Mangroves, a Blue Carbon Perspective: Communicating restorative benefits of mangrove ecosystems in rural KwaZulu-Natal, South Africa.

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This project could not be completed without the help of my wonderful committee. They have reviewed this work, shared their comments and given advice. I'm grateful for the entire committee. Thank you all so much.

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Contents

Table of Figures

1. Abstract

Blue Carbon is defined as carbon that is collected and stored in sediment from sources such as seagrass, salt marshes, and mangrove forests. This project focused on mangrove forest sequestration rates and how local communities can contribute to the preservation of these systems. These forests are being degraded for various reasons such as timber and fuel for fire. This project focused on an area of South Africa known as Kosi Lake, where mangroves occupy a small area along the North Eastern coast (Quisthoudt, 2013). Using Global Forest Watch, I determined rates of mangrove degradation over time and look at trends in which the forests are heading. Additionally, the study quantified and communicated to policy makers the importance of mangrove ecosystem services. This was done by providing the Tembe Tribal Council a list of recommendations that will be instituted at the local level; it contains information quantifying how much the community can gain through preservation. Given that communities can be incentivized to protect their ecosystem services if there is a greater alternative to not destroying them, I also designed and provided educational materials and hosted workshops in eManguzi, South Africa. The results demonstrated that perceptual changes are possible at the community level throughout meetings with fishermen and educators.

2. Motivation for Work

The Carbon Institute inspired me to focus on greenhouse gas mitigation, while Scripps Institution of Oceanography (SIO) inspired me about marine conservation. The information these organizations provided me gave me the knowledge to confidently educate others on mangrove restoration and their carbon sequestration potential. Natural ecosystems can often serve as the best mitigating factors from climate change.

Communities that rely on natural ecosystems to survive and thrive are often the same ones that are impacted by climate change the earliest. In KwaZulu-Natal, South Africa, there is a community, eManguzi that relies on the Kosi Lake system to survive. I lived and worked in this area with the Peace Corps and saw firsthand how various climate related emergencies were emerging. Being at Scripps, I learned about carbon offsetting through payments for ecosystem services. I knew I wanted to help eManguzi earn money to fund projects throughout the community.

This interdisciplinary project is being done as my Capstone Project for the Master of Advanced Studies in Marine Biodiversity and Conservation at Scripps Institution of Oceanography in San Diego, California.

3. Introduction

Figure 1: Area of focus in South Africa

3.1 Climate Change

Climate change is happening on a global level and no matter where you are, using natural processes are some of the ways to mitigate against these effects. There are existence values in protecting natural ecosystems which can change depending on what country you are in. Anthropogenic caused greenhouse gas (GHG) levels have been increasing rapidly and we need every available resource to mitigate the hazards they pose to the health of all species on this planet. Reductions in all sectors will help keep the planet from passing the 1.5^{o}C threshold recommended by the United Nation's Intergovernmental Panel on Climate Change (IPCC). The United Nations Environmental Program has created a list of seventeen sustainable development goals with targets to be reached by 2030. Preservation and restoration of certain ecosystems can contribute to the success of several of the development goals such as: food security, economic development through alternative livelihoods, sustainable development, climate action, life below water, life on land, and capacity building through partnerships.

3.2 Blue Carbon Explained

In coastal ecosystems, photosynthesis takes place and deposits carbon into the sediment. It is buried through the roots of various aquatic plants. The ecosystems that capture this carbon are those of mangroves, seagrasses and salt marshes. The roots go deep into the sediment where the carbon is taken out of the cycle. There is a layer of water that creates an anoxic environment that prevents the carbon from being released back into the atmosphere (Thomas, 2014).

In these forests, most of the carbon is stored belowground, unlike terrestrial systems where the carbon is stored throughout the plant. If there is a disturbance of the soil or the trees and grasses are cut down, this releases the stored carbon once it hits the air. The deleterious results of these actions cause carbon to reenter the atmosphere and remove carbon capturing plants.

The rate of sequestration varies depending on the type of ecosystem. Mangroves in general have the potential to sequester 1,450lb of carbon per hectare per year (Alongi, 2012).

3.3 Mangrove Ecosystems

Mangrove are halophytic trees that grow along the fringes of lagoons and estuaries. These salt tolerant trees serve several very important mechanisms in the ecosystem such as; sediment stabilization, nursery habitats for juvenile fish, storm protection, and carbon sequestration (Sidik, 2018). Mangroves are highly productive ecosystems that were overlooked until about fifteen years ago. The global coverage of these forests is around 2% yet they account for 10-15% of organic carbon stored in marine environments (Alongi, 2012). The roots of mangroves are where most of the carbon is stored (Sidik, 2018). The belowground root systems comprised of a lot of dead roots and soil keep most of the carbon underground. The sequestration happens rather quickly in newer trees but begins to taper off as the forests get older. The average burial rate of inorganic carbon comes to around 24 TgC $year^{-1}$ (Alongi, 2012). Since these forests grow quickly, the roots begin to die off but are still storing nutrients and inorganic carbon. Since these roots are underwater, it creates an anoxic environment for the carbon to be stored underground. Disturbance of this soil releases the inorganic carbon and converts in to carbon dioxide (CO_2) once it reaches the air.

Mangrove ecosystems serve several unique functions along regions where they are prevalent. These salt tolerant trees serve such services as; nursery areas for fish, prevention of coastal erosion, decreasing wave action and storm surges, carbon sequestration, and nutrient cycling. Mangrove forests are being degraded at a rate of 4.3% annually (Gardner, 2018). We need local communities to consider alternatives rather than development. It has been shown that fish populations increase in abundance along the fringe of mangroves (Aburto-Oropeza, 2008).

Rising sea level, inundation, storm surge are all reasons why mangroves need to be restored (Khan, 2012). Determining natural solutions to these issues will prove beneficial in the long term (Blankespoor, 2017). Conveying the importance of why we should care about blue carbon is a vital step is their restoration. Identifying the role that mangroves play in the ecosystem is pivotal in their preservation (Erwin, 2009).

3.3.1. Mangroves in eManguzi, South Africa

In eManguzi, South Africa, mangroves are slowly being degraded due to deforestation. Some protections are in place in certain areas, but the forest extent goes far beyond the protections. Coastal communities use the forests for fuel for fires and building materials. If the value of these trees is worth more than people in the community think, then they will want to preserve the forests.

eManguzi is located near three adjoining lakes that the villagers rely on for fish, water, and leisure. There are six different species of mangroves that exist throughout the Kosi Lake system. The white mangrove (*Avicennia marina*) were impacted the most by anthropogenic causes. They were being used for building materials such as thatch roofs. They informed me that the red species (*Rhizophora mucronata*) are rebounding the fastest. It was evident along the fringes of the lake where there were roots growing everywhere with new growth was observed. The land is protected but The Marine Living Resources Act allows for catch for sustenance. If the mangroves continue to be cut down, then there could be deleterious impacts on this local fishery. Isimangaliso Wetland Authority oversees the preservation of the fragile ecosystem. Relaying current information to this authority would aide in the restoration plans. The main species of mangroves that will be focused on are; *R. mucronata* (Red mangrove), and *A. marina* (White mangrove).

3.4 Ramsar Designation

Kosi Lake was designated as a Ramsar site (Ramsar Regional Center, 2017) in 1991. Figure 3 below shows the extent of Ramsar site 527. The Ramsar Convention is an intergovernmental panel that came together for the management of wetlands that serve as critical habitat for species. This means that wetlands designated under Ramsar's strict guidelines are of high global significant importance due to the ecosystem services it provides. The flora and fauna that exist in the Kosi Lake area are unique to this region and help the area to flourish. The guidelines that lead sites to be designated must fall into nine different criteria. The information has not been updated since 1995 and has no mention of blue carbon in it. The status on the mangrove distribution needs to be updated as there has been inconsistent data pertaining to the hectares covered. The addition of blue carbon to the newest guidelines of the Ramsar site could further promote the protection of the ecosystem. Creating a tenth criteria that includes organic carbon sequestration should be included into the newest set of guidelines. This addition could help designated more Ramsar site throughout the world.

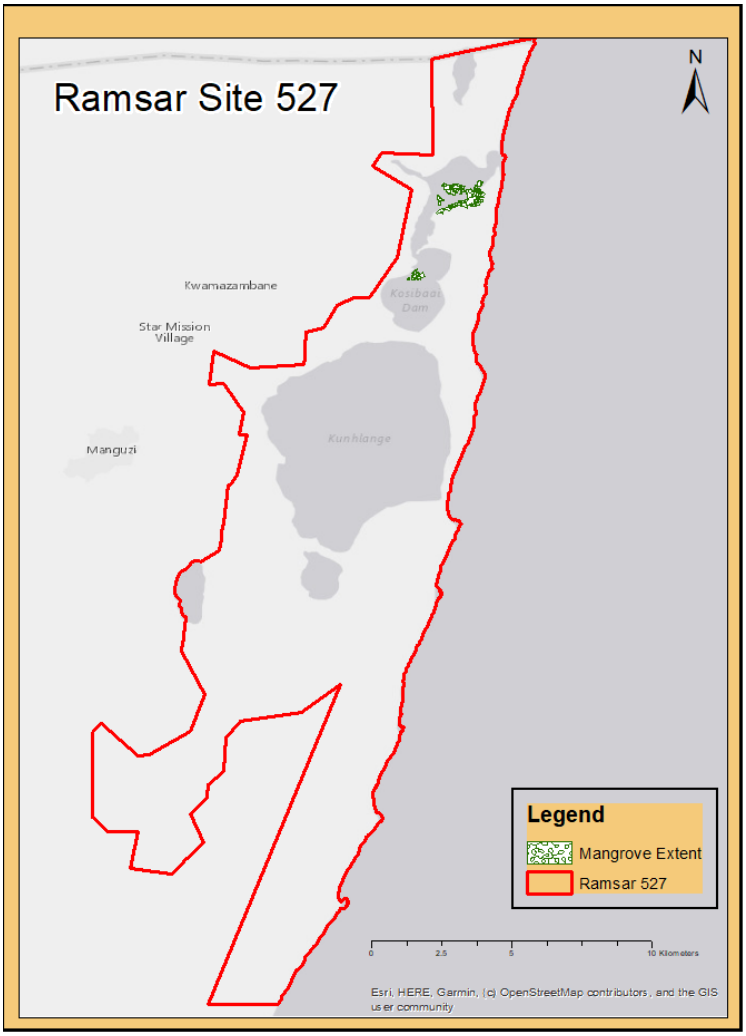

Figure 3: Ramsar Site Map with mangrove coverage

3.5 Management in Kosi Lake

Isimangaliso Wetland Authority is tasked with protecting the area under the umbrella of Department of Forestry. Put in place is a current framework of an Integrated Management Plans (IMP). These IMPs are in place to make sure the communities that survive off these areas have a voice. Each IMP is updated every five years, the current plan is 2017-2021.

The development of three Estuary Management Plans for iSimangaliso is governed by section 34 of the National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008) (ICM Act) read with the National Estuarine Management Protocol 2013. However, implementation is also governed by the World Heritage Convention Act (Act No. 49 of 1999) (WHC Act) read together with the ICM Act. This is because iSimangaliso is required to conduct its affairs in accordance with an Integrated Management Plan (Section 21 (2) WHC Act). The Department of Environmental Affairs (DEA) has also published Guidelines for the Development and Implementation of Estuarine Management Plans (DEA, 2015).

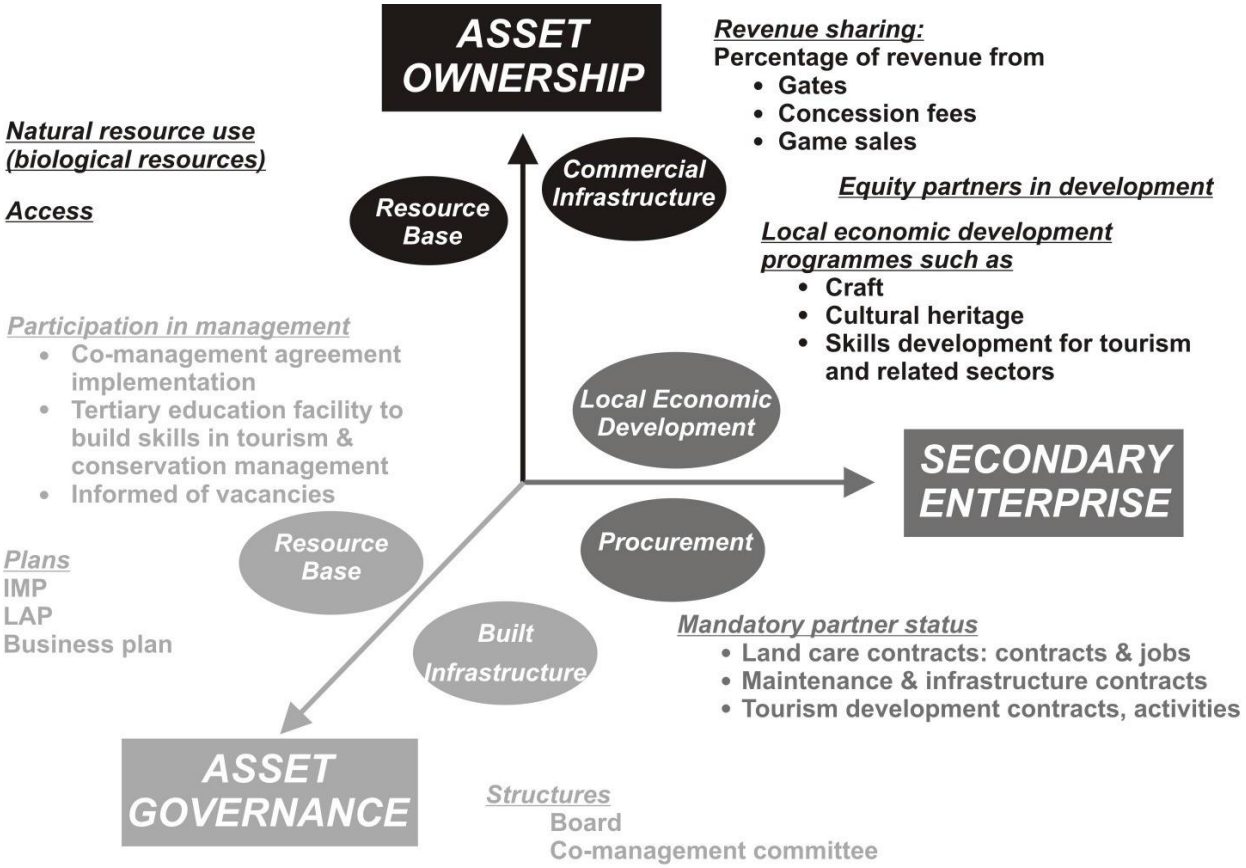

Figure 4: Isimangaliso Wetland Authority Framework of Co-Management

This framework is set up to keep the community involved and invested. The recognition that this area has ecotourism benefits serves the people the most. Revenue sharing through concessions and craft sales help drive the local economy. This framework is missing the payment for these ecosystem services. If blue carbon accounting were added to this framework then there could be a boost in economic development. In theory, everyone will be able to benefit should payments occur.

4. Goals

This project aimed to bring fundamental knowledge to policy makers to bring about restoration of mangrove ecosystem services. In addition to recommendations to policy makers, this project also aimed to increase communication about these ecosystem services and build capacity at the community level. A bottom up approach was used because perceptual changes at that level could have the greatest impact.

If perceptions of these fragile ecosystems are changed, then there would be more incentive to protect them. Workshops and capacity building are factors that could contribute to these perception changes.

Some deliverables that would result from this project are:

- A story map of the areas with the greatest levels of degradation over time that can be shared using ArcGIS online.
- An economic analysis of the social cost of carbon and monetary gains through payments for ecosystem services.
- A list of recommendations that policy makers can use to create their own mangrove management plans.
- Training materials that can be distributed throughout communities in areas with the highest levels of mangrove degradation such as; pamphlets and infographics that can be shared.

These benefits will inspire others to create policy frameworks that can contribute to the preservation of other mangrove ecosystems throughout the world.

5. Methods

5.1 Mapping of Study Area

Using historical data, I was able to create a map of the Kosi Lake region that showed where there was significant loss along the fringes. This was all publicly available through the South African forestry watch. I also gathered data from Global Forest Watch and Ocean wealth of the mangrove distribution through 2010.

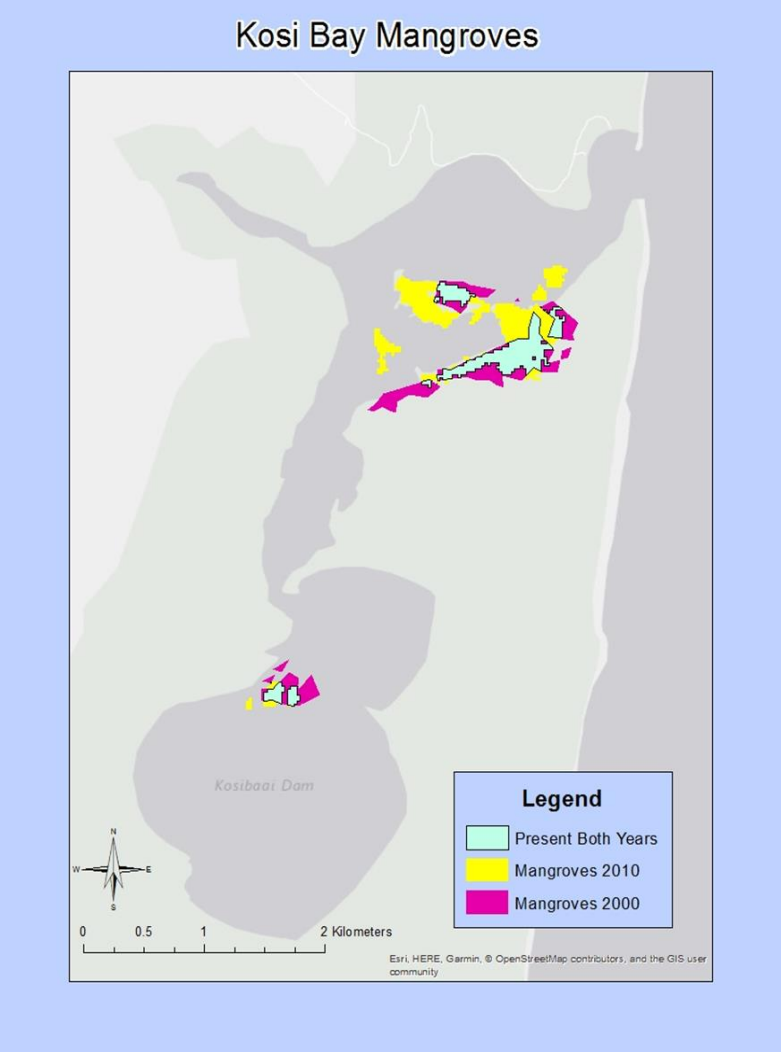

Figure 2: Kosi Lake system with Mangrove extent

The extent of mangrove coverage in Kosi Lake and decadal changes is shown in figure 2. This includes all the species that exist in the region. The total number of hectares are around sixty-one. The decadal changes that are apparent show that some species are beginning to move further north into the estuary. A complete GIS analysis is being finished now and I would like to see that data before making final conclusions. The current data set is based on historical data from 2010. We surveyed the perimeter of the lakes noting areas where there were trees cut down. We then examined the trees to determine which species it was destroyed.

5.2 Economic Modeling

The formula that I used to come up with the amount that could be made is as follows, it is a cost-based model:

The number of hectares of mangrove trees in the Kosi Lake system are around 61 hectares. Multiplied by the social cost of carbon in the year 2018, \$40/MtCO_2 per year (OECD, 2018)

1ha=658Kg/CO_2 annually of sequestrated carbon

61ha x 658Kg/CO_2= 40,138KgCO_2/ha or 40.13MtCO_2 Annually of sequestered carbon

40.13MtCO_2 x $40= $1604 USD annually or R22,495 ZAR

This economic model is an estimate because the pricing of carbon is dynamic. When meeting with the council, I used this estimate with the hope that carbon pricing will increase in time.

5.3 Education and Community Engagement

To complete this work, informal qualitative interviews were conducted with people in the community such as fishermen, local leaders, educators and staff from Isimangaliso Wetland Authority. This approach proved useful because there were no rigid questions to ask. People felt more comfortable to speak freely of the situation that was happening. There was worry that recorded responses would impact them negatively in the community. The meetings were done with the local fisherman on the lake. They took me out to the fish kraals (area where fish are trapped) to show me how the trees were used.

After meeting with the administrative secretary of the Tembe Council, there was immediate interest in economic benefits that eManguzi could gain. He was interested in companies that would want to invest in the community and businesses that would be created through ecotourism. The presentation was well received by everyone on the council. The blue carbon side of the equation seemed to get lost in translation, but the common theme of needing to fight climate change was important. It was understood that anything that could mitigate against the changing environment was necessary and such natural measures were apparent.

They had various questions such as; who are the beneficiaries of this project? how and where will the money come from? are there other payments for ecosystem services that the area can take advantage of? would the money be coming directly to eManguzi or would it have to go through The Department of Agriculture? how would the money funnel its way to the community where most of the problems arise?

Workshops and outreach were done at the local education center and schools. The workshop was open to anyone in the community that was interested in attending. This was similar to what the council was informed about but on a much simpler level. Getting the information out was crucial, the plan was to circulate the workshop information through local principals I used to work with. The staff at the center informed people of the workshop whenever they came in for information or another class. The concentration was on not cutting the trees down and alternatives timber sources that could be used. Outreach was done at two local high schools and one primary school during their natural science class. The lesson plans were created for different learning levels.

5.4 Policy Recommendations

The issue? There's been substantial degradation of mangroves in Kosi Lake. What can be done to mitigate against this issue? These forests serve a multitude of functions such as; nursery habitats, storm surge breaks, sediment stabilizers, carbon storage, and timber. We want to

prevent the timber from being used as a building material. Are there alternative fuel sources that can be used instead of cutting down the trees?

When it comes to greenhouse gas mitigation; blue carbon should be considered a major sink. The degradation of mangroves has a negative impact on the local ecosystem. The benefits of keeping the forests intact far outweighs the costs of destroying them. Having different mechanisms to sell back carbon credits to countries as offsets ensures the conservation of them. Refining programs like REDD+ to consider seagrass beds as sinks will only increase the value brought to the ecosystem. There are also the benefits to fisheries (Aburto-Oropeza et al., 2008) and other climate change impacts. Using a lower discount rate will benefit the forests in the long term.

Determining the total economic value of the ecosystem brings in all the aspects of why to keep the ecosystem intact. Should anything be done to change this, the contingent value needs to be taken into consideration by everyone living in that community. International unity and agreement on a carbon offset price should be considered. This would allow for countries to set a goal for how much of these areas they are willing to protect. The role of mangroves in their ecosystem of sequestering carbon has been understated and not represented in the Ramsar guidelines.

This serves as a reference to incorporate blue carbon into the Ramsar guidelines. Listed below are several recommendations that should be considered when policy makers create plans to manage these fragile areas.

5.4.1 Policy Recommendations:

1. Account for blue carbon before considering the deforestation of mangroves.
2. Consider all ecosystem services mangroves provide such as; habitat for juvenile fish, prevent high wave action, carbon sequestration, sedimentation.
3. Run a contingent valuation of residents in an area where mangroves are present.
    a. Measure the existence value of the forests from the residents
4. Determine a price of how much residents are willing to lose by conserving the forests. The possibilities making up that through the PES system. .
5. Consider the effects of what will happen when all the soil is disrupted, and carbon is oxidized when the forest is cut down.
6. The need for conservation of biological diversity and wildlife should be considered.

7. An international agreement on the price of each carbon offset. The agreement would be based up a certain price. This will ensure the value to conserve the ecosystem remains a priority.
8. Determine a valuation for seagrass beds and salt marshes in the area.

5.4.2 Community Level Recommendations:

1. Adopt a phased approach, beginning with capacity and awareness building. Highlighting changes in climate.
2. Community engagement involved in all stages of a payment for ecosystem service (PES) project.
3. Build community level technical, legal and financial capacity to undertake the PES/carbon projects.
4. Recognize that communities are seeking ways to generate cash from mangrove forests and other natural resources.
5. Remove barriers for starting ecotourism businesses.

6. Observations

The degradation of white mangrove (*A. marina*) species is the most noticeable. It is being used as a tool for building primarily (rafters in ceiling). There were instances of people being seen cutting down these trees and walking around with them on their heads. The red mangroves (*R. mucronata*) seems to be increasing steadily. Upon speaking with the local fisherman, they have concluded that this is growing everywhere. There is reason to believe that this would be the candidate species for afforestation. The range of this species is along the eastern coast of Southern Africa and its sequestration rates are comparable to other species. The rate of growth in the *R.mucronata* is much faster than the *A.marina*. The *R.mucronata* was growing between the pneumatophores of *A.marina.*

Meeting with the council, they were very receptive of the idea of afforestation in exchange for carbon credits. The main goal would be to locate an organization that would be willing to buy the offsets. Since this is a smaller operation, there is a finite amount of space that the organization would be able to buy. This would work out for all parties involved because a smaller scaled

project could be easily managed. The community would greatly benefit from the money being made, their suggestions would be to use the funds to build community centers and fix up certain roads to increase connectivity throughout the area. The discussion of ecotourism came up as well. Business would be able to take people out into the forests for game viewing and exploration. Bringing businesses to eManguzi would ensure jobs and this delighted the council.

The concept of blue carbon seemed to get lost in translation. It's understandable because the concept is very new and is a tough one to grasp. The sequestration rates were understood and where the carbon was stored was understood but how the community would benefit was also lost in translation. There seemed to be a lot of confusion as to how long the carbon would be stored. Climate change was very much understood though, the idea that anthropogenic changes are happening was apparent. The community doesn't seem to care much about the pollution aspect though.

7. Results

The results of this study can be interpreted as working. The level of perception changed was measured in the receptiveness of the entire proposal. Unfortunately, I will not know whether the Ramsar guidelines will be implemented until the current plans concludes.

The community workshop could've gone better. There were only 9 people in attendance. The people that attended were educators and principals in the area who were able to leave school to attend. An adjustment for the next time would be to have the workshop on a weekend so more people could attend. I would also focus on sending out a circular to the education department so people who are outside of eManguzi would know about it. The information was interpreted well but a lot of questions were raised in terms of how this will follow the CAPS curriculum. The idea of having an after-school workshop would've proved more effective.

7.1 Challenges

There are challenges that exist when creating a payment for ecosystems services. The main challenge is setting fixed carbon prices. These prices are dynamic from year to year with an ever-changing carbon market.

Another challenge that exists is convincing companies to buy the carbon credits. I think it would be best to go through third parties whose focus is to fund carbon projects. Another challenge is enforcement of protection of these forests. Since most of the region has people sporadically living throughout the area, it would be hard to enforce individuals cutting down the trees for usage. The incentives should go directly to the community that surrounds the areas. It would also be difficult to divide the incentives received between the people who directly live on the lake versus the ones who don't.

Local corruption also must be considered because whenever external money is received, there is a fight for it. It would be interesting to see how much money makes it to the individual person. A fund could be created to simply go to the improvement of the area such as building community centers or enhancing the educational experience of learners in the area.

8. Conclusions

Mangroves in Kosi Lake are highly productive ecosystems. The increase in these forests can help bring about a boost in an area that relies on subsistence living. This project was focused on communicating the importance of mangrove restoration with attention on afforestation as well. It was well received throughout the community with the intention of selling carbon credits. The recognition of the benefits would outweigh the costs of removing the *A.marina*.

Participation in payments for ecosystems could further bring about an economic boost in an area that doesn't have a lot. The people in the community would be the first to benefit from these payments. The tribal council has the final say in ways to divide up the monetary benefits. These actions could create enough incentive to decide not to continue to cut down the white mangroves. Since the red species is rebounding, this species would be a prime candidate for further afforestation. Funding afforestation would not only benefit eManguzi but would also help curb carbon dioxide in the atmosphere.

The benefits of a growing forest will also contribute to ecotourism. Since these systems are highly productive there are opportunities to take people out and explore them.

9. Future Applications

The goals of this work were to bring a model that is usable throughout the world while educating local communities on their ecosystem services. The same models can be applied throughout developing countries as a starting point for understanding their ecosystems and the monetary benefit they could receive. Governance in areas that rely on subsistence living are interested in finding additional income for their communities.

The knowledge that can be shared with these local ecosystems can really boost economics in the region. The improvement of the area can add to local tourism as well as fishery support. Identifying the best areas for afforestation and the right endemic species could provide more areas of habitat.

Nonprofits that focus on projects that contribute to ecosystem services can pair people or organizations to anyone that they want to fund. If someone wants to lower their carbon footprint or become carbon neutral, they can contribute annually to these ecosystem services. Having a third-party auditor complete the verification of growth will ensure that there is fair carbon pricing and the restoration areas are increasing.

Appendix

Sample lesson plans that could be taught at the secondary school level on blue carbon ecosystems.

Introduction to Coastal Ecosystems

SUBJECT	TEACHER	GRADE	DATE
Blue Carbon	Hilliard Hicks	High School	05/14/2019

OVERVIEW

This purpose of this lesson is to provide an introduction into coastal ecosystems. What benefit do these serve? How can humans benefit from the protection of these areas? The animals that exist in them. What is blue carbon?

Phases	Teacher Guide	Student Guide
Objectives	Define Coastal Ecosystems Introduce Blue Carbon	Learn about the basics of the coastal ecosystems and their role in Kosi. Learn about carbon in the environment.
Information	Oceans Estuaries Mangroves	How carbon is absorbed in the environment. The major sinks in the world. How marine environments play a role in the carbon cycle.
Verification	Popcorn questioning	Testing knowledge with other learners. Asks challenging questions for further information.
Activity	-Listing various species that exist in ZA (20mins) -Define the Kosi Lake system	As a group, try to come up with 10 species that benefit from Kosi Lake.

Summary	What was learned today? How does this system contribute to the success of the area?	Have the learners come up with questions for the next class. Discussion on things they would like to learn about and have learned thus far.

REQUIREMENTS

- Define an ecosystem. Where does Kosi Lake fall on this scale?

RESOURCES

- Marine Biology book
- Adding CO2 to water experiment

NOTES

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