AN ABSTRACT OF THE PROJECT OF

Lisa Reifke for the degree of Master of Science in Marine Resource Management presented on December 16, 2009.

Title: Harnessing the Power of Google Earth for Seagrass Conservation in the Comoros Islands

Abstract approved:

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Google Earth has given internet users the power of a virtual globe at their fingertips. It is a free, easy to use tool that avoids the need for technical training, and uses a simple, intuitive interface. For this reason, Google Earth appeals to general and more specialized users. This project describes a case study of the use of Google Earth as a user-friendly and cost-effective tool for the conservation of seagrass in the Comoros Islands. The case study uses a baseline seagrass mapping study to help demonstrate the potential of Google Earth to be used by management agencies, non-governmental organizations, scientists, and the general public for marine conservation in developed and developing countries. The final product is a Google Earth file which includes GIS map layers of the seagrass coverage and distribution within the study area, 3-D graphs of the results, species profiles, a series of educational placemarks that guide the user through the importance of and threats to seagrass, and documentation of the methods used in the seagrass survey. All of this information is contained within a single file that can be easily and freely shared with anyone who has internet access. Specialized users such as management agencies, non-governmental organizations, and scientists are likely to find this tool most useful to visualize and communicate GIS data. For general users, the Google Earth file will provide awareness of seagrass ecosystems and the opportunity to explore data from a previously unstudied remote area, potentially narrowing the gap between science and the public. The use of Google Earth opens endless possibilities for easy data dissemination, collaboration, and education to a wide-audience across the globe.

Harnessing the Power of Google Earth for Seagrass Conservation
in the Comoros Islands

by
Lisa Reifke

A PROJECT

submitted to

Oregon State University

In partial fulfillment
of the requirements for
the degree of

Master of Science

Presented December 16, 2009

ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor, Michael Harte, whose encouragement, guidance and support throughout the process, enabled me to think more deeply about my project and pushed me to do the best work I can. I am grateful to Andy Lanier, my committee member, for his encouragement, reassurance and insightful comments. It is a pleasure to thank my committee member, Dr. K., for making his support available in a number of ways throughout my studies during the past year.

I am also grateful for the AquaFish team, particularly Jim Bowman, Laura Morrison and Hillary Egna for their continued support and interest in my academic career. They made themselves available to discuss and review my project from the initial to the final stages. I would also like to thank AquaFish for providing my GRA support for the last two years. Additionally I received a fellowship from them that help fund this research.

It is my pleasure to thank COAS student programs, Lori Hartline and Robert Allan, for their support and patience throughout all the ups and downs over the last 2 years.

I would like to thank my research partners in the Comoros Islands, Daniella Blake and Soizic Le Courtois. They diligently assisted in the collection of data for this project through inclement weather and unforgiving blisters and always maintained a positive attitude.

The support of my fellow MRMrs will not be forgotten. Their words of encouragement, insightful comments, and friendship were greatly valued and they were a highlight of my experience in the MRM program. I would especially like to thank Heather Reiff, Sarah Mikulak, Stephanie Ichien, and Neal McIntosh for their continued support and friendship throughout my time at OSU. I owe my deepest gratitude to Evan-Bing Sawyer for his never-ending support and encouragement even through the darkest and most trying times. Without his love and support, this project would not have been possible.

Last, but not least, I would like to express my gratitude to my family, for always believing in me even when I was filled with doubt. Their commitment and encouragement made it possible for me to pursue this degree. I am forever grateful to all the people that made this accomplishment possible. I feel tremendously lucky to have so many supportive people in my life and I am truly indebted to them for all they provided me.

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CHAPTER 1: EXECUTIVE SUMMARY

This project describes a baseline seagrass mapping study conducted in the Comoros Islands and the use of Google Earth to display and communicate the results in an effort to promote seagrass conservation to a wide audience. Seagrasses are one of the most productive and valuable ecosystems in the world. The greatest existing seagrass meadows occur along the coasts of developing tropical countries, which also experience the greatest rate of environmental degradation (Durate 2002). Present wide-spread seagrass loss is due largely to anthropogenic impacts such as eutrophication, siltation, pollution, and harmful fishing practices and is expected to accelerate as human populations continue to grow on and near the coastal zone (Durate 2002). The Comoros faces challenging environmental problems such as deforestation, soil degradation, mechanical damage to intertidal zones by octopus and shellfish collectors, pollution from household waste, and harmful fishing practices which can contribute to seagrass decline. While there has been an increase in scientific publications on seagrass, public awareness remains far lower than for other coastal habitats like mangroves, salt marshes, and coral reefs (Orth et al. 2006).

This baseline seagrass study used standardized methods to map the boundaries and collect survey data at 115 sample points along 16 transects in the study area of Bimbini Peninsula, Anjouan Island. A total of eight species of seagrass were encountered in the study area: *Thalassia hemprichii*, *Thalassodendron ciliatum, Halophila ovalis, Cymodocea rotundata, Cymodocea serrulata, Halodule uninervis*, *Halodule wrightii, and Syringodium isoetifoium*. Of the 115 points surveyed, 108 contained seagrass, indicating they were present 93.9% of the time. Average percent cover of seagrass for all the vegetated sites was 40.35%. *Thalassia hemprichii* and *Thalassodendron ciliatum* were the most dominant species and had the highest average percent cover while *Halodule uninervis* was encountered the least number of times and had the lowest average percent cover (Table 1).

Table 1. Number of sites present and average percent cover for each species present in the study area

Species	#of sites present	Average % cover
Thalassia hemprichii	91	61.73%
Thalassodendron ciliatum	40	53.11%
Cymodocea rotundata	11	47.97%
Cymodocea serrulata	34	34.5%
Halodule uninervis	7	8.9%
Halodule wrightii	17	21.61%
Halophila ovalis	5	34%
Syringodium isoetifoium	15	30.51%

The study in the Comoros revealed high richness compared to seagrass beds in the rest of the world and, as expected, a similar species composition to neighboring northern Mozambique. This is one of the first studies to contribute to the description of seagrass in the area. Recommendations for future studies include completion of baseline mapping on Anjouan Island and combining the results with surveys conducted on the other two islands in the Comoros to gain a more complete picture of seagrass composition and distribution for the Comoros Islands as a whole. As a baseline survey, it not possible to quantify the health (based on population extent or composition) or rate of change, if any, of the seagrass beds in the Comoros Islands. Baseline data on biomass variability, density and productivity, while necessary for measuring future change, were beyond the scope of this project. However, the geospatial data that was collected will provide a foundational GIS on which to add more data and build future monitoring programs.

As a way to promote seagrass conservation and share the survey results, a Google Earth file was created containing background information on seagrass biology, a description of survey methods, and results from this baseline survey. Google Earth was chosen as the preferred means of communicating the results of the survey as it is free and easy to use, making it a powerful tool to display and communicate data to the general public, decision makers, and scientists. Google Earth is the most ubiquitous of the virtual globe applications, possibly giving it the most potential for data dissemination and raising public awareness. The Google Earth file consists of: several ArcGIS map layers of seagrass coverage and distribution within the study area; a series of educational placemarks that guide the user through the importance of and threats to seagrass;

documentation of the methods used in the seagrass survey; 3-D graphs of the results; and profiles for each species identified.

The created Google Earth file is expected to be useful to a wide-audience in developed and developing countries. Some of the potential applications for this file include the basis for a classroom lesson plan, basic seagrass information for the general public, data dissemination for local and regional interested parties, and guidelines for future similar baseline seagrass mapping projects. The final product will provide C3 an easy way to visualize results from the survey, add additional data, freely distribute the packaged geospatial data in the form of a .KMZ file, and promote awareness of seagrass ecosystems. The file created for this project was intended to be used by management agencies, non-governmental organizations, scientists, and the general public in developed and developing countries. The file can be easily and freely distributed either via email attachment or as a download from C3's website (should they choose to make it available). Further studies on the usability of the created product and the needs of various user groups are recommended to ensure its effectiveness as a conservation tool.

Although this file was created specifically for seagrass conservation for C3, the model could be applied to any ecosystem or natural resource issue for any organization or agency. The work presented in this project was designed to highlight the many technologies that can make education and outreach more effective at reaching target audiences. The final KMZ file highlights one of the ways that science can be brought into non-traditional learning environments where the message of seagrass conservation may have a chance of being heard by the communities of people that depend upon them for the ecosystem services they provide. The use of the Google Earth platform creates many possibilities for easy data dissemination, collaboration, and education to a wide-audience across the globe and creates a framework for integrating not only data, but education and science.

It is impossible to effectively manage and conserve seagrass in the Comoros without considering the communities that depend on them as a resource. They need to be involved in the monitoring and management of their own resources and supportive of efforts taking place. They need training, employment, alternatives to the current destructive practices, and education. Specific management recommendations for seagrass in the Comoros are to continue building on baseline maps by completion of baseline mapping on Anjouan and addition of more GIS layers; targeted education efforts for coastal communities; and following education efforts, implementation of a monitoring program.

1.1 Objectives

This project describes a case study of the use of Google Earth as a potentially user-friendly and cost-effective tool for the conservation of seagrass in the Comoros Islands. Based on mapping data collected by the author, the case study helps demonstrate the potential of Google Earth to be used by management agencies, non-governmental organizations, scientists, and the general public for marine conservation in developed and developing countries.

The case study has the following objectives:

1) Document the distribution and coverage of seagrass for the study area, Bimbini Peninsula, Anjouan Island, Comoros
2) Develop an educational and informational Google Earth file providing access to the survey methods, results and information on the importance of and threats to seagrass
3) Provide recommendations for further research and seagrass management to the internship host, C3.

All the files and materials created will be submitted to the internship host, Community Centered Conservation (C3), for their use and distribution. Additionally, C3 has offered to translate this project to French to increase overall accessibility.

CHAPTER 2: CASE STUDY: BASELINE SEAGRASS MAPPING IN THE COMOROS ISLANDS

During the summer of 2008, I participated in a coastal resource management internship with Community Centered Conservation (C3), an international non-profit organization based in the UK. C3 has projects based in Mauritius, Palau, Madagascar, and the Comoros with the overarching goal to help communities manage their marine resources through capacity building of local stakeholders, education, and science. The internship, based in the Comoros Islands, was focused on baseline mapping of seagrass meadows on the remote Bimbini Peninsula of Anjouan Island. This research was part of C3's ongoing effort to map the previously unstudied seagrass meadows on all three islands of the Comoros. Anjouan Island was the final research site as seagrass surveys were completed previously by C3 on Moheli and Grande Comore Islands in the Comoros.

This chapter will introduce the Comoros Islands, provide an overview of seagrass biology, ecology and conservation, and then describe the baseline mapping study conducted during the summer of 2008 under the supervision of C3. This study represents one of the first of its kind in the area. The objectives of the baseline mapping are to document and map the distribution, coverage, and composition of seagrass in the Bimbini Peninsula.

2.1 Site Description

The Union of the Comoros is a group of four tropical volcanic islands (Grand Comore, Anjouan, Moheli, and Mayotte) located in the northern mouth of Mozambique Channel, almost equidistant between Madagascar and continental Africa (Figure 1). Mayotte, while physically part of the Comoros, is politically an overseas territory of France. The islands are approximately 2,235 km^2 in total, about twelve times the size of Washington DC, with 340km of coastline. The population is currently estimated to be 752,288 with a growth rate of 2.766%, the 18th highest growth rate in the world. The Comoros is facing demographic pressures with just over half of its population under the age of 20 (Abdoulhalik 1997). The population is overwhelmingly Sunni Muslim at 98%, the remaining 2% being Roman Catholic. The official languages are Arabic and French but the local language, Shikomoro, is wide-spread (a blend of Swahili and Arabic) with different dialects for each Island. Education remains at a low level with a school life expectancy average of eight years, 7 years for girls and 9 years for boys (CIA-The World Factbook 2009).

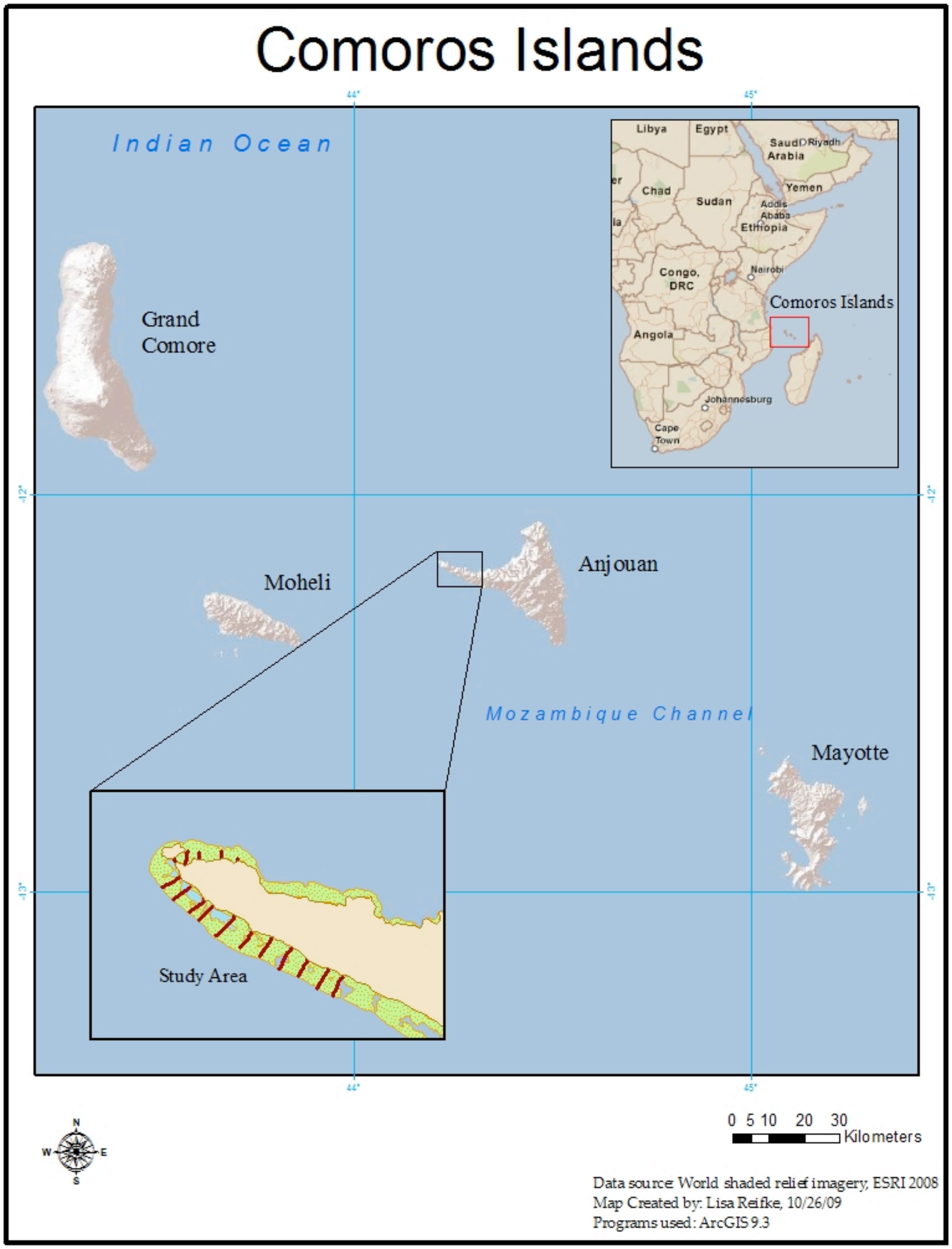

Figure 1. The Comoros Islands is located in the Mozambique Channel.

The Comoros remain politically unstable, with more than 20 coups since their independence from France in 1975. A coup in 1999 lead to the 2002 establishment of the current governmental system which consists of a power-sharing agreement in which a Union government for the country as a whole rotates among the three islands, and each island maintains an autonomous government. However, political instability has continued in the Comoros, most recently in March 2008, when African Union (AU) and Comoran soldiers seized the island of Anjouan in an attempt to remove the Anjouanais president, Mohamed Bacar, who had refused to step down from office for new elections. However, Bacar had already fled to Mayotte and was eventually expelled to Benin (CIA-The World Factbook 2009, personal accounts, Wikipedia 2009).

It is difficult for marine conservation to be at the forefront on the agenda of one of the poorest countries in the world. The gross domestic product (GDP) was estimated at \$98.50/capita in 2008, ranking 208th in the world. Agriculture and fishing employs 80% of the labor force, representing 40% of the total GDP. Fisheries are of considerable economic importance representing 10% of the total GDP and providing employment and protein to all three islands. The industrial and building sectors represent a small percentage of the GDP and other services comprise the rest. With limited transportation and poor hotel facilities, the Comoros is virtually unexploited for tourism. The overall low education level of the population results in a subsistence level economy, high unemployment, and dependence on foreign funds and assistance.

While the Comoros may be a poor country, it boasts a rich biodiversity in both marine and terrestrial habitats. Sheltering some of the least studied and most threatened species of the Western Indian Ocean region, the Comoros has a unique biological heritage in critical need of conservation (Abdoulhalik 1997). These valuable ecosystems are vulnerable to the Comoros' biggest environmental problems. These include soil degradation and erosion from cultivation on unterraced slopes, deforestation (CIA-The World Factbook 2009). The hillsides near the village of Bimbini have been deforested in order to plant the staple foods of banana and cassava. The resulting siltation can be seen flowing to the ocean directly into the seagrass beds (The author's observation). Additionally, coral reef degradation, clearing of mangroves, mechanical damage to intertidal zones by octopus and shellfish collectors, pollution from household waste, and harmful fishing practices continue to threaten marine environments in the area and may directly lead to a loss of natural resources and subsequent economic down turn (Le Courtois and Blake 2008).

There is no central institution charged with the responsibility of managing the marine and coastal resources in the Comoros. Different agencies separately manage environmental, fisheries, and scientific research issues. Due to a lack of material, financial and human resources, institutions remain weak and have little prospect for development without reform. Two of the main institutions involved in the marine sector are the Directorate of the Environment (DGE) and the Directorate of Fisheries (DGP), both under the Ministry of Agricultural Production. Additional organizations include the National Institute for Research in Agriculture, Fisheries and Environment (INRAPE), National Committee for Co-ordination of Sustainable Development, and the Directorate of Scientific Research and Higher Education. Currently no government fisheries policies exist and although legislation is in place for environmental damage and protected species, enforcement is seriously deficient. The current system needs definitive responsibilities, coordination, funding, human resources, and follow through in order to be truly operational and efficient (Abdoulhalik 1997).

2.2 Seagrass Overview

Seagrasses are not true grasses, but rather, marine angiosperms; flowering plants that grow in sediment on the seafloor. Most species live and reproduce while entirely submerged in seawater (McKenzie et al. 2003). They have an extensive lateral network of rhizomes, which take in nutrients, act as the source of asexual reproduction, and aid in the successional colonization of bare sediment (Levington 2001). Seagrass beds are widely distributed in coastal habitats including tropical and temperate coastal waters ranging from high intertidal to shallow soft bottoms, with the majority being found in soft substrate such as sand or mud (Green and Short 2003). They are found in shallow coastal waters worldwide, with the exception of the Arctic and Antarctic (Phillips and McRoy 1980). Presently, there are about 50-60 known species of seagrasses worldwide (Castro 2005). There is no single evolutionary origin of seagrasses and considerable debate over the taxonomic relations and nomenclature and therefore, the exact number of species, still continues today (Green and Short 2003). Seagrasses maintain wide variation from the large, wide blades of *Zostera caulescens*, found in the Sea of Japan at more than 4m long, to the tiny *Halophila decipiens* at 2-3cm found in the tropical waters of Brazil. Most tropical and sub-tropical species are found in water shallower than 10 m (McKenzie 2002), however, some seagrass species have been recorded as deep as 70 m (Green and Short 2003). The depth range of seagrasses is controlled on the shallowest edge by exposure to desiccation during low tide, wave action and turbidity, and salinity, and the deepest edge is controlled by light availability for photosynthesis (McKenzie et al. 2003).

Seagrasses may consist of extensive mono- or multi-specific communities known as beds or meadows. They can also grow in isolated patches or as part of other habitats such as mangroves, bivalve reefs, rocky benthos, or bare sediment (Green and Short 2003). There are a number of physical parameters and natural phenomena that control seagrass growth and health. Physiological activity is controlled by physical parameters such as temperature, salinity, waves, depth, currents, substrate, and length of day. The photosynthetic process of seagrasses is limited by natural phenomena such as light, nutrients, epiphytes, and disease (McKenzie and Kierkman 2001). These parameters control whether seagrasses will thrive or be eliminated from a given area. While seagrass systems typically remain stable on a scale of decades, their dynamic nature allows them to move into new areas and disappear in others, over a very short period of time.

2.2.1 The Value of Seagrasses

Seagrass beds are one of the most productive and valuable aquatic ecosystems in the world. With such a high plant biomass, primary production rates for seagrasses have been recorded to be as high as 8gC/m^2/day, some areas are thought to reach twice this rate (Phillips and McRoy 1980), ranking them as one of the most productive systems in the entire ocean (Castro 2005). This high productivity is essential to many coastal faunal communities, and in turn, to the people that depend on these resources for their livelihoods. While seagrasses are noted for their critical role as primary producers, they also play a crucial role in maintaining highly productive estuaries and nearshore marine systems (Phillips and McRoy 1980).

Since few organisms graze on the leaves directly, more of the seagrass biomass is available to decompose. The microbial decomposition of seagrass results in detritus, thus fueling the marine food web. Seagrass beds serve as effective barriers to waves and currents, therefore reducing turbidity and coastal erosion. Both the above and below ground biomass play an important role in binding sediment, as illustrated by several studies that compared erosion during a storm event in vegetated versus non-vegetated areas (Green and Short 2003). Their dense network of roots and rhizomes stabilizes the sediment, therefore inhibiting erosion. Above ground, their complex leaf structure helps to slow water currents and promote sedimentation (Green and Short 2003). In tropical systems, seagrasses, coral reefs and mangroves all interact to promote a stabilizing effect on the environment. Barrier reefs protect the coasts and allow for the growth of mangroves and seagrasses. Seagrass then traps sediment, thereby reducing the sediment load in the water, benefiting coral reefs. Sediment banks accumulated by seagrasses form substrate where mangroves can grow, and in turn, trap sediment from the land (Mckenzie et al. 2003).

Large numbers of epiphytic organisms are associated with and dependent on seagrasses. The biomass of these organisms is often as great as the biomass of the seagrass itself. The epiphytes, consisting of both plants and animals, are an indication of increased biodiversity associated with seagrass. The organisms also provide an important food source for larger organisms and their predators, including humans. Epiphytic algae associated with seagrass help to increase nutrient uptake, removing nutrients from the water column and increasing the biological productivity of the ecosystem (Green and Short 2003, Gullstöm et al. 2002).

Seagrass beds also function as foraging areas, refuge from predation, and nursery areas for numerous marine fish and invertebrate populations (Gullstöm et al. 2002). The combination of food and shelter provided by the seagrasses creates an environment where many species important to commercial and artisanal fisheries can flourish. A study by Dorenbosch et al. (2005) on the islands off the coast of East Africa showed that outside of coral reefs, seagrass beds are the most important juvenile habitats for marine fish. Seagrass beds had the highest juvenile fish densities of all species groups. Additionally, the presence of seagrass beds positively influenced the density of fish species on adjacent coral reefs (Dorenbosch et al. 2005). De la Torre-Castro and Rönnbäck (2004) also conducted a study on the East Coast of Africa, on Zanzibar, and found seagrass-associated fishes constituted the primary source of animal protein for the local people. Furthermore, fisherman there considered seagrass to be the most important feature of an ideal fishing ground and ranked it first for habitat importance for fish, above corals and mangroves (de la Torre-Castro and Rönnbäck 2004).

Although direct consumption of seagrasses plays a small role in overall productivity, there are two large threatened herbivores that depend on them as a food source. The dugong, *Dugong dugon,* and the green turtle, *Chelonia mydas*, consume seagrass as a major part of their diets (Lanyon et al. 1989). Taquet et al. (2006) found that green turtles have a high affinity to specific areas of the seagrass beds near Mayotte Island, in the Comoros. They need to spend a long time everyday foraging in the seagrass and may be sensitive to the presence of human activity on the seagrass beds, possibly altering their foraging success. Green sea turtles, listed as endangered by the IUCN (2007), depend on seagrass as a vital food source and habitat for juveniles. The Comoros Islands are one of the largest nesting rookeries for green sea turtles in the western Indian Ocean (IUCN 2007), highlighting the significance of seagrass beds in this region for foraging and refuge. Dugongs are seagrass specialists, feeding on the leaves, roots, and rhizomes of seagrasses. The dugong's survival and fecundity is highly sensitive to the availability of seagrass—when their food source is limited, breeding is delayed (IUCN 2007). Some islands in the Comoros once supported notable populations of dugongs (Granek and

Brown 2005), but now the vulnerable species is listed as declining in the Comoros region (IUCN 2007).

Seagrasses are extremely valuable to humans in terms of their economic value and the ecological services they provide. The global value of seagrass beds for their nutrient cycling and raw materials was estimated at 19,004USD/ha/yr, third highest in the world (Costanza et al. 1997). In addition to the ecological services of high primary and secondary production, their complex habitat supports numerous fish and invertebrate species, many of which are important for commercial and artisanal fisheries. Seagrass beds are valuable locally in the WIO region for protein, fisheries, and income. Although the size and importance of seagrass fisheries in the WIO has not been documented, several authors have suggested that they are substantial (Gullstöm et al. 2002).

2.2.2 Threats to Seagrasses

Unfortunately, widespread losses of seagrass beds have been reported in most parts of the world. Biological, environmental, and climatological events are the root causes of seagrass loss in both tropical and temperate regions (Orth et al. 2006). Climatic events such as hurricanes, cyclones, and tsunamis can cause wide-spread physical damage to seagrass beds. Other natural causes of decline include climactic events such as hurricanes, disease, and natural cycles of seagrass breakdown and development over many years or decades. Animal activity has also been documented as another natural threat to seagrass. Overgrazing by high densities of organisms such as small limpets and sea urchins have had devastating effects on some seagrass beds, which are often not able to recover from such disturbance (Hemminga and Duarte 2000).

While there are several natural threats to seagrass, the largest cause of seagrass loss results from human activities (McKenzie et al. 2003). One of the most devastating of these activities is eutrophication (Hemminga and Duarte 2000; Orth et al. 2006). High nutrient enrichment from sewage wastewater and agricultural phosphate fertilizer runoff is a serious issue facing coastal zones worldwide and is only exacerbated as human populations continue to grow. As nutrient inputs increase, nutrient-limited algae and phytoplankton grow and proliferate, reducing light availability for seagrass photosynthesis and ultimately resulting in mortality if the light reduction continues for a long time span (Hemminga and Duarte 2000). Light availability is, therefore, the most important factor affecting seagrass decline. Siltation from soil erosion is another major contributor to reduction in light availability. Increased soil erosion rates are caused by changes in land use patterns such as deforestation, particularly in tropical areas to increase agricultural land, and clearing land for population growth.

Other anthropogenic causes of seagrass decline include oil spills, water pollution from nearby aquaculture, dike and dam projects, decreased freshwater inputs, damage from destructive fishing practices, and exotic species invasions (Hemminga and Duarte 2000). There are also indirect human impacts on seagrasses such global climate change, sea-level rise, ultraviolet and CO_2 increase, and food web alterations through fisheries (Durate 2002). Direct and indirect human impacts on seagrass lead to seagrass loss, changes in community structure, and altered functions and distribution. Additionally, the disturbance of adjacent ecosystems such as mangroves and coral reefs can destabilize sediments, thereby making it impossible for seagrass to take root (Gullstöm et al. 2002).

2.2.3 Seagrass in the Western Indian Ocean Region

The Western Indian Ocean Region (WIO) encompasses the east African coast from Somalia to South Africa and includes the Comoros Islands. Extensive seagrass beds are found in all countries of the WIO region and encompass 13 reported seagrass species (figure 2). In this region, multi-specific communities are common, with up to eight or ten species in one locale. Two of the most common species, *Thalassia hemprichii* and *Thalassodendron ciliatum,* can be seen forming extensive beds in most parts of the region (Gullström et al. 2002). *Halophila ovalis, Cymodocea rotundata, Cymodocea serrulata,* and *Halodule uninervis* are also very common in the region while *Halodule wrightii, Enhalus acoroides,* and *Zostera capensis* have a more limited range. All the seagrasses in the WIO, with the exception of *Thalassodendron ciliatum*, need soft substrate like sand or mud (Gullström et al. 2002). Little is known about seagrass in the Comoros Islands but due to its proximity to northern Mozambique, a similar species composition with mixed seagrass species in intertidal areas and broad-leaves species such as *Thalassodendron ciliatum* dominating subtidal areas, is to be expected (Green and Short 2003).

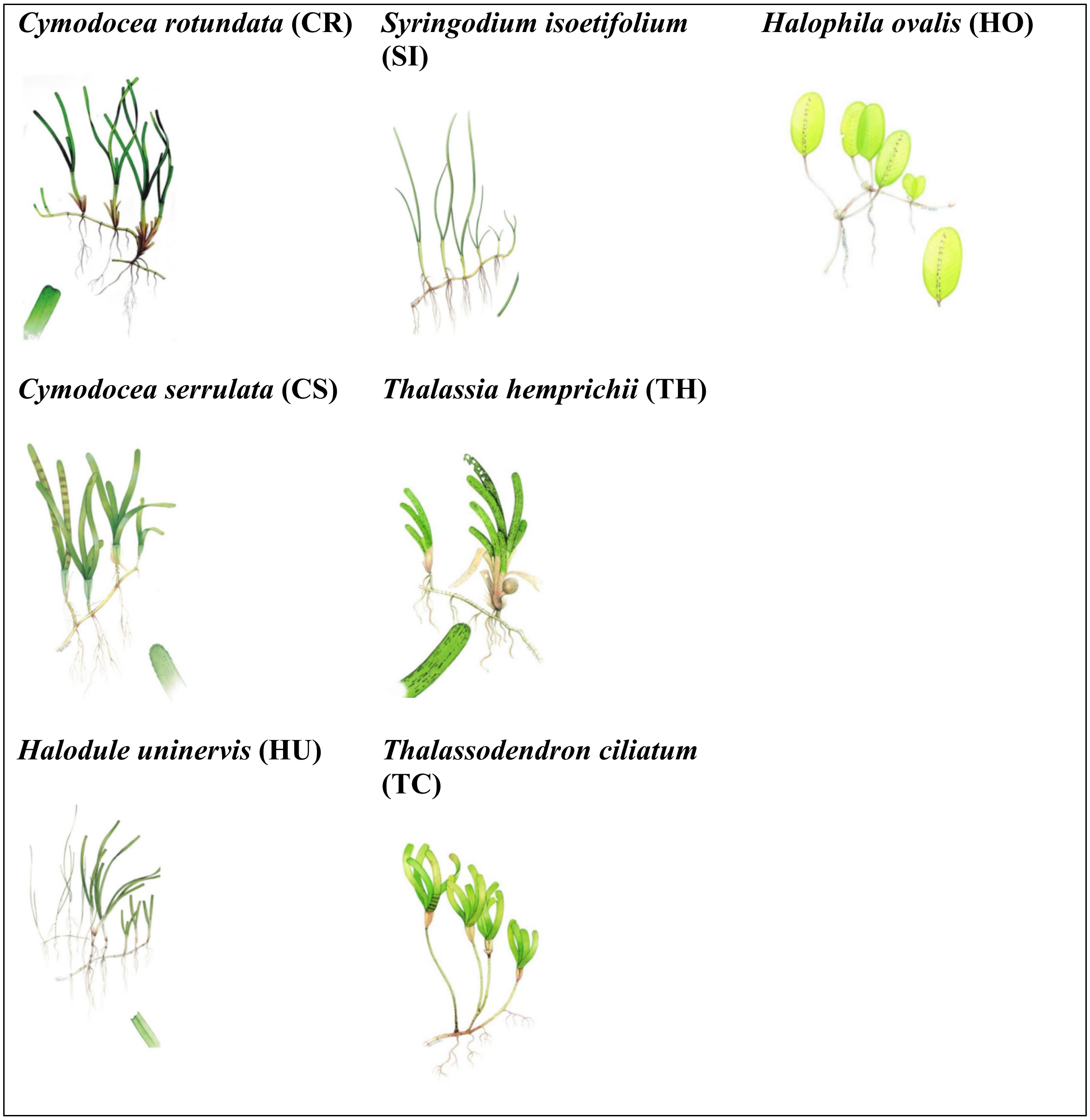

Figure 2. A sample of seagrasses found in the Western Indian Ocean region

2.3 Current seagrass conservation practices, barriers, and needs

Global seagrass decline, due to the threats mentioned previously, has led to conservation efforts to protect these valuable ecosystems. This section describes several conservation efforts currently in place, some of the barriers to implanting conservation practices, and critical actions necessary for future conservation of seagrass. Direct protection of seagrass by legislation can be a valuable and effective protection mechanism. For example, seagrass is protected by the Australian state of Queensland under the Fisheries Act of 1994. The Act requires a permit for destruction or damage to seagrass. The permit is only issued through a policy that requires the authorization of a person delegated under the Act. Non-permitted damage may incur hefty fines and restoration orders. However, legal protection is only effective when there is wide community support for seagrass protection or sufficient enforcement capacity (Coles and Fortes 2001). Developing countries, such as the Comoros, rarely have community support or enforcement capacity in government.

Another form of protection for seagrasses is the establishment of marine protected areas (MPAs), specified areas that are dedicated to the protection of marine resources by prohibiting or limiting human activities. While it appears no MPA has been designated solely for the protection of seagrass, it is often an indirect beneficiary of protected area status. There are around 4,000 MPAs world wide (UNEP-WCMC 2001 data from Green and Short 2003). Conservatively, there are about 247 MPAs in 72 countries and territories that include seagrasses. This number is far less than other coastal ecosystems, there are more than 660 MPAs protecting coral reefs and over 1800 with mangroves (Green and Short 2003). While there has been a dramatic increase in the number of MPAs that contain seagrass within the last 30 years, MPAs are not a fail safe solution for seagrass conservation. The selection, implementation and enforcement of MPAs can be a lengthy and complex process requiring stakeholder and government collaboration and long-term monitoring in order to be effective.

Seagrass restoration, another form of conservation, includes improvement for the overall health of the seagrass area such as water quality and direct seed planting or transplantation of seagrass. Seagrass transplantation for conservation has been conducted over the last half-century (Calumpong and Fonseca 2001). Seagrass transplanting is often used as mitigation for damage during coastal development. While widely used, transplantation of seagrass has had mixed success (Duarte 2002) and can be costly and labor intensive. This is of particular concern in developing countries, where funding for conservation projects is minimal or nonexistent. Additionally, transplantation methods often damage the donor population, rendering the method an inadequate management option (Durate 2002). While technologies for seagrass transplanting are improving, poor water quality remains the greatest hurdle to implementing seagrass restoration worldwide. In addition, efforts to conserve what is already present, before worrying about mitigation or restoration, is the best strategy for long term seagrass conservation.

Protecting seagrass as part of the greater coastal/marine ecosystem can be an effective conservation and management strategy. There has been a recent shift toward a more systems approach to management such as integrated coastal zone management (ICZM), the integration of all coastal zone components—political, social, biological, and physical, to achieve sustainable development and resource protection. The WIO region has made concerted efforts to adopt the ICZM approach. In 1993, the Arusha Resolution on Integrated Coastal Zone Management was signed, prompting many organizations and scientists to promote and participate (Gullstöm et al. 2002). Previously, coastal management had been issue- or sector-based but ICZM has allowed for a shift to sustainable development of communities (Francis and Torell 2004). While little attention has been given to seagrass or ICZM in the Comoros, future seagrass conservation and management efforts should look toward successful activities in neighboring countries that include community development and participation (Francis and Torell 2004). Seagrass is not only part of a dynamic coastal system, but an integral part of human coastal communities and sustainable livelihoods. However, developing countries such as the Comoros face significant barriers to conserving their natural resources. Some of these include governmental instability, inadequate enforcement capacity, ineffective knowledge transfer to local communities, and inaccessible or outdated science and data (Lundquist and Granek 2005).

Three necessary elements to conserve seagrass are society, management, and science (Durate 2002). A number of researchers have called for specific critical actions for seagrass conservation that fit within these three categories, see Table 1 below.

Table 2. Critical actions necessary for seagrass conservation called for by a number of authors and categorized by the necessary elements for seagrass conservation (society, management and science).

	Critical Actions Necessary for Seagrass Conservation		
Author (year)	***Society***	***Management***	***Science***
Duarte (2002)	education of the public on seagrass function and impacts of human activity	Development of coherent worldwide monitoring network	development of quantitative models predicting disturbance responses
Orth et al. (2006)	education for the public and resource managers	(1) reduction of watershed nutrient and sediment inputs to seagrass meadows (nutrient management schemes) (2) marine sanctuaries or protected areas	
Gullström et al. (2002)	combination of local participation and education	(1) highlight links of seagrass to local populations (2) highlight socioeconomic importance (3) monitoring and evaluation (4) Quickly acquire knowledge and baseline data of seagrass in the region (WIO)	more research
Coles and Fortes (2001)	community support	legislation protection	detailed ecosystem information and knowledge of economic values- for coastal development pressures in small areas
Green and Short (2003)	public education	(1) legal protection (2) MPAs	

(1) Society: Seagrass conservation is not likely without community support, public education and awareness, and increased media attention. While all five authors in Table 1 call for public education or community support, current conservation efforts fail to address society. This may be the most critical conservation element at this time. The methods for addressing society's general lack of knowledge about seagrass need to be multi-faceted, possibly coming in the form of education in the classroom, museum exhibits, media attention, and other non-traditional techniques. The use of Google Earth is one potential way to take a step toward public education and community support to protect seagrass resources.

(2) Management: Several management strategies are currently being utilized for seagrass conservation: direct protection by legislation, marine protected areas, restoration efforts, and systems management. However, all five authors (included in Table 2) call for improved or new management strategies including MPAs, comprehensive global monitoring, legislation, and baseline data, indicating current management is on the right track but insufficient for effective conservation. Current management efforts need to consider the barriers to implementing strategies in a given area.

(3) Science: Science is also a critical component for seagrass conservation. Management and education need to be based on a sound understanding of seagrass biology, ecology, and ecosystem interactions, including the response to disturbance from both human induced and natural causes. Basic science about species and populations of seagrass, once complete need to be enhanced by research including quantitative models for determining habitat suitability, and the capacity to predict ecosystem change in the response to global climate change and sea level rise.

Basic information on the physical characteristics of seagrass and the seagrass distribution is necessary to ensure proper management of seagrass ecosystems. Managers need maps of habitats, like seagrass, so they can better understand ecosystems, their inhabitants and effectively manage human activities that occur within the same area. Baseline seagrass mapping generally contains information on the extent and condition of the seagrass (Kirkman 1996). These data can then be used to look at seagrass response to human activities and natural variation. After baseline maps are created, monitoring programs need to be established to detect disturbance and distinguish it from natural variation (Kirkman 1996).

In general, baseline studies for seagrasses provide data on the natural and temporal variability of above-ground biomass, density, and productivity (Kirkman 1996). This type of data can then enable reliable detection and assessment of change and the impacts of the change. Even though details of biomass and productivity were beyond the scope of this project, information on extent, coverage, and composition was collected and provides the first information of its kind in the Comoros Islands. Given the current and predicted future seagrass decline, there is an urgent need to map and record the distribution of existing seagrass meadows. The lack of data in the Comoros Islands provides even more incentive to begin comprehensive baseline mapping in the area. Seagrass mapping in the Comoros may form the basis for future monitoring plans and will add to global knowledge of seagrass distribution and cover.

2.4 Methods

The seagrass mapping and surveys took place on Bimbini peninsula, Anjouan Island, Union of the Comoros (figure 1) between August 30, 2008 and September 29, 2008. The mapping and survey methods used follow the procedures recommended by Seagrass-Watch in their 2003 *Guidelines for Rapid Assessment of Seagrass Habitats in the Western Pacific* and their 2003 *Manual for Mapping and Monitoring Seagrass Resources by Community (citizen) Volunteers*. Seagrass-Watch is a global scientific assessment and monitoring program. Started in 1998 in Australia, the program now includes 26 participating countries and is the largest seagrass monitoring program in the world. They aim to raise awareness on the status and trend of seagrass ecosystems and help to provide an early warning for changing coastal environments. Seagrass-Watch's worldwide monitoring program has a strong scientific underpinning, ensuring the data collected can assist with seagrass health and human impacts on a global scale (www.seagrasswatch.org).

The initial intention of the internship project was to map all the seagrass meadows on Anjouan Island. However, due to financial, time and logistic constraints it was necessary to confine the study area to a 15km portion around the village of Bimbini. Prior to the start of mapping, several days were spent studying Seagrass Watch species identification sheets (appendix A) and preserved seagrass specimens from Grand Comore Island provided by C3. Additionally, upon arrival in Bimbini, two days of training sessions with the C3 Program Coordinator on species identification and percent coverage were conducted prior to beginning mapping and transects. Seagrass Watch percent cover standard guidelines (appendix B) were studied and used as a guide.

2.4.1 Mapping Boundaries of study area

Boundaries were mapped using a Garmin GPSMAP 76CSx unit. All points were taken in WGS- 1984 coordinate system and had an accuracy of <10m (33ft) 95% of the time. The inner boundary was mapped by walking along the seagrass meadow boundary on the shoreline side of the study area while taking and recording a GPS point every 20m. Small patches of seagrass were only considered as part of the bed if they continued in any direction for 10m or more, otherwise they were considered too small to be part of the meadow. Interior boundaries were mapped at low tide to ensure good visibility and for ease of navigating through water and around rocky outcrops along the coastline. A detailed map of the study area including boundaries of the mapped seagrass bed can be seen in Figure 3.

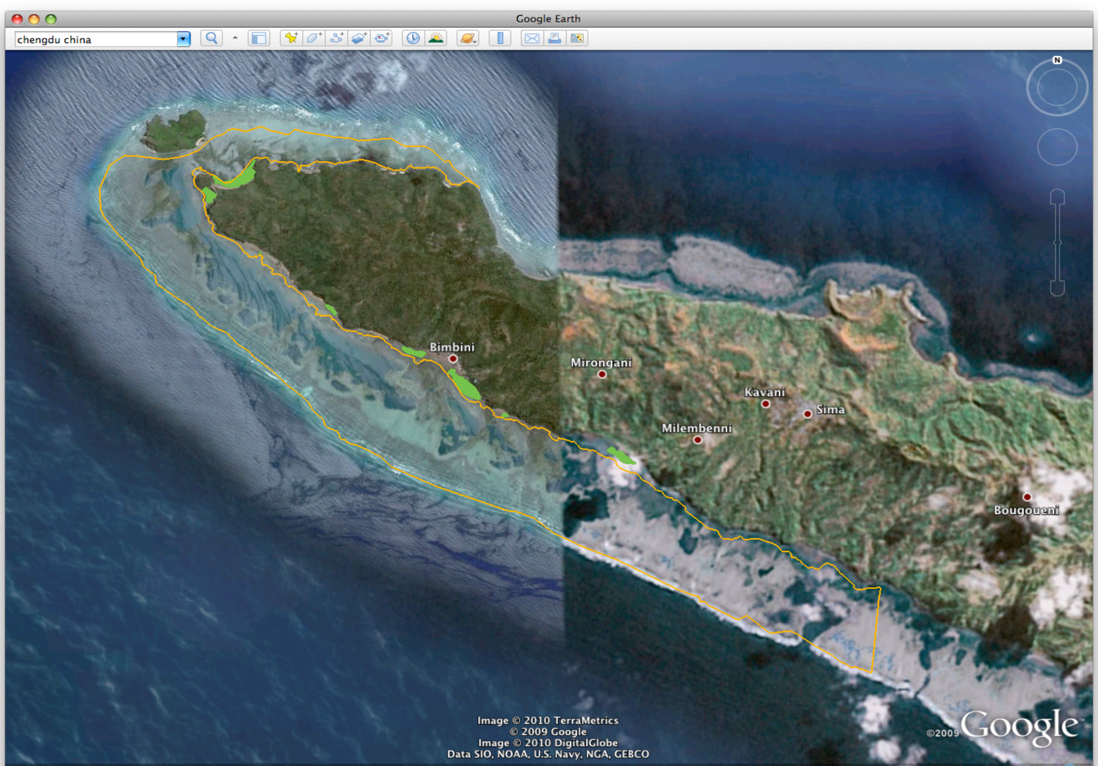

Figure 3. Boundaries of study area (in orange) and mangrove stands (in green). Lagoons are visible within the boundaries.

A motor boat rented on September 2, 2008 and September 12, 2008 was used to map the exterior boundary of the study area. The boat followed the outer seagrass meadow boundary while GPS points were taken and recorded every 30-50m. Due to the speed of the boat and for the purposes of practicality, GPS points were recorded less frequently for the exterior boundary than for the interior boundary. However, they were still within recommended range according to Seagrass Watch Guidelines (2003). Exterior boundaries were mapped when the tide was high enough to navigate but low enough for good visibility. A total of seven days were needed to map all the boundaries.

Additionally, all mangrove stands within the study area were mapped by walking around the perimeter and recording GPS points every 20m. Although not included in the original intent of the project, the mangroves were within the study area and time and logistics permitted for the addition to the dataset. Given the importance of seagrass-mangrove-coral reef interactions, it seemed appropriate to add as another layer to the survey.

2.4.2 Seagrass Surveys

A combination of transects and points were used to map the area of seagrass. Transects started near the end of the study area (approximately 15km) boundary and were placed regularly about every 1km. Approximate distance between transects was calculated with the GPS. Large lagoons were present throughout the study area so transect placement varied slightly in an attempt to avoid the deep lagoons. An additional transect was added between the peninsula mainland and Ile de la Selle, a small island off the tip of the peninsula.

A minimum of two researchers were needed to conduct transect and point surveys. At the beginning of each transect, the following information was recorded on the data sheet: observer names, name of transect, compass bearing, GPS location, date, time, and tide status. Researchers then walked along the transect perpendicular to shore following the compass bearing, stopping to take mapping points every 50-100m depending on the length of each transect. Seagrass Watch recommends 3-5 points per transect but some of the transects were over 1km long, resulting in up to 11 points per transect. At each point, one person would stay positioned on the point while the other person randomly tossed the quadrat 3 times within a 5m radius. Seagrass parameters within the quadrats were observed by one person and relayed to the other person positioned at the original point who would record information on the data sheet (appendix C). The following data were recorded for each quadrat:

1. *GPS point at location* (only for the mapping point, not for each quadrat)
2. *Sediment composition:* Substrate was examined to determine texture. Sediment(s) were recorded as: mud, sand, fine, sand, course sand, gravel, or a combination. Two additional substrate types were added: Coral rubble (broken pieces of coral) and dead coral (large dead coral flats)
3. *Water depth:* tape measure was used to measure water height (in cm)
4. *Percent seagrass coverage:* based on Seagrass Watch cover percentages of 5% (if seagrass coverage is estimated to be 15% or less than it falls in this category), 25% (if seagrass coverage is more than 15% it falls in this category), 30%, 40%, 55%, 65%, 80%, and 95%
5. *Species composition:* The composition estimate required the number of species in each quadrat with their total combined composition equal to 100%
6. *Canopy height:* One leaf was chosen and the height from base to tip was measured, ignoring the tallest and shortest leaf blades in the quadrat
7. Any additional comments were noted such as signs of grazing, algae presence, etc.

This process was continued for each mapping point for a total of 11 days resulting in 16 transects and 115 mapping points. Samples were taken of each species and preserved by C3 for future reference and training. Each night the daily data were copied from the waterproof data sheets used in the field to clean sheets of paper. Data were stored until in Bimbini until they could be returned to C3 headquarters in Iconi, Grand Comore. Upon completion of the seagrass project and return to Iconi, data were transferred from the data sheets into Excel.

2.4.3 Creating a GIS

Transect and boundary points that were still contained within the GPS unit were loaded into the Minnesota Department of Natural Resources' downloadable Garmin utility which easily converts GPS data from a Garmin unit directly into ArcView format. Boundary and transect coordinates that were contained only in the Excel file, were converted to decimal degrees and saved as a text file. All coordinates were then uploaded into ArcGIS

9.3 by using the add XY Data tool and defining the WGS 1984 projection. The associated seagrass data for each point was then joined from an excel sheet to existing attribute data

Free satellite imagery was added to the GIS from ESRI's Arc GIS Online Resource Center. The data and imagery were used as base map from which to create polygon layers of Anjouan Island and overall seagrass coverage of the entire island. The World Shaded Relief Imagery 2008 obtained from ESRI's ArcGIS Online Resource Center, was used to digitize Anjouan Island and create a polygon. Using the editor tool in ArcGIS and 1:50,000 scale, vertices were added along the outline of the satellite image until the entire island had been outlined. These vertices were then connected and formed into a polygon.

Similar methods were used to create a polygon of the seagrass beds. The seagrass polygon was created from ESRI's World Imagery, 2009, obtained from their ArcGIS Online Resource Center. The ArcGIS editor tool was used to create the polygon at a scale of 1:24,000. A third polygon was created of the lagoons present within the seagrass beds using the same methods as those used in the creation of the seagrass polygon. With the lagoons polygon on top of the seagrass polygon and both layers visible, the editor tool was used to clip the lagoons out of the seagrass, leaving the seagrass polygon with "holes" or spaces where the lagoons had been.

Polylines were also created for representing each transect by connecting the individual transect points. Separate line segments were created for areas with transect data and areas with no data, such as those areas where a lagoon was located. The segments were coded with an ID of zero for no data and 1 for data. A final polygon was created of the mangroves present within the study area using the same methods as those used in the creation of the seagrass polygon.

Metadata is a critical component of the created GIS. The metadata provides information that describes characteristics of data including properties and documentation. Some of categories used to describe the data are content, quality, projection, scale, accuracy, keywords, purpose, and origin. Metadata was created in ArcCatalog using the FGDC

Content Standards for Digital Geospatial Metadata. Standard required fields were completed using a metadata template that was then applied to all GIS files.

The seagrass, mangrove, and transect data layers created in ArcGIS 9.3 were each exported as kml files using the "Layer To KML" tool in the "Conversion" toolbox. Additionally, a brief overview of the data collection methods and all results discussed in the following section were made available for viewing in Google Earth within the KMZ file. A more thorough description of the presentation of survey results using the Google Earth file is found in the next Chapter, (section 3.4).

2.5 Results

A total of eight species of seagrass were encountered in the study area: *Thalassia hemprichii*, *Thalassodendron ciliatum, Halophila ovalis, Cymodocea rotundata, Cymodocea serrulata, Halodule uninervis*, *Halodule wrightii, and Syringodium isoetifoium*. Of the 115 points surveyed, 108 contained seagrass (Figure 4), indicating they were present 93.9% of the time. An assessment of the species presence revealed the most and least dominant species, in terms of the number of sites in which they were encountered over the entire survey (Figure 5). The most dominant species were *Thalassia hemprichii*, appearing at 91 sites; *Thalassodendron ciliatum*, appearing at 40 sites; and *Cymodocea serrulata*, appearing at 34 sites. *Halophila ovalis* and *Halodule uninervis* were encountered the least number of times, only five and seven times, respectively.

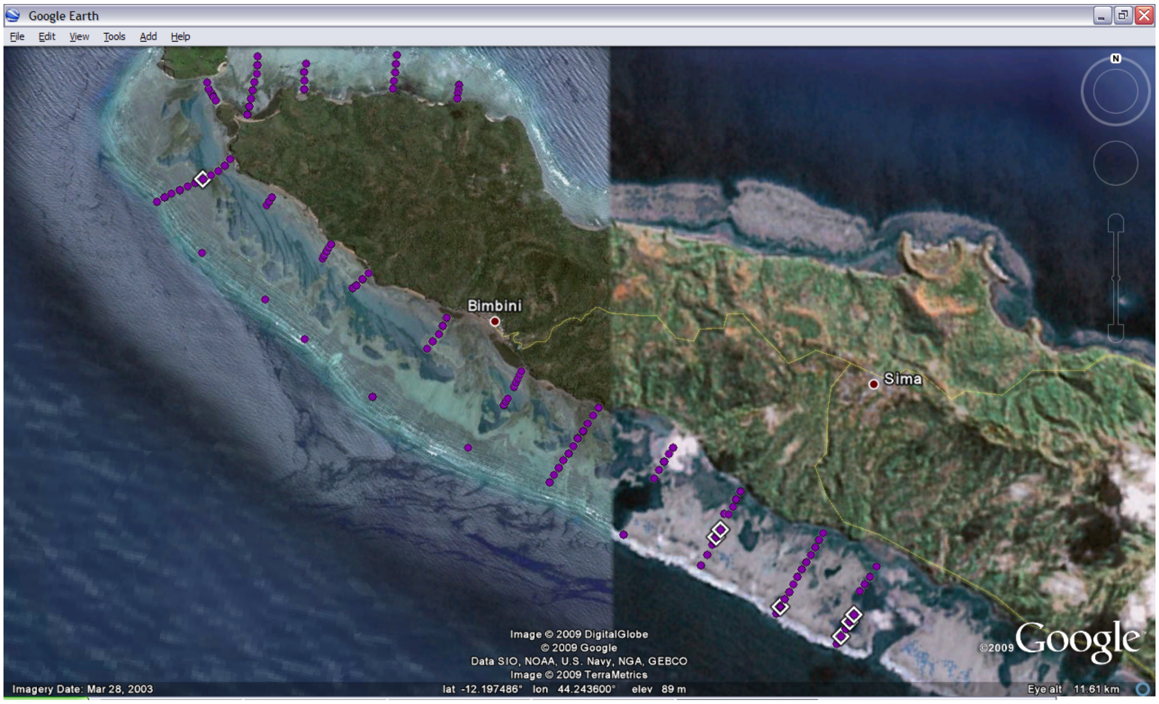

Figure 4. Location of survey area at Bimbini Peninsula. Purple dots represent the locations of sampling sites where seagrass was present and the white squares indicate no seagrass was present.

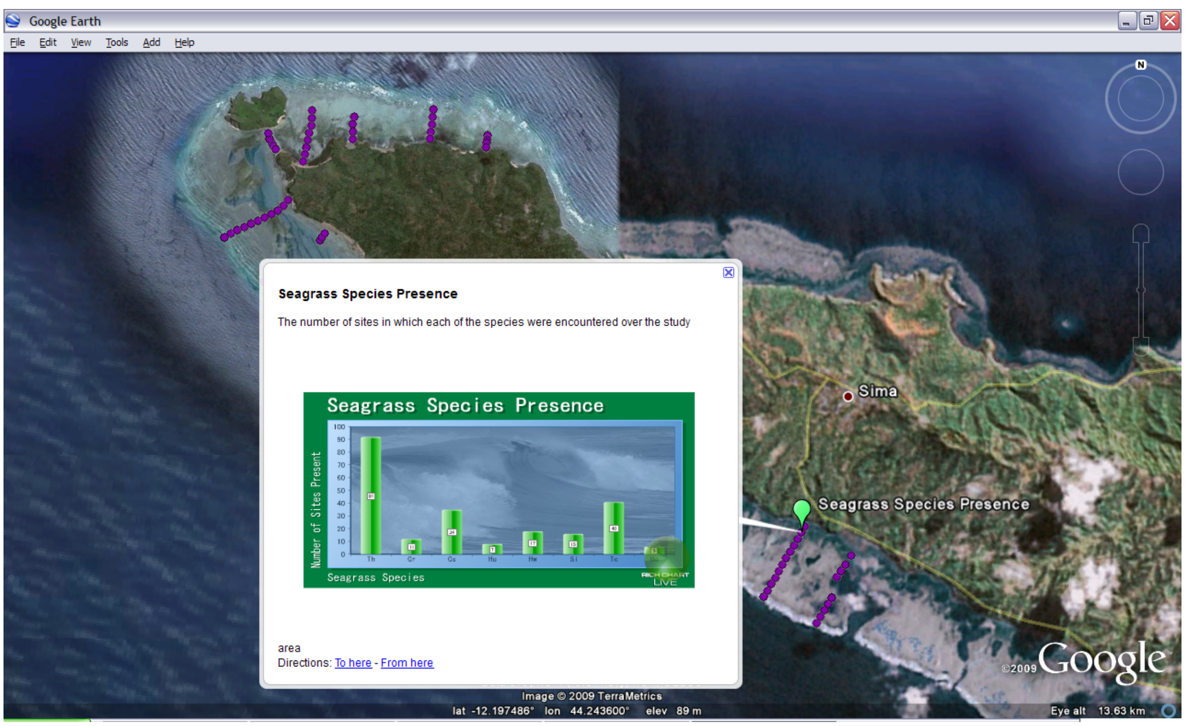

Figure 5. The number of sites in which the species were encountered over the study area (From left to right: Th, Cr, Cs, Hu, Hw, Si, Tc, Ho).

Average percent cover of seagrass for all the vegetated sites was 40.35%. The average percent composition of each species was also calculated (Figure 6). *Thalassia hemprichii* and *Thalassodendron ciliatum* had the highest percent composition on average: 61.73% and 53.11%, respectively. *Halodule uninervis* had the lowest percent cover on average at 8.9%. Table 3 shows the number of sites present and the average coverage for each species when it was present. The average percent coverage by transect shows the highest coverage near the tip of the peninsula and on the last transect in the southwestern direction (Figure 7).

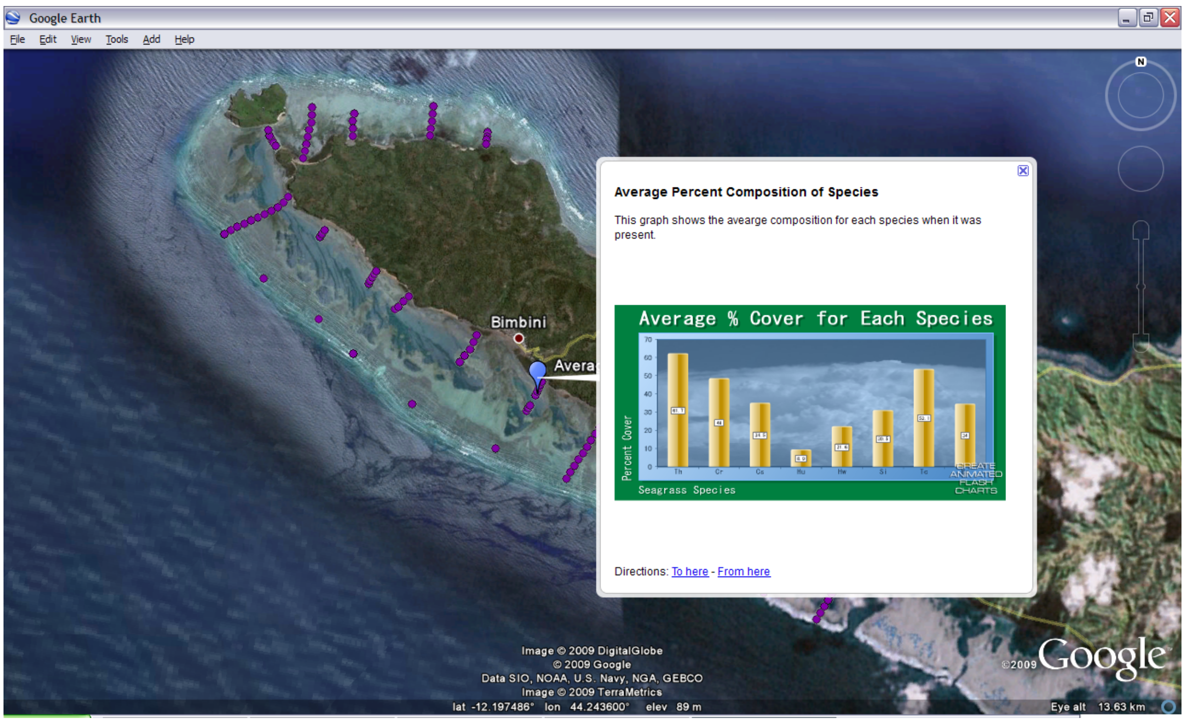

Figure 6. Average percent composition of each species (From left to right: Th, Cr, Cs, Hu, Hw, Si, Tc, Ho).

Table 3. Number of sites present and average percent cover for each species present in the study area

Species	#of sites present	Average % cover
Thalassia hemprichii	91	61.73%
Thalassodendron ciliatum	40	53.11%
Cymodocea rotundata	11	47.97%
Cymodocea serrulata	34	34.5%
Halodule uninervis	7	8.9%
Halodule wrightii	17	21.61%
Halophila ovalis	5	34%
Syringodium isoetifoium	15	30.51%

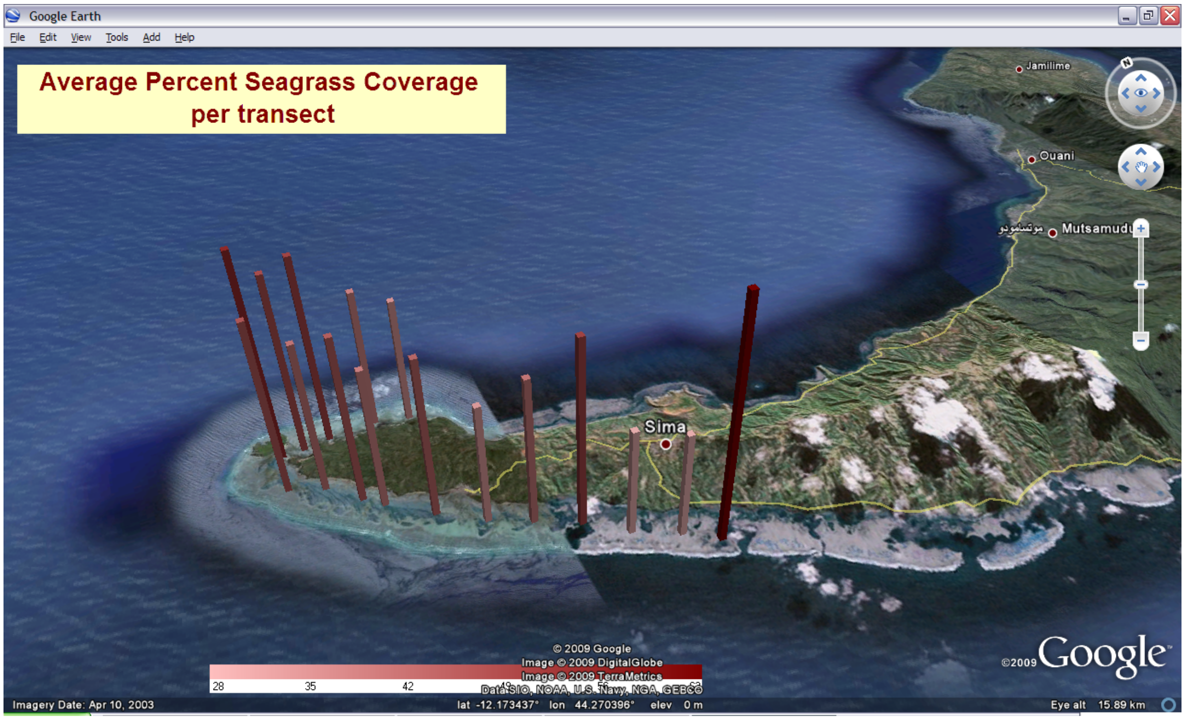

Fig 7. The graph shows the average percent cover of seagrass for each transect with light pink indicating a smaller percent coverage and the dark red indicating a higher coverage (28-63% cover).

The highest number of seagrass species (species richness) occurred near lagoons on the southwest side of the peninsula (Figure 8). There were seven sites with no seagrass present, 35 sites with one species present, 66 sites with 2-3 species present, and seven sites with 4-7 species present.

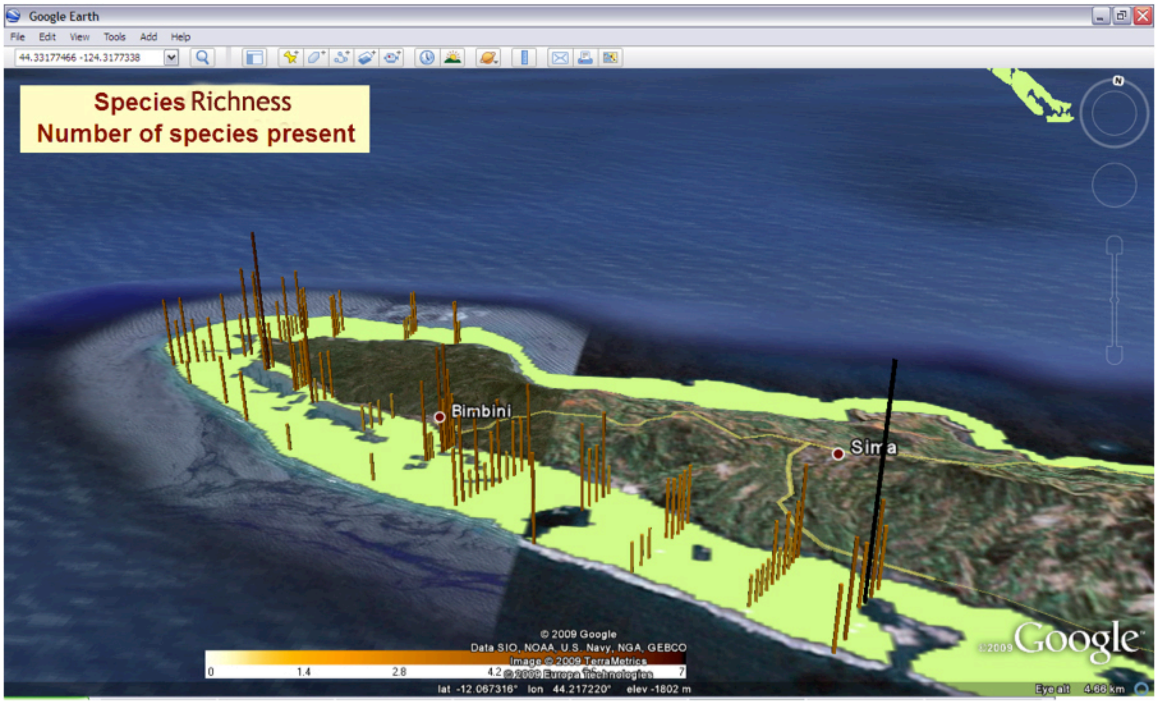

Figure 8. The graph shows species richness for each sample point with pale orange indicating low richness and dark red indicating high richness.

Seagrass along the exterior boundary (the outer most 50-100m) consisted of the four of species: Th, Si, and Tc. The average coverage was 55.1% and the sediment type was mostly sand and coral rubble. The inner boundary (100-200m) contained all 8 species and had an average percent cover of 39.8% and dominant sediment type of coral rubble, mud and fine sand. Individual species location maps (visible in the Google Earth file) clearly show *Thalassodendron ciliatum* and *Thalassia hemprichii* dominate the outer boundary. Maps created in ArcGIS for seagrass presence/absence, average percent cover, and species richness can be viewed in Appendix D.

2.6 Discussion

2.6.1 Seagrass distribution and abundance

The seagrass richness of the Bimbini Peninsula is high compared to seagrass beds worldwide (Green and Short 2003). The eight species present in the study area on Anjouan represent approximately 15% of the world seagrass species and about 62% of the 13 species that occur in the WIO region. This study represents one of first seagrass assessments completed on the Comoros Islands and the seagrass composition was expected to be similar to that of northern Mozambique because of its proximity (Green and Short 2003). Massingue and Bandiera (2005) studied the distribution of seagrasses around Nampula Province (northern Mozambique) and found 11 species of seagrasses and grouped them into nine community types. The seagrass in the area covered about 70% of the intertidal area and *Thalassia hemprichii*/macroalgae was the largest community. Areas furthest from shore were dominated by *Syringodium isoetifolium* and *Thalassodendron ciliatum* while areas closer to shore had mixed species composition. In Montepuez Bay, in the Quirimba Archipelago in northern Mozambique, 10 species of seagrass are present with intertidal areas dominated by *Thalassia hemprichii* and subtidal areas contained *Thalassodendron ciliatum* and *Enhalus acoroides* (Green and Short 2003).

The results of the survey indicate a species composition and richness were similar to locations in northern Mozambique. Eight of the 11 species found in Nampula Province and eight of the 10 species in Montepuez Bay were present in the study area on Anjouan Island. It is possible that more than eight species are present throughout the Comoros Islands but were not encountered during the study. A master's student who lived in the village of Bimbini reported encountering *Enhalus acoroides* during his survey (personal account). The three species present in Nampula Province but not in the Bimbini Peninsula are *Halophilia minor*, *Halophilia stipulacea*, and *Nanozostera campesis*. Species distribution was similar with the mixed species in intertidal areas and *Thalassodendron ciliatum* found in subtidal areas. *Thalassia hemprichii* and *Thalassodendron ciliatum* were the dominate species in the study area, in terms of the number of times present and the highest percent coverage. As expected, species composition and distribution in the Bimbini Peninsula were similar to that of northern Mozambique. Although this study looks at only a portion of seagrass on Anjouan Island, a similar species composition and distribution would be expected for the entire Comoros Islands.

As a baseline survey, it not possible to quantify the health (based on population extent or composition) or rate of change, if any, of the seagrass beds in the Comoros Islands.

Baseline data on biomass variability, density and productivity, while necessary for measuring future change, were beyond the scope of this project. However, the geospatial data that was collected will provide a foundational GIS on which to build future monitoring programs (Coles et al. 1996) and to add additional physical, biological, social, and economic data as necessary. Seagrass coverage (%) may have been one of the most significant pieces of data collected. In a survey conducted by Wood and Larvey (2000), researchers and managers were asked to identify healthy and unhealthy seagrass sites and the basis for their perceptions. The top four variables for perceived seagrass health were epiphyte biomass, shoot density, epiphyte (% carbonate), and canopy cover (%). Significant percent coverage data was collected at the study area on Anjouan on a fine scale and could likely be used to accurately monitor for future variability or recognize patterns. For example, the 3-D graphs in Google Earth reveal the area of highest coverage occurs at the last transect (furthest one in the southwestern direction) which is the same area that shows a high species richness. It might be useful to continue surveys here to determine if it is an isolated area of high coverage and richness or the beginning of a trend for that part of the island.

2.6.2 Issues with methods and potential uncertainty and error in data

There are several important issues that should be considered if this project, or a similar project, were to be undertaken again. The use of aerial photography or satellite imagery, generally, should be consulted before commencing a mapping project (McKenzie and Kierkman 2001). No aerial photos were available, and so were not consulted, for the project. The original intention of the project was to map all the seagrass beds on Anjouan Island. It was not clear how large the study area was until arrival on Anjouan Island. Only about 15km of the island's coastline could be mapped. The satellite or aerial images would also have been valuable to show the areas of large lagoons that could not be crossed without a boat. It was not possible to complete some the transects on foot because of the lagoons. A boat had to be used to take a point survey at the end of several of the transects. If aerial images had been available, transects could have been targeted to include areas without lagoons. Transects or point surveys could have been conducted throughout the island, based on the location of known seagrass beds. Additionally, a civilian code GPS receiver was used for the surveys, which is only accurate to <10m 95% of the time.

Given the limited budget, Google Earth, or other publically available digital globe, would have been an excellent imagery tool. Although the imagery quality is variable, especially in remote locations such as the Comoros, it still gives the user a general idea of the seagrass present in the study area. The imagery would have given a good idea of the location of the Island's seagrass and lagoons and allowed the surveys to be more efficiently executed. Transect locations could have been placed in appropriate locations to avoid the lagoons, based on the images. Other locations that were logistically reasonable to reach by taxi or bus could have been added to the survey to have a more complete assessment of the seagrass for the entirety of Anjouan Island.

Additionally, there were some difficulties in mapping the exterior boundaries because of three main issues. 1) The seagrass bed was not continuous from the inner boundary to the outer boundary. In many places there was seagrass for up 100-500m from shore, followed by one or more lagoons (with no seagrass) that were, in most cases, too wide to cross by swimming or inflatable boat. Then the seagrass would continue on the other side but often only in patches of 3-10m. It was difficult to know if the true external boundary was the edge of the seagrass bed or the edge of the patches that continued all the way to the reef. We mapped the edge of the patches as this was the most exterior point of the seagrass. Again, this is an issue that could have been resolved if publically available imagery had been consulted. 2) Communication with the boat driver. The driver did not want to follow the seagrass when it went too close to shore as it would require too much fuel and time. So some of the time the boat was not closely following the exterior boundary. Communication with the driver before the actual boat trip could have been more clear and direct to ensure everyone was following the required sampling methods. The Google Earth imagery could have been printed and shown to the boat driver ahead of time as a visual for the path that the boat trip should follow. 3) Inclement weather affected the mapping. Due to strong waves, there were times when the boat was unable to follow the seagrass boundary and had to come in closer to shore. Points could not be taken regularly (every 30m) when the boat was avoiding waves. It is difficult to avoid weather issues and given the budget, additional days on the boat were not possible.

There were also some equipment issues encountered during data collection. The GPS unit only held 999 points. This constraint was unknown until the memory became full during the mapping of the external boundaries. Previous points that had already been recorded on data sheets had to be erased from the GPS memory to make room for more points. It is a good idea to have multiple GPS units available, allowing for the storage of more than 999 points and providing insurance if something happens to the GPS unit. Alternatively, points could be uploaded to a computer if there is access.

Although similar seagrass surveys had been conducted by C3 on other islands in the Comoros, there was not a seagrass expert present during the surveys. Several species identification methods were used, including specimens from other islands, but there is still some uncertainty in species identification. For example, *Halodule uninervis* and *Halodule wrightii* are extremely similar in appearance and it is possible that misidentification could have occurred between these species. It is possible that *Enhalus acoroides* was misidentified as *Thalassia hemprichii*. As mentioned earlier, a villager completed a master's project on seagrass in the Bimbini Peninsula and he informed us that *Enhalus acoroides* occurred in an area where we conducted the surveys. However, we did not encounter the species.

2.7 Concluding Remarks

This study contributes to a description of seagrasses in the Comoros Islands, a remote and little studied area in the Western Indian Ocean region. Future studies could include completion of baseline mapping on Anjouan Island and compiling the results from the surveys conducted by C3 on the other two islands to gain a more complete picture of seagrass composition and distribution for the Comoros Islands as a whole. Additional studies on biomass variability, density and productivity are recommended to provide a more complete baseline of information. Given the limited budget for this project, the use of free aerial and satellite imagery tool would have been beneficial. This could have alleviated some of the issues with study area size and lagoon locations. In addition to an imagery tool, Google Earth would be an excellent platform for visualizing and communicating the results from this survey. As a way to promote seagrass conservation and share the survey results, the methods, results and seagrass background information from this baseline survey were added to Google Earth. The Google Earth file created will provide C3 an easy way to visualize results from the survey, add additional data, freely distribute GIS data, and promote awareness of seagrass ecosystems.

CHAPTER 3. GOOGLE EARTH AS AN EFFECTIVE, AFFORDABLE AND POPULAR TOOL FOR CONSERVATION

The release of freely downloadable virtual globe applications, such as Google Earth, has sparked public interest in spatial sciences (Aurambout et al. 2008). Google Earth is free and easy to use, making it a powerful tool to display and communicate data to the general public, decision makers, and scientists. The appeal of Google Earth to both the scientific community and conservation organizations can be seen in the number of applications already taking place. The Google Earth Outreach Showcase (http://earth.google.com/outreach/showcase.html) allows non-profit and public benefit organizations to visualize their cause using Google Earth and Maps. These are then available for viewing to the general public. For example, The Jane Goodall Institute uses Google Earth as a blog for the Gombe Chimpanzees. Users can meet Fifi and Frodo, among the other chimps from Gombe through short bios and follow researchers through Tanzania as they blog about the Chimpanzees (http://earth.google.com/outreach/showcase.html#kml=Jane_Goodall%27s_Gombe_Chimpanzee_Blog). Small scale organizations have found using Google Earth beneficial as well. Neighbors Against Irresponsible Logging (NAIL), a small community group based in the Santa Cruz Mountains of Northern California, defeated a plan to log redwood trees in their neighborhood with the help of Google Earth (http://earth.google.com/outreach/showcase.html#kml=Neighbors_Against_Irresponsible_Logging_(NAIL)). Larger organizations, such as NOAA, have also been able to use Google Earth to communicate their findings with the public. The U.S. NOAA Coral Reef Watch has a product suite of global satellite and model data to provide daily monitoring and forecasting of coral bleaching and other coral reef environmental conditions which are available for viewing in Google Earth (http://earth.google.com/outreach/showcase.html#kml=NOAA_Coral_Reef_Watch).

The appeal of Google Earth to the scientific community is also evident. In one example illustrated by Blower et al. (2007), researchers at the British Antarctic Survey use Google Earth to simultaneously visualize (in near-real time) the position of penguins in Antarctic waters and satellite measurements of chlorophyll levels. They are able to see a relationship between penguins' movements and the location of the high nutrient levels which control the locations of fish (the penguins' prey). Conroy et al. (2008) used Google Earth to visualize and share paleontological GIS data from the Great Divide Basin Project in Wyoming with colleagues who previously had little or no GIS experience or access. As more scientists take advantage of GE as an excellent visualization tool, more data will become available from various sources for easy data integration into Google Earth.

This chapter will provide an overview of virtual globes and Google Earth, discuss its application to seagrass conservation, and then describe the process used to create a Google Earth file for the seagrass mapping study in the Comoros. It will provide step-by-step instructions for how to use the file. The objective for this section is to develop an educational and informational Google Earth file providing access to the survey methods and results, and general seagrass information

3.1 Introduction to Virtual Globes

Google Earth is one of many virtual globe geo-browsers, also known as digital globes, virtual globes, earth browsers and digital earths, which allow for the visualization of digital images in an undistorted three-dimensional virtual space (Aurambout et al. 2008). Riedel (2007) defines digital globes as "scale-bound structured models of celestial bodies presented in virtual space in their undistorted three-dimensional wholeness." According to Riedel (2007), a 'digital globe' should not be confused with the term 'digital earth.' In his 1998 speech, then US Vice-President Al Gore called for an ambitious global undertaking to build a multi-faceted system for education and research, which he termed "Digital Earth." He proposed the concept of a digital earth as a: "multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of georeferenced data" (Gore 1998). Current virtual globe applications are arguably more of a hybrid between Riedel's cartographic definition of digital globes and Al Gore's vision of a digital earth. Most virtual globe applications allow for more than just visualization of images but don't yet have the ability to access "vast quantities" of data.

Virtual globes can provide a significant advantage over traditional mapping interfaces because data can be viewed at any scale and angle, they are highly interactive, and the imagery is free from distortion (Riedl 2007). There are currently at least 40 virtual globe technology software products available (Aurambout et al. 2008). A few of the more popular ones are: *NASA World Wind, ArcGIS Explorer, Skyline Globe, and Google Earth.* A comparison of features for the four virtual globes was adapted from Aurambout et al. (2008) and can be seen in Table 4. *NASA World Wind* was developed by NASA Learning technologies and released in 2004 as an open source program. It provides three-dimensional interactive globes of the Earth, the Moon, Mars, Venus, and Jupiter (including its four moons). *ArcGIS Explorer* is a product developed by ESRI designed to access online GIS content from ArcGIS Server and overlay them on a virtual globe but can also operate on a standalone basis. It can import data in a wide range of GIS formats and can perform data analysis with additional plug-ins.

Table 4. A comparison of four virtual globe software application. Table adapted from Aurambout et al. (2008)

Virtual Globe Application	Year of Introduction	Platform	Cost	Import Shapefiles?	Import GPS coordinates?	KML compatibility	Data format supported	Drawing tools
NASA World Wind	2004	PC, Mac	Free	Yes	Yes	Yes, partially	jpg, png, ESRI shapefile	Yes (point features only)
ArcGIS Explorer	2006	PC	Free	Yes	No	Yes, partially	img, bmp, jpg, gif, if, jpg, gif, tif, ArcInfo, ESRI shapefile	Yes
Skyline Globe	2006	PC	Free	Yes	Yes	Yes, partially	ESRI shapefile	Yes
Google Earth	2005	PC, MAC, Linux	Free Pro: $400	No Yes in Pro	 Yes	Yes, fully compatible	jpg, bmp, tga, png, gif, tif,	Yes

Google Earth, launched in 2005 by Google™, primarily uses Keyhole Markup Language (KML) for visualizing data. KML is simple language based on XML initially developed by Keyhole Inc. and later acquired by Google. KML is focused on geographic visualization which includes not only the presentation of graphical data on the globe, but also the control of the user's navigation in the sense of where to go and where to look (OGC website). KML is supported by many virtual globes and GIS systems and is in the process of being standardized by the Open Geospatial Consortium (OGC). This project focuses on the use Google Earth as a virtual globe geo-browser. The free version of Google Earth is used for this project. Although, Google Earth Pro does allow for additional features such as import of GIS data, higher resolution printing and area measurement, the free version of Google Earth is more accessible for a wider audience.

3.2 Google Earth overview

Google Earth is the most ubiquitous of the virtual globe applications, possibly giving it the most potential for data dissemination and raising public awareness. The popularity of Google Earth was evident early on when it was downloaded more than 100 million times within the first 15 months of its release (Spano 2006 as cited in Schoning et al. 2008). The UK reported that "Google Earth" was the eighth most popular search term during the month of January 2006 (Hopkins 2006 as cited in Sheppard and Cizek 2008), shortly after its release in June 2005. Today there are over 500 million users and an equal number of user generated KML files on the web (Peter Giencke 2009).

Google Earth has given every internet user the power of a virtual globe at their fingertips. It is free, easy to use software that superimposes high quality satellite and aerial images over a 3-D globe. It allows users to spin around the earth at 15,000km, fly from a 3-D view of the Grand Canyon to their neighborhood to the ocean floor. Since Google Earth is aimed at the public, it is an extremely easy to use tool that avoids the need for technical training and uses a simple, intuitive interface (Goodchild 2008). For this reason, it appeals to both the casual user (the general public) and the more specialized user (scientists and managers) (Butler 2006). According to Butler (2006), the appeal to the casual user is being able to go from space to street view of a particular location in a matter of seconds all the while seeing sharp, clear images. While its popularity with scientists lies in the ability to easily overlay data in a spatial context and to communicate GIS data with those that previously did not have access.

Google Earth may encourage spatial thinking and help develop critical technology and thinking skills (Patterson 2007). It has been effectively used in classrooms to help make spatial information more relevant to students and teachers. Studies have shown that the use of online resources has helped improve comprehension of concepts and skills while improving confidence in their knowledge of geographic issues (Solem and Gersmehl 2005 as cites in Patterson 2007). The National Research Council (2006) identified the importance of spatial thinking in primary and secondary education. They argue that spatial concepts can be effective paths to learning. Patterson (2007) claims that Google Earth can help foster spatial thinking and develop critical thinking and technology skills in the classroom. Furthermore, students can work independently and interactively or collaboratively and may extend their learning outside the classroom. Patterson (2007) also notes that Google Earth supports the "four E's" of the learning cycle model: engage, explore, explain, and evaluate.

3.2.1 Is Google Earth a GIS?

There is some confusion in the literature as to whether or not Google Earth is a GIS. There is yet to be a single agreed upon definition of Geographic Information Systems (GIS). A broad definition of GIS is the one provided by the National Centre of Geographic Information and Analysis: a GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources (NCGIA 1990 as cited in Longley et al. 2005). Longley et al. (2005) provides several definitions based on the groups that find them most useful (Table 5). The right hand column of table 5 was added to determine if Google Earth meets the definitions for GIS. Google Earth does meet some of the definitions, although most in a limited form. Based on this, Google Earth provides a basic or light GIS. It is a software that provides representation and display of georeferenced data with limited manipulation, modeling and management, but almost no analysis capabilities; And like GIS, may be useful for solving problems for planning and management.

Table 5. A Comparison of Google Earth to the Attributes of GIS

Definitions of GIS	Groups who find them useful	Google Earth compared
A container of maps in digital form	The general public	Yes
A computerized tool for solving geographic problems	Decision makers, community groups, planners	Yes, but only through visualization
A spatial decision support system	Management, scientists, operations, researchers	Yes, but need to combine with more powerful GIS
A tool for revealing what is otherwise invisible in geographic information	Scientists, investigators	Yes
A tool for performing operations on geographic data that are too tedious or expensive or inaccurate if performed by hand	Resource mangers, planners	Yes, but need to combine with more powerful GIS

Source: Adapted from Longley et al. (2005)

Google Earth has been described as 'the democratization of GIS' by Michael Goodchild (Butler 2006, p.77) due to its accessibility and ease of use. It has exposed geographic information science to anyone with internet access and stimulated them to develop novel applications (Goodchild 2008). This is particularly relevant to GIS use in developing countries. High software cost, lack of trained staff, and lack of data are a few of the barriers to GIS in both developed and developing countries (Britton 2000). But this issue is exacerbated in developing countries where monetary and technological resources are often extremely scarce or nonexistent. Often times GIS only provides information and data access for well-educated and privileged groups (Harris and Weiner 1998). Even in developed countries, GIS is still underutilized and remains a tool for specialists (Butler 2006). For example, its use in paleontology is still lagging behind other science disciplines (Conroy et al. 2008). Additionally, access to scientific publications, while one of the most important methods for disseminating best available conservation science, are out of reach for most researchers and practitioners in developing countries due to subscription costs and access issues (Hammond et al. n.d.). The use of Google Earth is a potential solution to these types of problems. Google Earth has the potential to disseminate knowledge and provide a basic GIS, free of cost and without the need for technical expertise, to all groups of people.

3.2.2 Potential risks and disadvantages of using Google Earth

On the most basic level, even though Google Earth is freeware, it still requires internet access on a reasonably fast connection. This is most likely to be an issue for developing countries and classroom use. Some of the disadvantages of Google Earth are the lack of complex spatial analysis tools. While Google Earth has the ability to allow for some GIS functions such as proximity, connectivity and modeling through visualization and interpretation by the user, it is not within its inherent capabilities. It might be necessary to shift our thinking that Google Earth should be like a traditional GIS with all the analytical capabilities and see it as different tool all together. Or, it may be that in the future, Google Earth and GIS will merge so that Google Earth will be able to provide users more analytical capabilities.

There are some assumptions and expectations that Google Earth is encouraging spatial thinking, particularly relevant for classroom use. However, Schoning et al. (2008) point out that an important part of the spatial thinking process involves generating and testing hypotheses and making pattern predictions. Essentially, spatial thinking involves individuals asking “what is where?” and “why? A survey by Schoning et al. (2008) showed that most individuals used virtual globe technologies, like Google Earth, for navigation and sightseeing (observational) purposes and therefore little spatial thinking was occurring. Most of the individuals surveyed were using these technologies to observe the “what” of spatial data but not the “why.” As virtual globe technology persists and evolves and is used more often for educational purposes, it is important to encourage spatial thinking through careful and appropriate design to facilitate learning.

Any new technology has the potential for misuse, and with widely accessible system such as Google Earth, there is greater potential for errors to have global consequences (Sheppard and Cizek 2009). So what are the risks of Google Earth that require careful examination? There is some concern that highly realistic visualization is subject to greater risk of bias. Google Earth can transform map data into something with value, perspective and emotion to many people. In landscape visualization, there is a belief that the greater the realism, the more similar responses will be to real life (Bishop and Rohrmann 2003 and cited in Sheppard and Cizek 2009). Google Earth's greatest attributes may also be the source of its greatest risks. It is easy to use, highly realistic, free, and fun, and therefore wide spread. Like other cartographic tools and computer-based visualizations, it is subject to misinterpretation and distorted meanings. As with any user-generated content put forth on the internet, special interests and amateurism may arise leading to both misleading and poor quality information being disseminated. In order to avoid a misled public, misinformed planning, poor decisions, and the reduced credibility of the visualizations, Sheppard and Cizek (2009) suggest possible solutions for the ethics of virtual globes. These include establishing codes and guidelines, metadata and labeling requirements, review and approval of user-generated content, and monitoring and evaluation research. As with most new science and technology, addressing issues of ethics and establishing standards and guidelines may avoid future problems and build credibility.

3.3 Application to seagrass

This project uses a case study based on the author's seagrass mapping internship in the Comoros Islands to investigate how Google Earth can be used as a conservation tool to visualize and communicate scientific data. Seagrasses are distributed in tropical and temperate coastal waters across the globe and create one of the most productive and valuable ecosystems in the world. Seagrasses provide important ecological services such as carbon production and export, sediment stabilization, enhanced biodiversity, and nutrient cycling (Orth et al. 2006). Additionally, seagrasses act as nursery grounds and foraging areas for many fish and invertebrate species, providing important economic benefits for commercial, recreational, and subsistence fisheries. (Gullstöm et al. 2002). For these reasons they maintain great significance in the Western Indian Ocean (WIO) region for local communities in the region (Gullstöm et al. 2002).

The greatest existing seagrass meadows occur along the coasts of developing tropical countries, which also experience the greatest rate of environmental degradation (Durate 2002). Present wide spread seagrass loss is due largely to anthropogenic impacts such as eutrophication, siltation, pollution, and harmful fishing practices and is expected to accelerate as human populations continue to grow on and near the coastal zone (Durate 2002). Although in recent decades seagrass degradation has received increasing attention, there is still very limited scientific attention in the WIO region compared to mangroves and coral reefs, and seagrass beds are not often considered in management plans (Gullstöm et al. 2002).

Orth et al. (2006) call attention to a disconnect between science and public awareness of seagrass ecosystems. They discovered that while there has been an increase in scientific publications on seagrass (Figure 9), public awareness remains far lower than for other coastal habitats like mangroves, salt marshes, and coral reefs, which receive 3- to 100-fold more media attention than seagrass (Figure 10). However, while seagrass receives less media attention than other coastal ecosystems, it has the highest monetary value for the ecosystems services it provides (Figure 10). Part of the reason public awareness of seagrass remains low may be due in part to the inconspicuous nature of seagrasses and the overall fewer publications on seagrasses than other coastal habitats (Orth et al. 2006). Public support is a necessary component for seagrass conservation efforts both on a global scale and locally for the Comoros Islands. The development of a Google Earth file may help ameliorate the gap between science and public awareness of seagrass ecosystems.

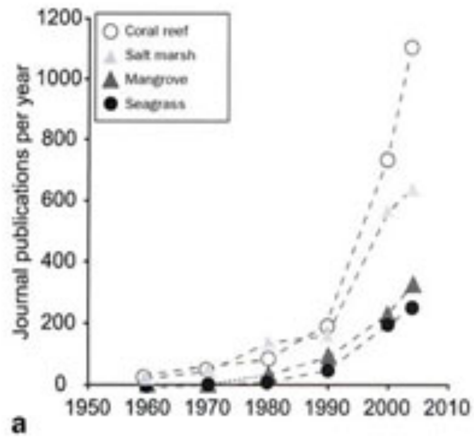

Figure 9. This graph from Orth et al. (2006) show a comparison of seagrass, salt marshes, mangroves, and coral reef habitats in terms of journal publications per year (web of science 1950-2006).

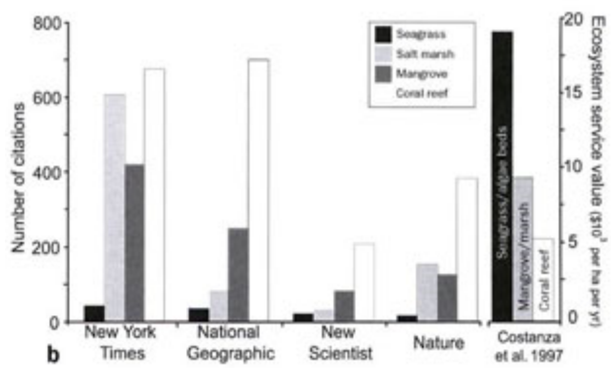

Figure 10. This graph from Orth et al. (2006) show a comparison of seagrass, salt marshes, mangroves, and coral reef habitats in terms of media attention and an estimated monetary value of the ecosystem services provided by these habitats (Costanza et al. 1997).

3.4 Methods for creating the Google Earth file

The Google Earth file contains: a series of informational placemarks about seagrass and the Comoros; a series of placemarks documenting the methods used for the seagrass survey; results from the survey including ArcGIS layers and associated attribute data and 3-D graphs; a series of species profile placemarks; and a fly-through tour highlighting some of the important placemarks. Several programs were used to create the various components of the Google Earth file. Figure 11 provides an overview of the process used to create the file and the following section provides greater detail of the process.

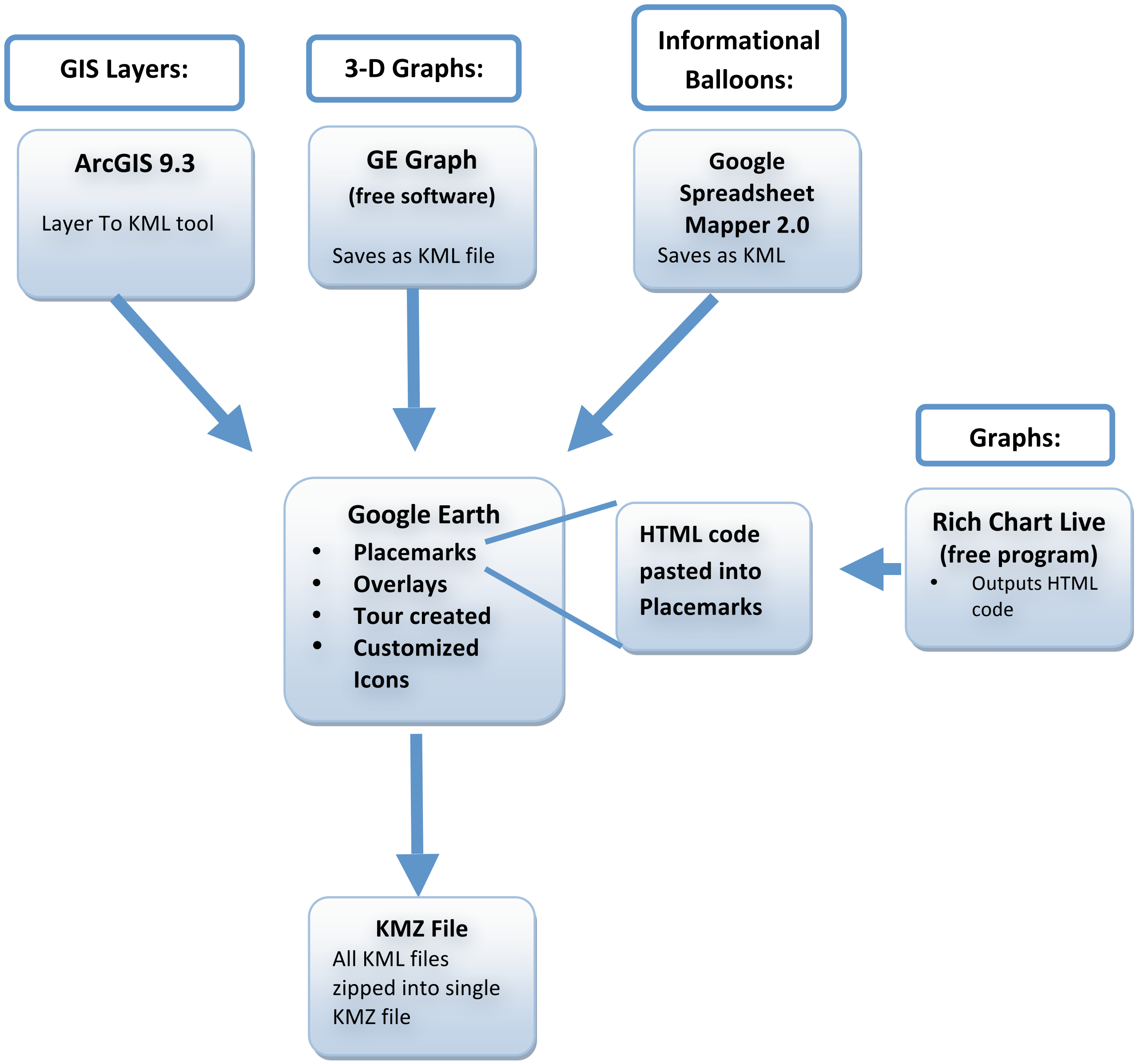

Figure 11. A diagram of the process used to create the various components of the Google Earth file.

GIS layers

The seagrass, mangrove, and transect layers created in ArcGIS 9.3 (a complete list of layers can be seen in Table 6) were each exported as kml files using the "Layer To KML" tool in the "Conversion" toolbox. There are two geoprocessing tools available for creating KML files from ArcGIS: Layer To KML and Map To KML. The Layer To KML tool allows individual layers to be exported directly from ArcMap while the Map to KML tool allows multiple layers to be exported into a single KML source. Both of the geoprocessing tools generate a zipped KML file (KMZ) in the specified output directory. Once the files were saved in the kmz format, they were ready to open in Google Earth.

Table 6. A list of data layers produced in ArcGIS 9.3 and exported as KML files.

ArcGIS Layer	Source
Observed seagrass boundaries	GPS points uploaded
Transect locations including all survey points and all associated attribute data	GPS points uploaded
Mangrove polygons	GPS points uploaded
Digitized seagrass boundaries for entire island	Created in ArcGIS
Thalassia hemprichii location points	Created in ArcGIS
Thalassodendron ciliatum location points	Created in ArcGIS
Cymodocea rotundata location points	Created in ArcGIS
Cymodocea serrulata location points	Created in ArcGIS
Halodule uninervis location points	Created in ArcGIS
Halodule wrightii location points	Created in ArcGIS
Halophila ovalis location points	Created in ArcGIS
Syringodium isoetifoium location points	Created in ArcGIS

Attribute data for all 115 transect sample points were included in the resulting kmz file as a feature description in the balloon pop-up for each sample point placemark. The feature description options are set in the Layer Properties dialog in ArcMap. The visible fields that are checked become the contents for the KML field descriptions for each feature. Additionally, the HTML properties were set for the transect layer by enabling the "show content for this layer using HTML Pop-up tool" in the HTML Popup tab of Properties. The option to display HTML formatting as a table of the visible fields was selected. The resulting KMZ file has all the selected fields visible as a table in the popup balloon for each of the sample point placemarks.

Informational Balloons

The Google spreadsheet-to-KML tool, Spreadsheet Mapper 2.0, was used to create a series of informational balloons for general seagrass information, species profiles and methods. The Spreadsheet Mapper tool is a free tool from Google Earth that allows the user to enter data in an on-line Google Docs spreadsheet including photos, text and coordinates and then generates corresponding placemarks for use in Google Earth and Maps. The template starter spreadsheet is available at http://earth.google.com/outreach/tutorial_spreadsheet.html. The starter spreadsheet was copied into the author's Google Account and filled out as requested with placemark data and templates. Once the basic information was filled out, the spreadsheet was published by clicking on the share feature and copying the URL from the "publish to the web" window. The URL was then pasted into "My Places" in Google Earth. The result is a network link to the spreadsheet which allows for the most up-to-date data from the spreadsheet to be immediately visible in Google Earth. The network link can also be saved as a standalone KMZ file which does not require an internet connection to access the file as it does with the network link.

Graphs

3-D graphs were created of the average percent cover for each sample point, the average percent cover for each transect, and the average species richness for each sample point. The graphs were created in GE Graph, a free software available at: http://www.sgrillo.net/googleearth/gegraph.htm, that develops and generates graphs from kml files saved by Google Earth or by typing data directly into the program and exporting as a kml file to Google Earth. The graphs were created as 3-D polygons with four sides and constant size (factor 50) and height (factor 100) according to value. Additional bar graphs for average percent cover for each species and species presence were created using Rich Chart Live, a free program that allows the user to create Flash charts online and then publish them to several formats including HTML to embed directly into a website. The graphs were created online at http://www.richchartlive.com and then published using the "Embed chart in blog" option which outputs the corresponding HTML code. The code was then copied and pasted into a placemark in Google Earth.

Customized features in Google Earth

Some additional features were created directly in Google Earth. For comparison of boundaries, polygons were drawn around the inner and outer most boundaries and then corresponding placemarks were created to display summary information on percent cover, species composition, and sediment type for sample points within the polygon boundaries. Placemark icons were customized within the placemark properties by selecting an image file of choice. Additional customization such as color and font size was done by editing the HTML tags in the placemark properties. A fly-through tour was created by using the Add Tour feature, selecting the record button, and then clicking placemarks in the desired order of appearance. Once all features were satisfactory, all kml files for the ArcGIS layers, graphs, and informational balloons were zipped into a single kmz file for ease of use and sharing. The singe file can be emailed, posted on a website, or shared with others as desired. When the file is opened, it initially appears under “Temporary Places” in the user’s Google Earth display and can then be moved to “My Places” for a permanent display anytime Google Earth is opened on that particular computer.

Each folder or layer contains metadata where appropriate. This includes information such as dates, descriptions of the contents, programs, and data used.

3.5 A step-by-step guide to the 2008 Seagrass Survey Google Earth file

After opening the KMZ file in Google Earth, the recipient will see the Seagrass Survey file next to a blue globe icon with four folders below it (figure 12): “Learn about the Comoros,” “Learn about Seagrass,” “Methods,” and “Results.” The “Learn about the Comoros” and “Learn about seagrass” folders contain informational balloons that appear when the icon is double clicked (figure 13). The informational balloons first walk the user through basic information about the Comoros Islands and then what seagrass is, why it is important, what the threats are, and background on seagrass in the Comoros. Additionally, there are two videos contained within this folder: one is an informational video on seagrass and the other depicts a sea turtle eating seagrass. Then the informational folders can be turned off and the “Methods” layer can be selected. This layer describes the methods for mapping the boundaries and for the seagrass surveys. When ‘seagrass surveys’ is clicked, a description of the methods for the surveys appears (figure 14). Transect points can also be selected at this time to a view all the sample points where seagrass survey data were collected. When any of the purple transect points are clicked, a table appears with all the field data (latitude and longitude, sediment type, water depth, average percent cover, species composition, and canopy height) for that point (figure 15). When ‘Mapping Boundaries’ is selected a similar balloon with a description of the methods appears. The ‘2008 seagrass boundaries’ can be turned on to view the boundaries mapped during the survey.

Results can be viewed by expanding the “Results” folder and selecting a layer of interest. The Results folder contains a digitized seagrass bed polygon of the entire island, mangrove polygons, Graphs (including 3-D graphs), and a comparison of the seagrass survey results for the inner and outer most boundaries. Each item can be turned on and double clicked one at a time to view the results. For example, if the viewer would like to see the average percent cover of seagrass by transect location, the ‘AvgCov by transect’ layer in the “Graphs” folder would be turned on and when doubled clicked, Google Earth will fly to the appropriate view point (figure 16). In a similar manner, other results such as Boundary Comparison and Seagrass species presence can be viewed.

Species profiles are available for each species encountered during the seagrass survey. The “Species Profiles” folder can be expanded to reveal each of the species present. The viewer can turn on a species of interest to reveal the locations where that species occurred over the study area. When the species name is clicked a profile will appear with a photo and description of the species and information about number of times present and average percent composition (figure 17).

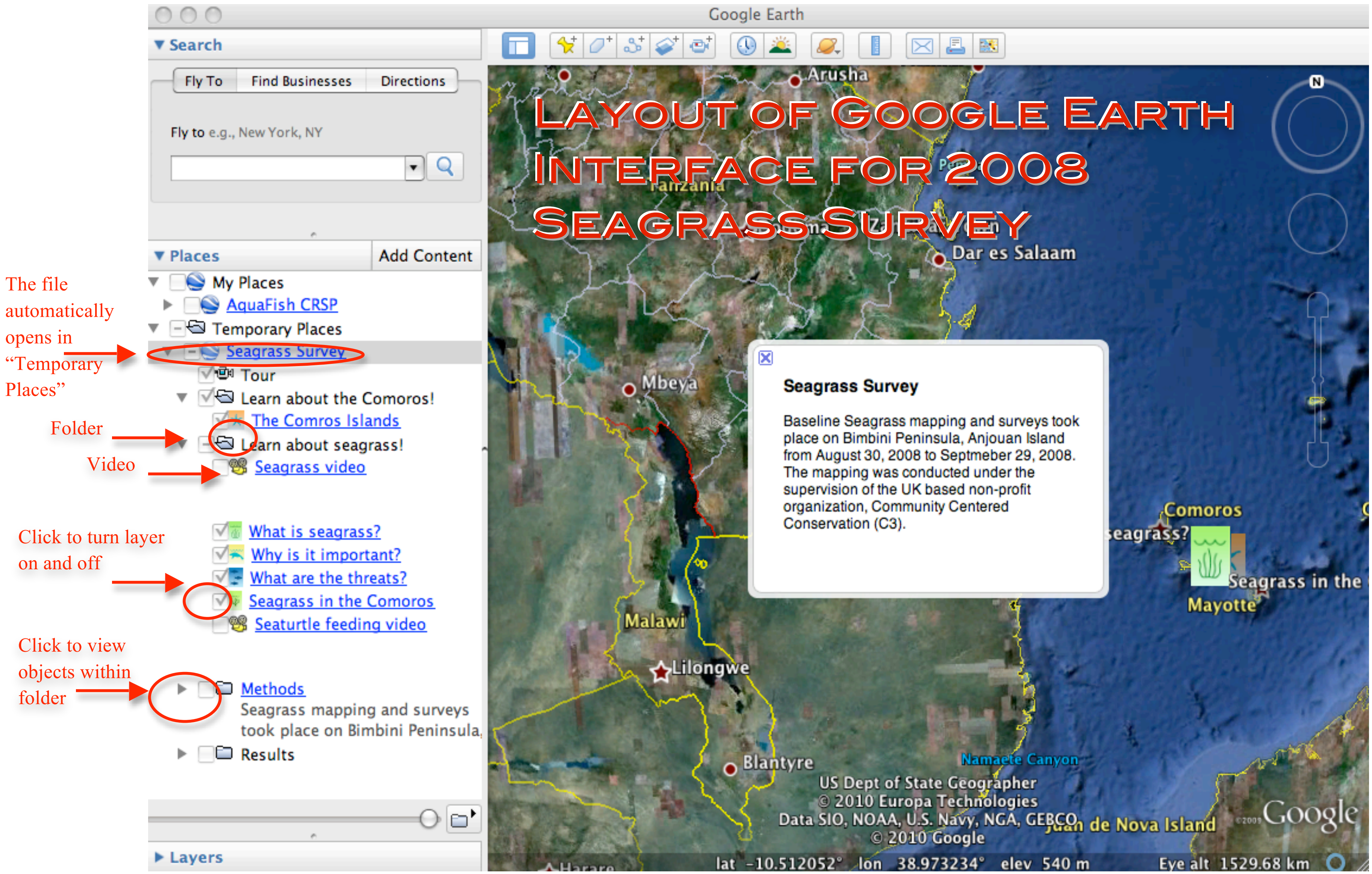

Figure 12. The layout of the Google Earth interface as it appears when the Google Earth file is opened. Added descriptions appear in red.

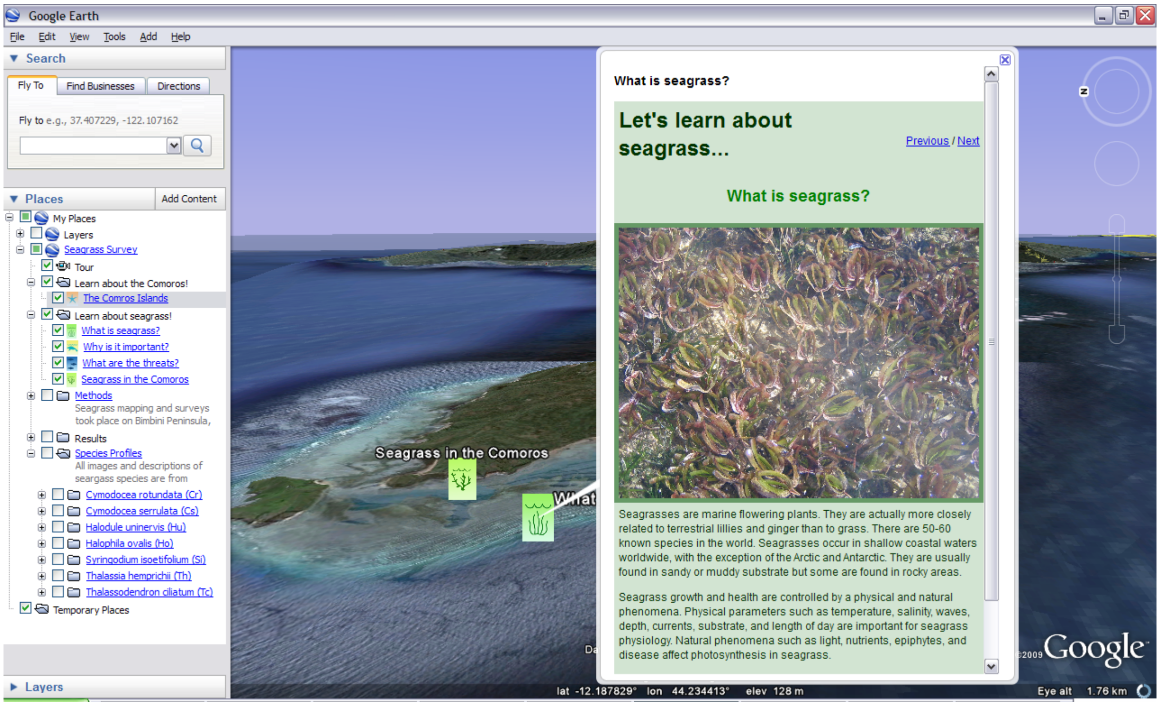

Figure 13. An example of one of the informational popup balloons. Each icon can be clicked on to reveal a different balloon about seagrass or the Comoros.

Figure 14. An example of a popup balloon describing the methods used to conduct the mapping and surveys.

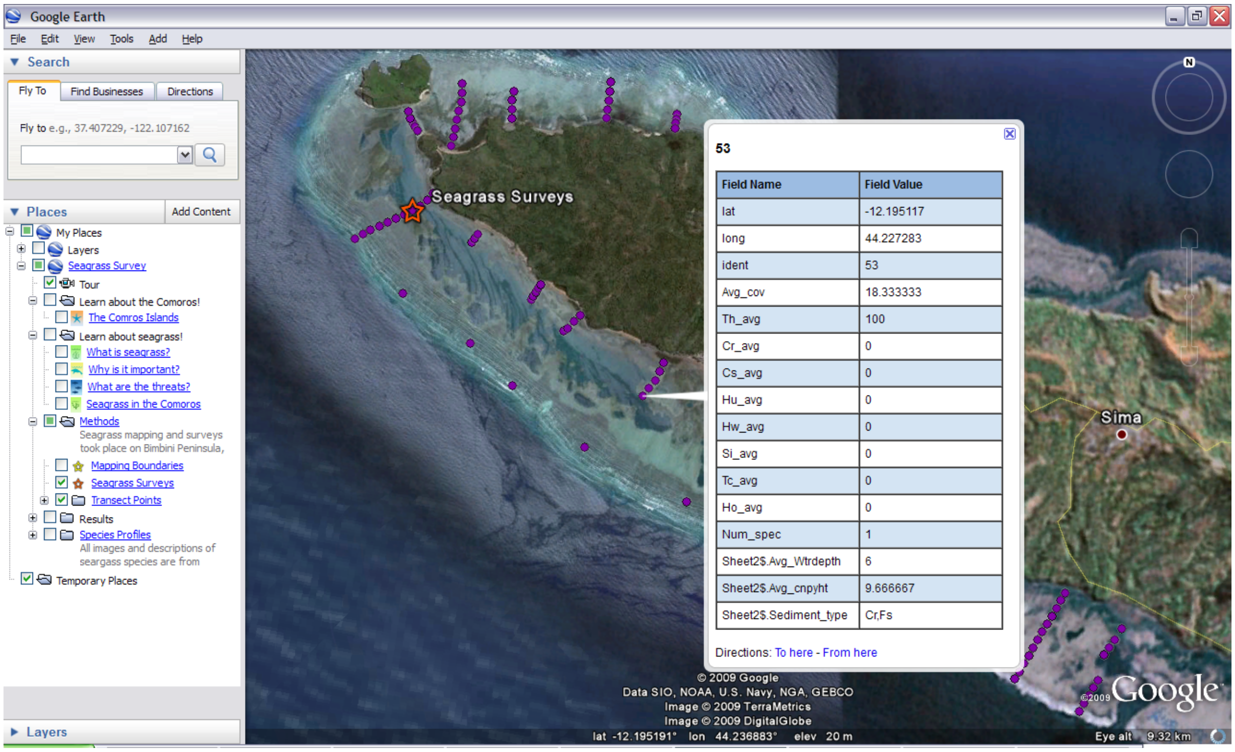

Figure 15. Each of sample points has a popup balloon displaying a table of associated field data.

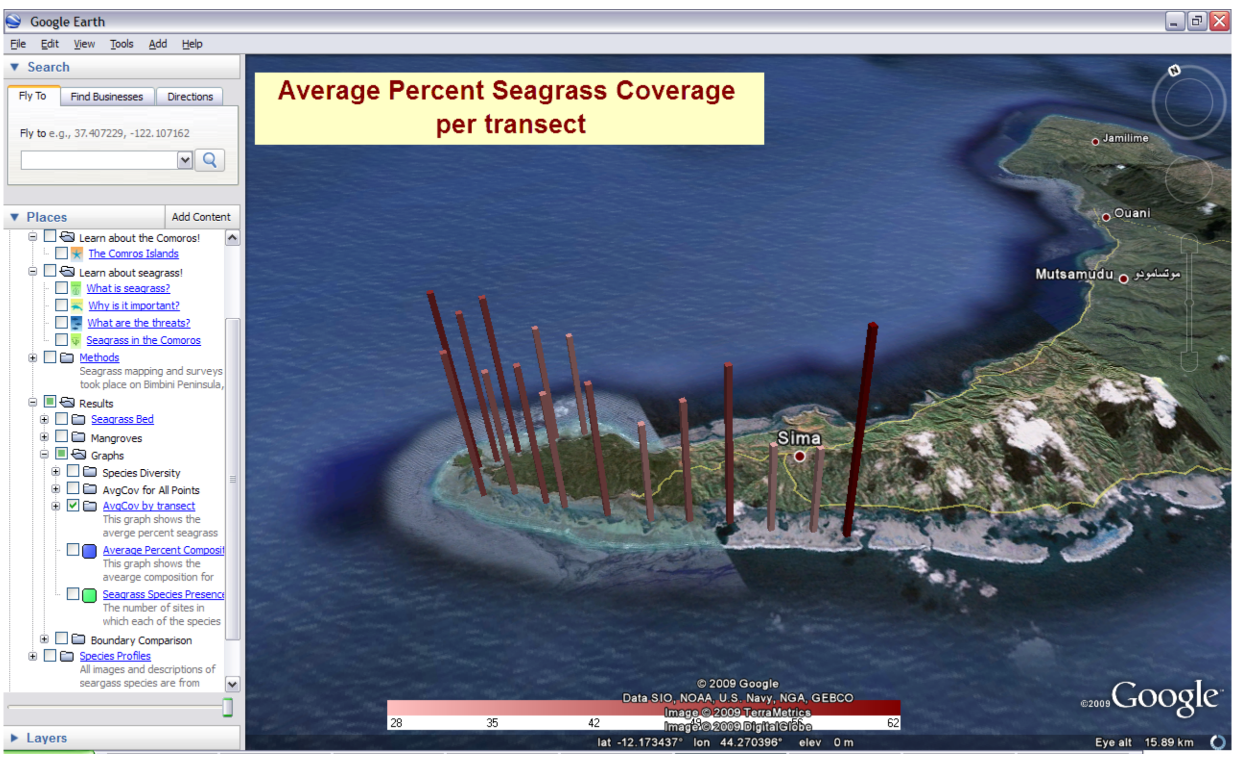

Figure 16. A 3-D graph displaying the average percent cover of seagrass for each transect.

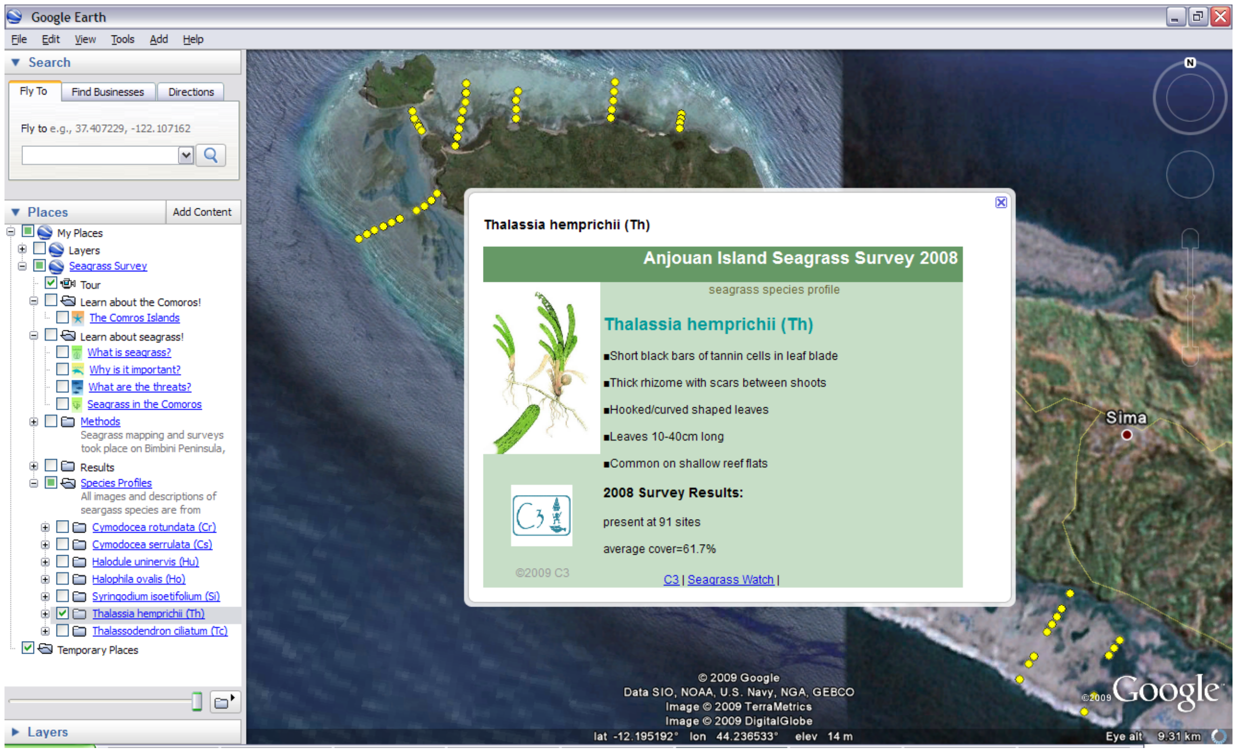

Figure 17. An example of a species profile for *Thalassia hemprichii*. In this profile, all the yellow points represent the locations where the species occurred in the study area and the balloon provides a photo and description of the species with survey data.

3.6 User identification and assessment

A Google Earth file, such as the one created for this project, has several potential user groups that would be interested in either accessing the file, creating a similar file, or both. As mentioned previously, Google Earth's wide appeal makes it popular with both general and specialized users. The following section will define these user group categories, identify some of their needs and barriers and discuss the usability and effectiveness of the created Google Earth file, or similar type of file, to these groups.

User Groups defined:

General users (public and educational use): this group of users consists of interested members of the general public. They are defined by Sheppard and Cizek (2009) as a group of people without any particular scientific or environmental expertise that can freely access the internet. This group is then broken down into general users in developed countries and general users in developing countries. This group is then broken down into:

- *General users in developed countries*: This group is expected to have technology readily available, for the most part. This group is likely to prefer a highly interactive and dynamic tool that is user-friendly, holds their interest and allows them to explore their own ideas.

- *General users in developing countries:* this group is expected to have limited availability of technology. When technology is available, it may be slower and shared or expensive (such as an internet café). This group is likely to prefer a tool that would be as accessible and cost-effective as possible while still being user-friendly.

Specialized users (scientists and managers): this user group consists of environmental and natural resource managers, scientists, and experts. Sheppard and Cizek (2009) refer to this group's purpose as using these tools to inform, present and contextualize their work. This group is then further broken into:

- *Specialized users in developed countries*: this group is expected to place importance on high analytical capabilities and a highly accurate product. They are not expected to have monetary, staff or access issues. Most will likely already have access to more sophisticated GIS technology.
- *Specialized users in developing countries*: This group is expected to have limited technology, however, they are assumed to have more access to technology than general users in developing countries. They are not likely to have the monetary or the skilled staff resources that developing countries have. They will need higher analytical capabilities than general users in developing countries.

General users in developed countries are expected to find the Google Earth file well suited to their needs because it is user-friendly, dynamic, educational, easy to access, and free to use. Since this group is not expected to have technical expertise, Google Earth can provide them with a basic GIS so they can explore the data provided in the file. This group will likely be most interested in this file to provide general information about seagrass and gain some insight into a study in a remote part of the world. General users are expected to be more interested in accessing the file than creating their own. However, more advanced or classroom users may be interested in incorporating some of the customized balloon creation or fly-through tours for their own purposes.

General users in developing countries are also expected to find Google Earth to be useful and effective for the same reasons as general users in developed countries. The largest barrier for developing countries is access to technologies such as computers and internet. Information technology such as cell phones and computers are becoming more common in developing countries. Programs such as the One Laptop per Child initiative are providing computers to children and schools allowing them to connect with the world via internet. Revolutionary programs like this are expediting the globalization of information technologies. While some poorer and more remote countries, such as the Comoros, may have a longer road ahead of them for equal and easy access to computers, they do have organizations and agencies with computer access that might be able to broaden access to the public through education programs. There are also internet cafes which allow the internet to be accessed by anyone for a small fee. Since access can be an issue in developing countries, use of the created Google Earth file might be more realistic in an educational or formal setting. For example, an organization such as C3 might have the technological and monetary resources to use the Google Earth file as part of an environmental educational program.

Specialized user groups in developing countries will also find Google Earth to be a useful tool for many of the same reasons as general users. Since this group has additional needs for accuracy and analytical capabilities, it might be useful to use Google Earth in combination with a more sophisticated and powerful GIS. They could use GIS for analyses and then transfer layers into Google Earth, similar to the file that was created for this project. This could be particularly beneficial to an organization such as C3 with some, but limited GIS access. They could use Google Earth to share GIS data with agencies, colleagues and others to which GIS data would have been otherwise inaccessible. A similar recommendation applies to specialized user groups in developed countries. Google Earth might be most useful when used in conjunction with GIS. Specialized users in developed countries might be most interested in creating Google Earth files to share their data with the general public. In some cases, they may also want to share with colleagues, agencies, or organizations that don't have access to a more sophisticated GIS.

The created Google Earth file is expected to be useful to all four potential user groups. General users might be more likely to access and use the file for general informational and exploratory purposes, while specialized users would be more interested in accessing the GIS data and creating their own files to share with others.

3.7 Concluding Remarks

If similar Google Earth files are to be created in the future, it will be important to know the intended audience. If the file is being created solely for the purpose of disseminating GIS data to colleagues with access to sophisticated GIS software for example, then Google Earth is not the right choice for distribution because of its limitations for data manipulation and analysis. But if the file is being created as classroom lesson or museum exhibit, it will be necessary to include general knowledge of the topic (basic biological and ecological information on seagrass for this example), focus on and effectively communicate a few important results, and include additional media such as photo and videos. The file created for this project was intended for a wide audience with all skill levels and interests. This is a demonstration project to help C3 understand the potential uses of a communication tool, like Google Earth, so it should not be assumed that the file is meeting its performance goals and reaching all the intended user groups. Once C3 understands the potential, it will be able to use this project to then help target specific audiences, and develop materials to suit those needs.

One way to test the usability of the file would be to conduct surveys to determine who the user groups are and how the individuals are using the Google Earth file. The evaluation could be used to make changes to the file accordingly. Focus groups could be held with the identified user groups to develop criteria to evaluate the Google Earth file and determine if it is meeting their needs. Some type of usability evaluation is very important for the file to be an effective conservation tool.

There are numerous possibilities for this file such as the basis for a classroom lesson plan, basic seagrass information for the general public, data dissemination for local and regional interested parties, and guidelines for future similar baseline seagrass mapping projects. The file can be easily and freely distributed either via email or as a download from C3's website (should they choose to make it available). Although this file was created specifically for seagrass conservation for C3, the model could be applied to any ecosystem or natural resource issue for any organization or agency. The use of Google Earth opens endless possibilities for easy data dissemination, collaboration, and education to a wide-audience across the globe and creates a framework for integrating not only data, but education and science.

CHAPTER 4: DISCUSSION AND CONCLUSIONS

4.1 The need for Community based conservation

Developing countries such as the Comoros face significant barriers to conserving their natural resources. Some of these include government instability, inadequate enforcement, knowledge transfer to local communities, and inaccessible or outdated science and data (Lundquist and Granek 2005). The people in the villages of Bimbini, Sima and the surrounding area have direct effects on their marine environment. Deforestation and unsustainable agricultural practices are eroding the hillsides and causing increased sedimentation in the ocean (author's observation). On a daily basis, octopus and shellfish collectors break coral/rock where seagrass grows (author's observation). Harvesting sea turtles, cutting down mangroves, and fishing with poison are also common in the area (author's observation). Based on interactions with villagers, there appeared to be awareness that some of the se practices are unsustainable and they showed little interest in changing behaviors in order to protect the natural resources they depend upon. For example, many of the villagers enjoyed teasing about eating sea turtle because they knew it was something that they weren't supposed to do.

These attitudes toward conservation are not surprising for one of the poorest countries in the world. Planting food staples such as banana and cassava on their hillsides and catching as many fish as possible (even if it means poisoning everything in nearby areas) are understandably a higher priority than conserving seagrass. Sustainable resource use in developing countries must begin with poverty alleviation, community empowerment and participation, education, and alternatives. Francis and Torell (2006) refer to sustainable livelihoods as a practice to meet the goals of conservation and development. They refer to four principles for sustainable livelihoods: people-centered, participatory and responsive, sustainable, and empowering. These are important principles that include social, environmental, and economic integration. They may be integral for successful conservation and management of seagrass in the Comoros. It is impossible to effectively manage and conserve seagrass in the Comoros without considering the communities that depend on them as a resource. They need to be involved in the monitoring and management of their own resources and supportive of efforts taking place. They need training, employment, alternatives to the current destructive practices, and education.

4.2 Management needs, recommendations and future research for seagrass conservation in the Comoros

The following management recommendations are directed toward C3 but could also be completed by another non-profit organization or local governmental agency. The recommendations are meant to be realistic given the social, economic, and political framework of the Comoros. They fit within the context of creating sustainable livelihoods but only address management for seagrass based on the surveys completed for this project.

4.2.1 Education

As discussed in chapter 2, the need for education is a critical step toward seagrass conservation. Even though it is repeatedly called for by scientists and managers, very little seems to be taking place. While there has been an increase in scientific publications about seagrass (Orth et al. 2006), the transfer of knowledge to society and the public does not seem to be occurring. Public and community education about marine resources is even more important within the coastal community where the resources exist, especially in developing countries. Education and awareness of the importance of seagrass to the community specifically, is necessary to earn community support for any conservation measure. Education and campaigns to raise awareness within communities need to target specific issues facing the coastal communities in the area.

The development of an educational and informational Google Earth file for seagrass conservation will hopefully aide in education and outreach of seagrass for the general public and the local people of the Comoros Islands. The file will be submitted to C3 for use on their website and if they choose, they may submit it to the Google Earth gallery for viewing by the general public. C3 has several programs and avenues for environmental education on the Comoros from summer camps to radio broadcasts. The Google Earth file can be used in some of C3's outreach and education efforts to help teach the value of and threats to seagrass in general and in the Comoros specifically. The file also allows for exploration of the seagrass data beyond the basic ‘where is it located?’ type of question. The application can continue to be updated with survey results from the other islands, adapted for specific local seagrass issues, and expanded to include other coastal ecosystem data and information.

Being able to view the results of the seagrass survey in Google Earth will not only make the data easily accessible for future studies, but could also provide the educational element which is often missing from conservation science or significantly lags behind the published science. One potentially effective tool is to utilize Google Earth as a media tool to reach many people of varying ages, backgrounds, skill levels, and geographic locations. Google Earth can reach both the scientist and the child in primary school using the same product.

If a monitoring program or other seagrass conservation efforts are going to take place in communities on Anjouan, such as Bimbini, the community needs to be supportive of the efforts for them to be successful. In order to determine local significance of seagrass resources and create community support for conservation efforts, surveys could be used to determine existing knowledge. This is also essential if outreach efforts will take place in the coastal communities that depend on the seagrass resources. Torre-Castro and Rönnbäck (2004) conducted surveys in Zanzibar to identify and describe the interactions between humans and seagrasses. Ideally, surveys similar to those conducted by Torre-Castro and Rönnbäck (2004) should be distributed to community members to determine the social-ecological links of seagrass that exist in the community. The surveys would help identify how the community benefits from the goods and services provided by seagrass, allow local knowledge to be incorporated into management plans and assess the current knowledge base so an effective education program could be designed. In the absence of formal surveys, an education program for the Bimbini Peninsula should focus on aspects of seagrass that are relevant to the community members. Based on observations of the community connections to seagrass, an education program in the area should focus on the importance of seagrass for fish and shellfish and the effect of land use practices on the surrounding nearshore marine environment, including seagrasses.

4.2.2 Monitoring

Monitoring seagrass is important as a tool for improving management practices and for detecting change in the status and condition of the seagrass (McKenzie and Campbell 2002). There is no universally correct way to implement a monitoring program. The type of monitoring program will depend on the reasons for monitoring and the parameters (physical and biological) chosen to monitor (McKenzie and Campbell 2002). Parameters need to be logistically and financially achievable but still be able to detect change. For the Comoros, the baseline maps from this project could be used as a starting point. The parameters measured in this study: depth, sediment type, percent cover, and species composition, could continue to be recorded with minimal equipment and training and are commonly measured parameters in existing monitoring programs (McKenzie and Campbell 2002). A monitoring program in the village of Bimbini or another coastal village in the Comoros, could provide a sense of resource ownership and promote stewardship of marine resources, raise community awareness of coastal issues, educate the community on the importance of seagrass, empower the community through participation, and encourage communication and relations with management agencies.

Based on the observed lack of interest from the people in the village of Bimbini, it may be difficult to establish a community-based monitoring program. However, sufficient education and outreach prior to implementation of a monitoring program, may invoke community support and interest in the idea. If motivation is still lacking for a volunteer monitoring program, a funded monitoring project that could create jobs for some community members should be considered. Volunteer or paid monitoring will require some amount of training. C3 is in a good position to organize and conduct training given their connections with key community members, government and organizations. Community training during the project on seagrass mapping and survey methods was very minimal. A one-day training session was held with three members of a local environmental organization. A similar type of training, but over a longer period of time, would be necessary to implement an effective monitoring program.

4.2.3 Continue building on baseline maps

Limited time and monetary constraints during the project prevented the completion of baseline seagrass mapping of the entire Anjouan Island. With access to the free imagery provided by Google Earth and the digitized seagrass bed layer created in ArcGIS, C3 could complete the baseline map of seagrass occurrence. Points or transects in those areas could then be used in those areas to verify the results from this initial survey. Due to the remoteness of Anjouan, some areas such as the northern part of the island may not be accessible by road. However, areas such as Pomoni, Moya, Ouani, and Bambao can be accessed by road and might be a good starting point for continuing the seagrass mapping effort initiated by this survey.

The results of this survey, together with the results from additional surveys conducted by C3 on the other two islands, would provide a complete picture of seagrass composition and distribution for the Comoros Islands as a whole. This will also add to the greater knowledge base for global seagrass distribution and diversity. The base maps, GIS, and Google Earth file created for this project can be used by local government agencies and non-profits such as C3, as a foundation on which to build and add more data. Additional data sets such as social and economic information (population, income, etc.), biological (flora, fauna, etc.), and physical (terrain, bathymetry, etc.) will allow for management of more complex environmental and human interactions. A detailed geospatial database of seagrass information is an important tool for evaluating many environmental questions such as: seagrass population change over time, the value of seagrasses as nursery habitats, their importance to adjacent fishing grounds, their value for marine protected areas, and the evaluation of land-sea connection, specifically watershed impacts.

4.3 Conclusion

This baseline seagrass study contributes to a description of seagrasses in the Comoros Islands, a remote and little studied area in the Western Indian Ocean region. The results of the survey indicate a high species richness for Bimbini Peninsula compared to seagrass beds worldwide (Green and Short 2003). As expected, species composition and distribution in the Bimbini Peninsula proved to be similar to that of northern Mozambique, a region in close proximity to the Comoros. Seagrass beds represent a highly valuable part of the tropical coastal zone. However, they still receive less attention than other coastal ecosystems in terms of research and management. The Comoros faces challenging environmental problems such as deforestation, soil degradation, and mechanical damage to intertidal zones by octopus and shellfish collectors, pollution from household waste, and harmful fishing practices. Specific management recommendations for seagrass in the Comoros are to continue building on baseline maps by completion of baseline mapping on Anjouan and addition of more GIS layers; targeted education efforts for coastal communities; and following education efforts, implementation of a monitoring program.

As a way to promote seagrass conservation and share the survey results, a Google Earth file was created containing background information on seagrass biology, a description of survey methods, and results from this baseline survey. The Google Earth file created will provide C3 an easy way to visualize results from the survey, add additional data, freely distribute the packaged geospatial data in the form of a .KMZ file, and promote awareness of seagrass ecosystems. The file created for this project was intended to be used by management agencies, non-governmental organizations, scientists, and the general public in developed and developing countries. The file can be easily and freely distributed either via email attachment or as a download from C3's website (should they choose to make it available). Further studies on the usability of the created product are recommended to ensure its effectiveness as a conservation tool.

Although this file was created specifically for seagrass conservation for C3, the model could be applied to any ecosystem or natural resource issue for any organization or agency. The work presented in this project was designed to highlight the many technologies that can make education and outreach more effective at reaching target audiences. The final KMZ file highlights one of the ways that science can be brought into non-traditional learning environments where the message of seagrass conservation may have a chance of being heard by the communities of people that depend upon them for the ecosystem services they provide. The use of the Google Earth platform creates many possibilities for easy data dissemination, collaboration, and education to a wide-audience across the globe and creates a framework for integrating not only data, but education and science.

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Appendix A. Species identification sheets

SEAGRASS SPECIES CODES

Cs *Cymodocea serrulata*

- Serrated leaf tip
- Wide leaf blade (5-9mm wide)
- Leaves 6-15cm long
- 13-17 longitudinal veins

Cr *Cymodocea rotundata*

- Rounded leaf tip
- Narrow leaf blade (2-4mm wide)
- Leaves 7-15 cm l o n g
- 9-15 longitudinal veins
- Well developed leaf sheath

Ea *Enhalus acoroides*

- Very long ribbon-like leaves with inrolled leaf margins
- Thick rhizome with long black bristles and cord-like roots
- Leaves 30-150 cm long

Th *Thalassia hemprichii*

- Short black bars of tannin cells on leaf
- Thick rhizome with scars between shoots
- "Sickle" shaped leaves
- Leaves 10-40 cm long

Hu *Halodule uninervis*

- trident leaf tip
- 1 central vein
- Usually pale rhizome, with clean black leaf scars

Hp *Halodule pinifolia*

- rounded leaf tip
- 1 central vein
- Usually pale rhizome, with clean black leaf scars

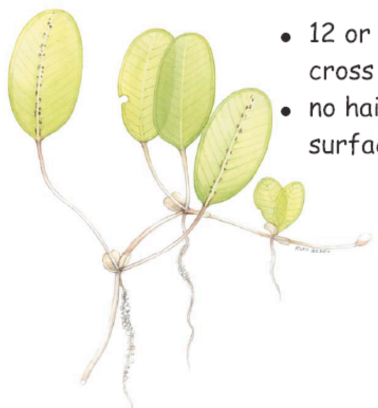
Hx

Hu or **Hp** species cannot be distinguished (i.e., not sure of the ID)

Compiled by the Marine Plant Ecology Group, Northern Fisheries Centre CAIRNS, AUSTRALIA July 2002

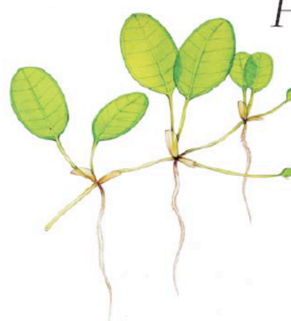
SEAGRASS SPECIES CODES

Ho *Halophila ovalis*



- 12 or more cross veins
- no hairs on leaf surface

Hm *Halophila minor*



- Less than 12 pairs of cross veins
- Small oval leaf blade

Hy

Ho or **Hm** species cannot be distinguished (i.e., not sure of the ID)

Si *Syringodium isoetifolium*

- Cylindrical in cross section
- leaf tip tapers to a point
- Leaves 7-30cm long

Hd *Halophila decipiens*

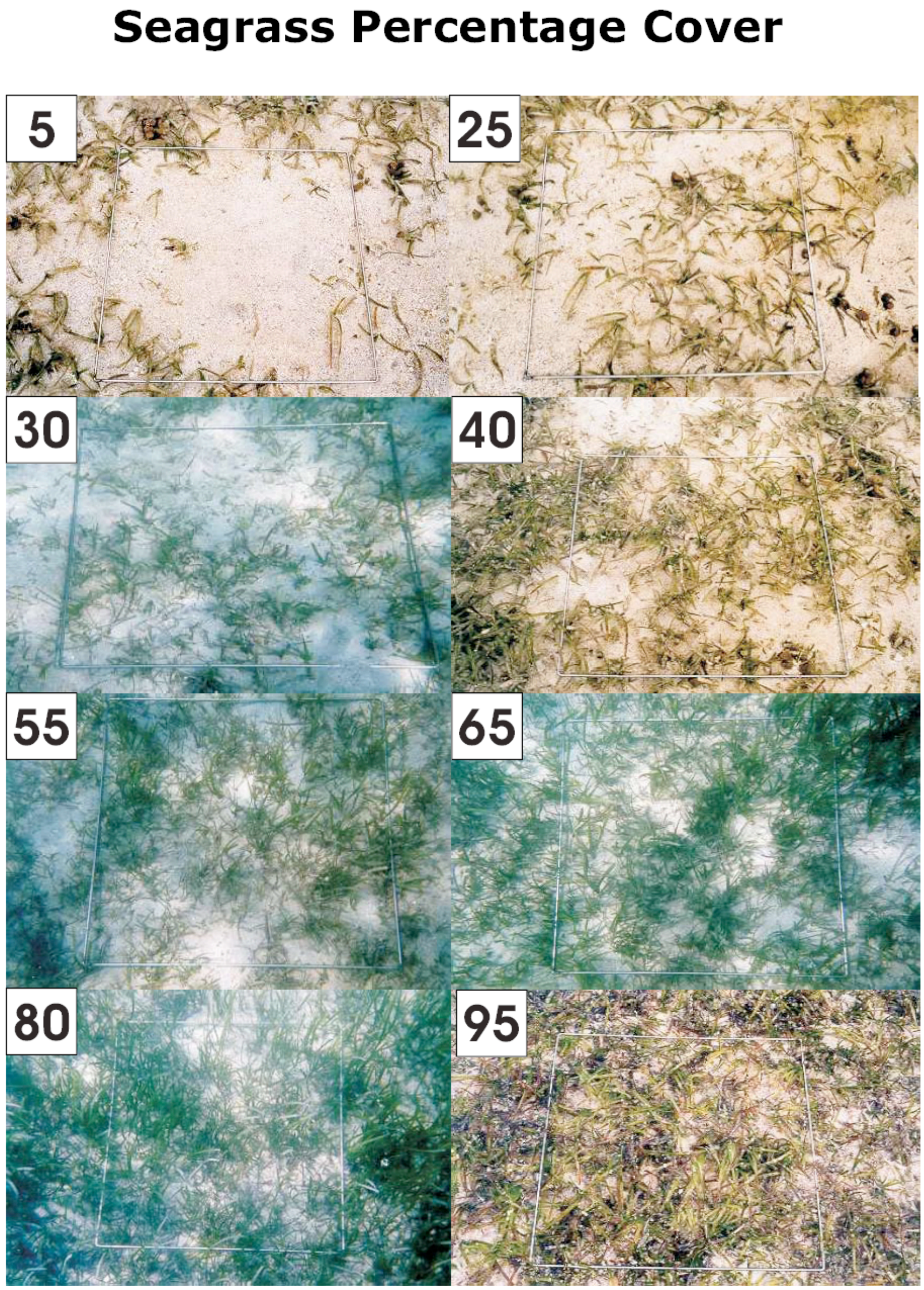
- Small oval leaf blade 1-2.5cm long
- 6-8 cross veins
- Leaf hairs on both sides

Tc *Thalassodendron ciliatum*

- cluster of leaves on elongate shoot
- "Sickle" shaped leaves with serrated tip
- ligule present
- rhizome "woody"

Compiled by the Marine Plant Ecology Group, Northern Fisheries Centre CAIRNS, AUSTRALIA July 2002

Appendix B. Standard percent coverage categories



Appendix C. Data sheet

C3-Comores Seagrass Data Sheet 2007

Observers: ________________________ Location: ______________________________ **GPS** Start Point:__________ End Point: __________

Date: ____/____/____ Start Time: __________ End Time: ____________ Compass bearing: _______°

Tide: High Low Incoming Outgoing

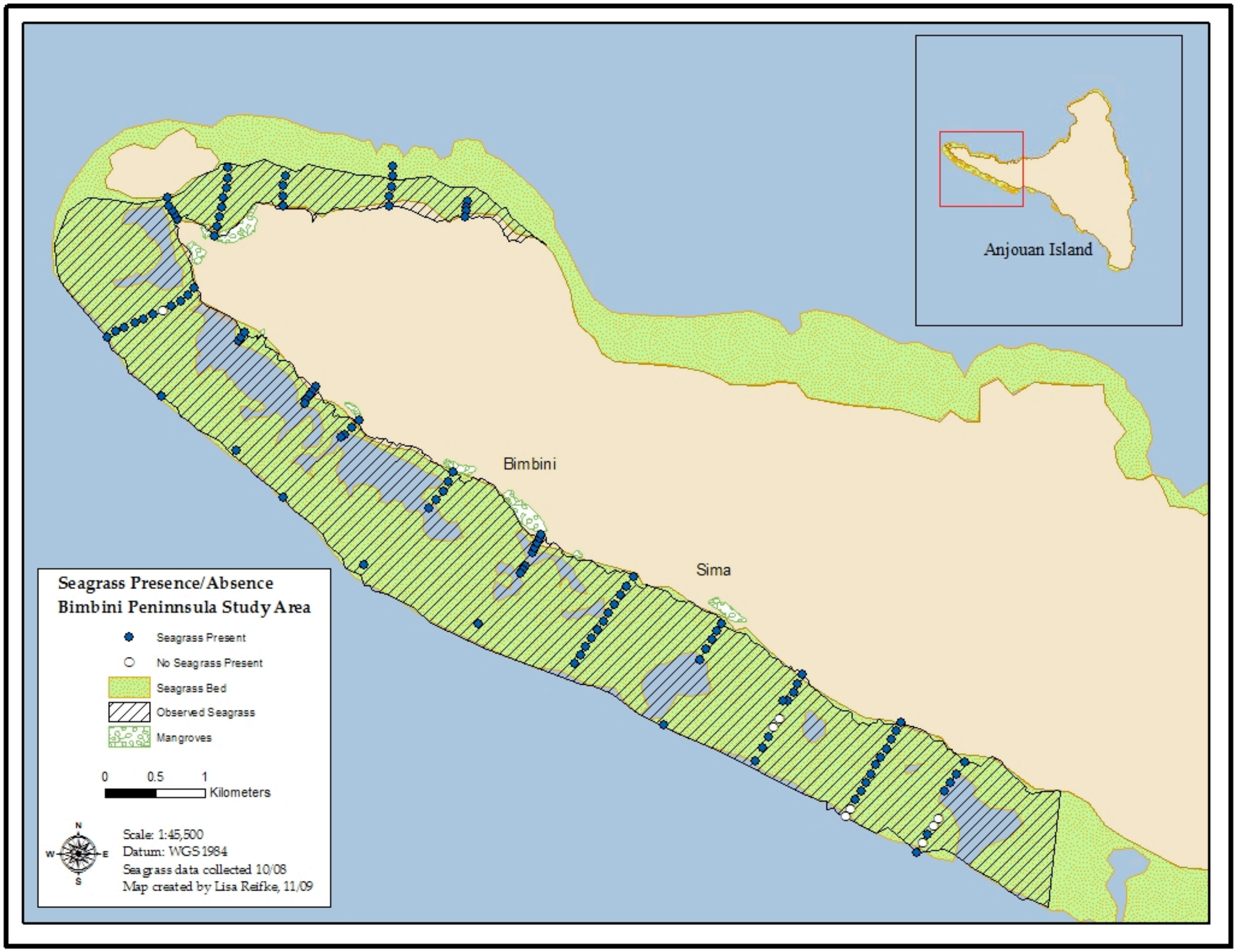
Point (GPS)	water depth (cm)	Quadrat	Sediment (M, Fs, S, Cs, G)	√ Photo	% seagrass cover	canopy height (cm)	% of Seagrass Species Composition									
							Th	Cr	Cs	Hu	Hw	Si	Tc	Ea	Ho	Zc
1		1														
		2														
		3														
Comments:																
2		1														
		2														
		3														
Comments:																

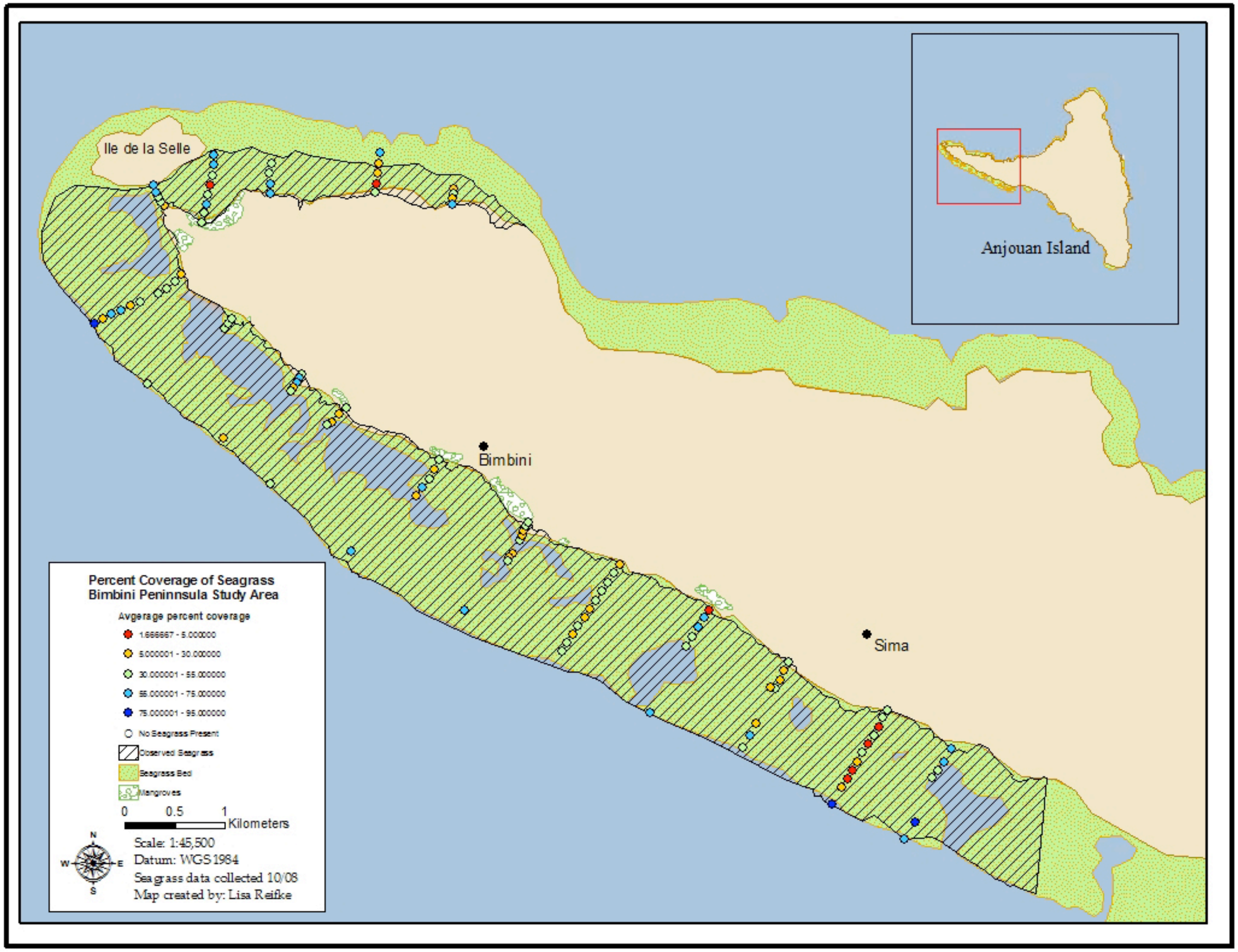
M=mud, Fs=fine sand, S=sand, Cs=coarse sand, G=Gravel
Th=Thalassia hemprichii, Cr=Cymodocea rotundata, Cs=Cymodocea serrulata, Hu=Halodule uninervis, Hw=Halodule wrightii, Si=Syringodium isoetifolium, Tc=Thalassodendron ciliatum, Ea=Enhalus acoroides, Ho=Halophilia ovalis, Zc=Zostera capensis

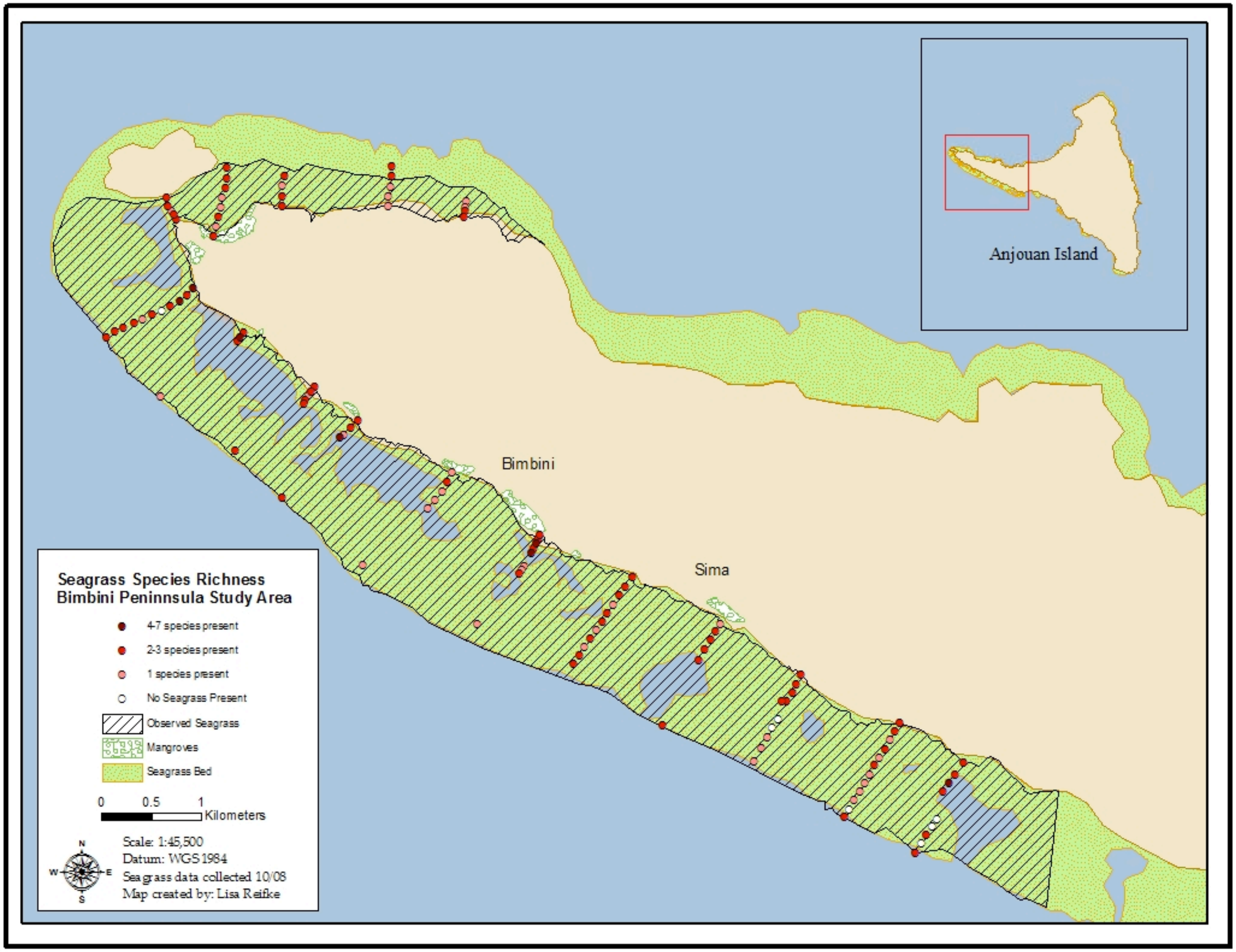
C3-Comores Seagrass Data Sheet 2007

Point (GPS)	Water depth (cm)	Quadrat	Sediment (M, Fs, S, Cs, G)	√ Photo	% seagrass cover	canopy height (cm)	% of Seagrass Species Composition									
							Th	Cr	Cs	Hu	Hw	Si	Tc	Ea	Ho	Zc
3		1														
		2														
		3														
Comments:																
4		1														
		2														
		3														
Comments:																
5		1														
		2														
		3														
Comments:																

Appendix D. Maps created in ArcGIS




Ile de la Selle
Bimbini
Sima
Anjouan Island
Percent Coverage of Seagrass
Bimbini Peninnsula Study Area
Avgerage percent coverage
1.666667 - 5.000000
5.000001 - 30.000000
30.000001 - 55.000000
55.000001 - 75.000000
75.000001 - 95.000000
No Seagrass Present
Observed Seagrass
Seagrass Bed
Mangroves
0 0.5 1
Kilometers
N
W
E
S
Scale: 1:45,500
Datum: WGS 1984
Seagrass data collected 10/08
Map created by: Lisa Reifke


Anjouan Island
Bimbini
Sima
Seagrass Species Richness
Bimbini Peninnsula Study Area
4-7 species present
2-3 species present
1 species present
No Seagrass Present
Observed Seagrass
Mangroves
Seagrass Bed
0 0.5 1
Kilometers
Scale: 1:45,500
Datum: WGS 1984
Seagrass data collected 10/08
Map created by: Lisa Reifke