COST-BENEFIT ANALYSIS OF MANGROVE RESTORATION FOR COASTAL PROTECTION AND AN EARTHEN DIKE ALTERNATIVE IN MOZAMBIQUE

CEADIR

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ACRONYMS AND ABBREVIATIONS

ANAMA	Associacão dos Naturais e Amigos de Madal (Association of Nature and Friends of Madal)
CBA	Cost-benefit analysis
CCAP	Coastal City Adaptation Project (USAID-funded)
CCP	Community Council of Fisherman
CEADIR	Climate Economic Analysis for Development, Investment, and Resilience
DPTADER	Direção Provincial da Terra, Ambiente e Desenvolvimento Rural (Provincial Directorate of Land, Environment and Rural Development) (Mozambique)
DW	Dry weight
EMUSA	Empresa Municipal de Saneamento e Mudanças Climáticas (Municipal Company for Sanitation and Climate Changes) (Mozambique)
Ha	Hectare
IDEPA	Instituto Nacional de Desenvolvimento da Pesca e Aquacultura (National Institute for the Development of Fisheries and Aquaculture) (Mozambique)
IIP	National Institute for Fisheries Research (Mozambique)
INGC	National Institute of Disaster Management (Mozambique)
MRV	Measurement, reporting, and verification
NPV	Net present value
RGGI	Regional Greenhouse Gas Initiative (US)
SLR	Sea level rise
tCO_2e	Metric ton of carbon dioxide equivalent
UEM	Universidade Eduardo Mondlane (Eduardo Mondlane University) (Mozambique)
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
USD	United States dollar

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EXECUTIVE SUMMARY

The Climate Economic Analysis for Development, Investment, and Resilience (CEADIR) Activity conducted a cost-benefit analysis (CBA) with financial support from USAID/Mozambique and the USAID Global Climate Change Office in Washington DC. The purpose of this analysis was to inform the decisions of the USAID/Mozambique-funded Coastal City Adaptation Project (CCAP) and the Government of Quelimane to protect the most climate-vulnerable residents in the peri-urban areas of this coastal city from climate change risks. This city and others along the coast of Mozambique are highly vulnerable to sea level rise, cyclones, flooding, and erosion (World Bank 2011). The CCAP project focused on the Icídua and Mirazane communities after consultation with the municipal government.

This study estimated the costs and benefits of mangrove restoration and an earthen dike alternative to reduce coastal flooding to protect the residents of these two communities. The analysis used CCAP data on the economic and environmental costs and benefits of mangrove restoration and evaluated it against the costs and benefits of a simple, earthen dike alternative. CEADIR conducted the CBA in a Microsoft Excel workbook that serves as a companion to this report (Cooley et al. 2017). This workbook allows users to adjust the assumptions in the analysis and examine additional scenarios. The Excel analysis is available at http://abtassociates.com/Tools/2017/Mozambique-Mangrove-CBA-Workbook.aspx.

SCOPE

The CBA quantified the potential costs and benefits of mangrove restoration and an earthen dike in monetary terms to help determine whether one adaptation option would be preferable in the study area. The study area for this analysis included the peri-urban communities of Icídua and Mirazane s Quelimane City. The study area encompasses 745 hectares (ha) of land, including 22 ha selected for potential mangrove restoration that the city has designated as a protected area. The total population of Quelimane was 192,876 in the last census in 2007.[1] Icídua and Mirazane along the Rio dos Bons Sinais had a population of approximately 9,100 in 1,817 households (DPTADER 2014).

CEADIR developed three scenarios:

- A "without-project" scenario with no additional coastal adaptation measures (business as usual) and higher costs from storm damage to the houses;
- A mangrove restoration project that included replanting of mangrove seedlings on 22 ha of elevated riverbank and coastal flood plains near Icídua and Mirazane; and
- A 5,000-meter earthen dike around the perimeter Icídua and Mirazane, to protect the communities from flooding after storms.

For each scenario, CEADIR estimated costs and benefits using primary data from field visit interviews with key stakeholders and community members and benefit-transfer methods, and secondary data from a literature review.

[1] "Mozambique: largest cities and towns and statistics of their population". World Gazetteer. Archived from the original on December 31, 2008.

ASSUMPTIONS

The key assumptions for the CBA follow:

- **With-project scenarios**: (1) Restoration of 22 ha of mangroves near the communities of Icídua and Mirazane and (2) a hypothetical earthen dike 5,000 meters long around the 745 ha study area.
- **Time period**: The base case was a 50-year time horizon, equal to the expected life of the earthen dike. A sensitivity analysis extended the time horizon to 100 years.
- **Discount rate**: The base case used the standard USAID real rate of 12 percent for economic analyses. Sensitivity analyses used discount rates of 0 percent, 3 percent, and 7 percent. The 12-percent discount rate was used in the sensitivity analysis of other parameters.
- **Mangroves**: Data on mangrove growth rates came from literature reviews and expert judgments. CEADIR assumed that the mangroves would reach full maturity and a height of 15 meters within 10 years. The base case assumed an 80 percent survival rate for seedlings based on CCAP's experience. It assumed a 95 percent survival rate for mature trees since the area was on protected land provided by the municipality and enforcement costs were included to support this survival rate.
- **Price of carbon**: After reviewing carbon prices in the U.S. Regional Greenhouse Gas Initiative (RGGI) and California Air Resources Board cap-and-trade markets as well as the voluntary carbon offset market, CEADIR conducted a sensitivity analysis using four carbon prices—$0, $8, $15, and $25 per metric ton of carbon dioxide equivalent (tCO_2e).
- **Costs**: CEADIR estimated the costs of mangrove restoration, maintenance, and labor from CCAP data and costs of the earthen dike from secondary literature and expert judgments.
- **Benefits**: CEADIR estimated the benefits from storm protection and mangrove ecosystems, including market values of fish, aquaculture, and apiculture, and economic values of carbon sequestration. Although mangroves also provided additional benefits from fuelwood production, biodiversity, water filtration, and existence value, these benefits were not included in the analysis due to a lack of data. The earthen dike also provided benefits from storm protection. The storm protection benefits from the mangroves or the earthen dike are likely to increase the quality of life and reduce mortality and human health impacts. Although these benefits could be large for both alternatives, CEADIR did not estimate them due to a lack of data.
- **Without-project scenario:** The base case assumed storm damage costs under a constant probability of storm events from INGC (2009). This assumption would not be realistic if severe storm risks increase over time due to climate change. As a result, the benefits of both project alternatives may be underestimated. However, the without-project scenario assumed that the municipality would not use the 22 ha protected area for economic development. Without this assumption, the opportunity costs of mangrove restoration would have been higher.
- **Financial and economic analysis:** The financial analysis reflected the perspective of communities in the study area. Most of the available cost data was in U.S. dollars (USD). CEADIR adjusted the USD costs to 2016 values using the U.S. Consumer Price Index. The team converted local currency costs and benefits to USD at an exchange rate of 59 meticais per dollar (based on oanda.com for June 26, 2017). The economic analysis adjusted for taxes and subsidies and included extra market benefits of mangroves, while the financial analysis excluded these adjustments.

KEY FINDINGS

The financial and economic net present values (NPV) of mangrove restoration were positive and exceeded those of the earthen dike under all scenarios. Mangrove restoration had positive financial and economic net present values in the base case and all of the sensitivity analyses using mangrove survival rates based on CCAP experience. However, mangrove restoration would not generate the projected returns if mangrove survival rates were very low due to poor planting and maintenance, clearing for other land uses, unsustainable cutting for polewood or woodfuels, or unfavorable hydrological conditions.

The earthen dike alternative was not financially or economically viable under any of the scenarios, largely due to the high upfront costs of construction and the low benefits of protecting the inexpensive houses in the study area from storms. Although the storm protection benefits from mangrove restoration were similarly low, this alternative had a higher present value because of the other benefits, particularly carbon sequestration and fish production. Although sensitive to the carbon price assumption, mangrove restoration still had a positive economic NPV at a carbon price of zero.

The sensitivity analysis showed that earthen dikes could have a positive net present value if the average house price exceeded $6,000; but the financial and economic NPVs restoration would still be higher for mangroves than earthen dikes under this scenario. The study area did not contain significant infrastructure or land use investments other than the low-income housing that the project alternatives would protect from storm damage. An earthen dike may be more appropriate than mangrove restoration if there is a high, quantified value from reduced human health and safety risks because the dike can be constructed faster than mangroves mature and may provide more complete protection from flooding.

Mangrove restoration also had higher financial and economic NPVs than the without-project case (see Table ES-1). The earthen dike had a negative present value under all sensitivity analysis scenarios, even at the low-end estimate of construction costs. The earthen dike could have a positive present value if there were substantially lower construction costs, a higher average value of the houses protected from storm damage, or values were included for reduced deaths and injuries. This CBA did not account for the health and safety impacts due to a lack of local data.

TABLE ES-1. Financial and Economic Net Present Values of Mangrove Restoration and an Earthen Dike at a 12 Percent Discount Rate (Per Hectare)

Scenario	Mangrove Restoration	Earthen Dike
$0 Carbon Price		
Financial Net Benefits	$33,165	-$34,251
Economic Net Benefits	$35,708	-$28,647
$8 Carbon Price		
Financial Net Benefits	$33,165	-$34,251
Economic Net Benefits	$153,575	-$28,647
$15 Carbon Price		
Financial Net Benefits	$33,165	-$34,251
Economic Net Benefits	$256,708	-$28,647
$25 Carbon Price		
Financial Net Benefits	$33,165	-$34,251
Economic Net Benefits	$404,041	-$28,647

1. INTRODUCTION

The increasing frequency and intensity of cyclones and other storms threaten the livelihoods and health of many communities along the Mozambican coast, as well as infrastructure, fisheries, aquaculture, and biodiversity (Gerston et al. 2015). One example is Quelimane, the administrative capital of the Zambezia Province (see Figure A-2). This municipality is highly vulnerable to climate change impacts, including sea level rise, cyclones, flooding, and erosion (World Bank 2011). The municipality contains a coastal seaport and has areas prone to flooding, particularly in the rainy season. Mozambique's Civil War from 1977–1992 brought an influx of people from rural areas to Quelimane to avoid fighting and access better income-generating opportunities, schools, and health care. The population continued to increase since then, in part due to declining agricultural productivity in rural areas (including the effects of coconut lethal yellowing disease). The population influx also resulted in more informal settlements in flood-prone parts of the municipality, exposing more people to potential climate change impacts (CCAP 2016).

In 2013, USAID/Mozambique launched the Coastal City Adaptation Project (CCAP) to help coastal cities in Mozambique improve their resilience to climate change impacts. With technical assistance and funding from CCAP, Quelimane restored 22 hectare (ha) of mangroves to reduce flood risks in two vulnerable coastal communities, Icídua and Mirazane. The mangrove restoration site was designated as a protected area.[2]

In 2016, USAID Mozambique requested the Climate Economic Analysis for Development, Investment, and Resilience (CEADIR) Activity to conduct a cost-benefit analysis (CBA) of mangrove restoration, a gray infrastructure alternative, and a without-project scenario. USAID/Mozambique and the USAID/Washington Global Climate Change Office shared the costs of this study. The purpose of this analysis was to inform the efforts of CCAP and the Government of Quelimane to protect the most climate-vulnerable residents in the peri-urban areas of the city from climate change risks. CCAP focused on the Icídua and Mirazane communities after consultations with the municipal government.

This study estimated the potential costs and benefits of mangrove restoration and a physical ("gray") infrastructure alternative to help determine whether one of these adaptation options would be preferable in reducing coastal flooding in the study area. The study area included the peri-urban communities of Icídua and Mirazane surrounding Quelimane City. The study area encompassed 745 hectares (ha) of land, including 22 ha selected for potential mangrove restoration and designated by the municipality as a protected area. The analysis used CCAP data on the economic and environmental costs and benefits of mangrove restoration and estimated the costs and benefits of a simple, earthen dike alternative.

This CBA builds on CCAP's initial assessment of the flood protection benefits of mangroves and its experience implementing a mangrove restoration pilot. CEADIR selected an earthen dike as the most appropriate gray infrastructure alternative after an initial site assessment and discussions with the community and local experts. An earthen dike around the communities of Icídua and Mirazane would reduce floodwater flows.

Icídua and Mirazane are peri-urban communities in Quelimane along the Rio dos Bons Sinais. They have a total land area of 745 ha and had a population of approximately 9,100 people in 1,817 households.

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[2] http://www.chemonics.com/OurWork/OurProjects/Documents/2015%20-Frontlines%20Climate%20Issue%20-%20CCAP.pdf

Quelimane had approximately 192,876 people[3] as of the last census in 2007 (DPTADER 2014). The two communities mainly consisted of low-income people. The residents lived in houses made of mud and mangrove poles and relied on mangroves for poles, fuel, and food.

Quelimane experiences strong winds and storm surges that accompany seasonal rains as well as cyclones and other tropical storms that typically batter coastal communities between October and February every year (Gerston et al. 2015). During the rainy season, 20 percent of Quelimane's total surface area faces significant risk from inland flooding from the Rio dos Bons Sinais (INGC 2012). In 2007 alone, floods and winds in Quelimane destroyed 100 schools and 3,000 houses, resulting in the evacuation of nearly 16,000 people and the death of 21 people (INGC 2012). However, there were no records of impacts specific to Icídua and Mirazane.

In 16 years, six cyclones have hit the coast of central Mozambique. Large floods have occurred in Mozambique an average of once every 2.6 years. Global warming is expected to bring more intense, frequent cyclones; however, the frequency of flooding in Mozambique could decrease slightly if water flows from upland areas also decline (INGC 2009). The National Institute of Disaster Management (INGC) projected that climate change would increase wind speeds from a 100-year storm in Quelimane from 216 km/h to 247 kilometers per hour. INGC also predicted that average weekly rainfall during the December to March rainy season would increase 3 mm under a moderate global warming scenario and 8.4 mm under a high global warming scenario (INGC 2012).

Economic pressures have increased mangrove deforestation and degradation in and around Quelimane, exacerbating storm impacts since mangroves provide natural protection from coastal flooding due to sea level rise and storm surge. Cote and King (2017) reported that 50 percent of the 5,700 hectares of mangroves in the Quelimane area have been cut, cleared, or degraded. The Government of Mozambique has imposed a ban on exporting all unprocessed timber and commercial harvesting of mangrove species. The law allows local communities to harvest fuelwood and polewood from mangroves for household consumption on the assumption that local use of mangroves would be sustainable with good enforcement of the commercial harvesting ban. Communities are responsible for enforcement of the commercial harvesting ban and sustainable local harvesting, but lack the resources and capacity to do so. This has often resulted in unsustainable harvest rates.

There is a thriving market for mangrove poles and charcoal in peri-urban areas of Quelimane and other locations. Mangrove poles and charcoal have become an increasingly important source of income due to limited alternative livelihood opportunities, despite the relatively large amount of labor required to harvest mangrove wood. Icídua and Mirazane are close to natural mangrove forests and have faced pressure to develop the land. Mangroves have continued to be converted or degraded in Mozambique due to competition from other land uses and inadequate controls on land access and use. Since the late 1990s, the annual rate of loss of mangroves in Mozambique has averaged almost 4 percent per year (Gerston et al. 2015).

[3] "Mozambique: largest cities and towns and statistics of their population". World Gazetteer. Archived from the original on December 31, 2008.

FIGURE 1. Mangrove-Lined Channels in Quelimane, Mozambique

Source: Lindsay Foley, Abt Associates

Mangrove restoration is a natural approach to reducing damage from coastal flooding from storm surges and sea-level rise, as well as strong winds. This "green infrastructure" can reduce coastal erosion and saltwater intrusion into freshwater aquifers, reducing risks to agriculture. Mangroves also support fish and shellfish production (Ronnback 1999). However, it may take up to 10 years to regrow cleared or degraded mangroves to a sufficient height and density to obtain these benefits. Although mangroves may not provide full protection from flooding, this green infrastructure offers multiple benefits that physical infrastructure cannot provide.

Physical infrastructure is often called "gray" infrastructure because of the concrete used in its construction. Examples include seawalls and dikes, sand bags, culverts, detention basins, and storm sewers. Gray infrastructure can offer faster protection against flooding than mangroves since construction takes less time than it takes for planted mangrove seedlings to reach maturity. However, gray infrastructure is often more costly and has adverse environmental effects because concrete, pipes, gutters, and mechanical systems are impervious and do not support natural infiltration. If gray infrastructure is not appropriately designed and built, it can increase flooding and pollution locally or in other locations. Therefore, careful engineering and siting is essential. The technical and financial feasibility of gray infrastructure are site specific. In addition, gray infrastructure does not provide the environmental services of mangroves for carbon sequestration and fish and shellfish production.

2. SCOPE AND METHODS OF THE COST-BENEFIT ANALYSIS

The CBA compared mangrove restoration and a gray infrastructure alternative to reduce flooding and other climate impacts in Icídua and Mirazane. CEADIR conducted the CBA in a Microsoft Excel workbook that serves as a companion to this report (Cooley et al. 2017). This workbook allows users to adjust the assumptions in the analysis and examine additional scenarios. The Excel analysis is available at http://abtassociates.com/Tools/2017/Mozambique-Mangrove-CBA-Workbook.aspx.

The mangrove-restoration option in this analysis covers 22 ha of protected, coastal land. The earthen dike alternative would surround the perimeter of the two communities (see Annex A). CEADIR selected an earthen dike as the gray infrastructure alternative after discussions with community members in Icídua and Mirazane, staff of CCAP, USAID/Mozambique, USAID/Washington, and local government officials. An extension of the existing, concrete sea wall in the port of Quelimane was another option, but CEADIR concluded that this alternative was not feasible for the study due to the high cost. There were also concerns from local government stakeholders. João de Brito (Director of Quelimane's Department of Environment and Climate Change) noted the high level of disrepair of the existing sea wall and the high costs of fixing and maintaining it. The Government of Quelimane commissioned a study that found that it would cost $5 million to fully repair the sea wall. Since it only had $1.8 million available, the municipal government proceeded with a temporary repair, but lacked sufficient funds to provide ongoing maintenance, leaving the seawall structurally deficient and open to further degradation.

CEADIR analyzed three scenarios:

- A "without-project" scenario with no additional coastal adaptation measures (business as usual), which assumed continuing costs from storm damages to the houses in the two communities;
- A mangrove restoration project that included replanting of mangrove seedlings on 22 ha of elevated riverbank and coastal flood plains near Icídua and Mirazane; and
- A 5,000-meter earthen dike around the perimeter of the two communities.

FIGURE 2. A Typical Mud and Mangrove Poles House in Mirazane

Source: Tulika Narayan, Abt Associates

CEADIR estimated the costs and benefits from primary data collected during a field visit in October–November 2016 and secondary data from existing literature. CEADIR held consultations with 35 stakeholders (listed in Annex C). CEADIR also conducted nine community consultations with a total of over 30 members of community leadership councils, fishermen, farmers, women, and market vendors. CEADIR used data from a literature review and expert judgments to supplement the data gathered in the site visits and consultations.

Source: Tulika Narayan, Abt Associates

CEADIR obtained information on mangrove restoration costs from CCAP, the Association of Nature and Friends of Madal (ANAMA), Icídua Community Council of Fisherman (CCP), University of Eduardo Mondane, and community members in Icídua and Mirazane. CEADIR estimated the benefits of mangrove restoration from CCAP reports and interviews, national and local experts, USAID/Mozambique staff, and CCAP partners. This information included the results of mangrove replanting on the density, depth, species composition, and growth rates and benefits over time. In addition to the storm protection benefits, some stakeholders noted the importance of mangroves for water quality, fisheries, honey production, and aquaculture (especially for shrimp, fish, and crabs). Community interviewees identified mangrove snails as an important food, but CEADIR did not include the benefits from snail production in the analysis due to a lack of data on harvests and prices.

Where local data were not available, CEADIR considered benefit-transfer methods based on data from studies in other locations on the monetary value of mangroves for fish production, aquaculture, and apiculture. CEADIR adapted cost estimates for the earthen dike from existing reports including Rogers et al. (2016), who summarized global values for earthen dike construction.

CEADIR prepared both a financial analysis and an economic analysis. The financial analysis included market-based benefits to the local government and community. The economic analysis also included extramarket benefits of mangrove restoration, such as carbon sequestration. Both the financial and economic analyses accounted for the total costs of each option, but taxes were only included in the financial analysis.

2.1 FINANCIAL ANALYSIS

The financial analysis reflected the perspective of the Icídua and Mirazane communities and used market prices where available. CEADIR estimated the annual cash flows for benefits (including revenues and subsidies) and costs (construction investment, maintenance, and labor), as well as annualized net cash flows. CEADIR assumed that the communities would incur the full costs for mangrove restoration and earthen dike construction although it is possible donors may cover some of the costs. This assumption may make the results more relevant for other locations where donor support may not be available.

The financial analysis also included the cost of the 17 percent value-added tax on goods and services, but not the opportunity cost of unpaid community labor for mangrove planting and polewood harvesting.

There was corroborating evidence that even low-income communities in Mozambique will invest in mangrove restoration, based on the experience of ANAMA, a local not-for-profit organization that grew mangrove seedlings for sale to CCAP in Icídua. ANAMA has also done other work on mangrove restoration in the study area and with other communities in the country.

The financial analysis accounted for the following benefits to the communities:

- Reduction in storm damage to houses;
- Fish production;
- Aquaculture; and
- Apiculture.

Section 3.2 contains additional information on these benefits.

2.2 ECONOMIC ANALYSIS

The economic analysis accounted for all financial costs and benefits within Mozambique as well as the value of the carbon sequestered by the growing mangroves. The costs included in the economic analysis were the same as in the financial analysis, except for taxes and licensing fees, which were excluded from the economic analysis as transfer payments (USAID 2015).

Although mangroves provide many other economic benefits (including reduced mortality and health and safety impacts from storms, water filtration, biodiversity, and existence value), CEADIR did not value them in monetary terms due to a lack of data. However, Section 3.3.5 discusses these other benefits.

3. ASSUMPTIONS

The green infrastructure alternative involved 22 ha of mangrove restoration along the coast adjacent to Icídua and Mirazane. The gray infrastructure alternative addressed a 5,000-meter long earthen dike around the entire perimeter of the study area (Figure 3). Interviewed villagers reported that the storm surge during cyclones often flooded the river and channels that surround the community on all sides. A CEADIR expert determined that a dike would have to surround the entire area to prevent this flooding. The analysis did not consider possible external impacts of this dike on other communities, which should be addressed in a subsequent technical assessment before construction.

FIGURE 3. Perimeter Around Study Area for Protection from Rising Water

Following USAID (2015) guidelines for the period of analysis in a CBA, CEADIR adopted a time frame equal to the expected lifetime of the earthen dike—50 years. CEADIR used the same time horizon for mangrove restoration, which could last longer if sustainably managed. For both these cases and the without-project case, CEADIR also conducted a sensitivity analysis covering a 100-year period. In the 100-year analysis, CEADIR assumed the original earthen dike would need a full replacement in year 51.

CEADIR followed USAID (2015) guidance in using a real discount rate of 12 percent in the base case for the economic analysis. CEADIR used the same 12-percent discount rate in the financial analysis, although the USAID guidance allows a different discount rate in the financial analysis that reflects the expected cost of financing for the investment. CEADIR also applied discount rates of 0 percent, 3 percent, and 7 percent in sensitivity analyses for the economic analysis. Higher discount rates reduce the present value of both costs and benefits incurred in the more distant future.

The coastal protection benefits of an earthen dike occur as soon as construction is completed. CEADIR assumed completion of dike construction in the first year with full flood protection benefits at that time. By contrast, the benefits of mangrove restoration are low at first and increase as the mangroves grow to maturity. CEADIR assumed that some benefits, such as storm protection and fish production, increase in proportion to the mangrove growth rate and reach a maximum after the mangroves attain their full height after 10 years.

Although USAID (2015) generally recommended conducting a CBA in local currency, this analysis was done in USD because much of the cost and benefit data was in this currency. The CBA used real prices in 2016 US dollars (USD). CEADIR used an exchange rate of 59 meticais per USD, based on the exchange rate as of June 26, 2017 on oanda.com.

3.1 MANGROVE RESTORATION ASSUMPTIONS

The benefits from mangrove restoration vary with the species of mangrove planted since that affects the growth rate and tree density over time. The number of seedlings planted and the projected survival rates of seedlings and trees over time also affect the tree density. The mangrove growth rate and tree density affects the benefits from storm damage reduction; carbon sequestration; and fishing, aquaculture, beekeeping, and ecosystem services.

3.1.1 MANGROVE GROWTH AND CARBON SEQUESTRATION ASSUMPTIONS

CCAP planted three native species—*Avicennia marina*, *Ceriops tagal*, and *Rhizophora mucronata. Avicennia marina* was the dominant mangrove species in the area[4] Since growth curves for all three species in Mozambique were not available, CEADIR estimated a single growth rate based on Trettin et al. (2015) analysis of the relationship between tree height in meters and diameter in centimeters for *Avicennia marina*. CEADIR used the following equation to estimate mangrove growth:

$$\text{Height} = 5.65 * \text{inches (diameter)} - 4.29 \quad (1)$$

Following interviews with Professor Bandiera of Eduardo Mondlane University, CEADIR assumed that mangroves began growing at an increasing rate and then leveled off after six years, reaching a maximum height of 15 m after 10 years.

Using the height assumptions in Figure 4 and the equation from Trettin et al., CEADIR estimated the tree diameter in each year through full maturity. CEADIR estimated the above ground carbon stock in each tree in each year with the following formulas from Sitoe et al. (2014):

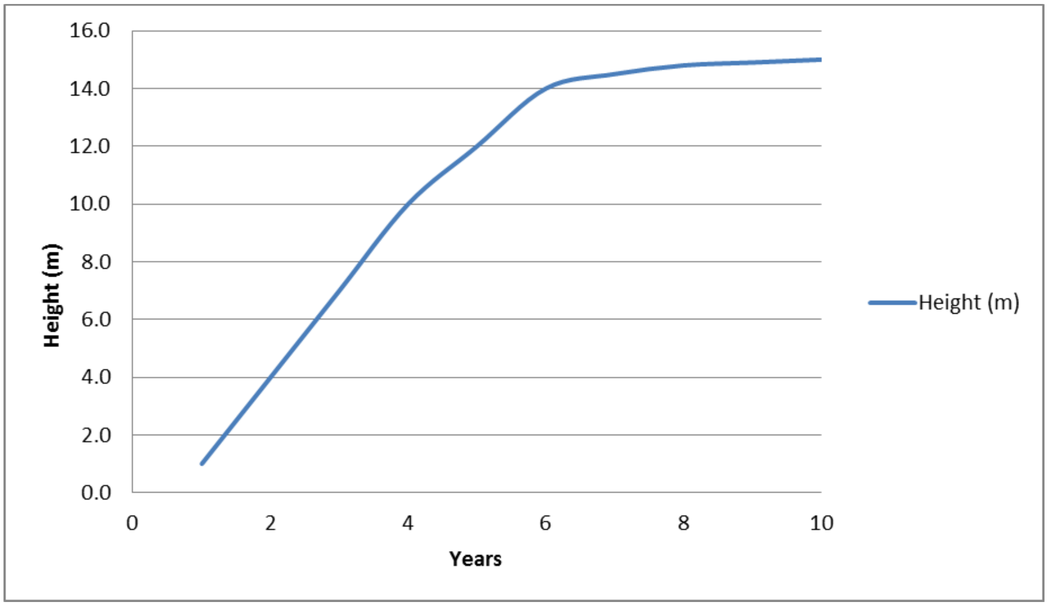
$$\text{Above-ground dry weight of mangroves (DW)} = 3.254 \times \exp(0.065 \times \text{tree diameter}) \quad (2)$$

$$\text{Carbon stock per tree (Mg/tree)} = 0.48 \times \text{DW} \quad (3)$$

Alongi (2012) estimated the below ground sequestration of carbon by mangroves at 6.38 tCO_2e/ha/year. However, the below ground carbon sequestration depends on site-specific factors, such as hydrologic disturbance and location within the wetlands. As a result, CEADIR did not include below ground carbon sequestration in the analysis.

[4] Bandeira 2016, personal communication.

FIGURE 4. Mangrove Growth Assumption



CEADIR estimated the increase in the mangrove tree density by using CCAP's seedling planting rate and demonstrated seedling and mature mangrove survival rates. CCAP planted seedlings at a spacing of 1 x 1 m for a density of 10,000 seedlings per hectare.

There were different assumptions for the survival rates of seedlings and mature trees. ANAMA reported that survival rates of mangrove seedlings in their nursery were typically 80-90 percent. Bandeira (2016) stated that survival rates of planted seedlings should average 70-80 percent. CEADIR's base scenario assumed an 80 percent survival for planted mangrove seedlings. The sensitivity analysis looked at the effects of reducing the seedling survival rate to 50 percent.

The Government of Quelimane imposed a ban on commercial harvesting of mangroves and gave community leaders the responsibility to enforce the ban, without any funding or staffing. Local residents can legally harvest mangroves for their own woodfuel and polewood use since the government assumed they would do so sustainably. Since the study area was a protected area, CEADIR assumed that local mangrove harvesting would be limited to a sustainable level.

As a result, the base scenario assumed a 95 percent survival rate for mature mangrove trees, allowing some net losses due to mortality or harvesting. The sensitivity analysis also considered the effects of a 50-percent survival rate for mature mangrove trees. To estimate the increase in above ground carbon sequestration, CEADIR multiplied the increase in the number of live trees per ha by the average carbon stock per tree.

The benefits from mangrove restoration will vary with the mangrove density, site-specific hydrology, coastal features, and water salinity. Since these factors are complex, an analysis of their interrelationships was beyond the scope of this study. Instead, CEADIR examined stakeholder perceptions of mangrove restoration benefits.

ANAMA staff reported that mangrove seedlings planted in the study area could provide full ecosystem protection and economic benefits after 10 years. CEADIR used the mangrove growth function as a proxy for the proportion of total benefits during the first 10 years. Table 1 shows the replanted mangrove height as a percent of the height at 10 years. CEADIR used these percentages to estimate the annual benefits over the 10-year period, adjusted for the survival rate. For example, CEADIR assumed that fish and shellfish production benefits in the first year would be 7 percent of the full amount in the tenth year because the trees would be at 7 percent of their maximum height. This assumption appears to be conservative for fish and shellfish since Bandiera (2016) noted that their populations begin to increase a few months after mangrove replanting.

TABLE 1. Height of Replanted Mangroves as a Percent of Full Height by Year

Years	1	2	3	4	5	6	7	8	9	10
Height (m)	1.0	4.0	7.0	10.0	12.0	14.0	14.5	14.8	14.9	15.0
Percentage of full height	7%	27%	47%	67%	80%	93%	97%	99%	99%	100%

3.1.2 MANGROVE RESTORATION COSTS

CEADIR used CCAP data on actual mangrove restoration costs in 2016 (Table 2). These expenditures included the costs of buying the seedlings; labor for planting, maintenance, and support staff; and hydrological restoration. In the study area, restoration of hydrological flows was necessary to ensure healthy mangroves because previously constructed barriers had created a salt pan that remained in place even though it was no longer used. Re-establishment of the natural hydrological flows improves the likelihood of successful mangrove restoration and increases the density of mangroves through natural recruitment.

CCAP provided a site-specific cost quotation for restoration of hydrological flows for 30 hectares of mangrove restoration. CEADIR adjusted the cost to reflect the 22-ha study area for the cost-benefit analysis. CCAP's mangrove restoration relied on manual labor, without any earthmoving equipment. CCAP provided data on the costs of purchasing the seedlings and maintaining the planted area (see Section 4.2.1).

CEADIR estimated the costs for licensing and conservation enforcement to help ensure the assumed 95-percent survival rate of mature trees in the base scenario. Licensing costs included fees paid to the municipality for exclusive use of mangrove resources, including fish and shellfish harvesting and aquaculture. Licensing costs were 4,800 meticais ($81) per year for the 22-ha site.[5] The licensing fees may also motivate the local community to help prevent illegal mangrove harvesting. CEADIR estimated that the local enforcement costs would be $93 per year, based on a mid-level labor rate of $89 per person-day (the wage rate paid by CCAP) and 5 percent of this person's time all year. The local community valued the mangrove and understood the need to protect the area. CCAP estimated the labor required for planting the mangroves at 250 person-days per month for four months. Although the community contributed this labor, CCAP estimated that its opportunity cost at 150 meticais ($2.54) per person-day.

[5] Manuel José Maria, Director of Agriculture and Fish, 2016, personal communication.

TABLE 2. Mangrove Restoration Costs in 2016

Description	Units	Cost per Unit ($)	Number of Units per Month	Number of Months	Total Project Cost ($)	Cost per ha ($)
Hydrological restoration – labor	Total cost	NA	NA	NA	$3,107	$141
Hydrological restoration – materials and equipment	Total cost	NA	NA	NA	$5,105	$232
Maintenance after restoration	Person-days	$3	15	18	$686	$31
Seedlings	Plants	$0.29	10,000	18	$50,339	$2,288
Seedling maintainance	Person-days	$3	225	23	$13,157	$598
Mangrove planting labor	Person-days	$3	250	4	$2,542	$116
Safety equipment	Boots, masks, and gloves, for 150 people	NA	NA	NA	$1,637	$74
Transport of seedings from the nursery	Truck rental	$193	1	11	$2,119	$96
Plastic bags for seedlings	Bags	$0.03	180,000	1	$6,102	$277
Boat rental	Boat rental	$1,271	1	2	$2,542	$116
Senior-level staff time	Person-days	$119	10%	45	$31,500	$1,432
Mid-level staff time	Person-days	$68	50%	45	$90,000	$4,091
Junior-level staff time	Person-days	$42	50%	45	$56,250	$2,557
Travel costs	Trips	$15	8	45	$1,558	$71

Source: CCAP.

3.2 EARTHEN DIKE COST ASSUMPTIONS

A 5,000-m long earthen dike would be necessary to reduce flood damage in Icídua and Mirazane. CEADIR relied on expert judgments on the level of protection provided by the dike and conducted sensitivity analyses on this parameter. A more complete technical feasibility assessment would be advisable before proceeding with planning and construction.

CEADIR estimated the costs of the earthen dike at $15–$55 per linear foot based on Rogers et al. (2016). CEADIR selected the low-end estimate from this range as most feasible due to the low housing values in the study area. The estimated construction cost for the dike was $246,060 (5,000 m x 3.28 feet per m x $15 per foot). CEADIR estimated average annual maintenance costs at 5 percent of the construction cost ($12,303) based on the experience of Aquapesca, an aquaculture company across the Rio de Bons Sinais from Quelimane. CEADIR also conducted a sensitivity scenario using the high-end estimate of the construction costs.

Aquapesca also informed CEADIR that repair costs for their dike were twice the average annual maintenance costs after a medium-sized storm event and that complete rebuilding would be needed after a large storm event. INGC (2009) predicted that the probability of storms of various magnitudes would increase over the next two decades. CEADIR assumed an annual probability of 33 percent for a medium-sized storm and 1.7 percent for a large storm. To simplify the analysis and make it more conservative, CEADIR did not account for the possible effects of climate change on the frequency of storms. However, INGC (2009) projected that a moderate storm that occurred every five years in Mozambique in 2009 would recur every 3 years by 2030 with global warming. It also projected that what was considered to be a severe, 100-year storm would happen every 60 years by 2030.

CEADIR did not use Aquapesca's actual capital costs for its dike because the type of construction was too expensive to be economically viable for Icidua and Mirazane. Aquapesca's earthen dike included a 20-cm layer of compacted saibro (a mix of sand, clay, and gravel/pebbles/crushed stone) and had drainage pipes and flood flap gates. A 5,000-m dike of this type would cost $1.5 million.

3.3 BENEFITS

CEADIR estimated the benefits from the reduced risk of storm damage to housing with mangrove restoration and the earthen dike. CEADIR also included the financial and economic benefits of fish production, aquaculture and apiculture as well as the economic benefits of carbon sequestration for mangrove restoration only.

3.3.1 STORM PROTECTION

CEADIR valued the storm protection benefits at the estimated cost of rebuilding or repairing homes damaged or destroyed by storms. The main building materials for the houses in the study area were mangrove poles and a tin roof. Interviewees from Mirazane estimated that the roof of a typical house required 31 tin sheets that cost a total of 38,000 meticais ($644) in 2016. CEADIR obtained the retail price for a mangrove pole, 40 meticais ($0.67), from a local market. CEADIR estimated that a typical house in the study area required about 400 poles that cost a total of $268. Including the roof and the poles, the materials cost of a typical house in the study area was $915. The study area included 1,817 homes. Reducing damage from storms could help the local people avoid costs of major home repairs or reconstruction.

CEADIR used INGC's (2009) scenario of a low level of sea level rise (SLR) to estimate the risk of storm damage under each project option. The low-SLR scenario was based on data from Beira, which was also along the coast of Mozambique, 478 km from Quelimane. Under this low scenario, sea levels were projected to increase 10 cm by 2030, 20 cm by 2060, and 30 cm by 2100. INGC estimated an annual probability of 33 percent for a storm with 3.8 m tides and 1.7 percent for a storm with 4.4 m tides. Although INGC (2009) also developed a high-SLR scenario that resulted in permanent inundation of the coast and low-lying areas, CEADIR did not use it because INGC concluded that its timing was highly uncertain.

CEADIR labeled the 3.8 m tide storms as "medium" severity and the 4.4 m events as "high" severity. CEADIR then estimated the proportion of homes potentially damaged in the study area under three scenarios:

- **Without-project:** The 2004 tsunami that struck Southeast Asia and East Africa destroyed 80 to 100 percent of the houses in villages near degraded mangroves along the Andaman coast in Sri Lanka, (Dahdouh-Guebas, 2006).[6] Without mangrove restoration or an earthen dike to provide storm protection, CEADIR assumed that a medium severity storm would damage 80

[6] Dahdouh-Guebas (2006) is one of the key studies of the impact of tsunamis in coastal areas with intact and degraded mangroves.

percent of the houses in Icidua and Mirazane while a high severity event would damage 100 percent of the houses.

- **With mangrove restoration:** Dahdouh-Guebas (2006) reported that the 2004 tsunami destroyed 7 percent of the houses in an area with intact mangroves on the Andaman coast. CEADIR assumed that medium and large storms would destroy this same percentage of homes in the mangrove restoration scenario. Assuming that 80% of the houses in Icidua and Mirazane would be destroyed in a medium-sized storm may be too high since the South-East Asian tsunami was a large-scale event. However, most of the houses in Icidua and Mirazane had low resilience because they were made of mud, palm fronds, and mangrove poles. Although this assumption may overestimate the impact of a medium-sized storm, sensitivity analyses also included scenarios in which medium-sized storms only caused damage amounting to 33 percent or 67 percent of the value of the houses.
- **With earthen dike:** CEADIR assumed that the earthen dike would fully protect houses from medium-sized storms but not large storms.

The earthen dike would provide more protection from medium storms than mangroves. Dikes can provide complete flood protection if water remains below the dike's height. Mangroves would not provide complete flood protection and would not be fully re-established for 10 years. Large storms could destroy earthen dikes and leave the houses unprotected. An earthen dike may be more attractive in areas with higher population densities when storms are common and less severe.

3.3.2 AGRICULTURAL PRODUCTION

CEADIR conducted key informant interviews to determine the baseline production of major crops in Icídua and Mirazane and the perceived effects of saltwater intrusion, storms, and droughts on agriculture. There was a general perception that crop yields had declined, but respondents could not distinguish the effects of these three possible causes on the perceived yield reductions. As a result, CEADIR did not quantify benefits from reducing saltwater intrusion in terms of the increased net value of agricultural production. Although the effects of soil salinization from saltwater intrusion on crop yields can be reduced through intensive incorporation of organic matter crop, CEADIR did not have data on the costs of reclaiming saline soils in the study area. Although droughts can also reduce livestock productivity, the interviewees did not mention any impact on livestock production from saltwater intrusion or storms.

3.3.3 OTHER FINANCIAL BENEFITS FROM MANGROVE ECOSYSTEMS

The analysis considered the benefits of mangrove restoration for fish production, aquaculture, and apiculture.

3.3.3.1 FISH PRODUCTION

CEADIR used data from Rönnbäck (1999) on shrimp, crab, fish, and clam production in mangroves in tropical and subtropical Asia, Africa, and Australia. CEADIR collected data on fishing efforts, costs, and prices of small and large fish, crabs, shrimp, and clams through interviews in Icidua. The prices fishermen received varied by unit sizes, seasons, type of buyer, and whether the transaction was in cash or for bartered goods or services.

For example, fishermen sold a 30-kg box of crabs for $14.37, but received $20.28 when the same amount was sold in smaller transactions. A 30-kg box of shrimp sold for $42.25 wholesale or $76.05

retail in April to June. From July to December, the wholesale price was $101.40 and the retail price was $143.65. A large fish sold for $1.69-$2.54. In the cost-benefit analysis, CEADIR assumed an average price of $2.47/kg of fish or shellfish harvested. CEADIR also projected that fish and shellfish production would increase in proportion to the height of the restored mangroves and reach a maximum when planted mangrove seedlings became full-sized trees in 10 years.

TABLE 3. Fisheries Production in Mangrove Areas

Type of Fish or Shellfish	Production(kg/ha/year)
Shrimp	224
Crab	26
Fish	1,887
Clam	743

Source: Rönnbäck (1999)

CEADIR's aquaculture expert, Hervé Ohresser-Joumard, estimated costs of raising and harvesting fish and shellfish in large pens. These aquaculture pens consisted of a drag net ("arrasto") typically made from seven sections of netting sewn together and secured with four mangrove poles. A typical pen reportedly cost $1,017, but one respondent estimated the cost could be as much as $1,943. CEADIR used the lower cost estimate. Icídua's fishermen council reported that there were 32 of these pens in the community's area. CEADIR estimated that four pens would be needed in the 22 ha study area to catch and fatten crabs, shrimp, fish, and clams.[7] CEADIR estimated that aquaculture required one hour of labor per day for five days a week. The labor cost $0.32 per hour.

3.3.3.2 AQUACULTURE

Small-scale aquaculture producers in the Quirimbas Archipelago of northern Mozambique fattened crabs in mangrove areas. CEADIR identified only one small-scale aquaculture operation for tilapia fattening in the study area. A large aquaculture company, Aquapesca, operated across the Rio de Bons Sinais from Quelimane. It has expressed interest in using the restored mangrove habitat for its operations.

Due to insufficient data on the net income of small-scale aquaculture in the study area, CEADIR used a benefit-transfer method. UNEP (2011) and Tuah et al. (2013) found that aquaculture production in mangroves generated an annual net income of $5.16 to $370.47 per hectare. To be conservative, CEADIR used the low estimate of the net income from aquaculture in the analysis, $5.16/ha/year. Since the low estimate was so far below the high estimate, the benefits of mangrove restoration for aquaculture could be substantially higher if a high or intermediate estimate were used.

3.3.3.1 APICULTURE

Honey is used as a sweetener and input for alcoholic beverages in Mozambique. About 70 percent of the honey producers in the country use traditional methods of apiculture. The community in the study area has expressed interest in developing apiculture on the mangrove restoration site, but training would be needed. ANAMA reported that the nongovernmental organization, El Mundo, could be funded to provide this training.

[7] Although large arrasto pens were the primary fish production method used by fishermen in Icídua, they also used palangre hooks and lines, seine nets, drag nets, fixed gill nets, gamboa nets made from three sections of netting, smaller and less expensive malharnets, and illegal chicocota mosquito nets.

CEADIR used a benefit transfer approach to estimate the potential net income from apiculture in the mangrove restoration area, based on data from a project in Gazi Bay, Kenya. The Gazi Bay project generated an annual net income of $15.81/ha/year, after deducting the capital and maintenance costs of the hives (UNEP 2011). CEADIR also estimated the costs of training the local community in apiculture, based on a mid-level salary of $68 per month for one-tenth of a person-year for four years.[8]

3.3.3.2 FUELWOOD

Since CEADIR did not have data on the sustainable rate of mangrove harvesting for woodfuels, this potentially important value was not included in the cost-benefit analysis for mangrove restoration. However, the UNEP (2011) study on Gazi Bay, Kenya estimated the value of sustainable harvesting of woodfuels from mangroves at $16.80 per ha per year (UNEP 2011). CEADIR did not apply this estimate because more research is necessary to determine the sustainable harvesting rate for replanted mangroves in the study area.

3.3.4 VALUE OF CARBON

Mangroves are an important carbon sink due to their high biomass density and primary productivity. There are some prices for carbon emission reductions on compliance and voluntary markets. Sale of carbon offsets is a potential revenue source for large-scale mangrove restoration, but would incur substantial costs to arrange transactions and meet measurement, reporting, and verification (MRV) requirements for sale of carbon credits.

Two carbon compliance markets in the United States held carbon offset auctions in mid-2017 to enable companies to meet regulatory requirements. The Regional Greenhouse Gas Initiative (RGGI) reported a price of $2.79 per metric ton while the California Air Resources Board reported a much higher price of $13.80 per metric ton. There were also voluntary carbon markets that provided carbon offset credits to individuals or businesses interested in offsetting their carbon footprints. Terrapass (2017) offered voluntary carbon credits at $11.00 metric ton of carbon dioxide equivalent (tCO_2e). Ecobusinesslinks (2017) reported a survey of carbon offset prices on the voluntary market found prices ranging from $2.75 to $99.00 per tCO_2e.

Because of the wide range of values on the compliance and voluntary markets, CEADIR used four different levels of carbon prices in the sensitivity analysis for mangrove restoration benefits—$0, $8, $15, and $25 per tCO_2e. The analysis also assumed that these values were net of transaction and measurement, reporting, and verification (MRV) costs and would not increase over time with climate change.

Many factors make it challenging for a small mangrove restoration project in a remote location to access the carbon offset market -- the ability to find a buyer for the credits, transaction costs, the difficulty in meeting MRV requirements, and the limited involvement of Mozambique in the carbon offset market. Because of the low likelihood that these two communities could access the complex offset markets and lack of information on the transaction and MRV costs, this analysis assumed that the benefits of carbon sequestration could not be sold. Therefore, CEADIR did not include marketable carbon sequestration benefits in the financial analysis as a benefit to the communities or government. CEADIR did include carbon sequestration benefits in the economic analysis as an extramarket value to society.

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[8] The estimate for labor hours to maintain the hives was based on our interview with ANAMA who are currently implementing these activities in another area of Quelimane.

3.3.5 OTHER POTENTIAL ECONOMIC BENEFITS THAT WERE NOT INCLUDED

Reductions in human mortality and injuries from sea level rise and storm surges are an important economic benefit from mangrove restoration or an earthen dike. In the year 2000, floods in Mozambique resulted in 800 deaths (Lumbroso et al. 2008). Since then, smaller storms in the country have caused 9 to 150 deaths per event (United Nations et al. 2015; Davies, 2017). However, it is difficult to predict the number of fatalities from a specific storm. Also, improved warning and evacuation systems could decrease the risks.

The U.S. Environmental Protection Agency (2010) proposed an estimated value of a statistical life in the United States although other USG agencies have used lower values in regulatory analyses. Robinson and Hammitt (2009), Lindhjem et al. (2011), and Dekker et al. (2011) reviewed studies of the value of a statistical life in various developed and developing countries, although none of the reviewed studies were for countries in sub-Saharan Africa.

Although benefit transfer methods have been proposed to adjust estimates of the value of a statistical life across regions based on differences in income, there is controversy over value transfers, especially in adjusting values from developed countries to developing countries. Roy (2016) used the methods of Hammitt and Robinson (2011) to transfer a value of a statistical life from Organization of Economic Co-operation and Development (OECD) countries to Mozambique. This study estimated that the value of a statistical life in Mozambique ranged from $96,000 to $303,000 in 2013, with a central estimate of $171,000.

Roy's low-end estimate of $96,000 in 2013 was the equivalent of $98,766 in 2016 US dollars. Including this value in the analysis would substantially increase the storm protection benefits of both the mangrove restoration and earthen dike options. However, no data were available on the reductions in human mortality with mangrove restoration or the earthen dike to make it possible to apply the above estimate of the monetary value of a statistical life in Mozambique. Despite the uncertainty in the number of storm deaths that could be avoided with earthen dikes or mangrove restoration in Mozambique, these potential benefits could be relatively large. As a result, this analysis is a lower bound estimate of the total benefits.

Mangroves also provide a variety of other economic benefits, such as water filtration, biodiversity, and existence value. CEADIR found values for these benefits in other countries and adjusted them to 2016 USD values. World Wildlife Fund (2016) estimated the total value of mangroves at $4,185 per hectare. Table 4 reports estimates of biodiversity and existence values of mangroves in Kenya and a very high estimate of water filtration benefits in Costa Rica. Another CEADIR report (Smith et al. 2017) reviewed various estimates of the economic benefits of mangroves, but found that many of the studies were flawed and most focused on much larger areas than the 22-ha site in Quelimane. In addition, the benefits from the various studies were site specific and may not be applicable in other locations. For these reasons, CEADIR did not include any values for these other economic benefits of mangrove restoration in the economic analysis.

TABLE 4. Estimated Values for Other Economic Benefits of Mangroves in Other Studies (Not Included in this Cost-Benefit Analysis)

Study	Location	Benefit Stream	Average Annual Value (US Dollars Per Hectare)
UNEP (2011)	Kenya	Biodiversity	$5.38
UNEP (2011)	Kenya	Existence value	$639.45
Kocian et al. (2010)	Costa Rica	Water filtration	$11,782.43

4. RESULTS

4.1 WITHOUT-PROJECT CASE

The without-project case did not include any mangrove restoration or earthen dike. CEADIR used the without-project case as the baseline for estimating the incremental (marginal) costs and benefits of the mangrove restoration and earthen dike cases. For example, CEADIR did not consider the income households gained from operating bicycle taxis because these activities would occur with or without the projects, although they could be disrupted by storms. Table 5 lists the assumptions for the without-project case.

TABLE 5. Without-Project Scenario

Parameter	Base Scenario Value
Time horizon	50 years
Average house value	$915

4.2 MANGROVE RESTORATION

Table 6 contains the assumptions for the mangrove restoration analysis.

TABLE 6. Assumptions for the Mangrove Restoration Analysis

Parameter	Assumption
Time horizon	50 years
Mangrove survival after maturity	95%
Seedling survival rate	80%
Price of carbon ($/t$CO_2$e)	$0, $8, $15, and $25

4.2.1 FINANCIAL ANALYSIS

Table 7 contains per hectare financial costs for the first 10 years of mangrove restoration, including hydrological restoration, seedling planting, and maintenance. The number of new seedlings necessary would vary with site-specific characteristics because natural regeneration may also occur after hydrological restoration. The estimated number of seedlings per hectare came from CCAP's experience. CEADIR included estimated enforcement costs to help prevent unsustainable harvesting or felling of mangrove trees. Municipalities would receive licensing fees in return for the local communities' rights to use mangrove resources for local use, fishing, and aquaculture.

TABLE 7. Mangrove Restoration Costs Per Hectare (2016 US dollars)

Type of Cost	Data Source	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Hydrological restoration	CCAP	$373	$0	$0	$0	$0	$0	$0	$0	$0	$0
Initial planting	CCAP	$2,800	$1,096	$37	$27	$0	$0	$0	$0	$0	$0
Maintenance and replacement of plantings	CCAP	$369	$333	$37	$27	$0	$0	$0	$0	$0	$0
Travel for technical and managerial support	CCAP	$71	$71	$71	$71	$0	$0	$0	$0	$0	$0
Enforcement	CCAP	$71	$71	$71	$71	$71	$71	$71	$71	$71	$71
Licensing	Directorate of Agriculture and Fishing	$163	$163	$163	$163	$163	$163	$163	$163	$163	$163
Technical assistance for beekeeping[a]	Based on CCAP wage rates	$7	$7	$7	$7	$0	$0	$0	$0	$0	$0
Fish production using traps	Expert judgment	$251	$19	$19	$19	$19	$19	$19	$19	$19	$19
Taxes		$1,295	$97	$0	$0	$0	$0	$0	$0	$0	$0
Total Financial Costs		**$5,400**	**$1,856**	**$403**	**$385**	**$253**	**$253**	**$253**	**$253**	**$253**	**$253**
Total Economic Costs		**$3,942**	**$1,596**	**$241**	**$222**	**$90**	**$90**	**$90**	**$90**	**$90**	**$90**

Note: Costs for beekeeping included training, capital, maintenance, and labor costs.

Table 8 presents the incremental financial benefits to the communities from mangrove restoration, after subtracting the net cash flows from the without-project scenario. The largest component of the cash flows from mangrove restoration was the increased value of fish and shellfish production, which would rise as the mangroves mature and would not occur in the absence of the project. A sensitivity analysis assumed 50 percent of the fish and shellfish production in the base scenario. The second-largest benefit stream was from storm damage protection for houses. Apiculture and aquaculture were minor components of the financial benefits of mangrove restoration.

TABLE 8. Incremental Financial Benefits from Mangrove Restoration Per Hectare (2016 US dollars)

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fish production	$380	$1,519	$2,657	$3,796	$4,556	$5,315	$5,505	$5,619	$5,657	$5,694
Aquaculture	$0	$1	$2	$3	$3	$4	$4	$4	$4	$4
Beekeeping	$1	$3	$6	$8	$10	$12	$12	$12	$13	$13
Storm protection	$2	$7	$12	$17	$21	$24	$25	$25	$25	$26
Total Financial Benefits	**$383**	**$1,530**	**$2,677**	**$3,824**	**$4,590**	**$5,355**	**$5,546**	**$5,660**	**$5,699**	**$5,737**

The financial net present value (NPV) for mangrove restoration over a 50-year time horizon was $33,165/ha at a 12-percent discount rate. The NPV was sensitive to the discount rate since many of the benefits, such as fish production and storm protection, increased over time with mangrove growth.

Section 6 contains a sensitivity analysis showing the effects of three lower discount rates—0 percent, 3 percent, and 7 percent.

4.2.2 ECONOMIC ANALYSIS

The economic analysis adjusted the financial costs and benefits to take out transfer payments, such as taxes and licensing costs. The economic analysis also added in benefits from carbon sequestration. CEADIR did not include the carbon sequestration benefits in the financial analysis because it would be difficult for this small, remote mangrove restoration project to sell carbon credits and meet MRV requirements. Table 9 presents the economic benefits of mangrove restoration at four carbon values—$0, $8, $15, and $25 per ton of carbon dioxide equivalent.

TABLE 9. Incremental Economic Benefits from Mangrove Restoration Per Hectare (2016 US dollars)

Carbon Price	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$8	$4,290	$4,819	$5,871	$8,215	$11,614	$19,022	$22,170	$24,468	$25,315	$26,208
$15	$8,045	$9,035	$11,008	$15,403	$21,777	$35,667	$41,569	$45,877	$47,466	$49,139
$25	$13,408	$15,059	$18,347	$25,671	$36,295	$59,445	$69,282	$76,461	$79,109	$81,899

As discussed in Section 3.3.4, the economic benefits are an underestimate because they do not include the reductions in human health and safety risks from storm protection or the benefits from water filtration, biodiversity, and existence values.

Table 10 presents the NPV per ha for the four carbon prices included in the analysis. The economic NPV of mangrove restoration was highly sensitive to the carbon prices used. Over the 50-year time horizon, the economic NPV ranged from $35,708 at a carbon price of $0 to $404,041 at a carbon price of $25 per ton of carbon dioxide equivalent. Table 10 presents the NPV per ha for the four carbon prices included in the analysis.

TABLE 10. Economic Net Present Value of Mangrove Restoration Per Hectare (2016 US dollars)

Carbon Price	Net Present Value
$0	$35,708
$8	$153,575
$15	$256,708
$25	$404,041

4.3 EARTHEN DIKE

The financial and economic analyses for the earthen dike were similar, except that the economic analysis excluded the cost of taxes as transfer payments. Table 11 lists the key assumptions for the earthen dike analysis.

TABLE 11. Base Scenario Assumptions for the Earthen Dike

Parameter	Assumption
Time horizon	50 years
Earthen dike cost	$15 per linear foot
Average annual maintenance costs	5% of capital costs

Table 12 presents per hectare financial and economic costs of the earthen dike for the first 10 years, including the costs of construction and routine annual maintenance. CEADIR assumed a medium-sized storm would double the annual average maintenance costs. The probability of a medium-sized storm was 33 percent based on INGC (2009). The construction cost estimate was not site specific. CEADIR used the low-end estimate of $15 per linear foot from Rogers et al. (2016). The sensitivity analysis used the high-end estimate of $55 per linear foot from the same source. In subsequent planning, these estimates should be refined based on local specifications and costs.

The analysis assumed that the earthen dike would be completed in the first year and would have average annual maintenance costs of 5 percent of the capital costs, based on Aquapesca's experience. The analysis assumed that the earthen dike would need to be completely rebuilt after a large storm at the same real initial capital cost. CEADIR estimated the annual cost of rebuilding by multiplying the construction cost by the probability of a large storm in a given year, 1.7 percent based on INGC (2009).

TABLE 12. Incremental Costs Per Hectare of Earthen Dike (2016 US dollars)

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Construction of earthen dike	$11,185	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual maintenance	$559	$559	$559	$559	$559	$559	$559	$559	$559	$559
Dike repair or rebuilding after storm events	$2,237	$2,237	$2,237	$2,237	$2,237	$2,237	$2,237	$2,237	$2,237	$2,237
Taxes	$2,377	$475	$475	$475	$475	$475	$475	$475	$475	$475
Total Financial Costs	$16,358	$3,272	$3,272	$3,272	$3,272	$3,272	$3,272	$3,272	$3,272	$3,272
Total Economic Costs	$13,981	$2,796	$2,796	$2,796	$2,796	$2,796	$2,796	$2,796	$2,796	$2,796

Table 13 presents the incremental financial and economic benefits of the earthen dike, which were the same because this option did not have the extramarket benefits of mangrove restoration. The storm protection benefits were based on the average house value of $915. The analysis assumed that current land uses would continue over the time horizon. CEADIR did not estimate the monetary benefits from reduced human health and safety impacts from storms.

TABLE 13. Incremental Financial Benefits of the Earthen Dike Per Hectare (2016 US dollars)

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Storm protection	$153	$153	$153	$153	$153	$153	$153	$153	$153	$153
Total Financial and Economic Benefits	$153	$153	$153	$153	$153	$153	$153	$153	$153	$153

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The earthen dike had large negative financial and economic NPVs in the base case (-$34,251 and -$28,647 per hectare, respectively). The negative NPVs resulted from the low value of the informal housing in the area and the relatively high construction and rebuilding costs for earthen dikes. The NPVs would be higher if the value of reduced health and safety risks were included.

5. RESULTS OF THE BASE CASE SCENARIOS

Table 14 summarizes the financial and economic NPVs for mangrove restoration per hectare and the earthen dike at a 12-percent discount rate. Table 15 presents the financial and economic NPVs for the 22 ha study area. Mangrove restoration had a positive financial NPV in the base case. Unlike the financial analysis, the economic analysis considered carbon sequestration benefits at four carbon prices. The economic NPVs were positive under the four carbon prices and exceeded the financial NPV, even at a carbon price of zero.

The earthen dike was not financially or economically viable at the low-end estimate of its capital costs. The negative NPVs were due to the high capital and maintenance and replacement costs. The storm protection benefits of both mangrove restoration and the earthen dike were relatively low because of the low value of the informal sector housing in the study area. The storm protection benefits from both alternatives would have been higher if values had been estimated for the reduction in human health and safety impacts. Mangrove restoration was financially and economically viable because it provided substantial additional benefits that that earthen dike did not.

TABLE 14. Financial and Economic Net Present Value of Mangrove Restoration and an Earthen Dike Per Hectare at a 12-Percent Discount Rate (2016 US dollars)

Scenario	Mangrove Restoration	Earthen Dike
Financial Net Benefits	$33,165	-$34,251
$0 Carbon Price		
Economic Net Benefits	$35,708	-$28,647
$8 Carbon Price		
Economic Net Benefits	$153,575	-$28,647
$15 Carbon Price		
Economic Net Benefits	$256,708	-$28,647
$25 Carbon Price		
Economic Net Benefits	$404,041	-$28,647

TABLE 15. Total Financial and Economic Net Present Values from the Mangrove Restoration and Earthen Dike Options at a 12-Percent Discount Rate (2016 US dollars)

Scenario	Mangrove Restoration	Earthen Dike
Financial Net Benefits	$729,629	-$753,512
Financial Annualized Value	$78,446	-$81,014
$0 Carbon Price		
Economic Net Benefits	$785,580	-$630,227
Economic Annualized Value	$84,462	-$67,759
$8 Carbon Price		
Economic Net Benefits	$3,378,647	-$630,227
Economic Annualized Value	$363,255	-$67,759
$15 Carbon Price		
Economic Net Benefits	$5,647,580	-$630,227
Economic Annualized Value	$607,199	-$67,759
$25 Carbon Price		
Economic Net Benefits	$8,888,913	-$630,227
Economic Annualized Value	$955,690	-$67,759

The main limitations of this study follow:

- Since recent, local data were not available, the study estimated the probability of medium- and high-severity storms using 2009 data from the coastal city of Beira, Mozambique, 478 km from Quelimane.
- A local growth function was not available for the three main mangrove species in the study area. It was therefore necessary to use secondary data and apply a growth function from one species to the other two species and then estimate the relationships among tree height, width, and carbon stocks and flows.
- There was no site-specific hydrological study for the mangrove restoration site. The analysis assumed that the study area would be suitable for mangrove restoration after some restoration of hydrological flows.
- There was a large range of carbon-offset prices on the compliance and voluntary markets and the three nonzero price levels were assumed to be net of transaction costs and monitoring, reporting, and verification costs. However, carbon sequestration values were only included in the economic analysis and were assumed to be zero in one scenario.
- The study did not include Monte Carlo simulations to address probabilistic effects.

6. SENSITIVITY AND SWITCHING VALUES ANALYSES

6.1 SENSITIVITY ANALYSIS

CEADIR considered several sensitivity analyses to assess how the net present values changed when key assumptions were modified. Table 16 presents the various assumptions included in the sensitivity analyses.

TABLE 16. Assumptions Varied in the Sensitivity Analyses

Parameter	Base Scenario	Low	High
Time horizon (years)	50	50	100
Discount rates (0%, 3%, 7%, and 12%)	0%, 3%, 7%, 12%	0%, 3%, 7%, 12%	0%, 3%, 7%, 12%
Mangrove tree survival rate beyond the seedling stage	95%	50%	100%
Mangrove seedling survival rate	80%	50%	80%
Carbon price (per tCO_2e)	$0, $8, $15, $25	$0, $8, $15, $25	$0, $8, $15, $25
Fisheries production level	100%	50%	100%
Earthen dike construction cost per linear foot	$15	$15	$55
Average house value	$915	$915	$4,575
Extent of storm damage to houses without project	100%	33%	100%

(Note: All prices were in 2016 US dollars)

Tables 17 to 24 contain the sensitivity analyses results. Table 24 presents the combined sensitivity analyses based on the low and high values for all variables. The sensitivity analyses did not cause any of the net present values to change from positive to negative or vice versa. In all sensitivity scenarios, the NPVs were positive for mangrove restoration and negative for the earthen dike.

TABLE 17. Sensitivity Analysis on the Time Horizon at a 12 Percent Discount Rate (2016 US dollars)

		Mangrove Restoration		*Earthen Dike*	
	Carbon Price (per tCO_2e)	Low	High	Low	High
Project life		**50 years**	**100 years**	**50 years**	**100 years**
Financial NPV	N/A	$33,165	$33,365	-$34,251	-$34,369
Economic NPV	$0	$35,708	$35,913	-$28,647	-$28,746
	$8	$153,575	$153,845	-$28,647	-$28,746
	$15	$256,708	$257,035	-$28,647	-$28,746
	$25	$404,041	$404,450	-$28,647	-$28,746

TABLE 18. Sensitivity Analysis on Mangrove Tree and Seedling Survival Rates at a 12 Percent Discount Rate and 50-Year Time Horizon (2016 US dollars)

		Mangrove Restoration		*Earthen Dike*	
	Price Per tCO_2e	Low	High	Low	High
Mangrove Survival		**50% Seedling, 50% Mature**	**80 % Seedling, 100% Mature**	**50% Seedling, 50% Mature**	**80 % Seedling, 100% Mature**
Financial NPV	N/A	$17,133	$33,165	-$34,251	-$34,251
Economic NPV	$0	$19,676	$35,708	-$28,647	-$28,647
	$8	$49,982	$153,575	-$28,647	-$28,647
	$15	$76,499	$256,708	-$28,647	-$28,647
	$25	$114,381	$404,041	-$28,647	-$28,647

TABLE 19. Sensitivity Analysis on the Discount Rate at a 50-Year Time Horizon (2016 US dollars)

		Mangrove Restoration				*Earthen Dike*			
	Price Per tCO_2e	Low	Medium 1	Medium 2	High	Low	Medium 1	Medium 2	High
Discount Rate		0%	3%	7%	12%	0%	3%	7%	12%
Financial NPV	N/A	$313,914	$147,959	$68,191	$33,165	-$148,956	-$82,623	-$49,732	-$34,251
Economic NPV	$0	$323,192	$153,366	$71,663	$35,708	-$123,536	-$68,674	-$41,463	-$28,647
	$8	$909,139	$499,390	$271,602	$153,575	-$123,536	-$68,674	-$41,463	-$28,647
	$15	$1,421,842	$802,161	$446,550	$256,708	-$123,536	-$68,674	-$41,463	-$28,647
	$25	$2,154,275	$1,234,691	$696,474	$404,041	-$123,536	-$68,674	-$41,463	-$28,647

TABLE 20. Sensitivity Analysis on the Fishery Production Level at a 2 Percent Discount Rate and 50-Year Time Horizon (2016 US dollars)

		Mangrove Restoration		*Earthen Dike*	
	Price Per tCO_2e	Low	High	Low	High
Fishery Production Level		50%	100%	50%	100%
Financial NPV	N/A	$14,309	$33,165	-$34,251	-$34,251
Economic NPV	$0	$16,852	$35,708	-$28,647	-$28,647
	$8	$134,719	$153,575	-$28,647	-$28,647
	$15	$237,852	$256,708	-$28,647	-$28,647
	$25	$385,185	$404,041	-$28,647	-$28,647

TABLE 21. Sensitivity Analysis on the Earthen Dike Construction Cost at a 12 Percent Discount Rate and 50-Year Time Horizon (2016 US dollars)

		Mangrove Restoration		*Earthen Dike*	
	Price Per tCO_2e	Low	High	Low	High
Earthen Dike Cost		$15/linear foot	$55/linear foot	$15/linear foot	$55/linear foot
Financial NPV	N/A	$33,165	$33,165	-$34,251	-$137,857
Economic NPV	$0	$35,708	$35,708	-$28,647	-$117,199
	$8	$153,575	$153,575	-$28,647	-$117,199
	$15	$256,708	$256,708	-$28,647	-$117,199
	$25	$404,041	$404,041	-$28,647	-$117,199

TABLE 22. Sensitivity Analysis on the Average Housing Value at a12 Percent Discount Rate and 50-Year Time Horizon (2016 US dollars)

		Mangrove Restoration		*Earthen Dike*	
	Price Per tCO_2e	**Low**	**High**	**Low**	**High**
Average House Value		$915	$4,575	$915	$4,575
Financial NPV	N/A	$33,165	$47,018	-$34,251	-$16,009
Economic NPV	$0	$35,708	$49,562	-$28,647	-$10,405
	$8	$153,575	$167,428	-$28,647	-$10,405
	$15	$256,708	$270,562	-$28,647	-$10,405
	$25	$404,041	$417,895	-$28,647	-$10,405

TABLE 23. Sensivity Analysis on the Housing Damage From Medium-Sized Storms at a 12 Percent Discount Rate and 50-Year Time Horizon (2016 US dollars)

		Mangrove Restoration			*Earthen Dike*		
	Price Per tCO_2e	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Percent of Housing Damaged by Medium-Sized Storm		33%	67%	100%	33%	67%	100%
Financial NPV	N/A	$31,814	$32,489	$33,165	-$35,602	-$34,926	-$34,251
Economic NPV	$0	$34,357	$35,033	$35,708	-$29,998	-$29,322	-$28,647
	$8	$152,224	$152,899	$153,575	-$29,998	-$29,322	-$28,647
	$15	$255,357	$256,033	$256,708	-$29,998	-$29,322	-$28,647
	$25	$402,690	$403,366	$404,041	-$29,998	-$29,322	-$28,647

Note: The base case assumes that homes are completely destroyed by a medium storm in the without-project scenario (100 percent damage). The sensitivity case assumes partial damage.

TABLE 24. Sensitivity Analysis, Combined High and Low Scenarios

		Mangrove Restoration		*Earthen Dike*	
	Price Per tCO_2e	**Low**	**High**	**Low**	High
Financial NPV	N/A	$77,425	$47,268	-$157,091	-$120,029
Economic NPV	$0	$86,703	$49,815	-$131,671	-$99,300
	$8	$156,313	$167,747	-$131,671	-$99,300
	$15	$217,221	$270,937	-$131,671	-$99,300
	$25	$304,233	$418,352	-$131,671	-$99,300

6.2 SWITCHING VALUE ANALYSIS

Switching values are the level or percent change in a parameter that make a difference whether an investment is favorable or not (where a positive or negative NPV becomes zero). Switching values help decision makers undestand whether an investment is robust if key factors change. If the switching value for a parameter is close to the assumption in the base scenario, there is limited scope for the parameter to change.

For mangrove restoration, CEADIR calculated the switching values for the level of fisheries production, and the mangrove seedling and tree survival rates. For both mangrove restoration and the earthen dike, CEADIR calculated switching values for the average house value in the study area. CEADIR also estimated the switching value for the construction costs of the earthen dike.

Table 25 presents key base scenario assumptions and their switching values. The returns on mangrove restoration were most sensitive to the mangrove tree and seedling survival rates. The switching value analysis showed that mangrove restoration would not be financially viable if the tree survival rate fell below 15 percent. It would not be economically viable if the tree survival rate fell to 5 percent. However, the financial and economic viability of mangrove restoration was not sensitive to the level of fisheries production or the average value of the houses in the protected communities. The switching value analysis showed that the earthen dike would only become financially viable if the average value of the protected houses exceeded $7,800 or the construction cost of the dike were below $2/linear foot.

TABLE 25. Base Scenario Parameters and Switching Values

Parameter	Base Scenario	Switching Values			
		Earthen Dike		Mangrove Restoration	
		Financial Analysis	Economic Analysis	Financial Analysis	Economic Analysis
Mangrove tree survival rate	100%	N/A[a]	N/A[a]	15%	5%
Mangrove seedling survival rate	80%	N/A[a]	N/A[a]	15%	5%
Fisheries production value	$9,330	N/A[a]	N/A[a]	None	None
Average value of protected houses	$915	$7,800	$6,700	None	None
Earthen dike construction cost (per linear foot)	$15	$2	$2	N/A	N/A

N/A = not applicable; None means no analyzed value of the parameter would turn a positive NPV to zero

7. CONCLUSIONS

This cost-benefit analysis compared two options to protect the Icídua and Mirazane communities in peri-urban Quelimane from flooding from storm surges—22 ha of mangrove restoration in a protected area and an earthen dike around the perimeter of the study area. The earthen dike had negative financial and economic net present values because of its high construction and repair costs and the low average value of the houses it would help protect from storm damage. The houses in these two low-income communities were typically made of mud and mangrove poles. The earthen dike was not financially viable under the low or high estimates of construction and replacement costs. An earthen dike could be financially and economically viable in a different location with higher average housing values. It might even be financially and economically viable in the study area if the analysis accounted for the value of human health and safety benefits from protection against storms.

Mangrove restoration had positive financial and economic net present values in the base scenarios. However, the financial and economic viability of mangrove restoration was sensitive to large reductions in the mangrove tree and seedling survival rates. The study area has faced increasing population and resource pressures. With few options for their livelihoods, local communities have cut mangroves to sell to outsiders for poles and woodfuels despite the government's ban on commercial harvesting. Since the study area is a designated protected area and CCAP has demonstrated that good mangrove seedling and tree survival rates could be obtained. The base scenario assumptions for the survival rates were reasonable. Although carbon prices affected the economic net present value, mangrove restoration was economically viable even a carbon price of zero. More research could help estimate benefits that were not included in this analysis, such as reduced human mortality and safety impacts for mangrove restoration and the earthen dike as well as water filtration, biodiversity, and existence values for mangrove restoration.

The average value of the protected houses would have to increase 500 percent for the earthen dike to be financially viable. The NPVs for both mangrove restoration and the earthen dike would be higher if the human health and safety benefits were valued in monetary terms. The earthen dike would offer more storm protection than mangroves during the period before the trees reached maturity in 10 years. The dike might also provide greater protection from flooding than mature mangroves as long as its maximum holding capacity is not breached. Consequently, lower health and safety risks could potentially make the earthen dike a preferred alternative over mangrove restoration.

CCAP also demonstrated that the study area was conducive for mangrove restoration. Since the study area experiences frequent flooding, it is unlikely that the communities will convert it to other uses. Mangrove restoration might not be feasible in other locations where the demand for potential development may clear the trees for other land uses. The cost-benefit analysis included reasonable costs for hydrological flow improvements to support mangrove survival. Site-specific factors (such as projected changes in flooding patterns due to sea level rise) can make a feasible area for mangrove restoration site unsuitable in the future without additional investments in hydrological restoration or monitoring. Site-specific issues should be considered in applying the findings of this analysis to other locations. A more detailed site assessment for the study area would also be important to refine the specifications and construction cost estimates for the earthen dike. A subsequent analysis could also examine a hybrid approach combining smaller earthen dikes and some mangrove restoration.

ANNEX A. MAPS AND IMAGES OF PROJECT SITE

FIGURE A-1. Location of Quelimane

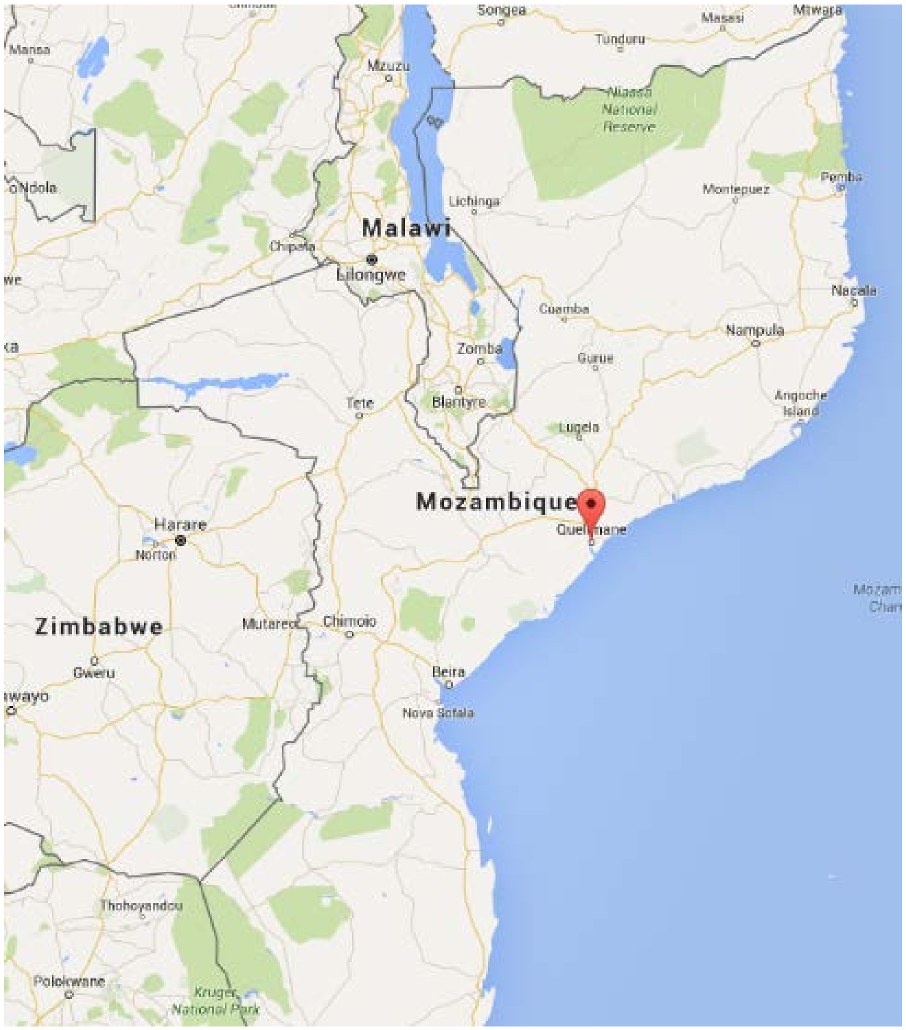

FIGURE A-2. Satellite Image of Quelimane Port District and CCAP Mangrove Restoration Project Site

ANNEX B: SENSITIVITY ANALYSIS RESULTS

TABLE B-1. Base ScenariosPer Hectare and Total Under Four Carbon Prices,at a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$33,253	-$33,959
Economic Net Benefits	$35,796	-$28,355
Financial Annualized Value	$3,575	-$3,651
Economic Annualized Value	$3,849	-$3,049
$8 Carbon Price		
Financial Net Benefits	$33,253	-$33,959
Economic Net Benefits	$153,663	-$28,355
Financial Annualized Value	$3,575	-$3,651
Economic Annualized Value	$16,521	-$3,049
$15 Carbon Price		
Financial Net Benefits	$33,253	-$33,959
Economic Net Benefits	$256,796	-$28,355
Financial Annualized Value	$3,575	-$3,651
Economic Annualized Value	$27,609	-$3,049
$25 Carbon Price		
Financial Net Benefits	$33,253	-$33,959
Economic Net Benefits	$404,130	-$28,355
Financial Annualized Value	$3,575	-$3,651
Economic Annualized Value	$43,450	-$3,049

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$731,570	-$747,094
Economic Net Benefits	$787,521	-$623,808
Financial Annualized Value	$78,655	-$80,324
Economic Annualized Value	$84,670	-$67,069
$8 Carbon Price		
Financial Net Benefits	$731,570	-$747,094
Economic Net Benefits	$3,380,587	-$623,808
Financial Annualized Value	$78,655	-$80,324
Economic Annualized Value	$363,463	-$67,069
$15 Carbon Price		
Financial Net Benefits	$731,570	-$747,094
Economic Net Benefits	$5,649,520	-$623,808
Financial Annualized Value	$78,655	-$80,324
Economic Annualized Value	$607,407	-$67,069
$25 Carbon Price		
Financial Net Benefits	$731,570	-$747,094
Economic Net Benefits	$8,890,853	-$623,808
Financial Annualized Value	$78,655	-$80,324
Economic Annualized Value	$955,899	-$67,069

TABLE B-2. Sensitivity Analysis on a 100-Year Project Life at a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$33,455	-$34,076
Economic Net Benefits	$36,002	-$28,452
Financial Annualized Value	$3,584	-$3,638
Economic Annualized Value	$3,857	-$3,038
$8 Carbon Price		
Financial Net Benefits	$33,455	-$34,076
Economic Net Benefits	$153,934	-$28,452
Financial Annualized Value	$3,584	-$3,638
Economic Annualized Value	$16,493	-$3,038
$15 Carbon Price		
Financial Net Benefits	$33,455	-$34,076
Economic Net Benefits	$257,125	-$28,452
Financial Annualized Value	$3,584	-$3,638
Economic Annualized Value	$27,549	-$3,038
$25 Carbon Price		
Financial Net Benefits	$33,455	-$34,076
Economic Net Benefits	$404,539	-$28,452
Financial Annualized Value	$3,584	-$3,638
Economic Annualized Value	$43,344	-$3,038

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$736,004	-$749,666
Economic Net Benefits	$792,055	-$625,954
Financial Annualized Value	$78,858	-$80,047
Economic Annualized Value	$84,864	-$66,837
$8 Carbon Price		
Financial Net Benefits	$736,004	-$749,666
Economic Net Benefits	$3,386,554	-$625,954
Financial Annualized Value	$78,858	-$80,047
Economic Annualized Value	$362,849	-$66,837
$15 Carbon Price		
Financial Net Benefits	$736,004	-$749,666
Economic Net Benefits	$5,656,740	-$625,954
Financial Annualized Value	$78,858	-$80,047
Economic Annualized Value	$606,087	-$66,837
$25 Carbon Price		
Financial Net Benefits	$736,004	-$749,666
Economic Net Benefits	$8,899,863	-$625,954
Financial Annualized Value	$78,858	-$80,047
Economic Annualized Value	$953,568	-$66,837

TABLE B-3. Sensitivity Analysis of Low Mangrove Seedling and Tree Survival Rates (50 Percent) at a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$17,179	-$33,959
Economic Net Benefits	$19,723	-$28,355
Financial Annualized Value	$1,847	-$3,651
Economic Annualized Value	$2,120	-$3,049
$8 Carbon Price		
Financial Net Benefits	$17,179	-$33,959
Economic Net Benefits	$50,028	-$28,355
Financial Annualized Value	$1,847	-$3,651
Economic Annualized Value	$5,379	-$3,049
$15 Carbon Price		
Financial Net Benefits	$17,179	-$33,959
Economic Net Benefits	$76,546	-$28,355
Financial Annualized Value	$1,847	-$3,651
Economic Annualized Value	$8,230	-$3,049
$25 Carbon Price		
Financial Net Benefits	$17,179	-$33,959
Economic Net Benefits	$114,428	-$28,355
Financial Annualized Value	$1,847	-$3,651
Economic Annualized Value	$12,303	-$3,049

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$377,947	-$747,094
Economic Net Benefits	$433,899	-$623,808
Financial Annualized Value	$40,635	-$80,324
Economic Annualized Value	$46,651	-$67,069
$8 Carbon Price		
Financial Net Benefits	$377,947	-$747,094
Economic Net Benefits	$1,100,621	-$623,808
Financial Annualized Value	$40,635	-$80,324
Economic Annualized Value	$118,333	-$67,069
$15 Carbon Price		
Financial Net Benefits	$377,947	-$747,094
Economic Net Benefits	$1,684,003	-$623,808
Financial Annualized Value	$40,635	-$80,324
Economic Annualized Value	$181,055	-$67,069
$25 Carbon Price		
Financial Net Benefits	$377,947	-$747,094
Economic Net Benefits	$2,517,406	-$623,808
Financial Annualized Value	$40,635	-$80,324
Economic Annualized Value	$270,659	-$67,069

TABLE B-4 Sensitivity Analysis at a Discount Rate of 0 Percent

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$315,808	-$146,408
Economic Net Benefits	$325,087	-$120,988
Financial Annualized Value	$6,316	-$2,928
Economic Annualized Value	$6,502	-$2,420
$8 Carbon Price		
Financial Net Benefits	$315,808	-$146,408
Economic Net Benefits	$911,033	-$120,988
Financial Annualized Value	$6,316	-$2,928
Economic Annualized Value	$18,221	-$2,420
$15 Carbon Price		
Financial Net Benefits	$315,808	-$146,408
Economic Net Benefits	$1,423,736	-$120,988
Financial Annualized Value	$6,316	-$2,928
Economic Annualized Value	$28,475	-$2,420
$25 Carbon Price		
Financial Net Benefits	$315,808	-$146,408
Economic Net Benefits	$2,156,169	-$120,988
Financial Annualized Value	$6,316	-$2,928
Economic Annualized Value	$43,123	-$2,420

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$6,947,778	-$3,220,965
Economic Net Benefits	$7,151,905	-$2,661,725
Financial Annualized Value	$138,956	-$64,419
Economic Annualized Value	$143,038	-$53,235
$8 Carbon Price		
Financial Net Benefits	$6,947,778	-$3,220,965
Economic Net Benefits	$20,042,727	-$2,661,725
Financial Annualized Value	$138,956	-$64,419
Economic Annualized Value	$400,855	-$53,235
$15 Carbon Price		
Financial Net Benefits	$6,947,778	-$3,220,965
Economic Net Benefits	$31,322,196	-$2,661,725
Financial Annualized Value	$138,956	-$64,419
Economic Annualized Value	$626,444	-$53,235
$25 Carbon Price		
Financial Net Benefits	$6,947,778	-$3,220,965
Economic Net Benefits	$47,435,723	-$2,661,725
Financial Annualized Value	$138,956	-$64,419
Economic Annualized Value	$948,714	-$53,235

TABLE B-5. Sensitivity Analysis at a Discount Rate of 3 Percent

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$148,718	-$81,403
Economic Net Benefits	$154,125	-$67,455
Financial Annualized Value	$5,612	-$3,072
Economic Annualized Value	$5,816	-$2,545
$8 Carbon Price		
Financial Net Benefits	$148,718	-$81,403
Economic Net Benefits	$500,149	-$67,455
Financial Annualized Value	$5,612	-$3,072
Economic Annualized Value	$18,872	-$2,545
$15 Carbon Price		
Financial Net Benefits	$148,718	-$81,403
Economic Net Benefits	$802,921	-$67,455
Financial Annualized Value	$5,612	-$3,072
Economic Annualized Value	$30,297	-$2,545
$25 Carbon Price		
Financial Net Benefits	$148,718	-$81,403
Economic Net Benefits	$1,235,451	-$67,455
Financial Annualized Value	$5,612	-$3,072
Economic Annualized Value	$46,618	-$2,545

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$3,271,805	-$1,790,875
Economic Net Benefits	$3,390,758	-$1,484,006
Financial Annualized Value	$123,457	-$67,576
Economic Annualized Value	$127,945	-$55,997
$8 Carbon Price		
Financial Net Benefits	$3,271,805	-$1,790,875
Economic Net Benefits	$11,003,289	-$1,484,006
Financial Annualized Value	$123,457	-$67,576
Economic Annualized Value	$415,192	-$55,997
$15 Carbon Price		
Financial Net Benefits	$3,271,805	-$1,790,875
Economic Net Benefits	$17,664,253	-$1,484,006
Financial Annualized Value	$123,457	-$67,576
Economic Annualized Value	$666,534	-$55,997
$25 Carbon Price		
Financial Net Benefits	$3,271,805	-$1,790,875
Economic Net Benefits	$27,179,916	-$1,484,006
Financial Annualized Value	$123,457	-$67,576
Economic Annualized Value	$1,025,593	-$55,997

TABLE B-6. Sensitivity Analysis at a Discount Rate of 7 Percent

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$68,457	-$49,155
Economic Net Benefits	$71,929	-$40,887
Financial Annualized Value	$4,636	-$3,329
Economic Annualized Value	$4,871	-$2,769
$8 Carbon Price		
Financial Net Benefits	$68,457	-$49,155
Economic Net Benefits	$271,868	-$40,887
Financial Annualized Value	$4,636	-$3,329
Economic Annualized Value	$18,411	-$2,769
$15 Carbon Price		
Financial Net Benefits	$68,457	-$49,155
Economic Net Benefits	$446,816	-$40,887
Financial Annualized Value	$4,636	-$3,329
Economic Annualized Value	$30,258	-$2,769
$25 Carbon Price		
Financial Net Benefits	$68,457	-$49,155
Economic Net Benefits	$696,740	-$40,887
Financial Annualized Value	$4,636	-$3,329
Economic Annualized Value	$47,183	-$2,769

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$1,506,057	-$1,081,413
Economic Net Benefits	$1,582,433	-$899,507
Financial Annualized Value	$101,989	-$73,233
Economic Annualized Value	$107,162	-$60,914
$8 Carbon Price		
Financial Net Benefits	$1,506,057	-$1,081,413
Economic Net Benefits	$5,981,107	-$899,507
Financial Annualized Value	$101,989	-$73,233
Economic Annualized Value	$405,037	-$60,914
$15 Carbon Price		
Financial Net Benefits	$1,506,057	-$1,081,413
Economic Net Benefits	$9,829,946	-$899,507
Financial Annualized Value	$101,989	-$73,233
Economic Annualized Value	$665,679	-$60,914
$25 Carbon Price		
Financial Net Benefits	$1,506,057	-$1,081,413
Economic Net Benefits	$15,328,288	-$899,507
Financial Annualized Value	$101,989	-$73,233
Economic Annualized Value	$1,038,024	-$60,914

TABLE B-7. Sensitivity Analysisat a 50 Percent Reduction in Fishery Production at a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	Mangrove Restoration	Earthen Dike
$0 Carbon Price		
Financial Net Benefits	$14,397	-$33,959
Economic Net Benefits	$16,940	-$28,355
Financial Annualized Value	$1,548	-$3,651
Economic Annualized Value	$1,821	-$3,049
$8 Carbon Price		
Financial Net Benefits	$14,397	-$33,959
Economic Net Benefits	$134,807	-$28,355
Financial Annualized Value	$1,548	-$3,651
Economic Annualized Value	$14,494	-$3,049
$15 Carbon Price		
Financial Net Benefits	$14,397	-$33,959
Economic Net Benefits	$237,940	-$28,355
Financial Annualized Value	$1,548	-$3,651
Economic Annualized Value	$25,582	-$3,049
$25 Carbon Price		
Financial Net Benefits	$14,397	-$33,959
Economic Net Benefits	$385,273	-$28,355
Financial Annualized Value	$1,548	-$3,651
Economic Annualized Value	$41,423	-$3,049

Total Value in 2016 USD (for 22 hectares)		
Scenario	Mangrove Restoration	Earthen Dike
$0 Carbon Price		
Financial Net Benefits	$316,732	-$747,094
Economic Net Benefits	$372,684	-$623,808
Financial Annualized Value	$34,053	-$80,324
Economic Annualized Value	$40,069	-$67,069
$8 Carbon Price		
Financial Net Benefits	$316,732	-$747,094
Economic Net Benefits	$2,965,750	-$623,808
Financial Annualized Value	$34,053	-$80,324
Economic Annualized Value	$318,862	-$67,069
$15 Carbon Price		
Financial Net Benefits	$316,732	-$747,094
Economic Net Benefits	$5,234,683	-$623,808
Financial Annualized Value	$34,053	-$80,324
Economic Annualized Value	$562,806	-$67,069
$25 Carbon Price		
Financial Net Benefits	$316,732	-$747,094
Economic Net Benefits	$8,476,016	-$623,808
Financial Annualized Value	$34,053	-$80,324
Economic Annualized Value	$911,298	-$67,069

TABLE B-8. Sensitivity Analysis at Earthen Dike Costs of $55 per Linear Foot at a 12-percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$33,253	-$137,565
Economic Net Benefits	$35,796	-$116,907
Financial Annualized Value	$3,575	-$14,790
Economic Annualized Value	$3,849	-$12,569
$8 Carbon Price		
Financial Net Benefits	$33,253	-$137,565
Economic Net Benefits	$153,663	-$116,907
Financial Annualized Value	$3,575	-$14,790
Economic Annualized Value	$16,521	-$12,569
$15 Carbon Price		
Financial Net Benefits	$33,253	-$137,565
Economic Net Benefits	$256,796	-$116,907
Financial Annualized Value	$3,575	-$14,790
Economic Annualized Value	$27,609	-$12,569
$25 Carbon Price		
Financial Net Benefits	$33,253	-$137,565
Economic Net Benefits	$404,130	-$116,907
Financial Annualized Value	$3,575	-$14,790
Economic Annualized Value	$43,450	-$12,569

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$731,570	-$3,026,430
Economic Net Benefits	$787,521	-$2,571,959
Financial Annualized Value	$78,655	-$325,386
Economic Annualized Value	$84,670	-$276,524
$8 Carbon Price		
Financial Net Benefits	$731,570	-$3,026,430
Economic Net Benefits	$3,380,587	-$2,571,959
Financial Annualized Value	$78,655	-$325,386
Economic Annualized Value	$363,463	-$276,524
$15 Carbon Price		
Financial Net Benefits	$731,570	-$3,026,430
Economic Net Benefits	$5,649,520	-$2,571,959
Financial Annualized Value	$78,655	-$325,386
Economic Annualized Value	$607,407	-$276,524
$25 Carbon Price		
Financial Net Benefits	$731,570	-$3,026,430
Economic Net Benefits	$8,890,853	-$2,571,959
Financial Annualized Value	$78,655	-$325,386
Economic Annualized Value	$955,899	-$276,524

TABLE B-9. Sensitivity Analysis of a 500 Percent Increase in Averagea House Values oat a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$47,107	-$15,717
Economic Net Benefits	$49,650	-$10,113
Financial Annualized Value	$5,065	-$1,690
Economic Annualized Value	$5,338	-$1,087
$8 Carbon Price		
Financial Net Benefits	$47,107	-$15,717
Economic Net Benefits	$167,517	-$10,113
Financial Annualized Value	$5,065	-$1,690
Economic Annualized Value	$18,011	-$1,087
$15 Carbon Price		
Financial Net Benefits	$47,107	-$15,717
Economic Net Benefits	$270,650	-$10,113
Financial Annualized Value	$5,065	-$1,690
Economic Annualized Value	$29,099	-$1,087
$25 Carbon Price		
Financial Net Benefits	$47,107	-$15,717
Economic Net Benefits	$417,983	-$10,113
Financial Annualized Value	$5,065	-$1,690
Economic Annualized Value	$44,939	-$1,087

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$1,036,346	-$345,775
Economic Net Benefits	$1,092,297	-$222,490
Financial Annualized Value	$111,423	-$37,176
Economic Annualized Value	$117,438	-$23,921
$8 Carbon Price		
Financial Net Benefits	$1,036,346	-$345,775
Economic Net Benefits	$3,685,364	-$222,490
Financial Annualized Value	$111,423	-$37,176
Economic Annualized Value	$396,231	-$23,921
$15 Carbon Price		
Financial Net Benefits	$1,036,346	-$345,775
Economic Net Benefits	$5,954,297	-$222,490
Financial Annualized Value	$111,423	-$37,176
Economic Annualized Value	$640,175	-$23,921
$25 Carbon Price		
Financial Net Benefits	$1,036,346	-$345,775
Economic Net Benefits	$9,195,630	-$222,490
Financial Annualized Value	$111,423	-$37,176
Economic Annualized Value	$988,667	-$23,921

TABLE B-10. Sensitivity Analysis of Medium Storm Damage of 33 Percent of Houses Without-Project at a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$31,902	-$35,310
Economic Net Benefits	$34,445	-$29,706
Financial Annualized Value	$3,430	-$3,796
Economic Annualized Value	$3,703	-$3,194
$8 Carbon Price		
Financial Net Benefits	$31,902	-$35,310
Economic Net Benefits	$152,312	-$29,706
Financial Annualized Value	$3,430	-$3,796
Economic Annualized Value	$16,376	-$3,194
$15 Carbon Price		
Financial Net Benefits	$31,902	-$35,310
Economic Net Benefits	$255,445	-$29,706
Financial Annualized Value	$3,430	-$3,796
Economic Annualized Value	$27,464	-$3,194
$25 Carbon Price		
Financial Net Benefits	$31,902	-$35,310
Economic Net Benefits	$402,778	-$29,706
Financial Annualized Value	$3,430	-$3,796
Economic Annualized Value	$43,305	-$3,194

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$701,842	-$776,821
Economic Net Benefits	$757,794	-$653,535
Financial Annualized Value	$75,458	-$83,520
Economic Annualized Value	$81,474	-$70,265
$8 Carbon Price		
Financial Net Benefits	$701,842	-$776,821
Economic Net Benefits	$3,350,860	-$653,535
Financial Annualized Value	$75,458	-$83,520
Economic Annualized Value	$360,267	-$70,265
$15 Carbon Price		
Financial Net Benefits	$701,842	-$776,821
Economic Net Benefits	$5,619,793	-$653,535
Financial Annualized Value	$75,458	-$83,520
Economic Annualized Value	$604,211	-$70,265
$25 Carbon Price		
Financial Net Benefits	$701,842	-$776,821
Economic Net Benefits	$8,861,126	-$653,535
Financial Annualized Value	$75,458	-$83,520
Economic Annualized Value	$952,703	-$70,265

TABLE B-11. Sensitivity Analysis of Medium Storms Damage of 67 Percent of Houses Without-Project at a 12 Percent Discount Rate

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$32,578	-$34,634
Economic Net Benefits	$35,121	-$29,031
Financial Annualized Value	$3,503	-$3,724
Economic Annualized Value	$3,776	-$3,121
$8 Carbon Price		
Financial Net Benefits	$32,578	-$34,634
Economic Net Benefits	$152,987	-$29,031
Financial Annualized Value	$3,503	-$3,724
Economic Annualized Value	$16,448	-$3,121
$15 Carbon Price		
Financial Net Benefits	$32,578	-$34,634
Economic Net Benefits	$256,121	-$29,031
Financial Annualized Value	$3,503	-$3,724
Economic Annualized Value	$27,537	-$3,121
$25 Carbon Price		
Financial Net Benefits	$32,578	-$34,634
Economic Net Benefits	$403,454	-$29,031
Financial Annualized Value	$3,503	-$3,724
Economic Annualized Value	$43,377	-$3,121

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$716,706	-$761,957
Economic Net Benefits	$772,657	-$638,672
Financial Annualized Value	$77,057	-$81,922
Economic Annualized Value	$83,072	-$68,667
$8 Carbon Price		
Financial Net Benefits	$716,706	-$761,957
Economic Net Benefits	$3,365,724	-$638,672
Financial Annualized Value	$77,057	-$81,922
Economic Annualized Value	$361,865	-$68,667
$15 Carbon Price		
Financial Net Benefits	$716,706	-$761,957
Economic Net Benefits	$5,634,657	-$638,672
Financial Annualized Value	$77,057	-$81,922
Economic Annualized Value	$605,809	-$68,667
$25 Carbon Price		
Financial Net Benefits	$716,706	-$761,957
Economic Net Benefits	$8,875,990	-$638,672
Financial Annualized Value	$77,057	-$81,922
Economic Annualized Value	$954,301	-$68,667

TABLE B-12. Sensitivity Analysis, Combination of Low Scenarios

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$78,422	-$154,543
Economic Net Benefits	$87,700	-$129,123
Financial Annualized Value	$1,568	-$3,091
Economic Annualized Value	$1,754	-$2,582
$8 Carbon Price		
Financial Net Benefits	$78,422	-$154,543
Economic Net Benefits	$157,310	-$129,123
Financial Annualized Value	$1,568	-$3,091
Economic Annualized Value	$3,146	-$2,582
$15 Carbon Price		
Financial Net Benefits	$78,422	-$154,543
Economic Net Benefits	$218,218	-$129,123
Financial Annualized Value	$1,568	-$3,091
Economic Annualized Value	$4,364	-$2,582
$25 Carbon Price		
Financial Net Benefits	$78,422	-$154,543
Economic Net Benefits	$305,230	-$129,123
Financial Annualized Value	$1,568	-$3,091
Economic Annualized Value	$6,105	-$2,582

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$1,725,281	-$3,399,948
Economic Net Benefits	$1,929,408	-$2,840,708
Financial Annualized Value	$34,506	-$67,999
Economic Annualized Value	$38,588	-$56,814
$8 Carbon Price		
Financial Net Benefits	$1,725,281	-$3,399,948
Economic Net Benefits	$3,460,815	-$2,840,708
Financial Annualized Value	$34,506	-$67,999
Economic Annualized Value	$69,216	-$56,814
$15 Carbon Price		
Financial Net Benefits	$1,725,281	-$3,399,948
Economic Net Benefits	$4,800,796	-$2,840,708
Financial Annualized Value	$34,506	-$67,999
Economic Annualized Value	$96,016	-$56,814
$25 Carbon Price		
Financial Net Benefits	$1,725,281	-$3,399,948
Economic Net Benefits	$6,715,054	-$2,840,708
Financial Annualized Value	$34,506	-$67,999
Economic Annualized Value	$134,301	-$56,814

TABLE B-13. Sensitivity Analysis, Combination of High Scenarios

2016 USD Per Hectare		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$47,357	-$119,736
Economic Net Benefits	$49,905	-$99,006
Financial Annualized Value	$5,074	-$12,785
Economic Annualized Value	$5,347	-$10,571
$8 Carbon Price		
Financial Net Benefits	$47,357	-$119,736
Economic Net Benefits	$167,837	-$99,006
Financial Annualized Value	$5,074	-$12,785
Economic Annualized Value	$17,983	-$10,571
$15 Carbon Price		
Financial Net Benefits	$47,357	-$119,736
Economic Net Benefits	$271,027	-$99,006
Financial Annualized Value	$5,074	-$12,785
Economic Annualized Value	$29,039	-$10,571
$25 Carbon Price		
Financial Net Benefits	$47,357	-$119,736
Economic Net Benefits	$418,442	-$99,006
Financial Annualized Value	$5,074	-$12,785
Economic Annualized Value	$44,834	-$10,571

Total Value in 2016 USD (for 22 hectares)		
Scenario	**Mangrove Restoration**	**Earthen Dike**
$0 Carbon Price		
Financial Net Benefits	$1,041,860	-$2,634,182
Economic Net Benefits	$1,097,911	-$2,178,139
Financial Annualized Value	$111,629	-$281,265
Economic Annualized Value	$117,635	-$232,571
$8 Carbon Price		
Financial Net Benefits	$1,041,860	-$2,634,182
Economic Net Benefits	$3,692,410	-$2,178,139
Financial Annualized Value	$111,629	-$281,265
Economic Annualized Value	$395,620	-$232,571
$15 Carbon Price		
Financial Net Benefits	$1,041,860	-$2,634,182
Economic Net Benefits	$5,962,596	-$2,178,139
Financial Annualized Value	$111,629	-$281,265
Economic Annualized Value	$638,857	-$232,571
$25 Carbon Price		
Financial Net Benefits	$1,041,860	-$2,634,182
Economic Net Benefits	$9,205,719	-$2,178,139
Financial Annualized Value	$111,629	-$281,265
Economic Annualized Value	$986,339	-$232,571

ANNEX C: STAKEHOLDERS INTERVIEWED

Associacão dos Naturais e Amigos de Madal (Association of Nature and Friends of Madal) (ANAMA)

Associacão dos Naturais e Amigos de Madal
Madal, Quelimane – Mozambique

- Tomas Vitorino Amissande, President
- José Maria, Secretary

USAID/Mozambique Coastal City Adaptation Project (CCAP)

Maputo Head Office – Av. Armando Tivane 196, Mauto

- Olanda Bata, COP
- Gilberto Muai, GIS Technician
- Brant Paulson, Financial Officer

Quelimane Office

- Sharmila Flavia Moiane, Project Officer

Direção Provincial da Terra, Ambiente e Desenvolvimento Rural (Provincial Directorate of Land, Environment and Rural Development) (Mozambique) (DPTADER)

Direção Provincial da Terra, Ambiente e Desenvolvimento Rural
Provincial Directorate of Land, Environment and Rural Development
Avenida 1º de Julho, Quelimane – Zambezia

- Mussa Nambera, Head of Planification
- José Manuel Dias, Forestry Techinician

Empresa Municipal de Saneamento e Mudanças Climáticas (Municipal Company for Sanitation and Climate Changes) (Mozambique)(EMUSA)

Município de Quelimane - Empresa Municipal de Saneamento e Mudanças Climáticas
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REFERENCES

Alongi, Daniel. 2012. "Carbon Sequestration in Mangrove Forests." *Carbon Management.* 3(3): 313-322.

California Air Resources Board. 2017. *California Cap-and-Trade Program: Summary of Joint Auction Settlement Prices and Results.* https://www.arb.ca.gov/cc/capandtrade/auction/results_summary.pdf

Cote, Michael and Robin King. 2017. *Urban Resilience Planning for Secondary African Cities: A Case Study of Mozambique.* Washington, DC: Support of the Urban Policy (SOUP) Project, Ecodit, and World Resources Institute. Prepared for the US Agency for International Development (USAID).

Dahdouh-Guebas, Farid. 2006. "Mangrove Forests and Tsunami Protection." *McGraw-Hill Yearbook of Science and Technology.* New York: McGraw-Hill Professional.

Davies, Richard. 2017. "Mozambique—More Deaths Confirmed as Ex Cyclone Dineo Moves West." Floodlist. http://floodlist.com/africa/mozambique-deaths-cyclone-dineo-february-2017

Dekker, Thijs; Roy Brouwer;, Marjan Hofkes;, and Klaus Moeltner. 2011. "The Effect of Risk Context on the Value of a Statistical Life: a Bayesian Meta-Model." *Environmental and Resource Economics*. 49: 597-624.

Ecobusinesslinks. 2017. "Carbon Offsetting + Price Survey." http://www.ecobusinesslinks.com/surveys/carbon-offsetting-price-survey/

Gerston, Lee; Carlos Quintela; and Colin Quinn. 2015. "Mozambique Cities Adapt to Climate Change One Tree and One Text Message at a Time." *USAID Frontlines.* https://www.usaid.gov/news-information/frontlines/climate-change-2015/mozambique-cities-adapt-climate-change-one-tree-and

Hammitt, James and Lisa Robinson. 2011. "The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations." *Journal of Benefit-Cost Analysis.* 2:1-27.

Instituto Nacional de Gestao de Calamidades (INGC). 2009. *Study on the Impact of Climate Change on Disaster Risk in Mozambique.* Maputo: Government of Mozambique.

Kocian, Maya; Dave Batker; and Jennifer Harrison-Cox. 2010. *Nature's Value in the Terraba-Sierpe National Wetlands: The Essential Economics of Ecosystem Services.* Tacoma, WA: Earth Economics.

Lindhjem, Henrik; Stale Navrud; Nils Braathen; and Vincent Biausque. 2011. "Valuing Mortality Risk Reductions from Environmental, Transport, and Health Policies: a Global Meta-Analysis of Stated Preference Studies." *Risk Analysis.* 31:1381-1407.

Lumbroso, Darren; David Ramsbottom; and Mathias Spaliveiro. 2008. "Sustainable Flood Risk Management Strategies to Reduce Rural Communities' Vulnerability to Flooding in Mozambique." *Journal of Flood Risk Management.* 1:34-42.

Regional Greenhouse Gas Initiative. 2017. *Market Monitor Report for Auction 36*. Prepared by Potomac Economics for the Regional Greenhouse Gas Initiative. https://www.rggi.org/docs/Auctions/36/PR060917_Auction36.pdf

Robinson, Lisa and James Hammitt. *The Value of Reducing Air Pollution Risks in Sub-Saharan Africa.* Prepared for The World Bank by ICF International.

Rogers, Megan; Bryan Wilfong;, Craig Voros;, and Anna Kishore, 2016. Best Management Practices for Clermont County. Prepared for Stormwater Management Department of Clermont County, Ohio.

http://swcd.sites.clermontcountyohio.gov/wp-content/uploads/sites/23/2016/09/constructionbmpmanual.pdf

Ronnback, Patrik. 1999. “The Ecological Basis for Economic Value of Seafood Production Supported by Mangrove Ecosystems.” *Ecological Economics*. 29:235-252.

Roy, Rana. 2016. *The Cost of Air Pollution in Africa.* Paris: Organization for Economic Co-operation and Development, Development Centre. Working Paper No. 333.

Sitoe, Almeida; Luis Mandlate; and Bernard Guedes. 2014. “Biomass and Carbon Stocks of Sofala Bay Mangrove Forests.” *Forests*. 5:1967-1981.

Smith, Gordon; Lindsay Foley; Charlotte Mack; and Eric Hyman. 2017. *Analysis of Mangrove Valuation: Methods and Values*. Washington, D.C.: Climate Economic Analysis Development, Investment, and Resilience (CEADIR) Activity, Crown Agents USA and Abt Associates. Prepared for the US Agency for International Development.

Terrapass. 2017. Personal Carbon Offset. https://www.terrapass.com/product/individuals-families

Trettin, Carl; Christina Stringer;, and Stanley Zarnoch. 2015. “Composition, Biomass, and Structure of Mangroves Within the Zambezi River Delta.” *Wetlands Ecology and Mangement*. 24:173-186.

Tuah, Tran Huu and Bui Duc Tinh. 2013. *Cost-Benefit Analysis of Mangrove Restoration in Thi Nai Lagoon, Quy Nhon City, Vietnam. Asian Cities Climate Resilience project*. London: International Institute for Environment and Development (IIED). Working Paper Series No. 4.

United Nations Environment Programme (UNEP). 2011. *Economic Analysis of Mangrove Forests: A Case Study in Gazi Bay, Kenya*. Nairobi, Kenya: United Nations Environment Program.

United Nations, International Organization for Migration (IOM), and Red Cross. 2015. *Mozambique Floods 2015: Response and Recovery Proposal.* https://www.wfp.org/sites/default/files/Response%20and%20Recovery%20Proposal%20to%20Floods%20in%20Mozambique%202015_Final.pdf

USAID. 2011. *USAID Guidelines: Cost-Benefit Analysis*. Washington, DC: US Agency for International Development.

U.S. EPA. 2010. *Guidelines for Preparing Economic Analyses*. Washington, DC: U.S. Environmental Protection Agency, National Center for Environmental Economics.

Van Logchem, Barbara and Antonio J. Queface (eds.). 2012. *Responding to Climate Change in Mozambique: Synthesis Report.* Maputo: Instituto Nacional de Gestao de Calamidades (INGC).

World Bank. 2011. “Vulnerability, Risk Reduction, and Adaptation to Climate Change: Mozambique. Climate Risk and Adaptation Country Profile. Global Facility for Disaster Reduction and Recovery, Climate Investment Funds, and Climate Change Team.” http://sdwebx.worldbank.org/climateportalb/doc/GFDRRCountryProfiles/wb_gfdrr_climate_change_country_profile_for_MOZ.pdf

WWF. 2016. *BCG Economic Valuation: Methodology and Sources. Reviving the Western Indian Ocean Economy: Actions for a Sustainable Future.* Gland, Switzerland: Worldwide Fund for Nature.