacts of these sources would mainly be beneficial through additional bioremediation of harmful wastewater effluents. However, in consideration of potential negative environmental impacts, additional remediation could still hold the potential for invasiveness of any of the implemented organisms, which would need to be addressed and monitored before and during the application of the techniques. In this way however, the addition of more types of organisms lessens the chance that any one organism could become overly dominant in the ecosystem. Another possible negative environmental impact of bioremediation mariculture is the use of space in the ecosystem, which could affect the survival of other organisms. To address this issue, further research into ideal placement of the mariculture to prevent light, surface, and/or vertical blockage of the ecosystem is required.

3.0 Affected Environment

3.1 A brief description of the physical setting for the proposed action

The physical setting for the proposed action mainly pertains to the coral reefs themselves, but also to the human population that is closely connected to those reefs. As displayed in Figure 2.1, the barrier coral reefs off of Stone Town, Zanzibar are closely connected to the concentrated population center as well as the effects of that concentration (such as runoff pollution). What is also evident in this image is the extent of these fringing reefs around small coral islands off of Zanzibar's population center. The creation of these barrier islands off of Stone Town was facilitated by corals' settlement and reef construction based on advantageous flow and depth placement. Thus other organisms had the means with which to thrive in these ideal conditions as well. This archipelago of barrier reefs off of Stone Town represents some of the most dominant around Zanzibar, as represented in a study of distribution (Mbije et al, 2002). This study had the specific goal of identifying the patterns and distribution of coral around Zanzibar to aid in threat-evading management efforts. Yet since this study, the population and associated pressure on environmental resources has been constantly amplified (as evident in the growth rates represented in section 1.1).

Coral reefs are renowned worldwide for their incredible ability to provide ecosystem services to both humans and the natural environment. A particularly beneficial attribute of the reefs is in their ability to hold incredible biodiversity in the provision of species richness, abundance, and evenness. The provision of this biodiversity is not only because of their ability to create habitat for other organisms, but in the complexity of the habitat created. Structural complexity is closely correlated to the resilience of trophic structures within an ecosystem, such as through the support of herbivores in supporting high densities and, most importantly, shelter from predation (Mumby and Steneck, 2011). Shelter is not only necessary as a means of survival from predation throughout organisms' lives, but also provides the archetypal conditions for the nursery habitat of a variety of species, including the coral organisms themselves.

An incredible service corals provide to their environment is in ecosystem engineering. Through the construction of calcium carbonate exoskeletons, the Cnidarian polyp organisms create vast systems of complex habitat that supports not only the diversity emphasized above, but also a number of physical features that explicitly support the livelihood of humans and other organisms in the region. Coral reef ecosystems are known for their ability to not only protect coastlines from violent action of the ocean during tropical storms, but also to control much more specific oceanographic features below the water column. Part of what gives this issue of pollution such complexity is the seawater current system off of

Zanzibar, which is dictated by the alteration of currents by the corals. In the regulation of current direction, corals also dictate the currents' speed and the water columns' siltation/sedimentation rates as 'autogenic' (resource facilitating) ecosystem engineers (Jones et al, 1994). This is delineated in the fact that they are not only providing the source of habitat for numerous organisms, nor are they simply a food source for some organisms, but they are actually moderating the distribution and abundance of the vital resources that support these organisms.

For the local human population, coral reefs provide up to 70% of all fishery stocks. This is not only an important source of economic exportation for the local communities, but also of sustenance. Fisheries provide 90% of the animal protein to the nutrition of coastal communities (Wagner, 2004).

3.2 Concise descriptions of each component of the environment that will be affected by the project (keyed to issues in Chapter 1 and to impacts in Chapter 4)

Under the proposed mariculture remediation project, and perhaps with the incorporation of other remediation techniques, the reefs have the potential to be greatly relieved of pollution pressure.

As introduced in section 1.0, coral organisms require certain biochemical conditions for survival and vitality, which allows them to provide the same to so many other organisms. As holobiont organisms in robust symbiosis relationships with algae and bacteria, corals are actually primary producers of organic nitrogen, which is internally cycled within the reef ecosystem (Suzuki and Casareto, 2011). This implies that additional sources of nitrogen (such as from wastewater), which could overwhelm the delicate balance created within the internal environment of the corals and the ecosystem as a whole. Most marine organisms, and all marine invertebrates, are stenohaline, meaning they are isosmotic with the surrounding water column (Willmer et al, 2005; UNFAO, 1972). An unnatural increase in certain compounds within the marine environment could therefore lead to stress of the coral organisms and consecutive rejection of symbionts (the definition of coral bleaching) (Fabricius, 2011). In the theory of the mariculture project, oysters and sponges are strong *in situ* remediators of nitrogen (to be discussed further in section 4.0). Therefore, the mariculture could result in remediation biochemically of the water column if placed in the foreground of the reef ecosystems.

Adequate physical conditions are also a necessary feature to the coral organisms' success. In the reproductive cycle of corals themselves and also other sessile invertebrates, mobile invertebrates and vertebrates alike require certain oceanographic conditions for spawning and juvenile settlement and development. In the process of coral recruitment (spawning and then settlement), the zooplanktonic stage is when the newly spawned coral plankton, the preliminary stage to the polyp form, that are among a diversity of other mero- (part of life spent in plankton) and holoplanktonic (whole life spent in the plankton) forms (Willmer et al, 2005). Suspended organic material from wastewater pollution can cause turbidity of the water column and disallow the settlement of the plankton, whether sessile or not. Most to all marine organisms, from salmon eggs to barnacles, require clean surfaces for reproductive survival (Trowbridge, 2013). Exposure to suspended particles associated with the runoff and wastewater pollution can create siltation within the reef, which although this can typically be cleansed to some extent by the developed corals, is not sustainable in mass quantities in that it disallows planulae settlement and survival and stresses the developed corals. Similarly, not only contact with suspended sediment, but also the associated turbidity of the water column is stressful to the coral communities (UNFAO, 1972). Much of the dissolved organic nutrients cannot even be used as food (like other nutrients can, to cause plankton/bacterial blooms), so is simply a source of highly concentrated turbidity (Fabricius, 2011). The solution offered in the project plan would be the remediation of the suspended particles by the filtration mechanisms in sponges and oysters. As will be discussed further in section 4.0, the filtration abilities of the maricultured organisms are not only chemically remediation, but physically remediation as well.

Biochemical and physical conditions both contribute to the resilience of the ecological conditions of these ecosystems. As introduced in the biochemical discussion, coral reefs are contained in somewhat of a 'closed' system of nutrient exchange, that if disturbed could lead to eutrophication and consequential coral bleaching (Suzuki and Casareto, 2011; Fabricius, 2011). Apart from the concern of coral survivability alone, much of the ecological biodiversity in the region relies on these reefs, which human populations rely on as a source of sustenance. In the discussion of physical conditions, it was indicated that not only corals, but many other organisms also rely on certain environmental conditions for reproductive success. Similarly, many organisms require the survival of coral organisms themselves for their reproductive survival. For instance, many organisms rely on the shelter from predation and other sessile invertebrates rely on the hard, clean substrate provided by the corals' physical structures for settlement and development. Corals are known for their biodiversity and high level of trophic structures, which was traditionally thought to provide greater resilience, but in comparison to other ecosystems in the region, such as sea grass meadows and mangrove stands, corals are much less resilient to pollution pressure (UNFAO, 1972). Another issue in this resilience is the potential for trophic shifts within the ecosystem. As described in many studies, ecosystems typically have varying states that can lead to sudden drastic shifts when thresholds are reached. In the case of coral reefs, the shifts are often to states of urchin domination (usually caused by overfishing) or macroalgal takeover (typically caused by algae's higher tolerance to pressures, such as water pollution) (Folke et al, 2004). In this way, the mariculture of filter feeding organisms like sponges and oysters, and potentially the addition of other organisms (such as macroalgae) provides the ability to release pressure on the trophic structure of the ecosystems to prevent these large-scale shifts in ecosystem states.

Ecological conditions are a necessary analysis of the mariculture techniques as well. Organisms that supply local fisheries include fishes and invertebrates, such as octopi and molluscs. In addition to the human-valued organisms, other organisms include echinoderms like urchins and starfish, cnidarians such as jellyfish and hydroids (and of course corals), and macroalgae (seaweeds and seagrasses) (Fabricius, 2011). These organisms are involved in a fairly structured trophic system, so introductions to any aspect of the trophic system may offset the entire structure (Fabricius, 2011). This is the logic behind the additional organisms proposed in section 2.2, which should provide an adequate ecosystem-based approach to prevent dramatic trophic shifts.

As mentioned, coral reefs provide the significant means of sustenance for local human populations. Zanzibaris rely on the marine source of animal protein for survival and economic development. Stone Town in particular has a growing demand for fishery products in its growing population and tourism industry in recent decades. Therefore, the protection of the coral reefs through this project, or some similar means of pollution mitigation, is necessary for the survival and vitality of not only the ecology of the reefs, as described above, but also of the local human population.

4.0 Environmental Consequences

The complexity and vulnerability discussed above of the ecosystems themselves—both in the terrestrial human and marine reef environments—dictates that there are inherent complexities when discussing environmental ramifications. However, each component of the following discussion is consequential in addressing the range of overall impacts that any efforts to remediate this continual pollution problem would entail.

4.1 Affects of each alternative, including 'No Action' (direct and indirect; positive, negative and neutral)

As presented in section 3.0, coral reef ecosystems live in a constant balance of biochemical, physical and ecological conditions. These conditions dictate not only the survival of the corals as organisms, but of the ecosystems as well, which is closely connected to the endurance of local human communities in the region.

Alternative: No Action

In terms of effort, 'No Action' could be argued to be the most convenient option. This option aligns with much of the current economic development practices of 'business as usual' growth. This option of 'no action' towards environmental consequence mitigation is advantageous to developing capitalist economies because it is inexpensive and uncomplicated in the short-term. However, in the long-term, the biosphere is responding to the constant pollution of economic growth with shifts that will end up far more costly and complicated than simply introducing environmental mitigation in the first place.

Under 'No Action,' the reef environment is greatly affected. If pollution continues in the present manner, the ecosystem will continue on the trajectory into eutrophication and ultimately hypoxia or anoxia (lack of adequate dissolved oxygen concentrations that support life). This process is described in Section 1.1 ("Need for Action"), which states that with continual uncontrolled effluent runoff into the coastal waters off Stone Town/Zanzibar City, the reefs will only become more stressed, leading to continual coral bleaching (rejecting symbionts) and eventually entire coral reef deaths. The stress of the corals comes from the eutrophication (high nutrient concentration) of the waters, which can both deplete the source of oxygen in the water column and bring disease in the form of HABs (section 1.2). Without coral reefs, the ecosystem services described in sections 1.0 and 3.0 will no longer be provided, and the local population will no longer be able to rely on the reefs for the source fishery protein, thereby losing a major source of livelihood.

Additionally, eutrophic conditions and the associated consequences can lead to other physical, biological and ecological conditions (as partially discussed in Section 3.2) that can damage the ecosystems (even without the loss of oxygen or the disease of the corals). First of all, high algal biomass can create challenging conditions for coral recruitment (Mumby and Steneck, 2011). There is no doubt that other open-water spawning invertebrates, and perhaps a diversity of other organisms, would also be damaged by high algal biomasses.

Continued effluent loading on the coastal water also leads to changes in ecological conditions. One of the major issues with nutrient enrichment is the potential to change the trophic structure (Fabricius, 2011; Folke et al, 2004; Mumby and Steneck, 2011). Coral reefs are traditionally thought of as ecologically resilient since they have a fairly large threshold for disturbance before the ecosystems succumb to a trophic shift. However, after enough disturbances, just as dramatically as coral ecosystems display resilience, they also display large trophic shifts (Holling, 1973; Mumby and Steneck, 2011). The succession of reef ecosystem shifts is typically from hard coral dominance either straight to macroalgal dominance, or in between the two stages, sea urchin dominance (Folke et al, 2004; Mumby and Steneck, 2011). A shift to macroalgal dominance would be an especially likely scenario in the case of eutrophication because the growth of macroalgae—and photosynthetic organisms in general, like the plankton discussed in Section 1.0—is limited by access to nutrients. (This will be a good case for including macroalgal mariculture, which will be discussed later in this section). Overfishing typically causes the shift to sea urchins' dominance, however urchins play a similar trophic role as Crown-of Thorns starfish (as predators of corals), and are the other species that can proliferate, damage and dominate coral reefs. Urchin and Crown-of Thorns starfish have been traditionally thought to dominate reefs when the ecosystems are overfished through top-down trophic cascades, or a shift in ecosystems' trophic structures following some disturbance (Fabricius, 2011; IMS, 2013). However, in the case of Crown-of-Thorns starfish, it is possible that both overfishing and eutrophication have caused their proliferation on the reefs surrounding Stone Town, and could even be providing a positive feedback loop of both top-down and bottom-up (planktonic proliferation) trophic cascades for these destructive organisms. In the life history of these starfish, the zooplankton stage feeds off of pelagic phytoplankton, and it is suggested that the increase in phytoplankton from high nutrient concentrations can increase the survival of Crown-of-Thorns starfish that can consequentially ride currents to coral reefs and proliferate and erode the reefs (Fabricius, 2011). Consequentially, the continued eutrophication of the coastal waters surrounding Stone Town (and Zanzibar City) results not only in the nutrients directly affecting the coral organisms, but also may lead to indirect effects from the nutrients affecting ecological processes.

While the role of organic nutrients in coral reef ecosystems is complex, and it may even be argued that introducing more would not be harmful, there is an internal cycle of nutrients of which the balance should not be disturbed without the destructive consequences described above. Coral reefs have often been thought to be oligotrophic (contain low nutrient concentrations), making nutrients as limiting factors (Mumby and Steneck, 2011; Suzuki and Casareto, 2011). However, recent studies have actually shown that coral reefs are quite balanced in their nutrient regimes, and that they contain fixed cycles of these nutrients, which can be disturbed past the thresholds and lead to entire ecosystem shifts (as described above). For example, dissolved organic nitrogen and phosphorus (DON/PON) have unique and controlled cyclical systems within the reef, that when offset by foreign nutrient inputs, can lead to drastic shifts in the structural complexity of the ecosystems, such as shifts to coral-predator overpopulation or macroalgal takeover (Mumby and Steneck, 2011; Suzuki and Casareto, 2011). It is therefore evident that the introduction of nutrients is not beneficial to coral ecosystems as they command a fine balance of physical, biochemical, and ecological conditions.

Alternative: Bath Sponge and Pearl Oyster Mariculture Bioremediation

Bioremediation is therefore the proposed method with which to aid in many of these issues for the reef ecosystems. Even so, the ecosystem costs and benefits must be addressed to ensure the adequacy and responsibility of whatever remediation method is implemented.

The first remediation method proposed is the sponge and oyster mariculture, which has potential positive and negative effects on both the reef ecosystems and the connected local human communities.

In the 2013 study of the proposed oyster and sponge mariculture on its own, the filtration abilities of each organism was tested *in situ*. These results demonstrated the potential capacity for the mariculture of these organisms *en masse* to filter the water column surrounding the farms of phosphates and nitrates associated with concentrated effluent pollution. Given the results of the study, both oysters and sponges displayed the ability to transform the chemical nature of their associated water columns (Oakland, 2013).

Wild species of marine oyster and sponge sample organisms were collected from the intertidal ecosystems of Zanzibar. At the Institute of Marine Science in Stone Town, the organisms were kept in oxygenated seawater pumped in from the coast. During the tests, the organisms were transferred from the 'control' seawater to 'contaminated' seawater (collected from an area of known pollution, (Mmochi 1998 and Moynihan, 2012)).

The spectrophotometer tests demonstrated that for both the sponges and the oysters, the concentration of phosphates decreased significantly (see figure 4.1). 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 (the least contaminated source) contained 1.86 ug/L phosphate.

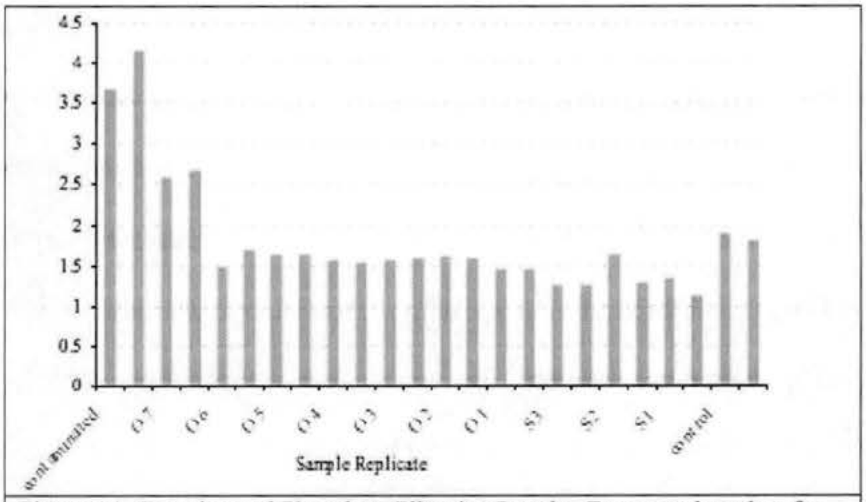

Figure 4.1. Experimental Phosphate Filtration Results. Two samples taken for each replicate. One replicate for contaminated water (baseline conditions), seven replicates for oysters, three replicates for sponges, and one for control water (baseline conditions in a relatively-uncontaminated location (O=oyster; S=sponge.)

For the ammonium test, only completed for the oyster samples, the concentration of ammonium increased during the filtration period (see Figure 4.2). 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.

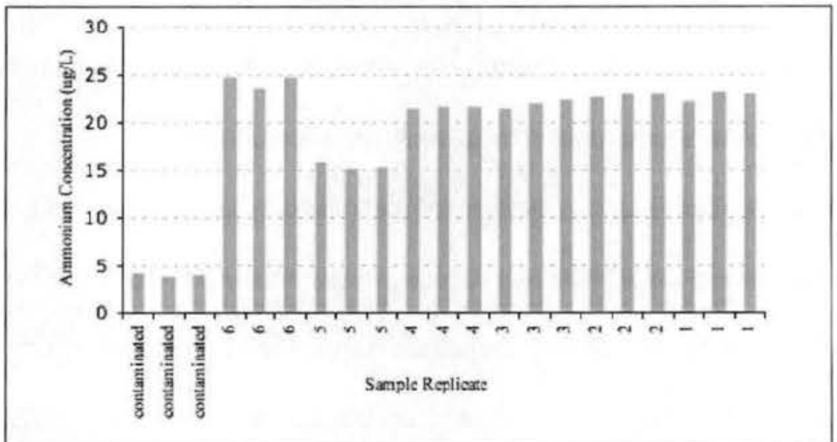

Figure 4.2. Experimental oyster nitrate filtration results. Replicates only completed for oysters and the contaminated water sample. Three samples were taken from each replicate, with one replicate of the contaminated water (baseline conditions) and six replicates of the oysters.

To interpret these results, the physiology and ecology of these two organisms will be discussed. 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 in 2003, 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 explains how incredibly essential sponges are to their ecosystems in retaining the particles harmful 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 4.1). 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 1.0, 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 bioremediating harmful chemicals from 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 for other organisms, such as reef fish and other invertebrates. When the sponges and oysters filter the water of these harmful 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 in the effluent runoff and can be deadly to humans if ingested, not to mention the damage done to other species. It has been found that, in some places, benthic sponges may even thrive closer to an enrichment source (Holmes 2000). Although this seems advantageous, it is an indicator of the potential for introduced sponges to overpopulate, (which will be discussed further later in this section). The idea that sponges can filter and retain these cells proves them to be vital to a prospective remediation mariculture for both humans and the surrounding impacted ecosystems.

An additional service of marine sponges—that is not organic effluents, but is often associated with unfiltered runoff—is the ability to degrade inorganic pollutants in effluents. This is suggested in studies demonstrating their ability to break down PCBs (polychlorinated biphenols) and surfactant molecules more rapidly than bacteria or oysters given their ability to concentrate halogenated biomolecules (organic molecules with associated halogens, such as chlorine, fluorine, or iodine) in their cells (Gifford et al, 2006). This is pivotal in preventing these molecules from reaching the coral ecosystems housing the majority of the local marine organisms. These biomolecules can have deleterious effects, such as interrupting reproduction and inhibiting growth (Gifford et al, 2006). The filtration by the sponges is therefore a significant ecosystem service and highly 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). For 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 (Oakland, 2013). Similarly, this class of sponges does not cause the characteristic of reef bioerosion, which is shown in boring sponge species. 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, which displays their adaptability to morphological manipulation and therefore their ability to successfully survive and grow throughout explantation (Oakland, 2013).

Correspondingly, 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 of phosphorus (Gifford et al 2005). These findings represent the power oysters have in seawater nutrient remediation, particularly large populations.

The filtration experiment supports these 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 harmful phytoplankton population in the seawater, and therefore the pivotal ecosystem service provided by oysters. [Oakland, 2013].

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 (Mmochi, 2013). 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 thought to be caused by the remediation of nitrates given that dissolved nitrogen exists in seawater in one of the two forms (Oakland, 2013; Mmochi, 2013). With the acute increase in ammonium concentration across replicates (see figure 4.2) 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 sequestered by a evolutionarily 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.

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. A study completed in 2006 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 accumulates when microalgae and bacteria overpopulate, preventing photosynthesizing organisms from using 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 by the pronounced filtration abilities of the two organism groups.

Negative environmental impacts that could result from the placement of the suggested mariculture practices as wastewater remediation stem mainly from the artificial alteration of the natural environment and natural processes. As mentioned in the sponge discussion, there is a family of sponges within the Demospongiae class that are reef bioeroders. The clionidae family of marine sponges has the ability to bore into calcium carbonate material, such as hard coral structures, and also into the shells of molluscs (Tribollet and Golubia, 2011). An additional destructive feature of this family of sponges is their ability to thrive in eutrophic conditions (Holmes, 2000). While the Clionidae family is natural to a certain extent in the reef ecosystems of Zanzibar (IMS, 2013; Oakland, 2013), they should not be selected for use in this mariculture project so that they will not invade and destroy the reefs. However, boring sponges would not be chosen to begin with as globular sponges are the type that are cultivated for bath sponge purposes (Duckworth et al, 2007).

The issue of overpopulation by introduced organisms should be considered with the introduction of pearl oysters. Previous attempts at pearl oyster mariculture have found that while there are not high environmental risks, the moderate and low risks must be addressed (Wells and Jernakoff, 2006; Ronnback et al, 2002). With the artificial introduction of any organism to an ecosystem, the potential for overpopulation or invasiveness is highly pertinent. As has been briefly mentioned and will be discussed further under mitigation methods, this can largely be controlled through the fact that these introductions will be an example of ecosystem- and community-based management. However, monitoring and ecosystem checks are not always sufficient in controlling every condition, such as disease or new species introduction. In the case of wild pearl oyster (*P. maxima*) mariculture in Western Australia, one of the moderate and low risk issues that were continually a problem was the introduction of disease, either from seedlings (moderate risk) or from translocation or hatcheries (low risk) (Wells and Jernakoff, 2006). A similar issue was found in the transplantation process of cultured sponges from in situ to ex situ conditions in the fact that the microbial communities within the sponge organisms changed in the transition (Webster et al, 2011). However, in both of these situations, the issues of bacterial communities could largely be a factor of introducing non-native specimen to the environments. While this is a broad assumption, the fact that wild species from the Zanzibar intertidal ecosystems will be utilized for these processes should indicate that the organisms would not introduce exotic associated bacterial communities. Yet this complex issue could be a factor that is further researched on location. Some bacterial community studies surrounding the reefs and sewage outflows have been completed through the Zanzibar Institute of Marine Science (Moynihan et al, 2011; Mmochi, 1996), however if the mariculture remediation effort is to be pursued, perhaps further studies could be completed to see the effects of effluent bacterial communities on organismal bacterial communities, and how microbial processes may effect the ecology of the ecosystems in question.

In the context of ecological impacts, the effects on the trophic structure of the coral ecosystems must be addressed in the pursuit of responsible introduction of mariculture. As previously discussed, coral reefs are highly diverse and organism-abundant ecosystems, however this highly structured environment does not necessarily imply resilience (Johannes, PME). As discussed above, shifts can occur in the ecosystem that can often lead to irreparable changes in the trophic structure. The predator-prey relationships of both sponges and oysters (as well as any other potential introduced organisms) need to be assessed in mitigation efforts. For example, echinoderms (sea urchins and Crown-of-Thorns starfish) are apex predators within the ecosystems, but they could provide reciprocal management to the oysters in particular given the predator-prey relationship (Trowbridge, 2013; Fabricius, 2011). The oysters would provide a means with which to control the overpopulation of the echinoderms' larvae, while the echinoderms would provide a means with which to control the potential overpopulation of the increased concentrations of oysters. This example of ecological relationships is necessary to note in the pursuit of introducing organisms in any manner.

In this way, any mariculture introduced to an ecosystem implies certain associated physical, biochemical and ecological changes. Physical impacts could include the competition for space or light by the mariculture structures and organisms themselves (particularly if introducing seaweed culture, which will be discussed further below) (Wells and Jernakoff, 2006). One risk also mentioned by Wells and Jernakoff includes entanglement in the mariculture structures, which may reduce livability for the organisms already in or around the ecosystem. However, upon observation of the bath sponge, pearl oyster, and seaweed mariculture around Zanzibar, it was evident that the farms actually attract more diversity than was previously in a place due to the structural creation of refuge. In fact, both the oyster and sponge farms, due to their depth, attracted many of the fish species that are present on the coral reefs in the area. The seaweed farms attracted sessile and mobile, benthic and pelagic invertebrate species and small fish (Oakland, 2013). The issue of entanglement has the potential to mainly be a problem for the larger organisms in the area, such as sharks and dolphins, so this is an issue to take into consideration upon placement and management of the potential mariculture. A last physical and biochemical issue would be the creation of ammonium by the oysters, which as discussed above, may be able to be mitigated through the use of seaweed mariculture, (which will be discussed further below).

It is possible that introducing this type of bioremediation mariculture would have no effect on the effluent enrichment of the water column. While there have been numerous studies showing the potential of this idea, there have been few studies into the actual implementation success (Angel et al, 2002; Gifford et al, 2005; Gifford et al, 2007; Milanese et al, 2003; Pandey et al, 2008; Saito, 2012; **Soper**). For instance, in the case of oysters, many studies claim theoretical filtration of an entire water column based off of *in situ* abilities of the organisms, but few ex situ experiments have taken place and shown concrete results. This is particularly important in the fact that laboratory conditions are highly different than natural environmental conditions in terms of physical, biochemical, and ecological controls.

Accordingly, there can never be complete certainty in implementing environmental management, but the inclusion and consideration of alternatives is a step towards more responsible implementation. As suggested in section 2.2, the inclusion of polychaetes and seaweed mariculture has the potential to aid in the suggested maricultures' abilities to be more biochemically and ecologically sound. While there may still be similar problems associated, such as overpopulation, resource-use, and success under environmental conditions, the addition of these organisms capability of the individual organisms combined under ecosystem-based management could have a highly favorable outcome, especially in comparison to present (and future, if unmitigated) conditions.

The first suggested addition or alternative to sponge and oyster mariculture is seaweed cultivation. Phytoremediation is a process by which plants can stabilize and/or extract pollutants from a degraded environment through their natural ability to sequester nutrients for photosynthesis and growth (Gifford et al, 2007; Ronnback et al, 2002; Souza et al, 2013). A review of aquatic bioremediation suggests that marine alga and photosynthesizing bacteria have the ability to "phytostabilize" pollutants to inhibit pollution migration and "phytotransform" or "phytodegrade" pollutants into less harmful compounds (Gifford et al, 2007). The implications of these proficient bioremediation mechanisms, as well as the in fact that seaweed mariculture is already employed around Zanzibar, allow the prospect of adding seaweed mariculture to the remediation methods proposed above.

Polychaetes are epibenthic invertebrate marine worms that are further useful in situations of marine pollution. It has been observed that many species of polychaetes, in a similar fashion to sponges, actually are relatively resistant to polluted seawater, and can thrive in areas of pollution (Dean, 2008). Because of this shared trait between sponges and polychaetes, both species (if used) should be carefully monitored to ensure they do not overpopulate. These marine worms are also filter feeders, but instead of the water column, they filter the sediment (as "deposit" feeders) (Trowbridge, 2013). There are a few species of polychaetes that can convert hydrocarbon (organic) pollution into less toxic metabolites through bioaccumulation, which also makes them effective "biomonitors" in observing the sequestration through bioassays (Dean, 2008). Thereby the polychaete species present in the ecosystems of Zanzibar would need to be studied further to address their individual tolerances and abilities. While the use of these organisms holds the apparent risk of bioaccumulation into the edible fishery stock, if the species were monitored by mariculture practices near/under the proposed mariculture, they could serve as successful monitoring species given the ability to bioassay the pollutants they appropriate.

As mentioned, the introduction of additional mariculture remediation still provides some of the same issues as those of the sponges and oysters alone, with the main problem being resource utilization. For the seaweed mariculture, rows would need to be placed downstream of the sponges and oysters to ensure they can sequester the nitrates and phosphates either not filtered by the farmed benthic invertebrates or the transformed nutrients, (as in the case of the ammonium levels from the oysters' remediation of nitrates). As the algae are photosynthesizing organisms, they would require having the primary access to sunlight in the area of mariculture, which would prevent algae from surviving below the mariculture. Analogously, if the polychaetes were cultured in the sediment, there would need to be space cleared and somehow blocked off to allow monitoring of the organisms and prevent their consumption by other benthic organisms. Additionally, both organisms (seaweed and polychaetes) would need close monitoring to prevent overpopulation within the adjacent ecosystems since they are both able to survive better than most organisms of the ecosystem, and correspondingly their overpopulations are indicators of pollution trophic shifts within the ecosystem. These issues are similar to those of sponge and oyster mariculture introduction in terms of resource (space and light) use, but if the projections of ecosystem recovery are possible, the mariculture practices have the potential to provide more benefits than costs to the ecosystems ecologically, biochemically, and physically.

Of course the idyllic and most effective remediation of the pollution off of Stone Town/ Zanzibar City would be controlling the sewage and wastewater runoff at the source. This method would meet the Global International Waters Approach (GIWA) methods by targeting a problem at its origin, which would not only solve the problems occurring in the ecosystems, but also those stemming from the waterborne disease spread to the local human population. However, as presented in figure 1.3, much of the city is on an uncontrolled system, and the part of the city that has a system is only goes through secondary treatment (Rijaal, 2013). Controlling the sewage and wastewater is a complex and substantial task that will require continued effort on the part of the local communities and policymakers.

4.2 Relation to other agency plans/policies

Integrated Coastal Management (ICM) was a concept enacted in 1993 in East Africa under the call by the UN Development Program to create a multiple-use, sustainable coastal zone management program (Wagner, 2004). This process, as described by Wagner, prescribes that policymakers involve all stakeholders (including planners, community members, and especially resource users, such as fishermen) in the coastal management regime. ICM is also suggested in the 1992 Zanzibar National Environmental Policy, so on both the mainland and in Zanzibar, the technique is already in its third decade of policy discourse (UNEP/FAO/PAP, 2000; ZDoE, 1992; ZDoE, 2009).

The implementation of the proposed mariculture remediation techniques would need to be a necessary part of responsible ICM. This would mean working with local fisheries, the shipping industry and, most importantly, the local mariculture industry. The local community would not only be employed in the mariculture, but would be in complete control of its management in correlation with fishing and tourism boat interests.

4.3 Urban quality, historic and cultural resources, and the design of the built environment, including reuse for each alternative

The bioremediation abilities of all of the organisms suggested for implementation are clear and indispensable, but what truly bolsters the argument to implement these organisms are the potential benefits they could 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. All supplies for the respective farming techniques are comparatively inexpensive, uncomplicated and low-maintenance, which is one of the main criteria for successful aquatic bioremediation techniques (Gifford et al, 2007). Advantageously, both methods require similar supplies, such as cement blocks for anchoring, rope for attachment, and buoys for flotation and marking (Oakland, 2013). 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 mariculture techniques. 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 in providing an economic stimulus to the community, it is not overly expensive for the farmer attempting to initiate the farms. The requisite locations (displayed in Figure 2.1) of the proposed farming techniques are further advantageous aspects of the cultivation pursuits. Accessibility to the local population is an important factor in the implementation of the mariculture, which is met through proximity to the coastline and shallow requisite depths for maintenance and cultivation.

4.4 Mitigation measures

The use of bioremediation mariculture would be an example of successful marine management because of the holistic approach it would take to the social and ecological issues specific to Zanzibar. However, the issues addressed in Section 4.1 must be mitigated, or at least confronted, to implement responsible environmental management. The main method of rationalizing the use of mariculture for pollution remediation is in the idea that the techniques are examples of ecosystem-based, community-based, and integrated coastal management.

As introduced in section 2.1 (when discussing alternatives to the proposed actions), 'hydrobiocoenoses' are regional units that take into account the majority of the connected hydrology, biology, and ecology of the local systems (Patin, 1982). The proposed mariculture takes into account these 'hydrobiocoenoses' by placing the bioremediation upstream of the ecosystems to be protected (hydrology), using organisms' filtration abilities to transform biochemical effluents (biology), and utilizing species already present in the ecosystems in question (ecology). Therefore, the proposed methods have the ability to be highly responsible means with which to implement bioremediation of pollutants off the coral reefs to fully employ ecosystem- (or hydrobiocoenoses-) based management.

With a hypothetical implementation of the proposed techniques, the location is a pivotal aspect. Placement directly upstream of the coral reef ecosystems allows that the mariculture is not overwhelmed by both the traffic of Stone Town and the intensity of the concentration at the sewage outflows (see figure 1.3), which has been shown to overwhelm previous attempts at mariculture off of Stone Town (Jiddawi, 2013). The proximities of these barrier reefs to the peninsula of Zanzibar City are also ideal because the shallow depths allow access to the local communities who will manage the 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 Figure 2.1).

Community-based management would be inherent in the pursuit of mariculture bioremediation given the fact that the local communities would be the source of all management for the practices. The economic benefits to the local communities are discussed in section 4.3. Management by the local communities would include the actual practice of mariculture cultivation, as well as the monitoring of the farms and organisms' successes. The *Marine Cultures* organization is an advantageous example for the proposed farming techniques given their ability to perform background research, ensure prosperity and aid in education and farming implementation.

The Institute of Marine Science (IMS) would oversee the monitoring efforts through employing local community members and staff researchers to monitor the physical, biochemical, and ecological conditions of both the farmed organisms and the ecosystems being protected. Management and monitoring in the realm of policy would be from Zanzibar's Department of Environment. In conjunction with the environmental policy of 1992, 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 (ICM) should be used as a framework and that efforts should pay particular attention to the progression of "coral reef degradation 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" (ZDoE, 1992). By these standards, the proposed project is the ideal primary solution to the pollution situation given that it takes 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 management (ICM) 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 (UNEP/FAO/PAP, 2000.) Implementing mariculture 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.

As indicated in section 4.2, the ICM framework was developed in the early 90s to be followed by the 1997 National Environment Management Council (NEMC), which established the Tanzania Coastal Management Partnership (TCMP). This partnership (between Tanzania's NEMC and the University of Rhode Island and USAID) actively attempts to influence the policymaking process related to coastal environmental management, as well as disseminating information to all stakeholders (Wagner, 2004). The implementation of these techniques would not only follow ICM, but would follow GIWA, the proposed global method to addressing shared waters and the connectedness that provides (Belausteguigoitia, 2004). Similarly, Belausteguigoitia challenged the comprehension that just because not every detail of every ramification is known about environmental recovery means it should not be implemented. With reference to the GIWA approach to marine management, he states that with the use of indigenous knowledge in collaboration with scientific technique and local policy frameworks, environmental management can in the least be responsible, if not predictable.

Conclusion

As is evident from the analysis given of the proposed mariculture bioremediation, there is a large degree of uncertainty, complexity and difficulty inherent in any proposed environmental management. However, the hope is that while the human realm of economic development dictating environmental destruction is navigated, in the very least the environmental ramifications of that development can be managed.

This study proposes implementing mariculture bioremediation techniques to filter the pollution in the waters off of Stone Town/ Zanzibar City, the main port and the historic and growing urban center of Zanzibar, Tanzania. With further research, these practices have the potential to create successful systems of effluent filtration to mitigate the sewage and wastewater pollution that is carried via the water current regime to the fringing coral reef ecosystems on the barrier islands off of the peninsula city. These coral reefs support not only the ecosystem service of biodiversity, but also the abundance of animal protein for the local communities, as well as many other physical, biological, and ecological services. Therefore, the ecosystems are necessary to manage for the security of environmental and local human populations' livelihoods.

Future research for the responsible implementation should include further inquiry into all aspects of the 'hydrobiocoenoses.' This could include looking further into the hydrological water current systems' flow through the reefs. Biological research could be done on the microbial communities within the organisms proposed for mariculture to determine whether they are the same as the reef organisms' microbial communities (to prevent exotic introduction). Further research into the trophic structure of the organisms implemented would be necessary for responsible introduction, for example by analyzing whether apex predators like echinoderms (such as sea urchins and Crown-of-Thorn starfish) would continue to be a threat, and whether they could prevent overpopulation of the maricultured organisms. As such, it is evident there are complexities and uncertainties that will always be present in the pursuits of environmental management, but the effort is necessary to ensure the prosperity of life in the region.

Bibliography

Dubinsky and Stambler. *Coral Reefs: An Ecosystem in Transition.* Book.

1. Mumby, P.J. and R.S. Steneck. Chapter: The Resilience of Coral Reefs and Its Implications for Management. 509-519.
2. Fabricius K. Chapter: Factors Determining the Resilience of Coral Reefs to Eutrophication: A Review and Conceptual Model. 493-505.

Environmental Training and Consulting International, Inc. (ETCI). 2006. Environmental Impact Statement: Generic Annotated Outline Format. *EIS Annotated Outline* 1: 1-4.

Gifford, S., Dunstan, H., O'Connor, W., & MacFarlane, G. (2005). Quantification of in situ nutrient and heavy metal remediation by a small pearl oyster (Pinctada imbricata) farm at Port Stephens, Australia. *Marine Pollution Bulletin, 2005*(50), 417-422.

Gifford, S., Dunstan, R.H., O'Connor, W., Koller, C.E., & MacFarlane, G.R. (2006). Aquatic zooremediation: employing animals to remediate contaminated aquatic environments. *Trends in Biotechnology.* 25 (2): 60-66.

Gunderson, L.H., C.R. Allen, and C.S. Holling. 2010. *Foundations of Ecological Resilience.* Island Press. Washington D.C. Print.

-Holling, C.S. 1973. Article 1: Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics.* 4: 1-23.

-Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C.S. Holling. 2004. Article 4: Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review of Ecology and Systematics.* 35: 557-581.

Harlan, D.K. (2008). The use of polychaetes (Annelida) as indicator species of marine pollution: a review. *International Journal of Tropical Biology,* 56(4), 11-38.

Holmes, K. Effects of eutrophication on bioeroding sponge communities with the description of new West Indian sponge, *Cliona* spp. *Invertebrate Biology*, 119(2), 125-138.

Jacobsen, G. 2014. Environmental Policy. *Planning, Public Policy, and Management Department, University of Oregon*. Lecture Series.

Jiddawi, Narriman. 8 April 2013. Pearl oysters and previous remediation efforts interview. Instistute of Marine Science. Personal communication.

Jones, C.G., J.H. Lawton and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69: 373-386.

McDowell, P. 2014. Watershed Science and Policy. *Geography Department, University of Oregon.* Lecture Series.

Milanese, M., Chelossi, E., Manconi, R., Sara, A., Sidra, M., & Pronzato, R. The marine sponge *Chondrilla nucula* Schmit, 1862 as an elective candidate for bioremediation in integrated aquaculture. *Biomolecular Engineering*, 20(2003), 363-368.

Mmochi, A.J. 1996. Marine Pollution on Zanzibar & Tanzania. *Institute of Marine Sciences Zanzibar, University of Dar Es Salaam.* Print.

Mmochi, A.J. 2013. Mariculture and Biochemical Toxicity in Zanzibar. *Institute of Marine Science, University of Dar Es Salaam.* Personal Communication and Lecture Series.

National Bureau of Statistics (NBS) and Office of Chief Government Statistician (OCGS). 2013. 2012 Population and Housing Census: Population Distribution by Administrative Areas. *The United Republic of Tanzania.* Table 1.

Schartl, M., U. Hornung, K. Hissman, J. Schauer and H. Fricke. 2005. Genetics: Relatedness among east African coelacanths. *Nature* 493: 901.

Souza, F.M., Brauko, K.M., Lana, P.C., Muniz, P., & Camargo M.G. (2013). The effect of urban sewage on benthic macrofauna: A multiple spatial scale approach. *Marine Pollution Bulletin*, 67(2013), 234-240.

Trowbridge, C. 2014. Marine Ecology. *Oregon Institute of Marine Biology, University of.Oregon*. Lecture Series.

United Nations Food and Agriculture Organization (UNFAO). 1972. Marine Pollution and Sea Life. Ruvio, M. Fishing News Ltd. London, England. Print.

-Fonselius, S.H. On Eutrophication and Pollution in the Baltic Sea. 23-26.

-North, W.J., G.C. Stephens and B.B. North. Marine Algae and their Relation to Pollution Problems. 330-336.

-Johannes, R.H. Coral Reefs and Pollution. 364-371.

-Stirn, J. Possibilites for Constructive Use of Domestic Sewage (with an Example of the Lake of Tunis). 517-518.

United Nations Food and Agriculture Organization (UNFAO). 2010. The State of World Fisheries and Aquaculture 2010. The United Nations. Online. http://www.fao.org/docrep/013/i1820e/i1820e01.pdf 64-70.

Van Bruggen, J.J.A. (1990) Preliminary Study on Environmental Pollution on Zanzibar. University of Dar Es Salaam. Department of Environment. Commission of Lands and Environment. Zanzibar Integrated Land Use Project of FINNIDA.
zooremediation: deploying animals to remediate contaminated aquatic environments. *TRENDS in Biotechnology, 25*(2), 60-65.

Willmer, P., G. Stone and I. Johnston. 2005. Environmental Physiology of Animals. Second Ed. Blackwell Science Ltd. Oxford, UK. Print.

Part 3: Coping with the Environment. Chapter 11: Marine Life. 393-442.