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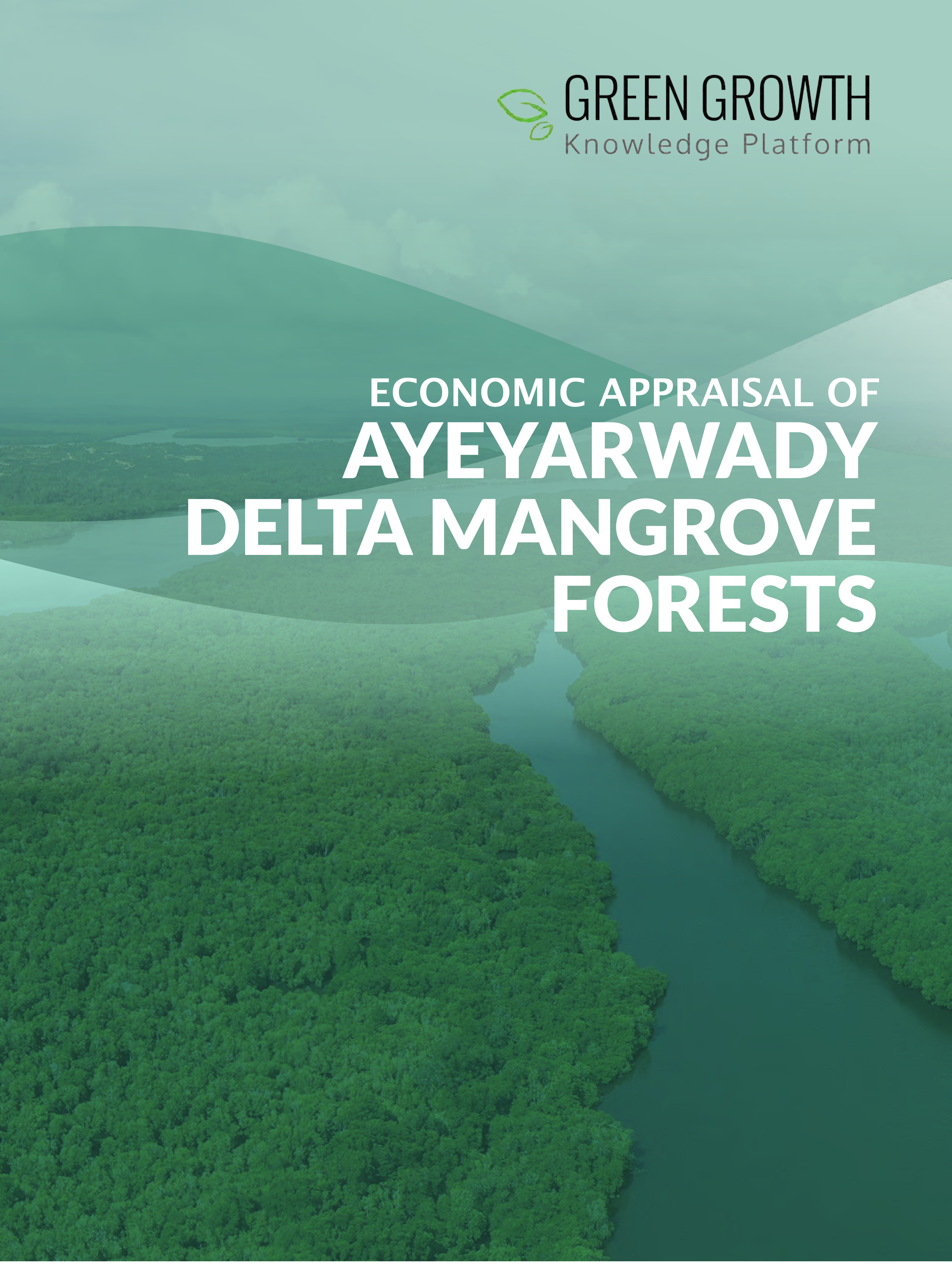
ECONOMIC APPRAISAL OF AYEYARWADY DELTA MANGROVE FORESTS



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Disclaimer

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Summary

The Ayeyarwady Delta is one of the major tropical deltas in the world. Mangrove forests are key elements in the evolution of tropical deltas such as the Ayeyarwady and provide a range of resources that support communities. The communities of the densely populated Ayeyarwady Delta are highly dependent on mangroves, for fuel, food and coastal protection from extreme storms. The mangroves of the Delta have been degraded through over-exploitation and land conversion, which has increased the vulnerability of people to extreme weather events, as demonstrated by the devastation caused by Cyclone Nargis in 2008. The decline of fishery and fuel wood availability have also affected the communities' wellbeing. Conservation, restoration and improved management of mangroves is a solution to the environmental degradation faced by the people of the Ayeyarwady Delta.

The conservation and restoration of coastal mangroves is a priority consistent with Myanmar's Nationally Determined Contribution commitments to the Paris Agreement because of the reduction in climate-associated vulnerability resulting from mangrove conservation and restoration, and because of the role of mangroves in carbon sequestration or blue carbon. However, conservation and restoration of mangroves require substantial investment. This can be justified and stimulated if the returns are clearly known. Thus, the aim of this project was to characterize the monetary and non-monetary benefits of restoration and improved management of mangroves in townships of the lower Ayeyarwady Delta. The end goal was to identify green growth alternatives to enhance the well-being of the communities of the Ayeyarwady Delta.

To estimate the return on investment for restoration and improved management of mangroves we followed the 3Returns Framework, which seeks to estimate returns on investment in environmental, social & human, and financial categories. We compared returns obtained under a Business as Usual (BAU) scenario, with current levels of investment in restoration and rates of illegal mangrove use, against scenarios where illegal use of mangroves is reduced, and where mangrove restoration is enhanced and mangroves currently under government management are allocated to community forestry and village woodlots. We used an extensive field data set that included land-use mapping, assessments of mangrove biomass, growth rates and carbon sequestration; costs and success of mangrove restoration; data on value chains of mangrove products; levels of employment and training, as well as information on government policies and practices. Our analyses also included estimates of the impacts of climate change on agriculture and mangrove distribution. However, it should be noted that these impacts are highly uncertain due to a lack of data and models for the region.

Improved management scenarios benefited communities above a BAU scenario in all three categories considered in the 3Returns Framework (environmental, social & human, and financial). Increases in benefits were particularly evident for natural capital, coastal protection and net present value. The high return on investment for all scenarios over 60 years, even in the BAU scenario, provided evidence that even limited investment in mangrove restoration provides high levels of benefits. However, the return on investment for the BAU declined over time, reflecting the decrease in benefits when there is limited reinvestment or replenishment of mangrove assets.

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List of Abbreviations

BAU	Business as usual
BCR	Benefit cost ratio
CAPEX	Capital expenditure
CF	Community forestry
CFUG	Community Forestry User Group
CIFOR	Center for International Forestry Research
CIRAD	The French Agricultural Research Centre for International Development
ES	Ecosystem services
FAO	Food and Agriculture Organization
FR	Financial return
FREDA	Forest Resource Environment Development and Conservation Association, Myanmar
GGGI	Global Green Growth Institute
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
MAI	Mean annual increment
MMK	Myanmar kyat
MRRP	Myanmar Reforestation and Rehabilitation Program
NCR	Natural capital return
NP	National Park
NPV	Net present value
NTFP	Non-timber forest products
ODA	Overseas Development Aid
OPEX	Operational expenditure
PES	Payment for ecosystem services
RECOFTC	The Centre for People and Forests
RF	Reserve Forest
ROI	Return on investment
SDG	Sustainable Development Goals
SLR	Sea level rise
SR	Social return
TEV	Total economic value
UN	United Nations
UQ	University of Queensland
VW	Village woodlot
Worldview	Worldview International Foundation, Myanmar

Background of the project

Mangroves and mangrove restoration address Sustainable Development Goal (SDG) 14, Life below water, which focuses on the health of oceans and sustainable fisheries. Mangroves also contribute to achieving SDG1 (end poverty), SDG2 (zero hunger) and SDG13 (climate action), due to their ecosystem service provision and the important role in food provision and coastal security that they play for coastal communities (UN, 2015). Programs to restore and manage mangroves better can also contribute to SDG10 (reduce inequalities), particularly if restoration can enhance community livelihoods and communities can trade climate change mitigation services.

Myanmar is one of the hotspots for mangrove loss in Southeast Asia (Friess et al., 2019). The Ayeyarwady (previously called the Irrawaddy) Delta has the largest mangrove forest area of Myanmar. This project conducted an economic appraisal of Ayeyarwady mangrove forest in order to support improved management of mangroves in the region.

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Objective of the project

The overall objective of this project is to conduct an economic appraisal of mangrove restoration in the Ayeyarwady Delta following the 3Returns Framework (described below), as an analysis of the effect of the enhancement of a natural asset to support Myanmar's economy and local livelihoods. Under this overall goal of the project, the specific objectives were:

a) To identify potential monetary and non-monetary benefits of mangrove restoration projects.

b) To evaluate the cost effectiveness of restoration projects over a range of scenarios.

c) To identify best management practices for mangrove restoration.

d) To enhance policy development that supports mangrove restoration in view of their importance in providing ecosystem services.

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3Returns Framework Overview

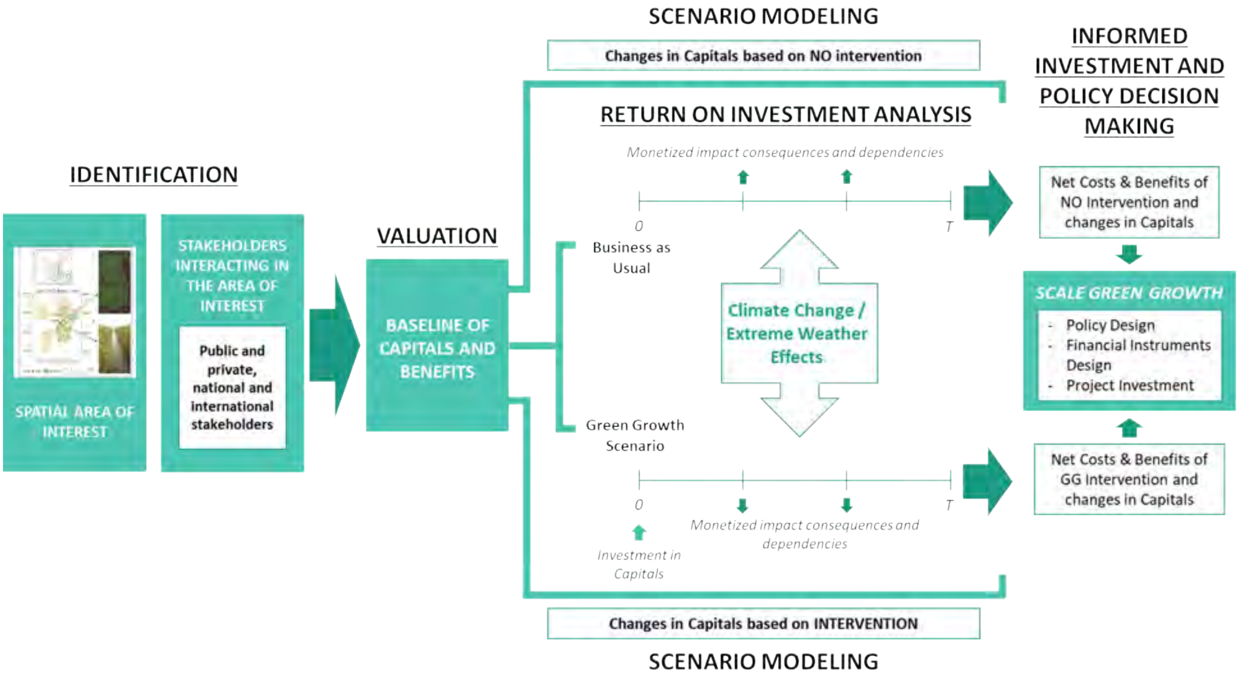

Figure 1.
A Conceptual model of the 3Returns Framework.

Ecosystem functions can be appraised with respect to their natural, social, human, and economic values. The productivity of ecosystems can be interpreted as a function of their contribution to natural, social, human and economic capital. At the same time, any management interventions in ecosystems will ultimately result in either positive or negative changes in these capitals. The 3Returns Framework accounts for interventions in a landscape as:

a.) investments in Natural Capital (resources allocated to increase the stocks of natural assets);

b.) investments in Social & Human Capital (resources allocated to increase cooperation within and among groups, individual and collective knowledge, skills, and competencies; while building/ strengthening institutions for resource management, decision making, and social integration); and

c.) Financial Capital Investment (resources allocated to acquire or increase the assets needed in order to provide goods or services).

The 3Returns Framework contrasts a Business as Usual (BAU) scenario against Green Growth scenarios to understand changes in capitals (Natural, Social & Human and Financial) with Green Growth interventions. In this report, the development of a range of Green Growth scenarios was based on literature review, expert consultation, and baseline survey in the study sites. The BAU scenario assumes continued mangrove degradation with limited mangrove restoration projects. The Green Growth scenarios are based on a range of investments in restoration projects with varying intensity and altering management arrangements of government-managed mangroves to community forestry, either in village woodlots (VW) or through Community Forestry User Groups (CFUG). This project evaluates management and restoration options for the mangroves of the Ayeyarwady Delta through the lens of the 3Returns Framework for sustainable landscapes assessment (Figure 1).

04
Identification Phase

4.1 Study area

The Ayeyarwady Delta is one of the major tropical deltas in the world. It comprises the main arms of Pathein River, Pyapon River, Bogale River and Toe River. Mangrove vegetation is a dominant feature of the large tropical deltas of the world; they influence the evolution of these deltas, including the Ayeyarwady, by trapping sediment and offering protection against the impacts of large storm events. The mangroves also support communities by providing a range of resources that include fuelwood and fisheries. However, the mangrove in the Ayeyarwady Delta is currently at risk due to widespread deforestation and unsustainable management practices (Webb et al., 2014).

Degradation of mangroves in the Ayeyarwady Delta is mainly associated with clearing and conversion to rice paddy cultivation, aquaculture, as well as to the harvest of timber and fuel wood. Giri et al. (2008) estimated that 98% of mangrove deforestation in Myanmar was associated with the expansion of agriculture. The Ayeyarwady Delta is the key rice and fish producing area of Myanmar; responsible for about 35% of rice production of the country (Webb et al., 2014). To support development in the region, road transport infrastructure was greatly increased during the 1990s and 2000s. Fishing is also an important industry in the region. Fishers use fixed fishing traps as well as small boats in the rivers and mangrove creeks. Prawn fishery and harvesting sea turtle eggs are also major commercial activities, both of which are now threatened by the loss of mangrove forests.

Deltas, including the Ayeyarwady Delta, have high vulnerability to climate change, and particularly those associated with sea level rise (Dasgupta et al. 2011 Horton et al. 2017). Sea level rise is anticipated to increase the impacts of storm surge (Horton et al. 2017), with negative effects on communities of the region (Oo et al. 2018). There are high levels of uncertainty around changes in the frequency and intensity of intense storms and wind fields (Knutson et al. 2010, Reguero et al. 2019, Young and Ribal 2019). However, recent observations indicate that the deltas of Asia are already experiencing erosion associated with mangrove clearing in conjunction with intense storms, sea level rise, and changes in wind-driven waves and tidal currents (IPCC 2019). For example, large areas of the Sundarbans and the Mekong Delta are projected to be submerged under even moderate climate change scenarios (Minderhoud et al. 2019). In the same way, the Ayeyarwady Delta is vulnerable to sea level rise, changes in storm frequency and intensity, and wave energy. However, detailed studies of changes in elevation of the delta and the influence of climate change on the delta and deltaic processes (e.g. sediment delivery, erosion) are not available, which prevents spatial modelling of future impacts of sea level rise and other oceanic change.

The analysis presented in this report focussed on a project area in the lower Ayeyarwady Delta (Figure 2). This area is currently facing tremendous challenges in preventing mangrove loss, which is essential for climate mitigation and sustainable development. The townships in the project area have some of the largest remaining mangrove cover of Myanmar. The communities are highly dependent on the mangrove resources for their livelihood. In this context, it is urgent to determine the management options that can facilitate protection and restoration of the mangroves of the Ayeyarwady Delta.

The study project area comprised Pyapon, Bogale and Labutta townships in the Ayeyarwady Delta. A high accuracy land-use map and other data and information were collected and used for the economic appraisal of different management scenarios for the Ayeyarwady mangroves.

The management of the mangroves of the Ayeyarwady Delta is mostly the responsibility of the Department of Forestry, which established the Myanmar Reforestation and Rehabilitation Plan (MRRP). Community forestry (CF) arrangements also occur over limited areas. In the study area, mangroves are contained within lands with a range of management arrangements:

1) the Mein-ma-hla Kyun Wildlife Sanctuary, which is referred to in this report as National Park (NP) where extractive activities are not permitted,

2) Reserve Forests (RF), which are mangroves managed by the Department of Forestry and include mangrove plantations and where extractive activities are not permitted,

3) Community forestry plots managed by Community Forestry User Groups (CFUGs) where the CFUG controls use of, and access to, the mangrove,

4) Community forest land which are common village woodlots (VW) where all community members have access to the mangrove, and

5) Private land.

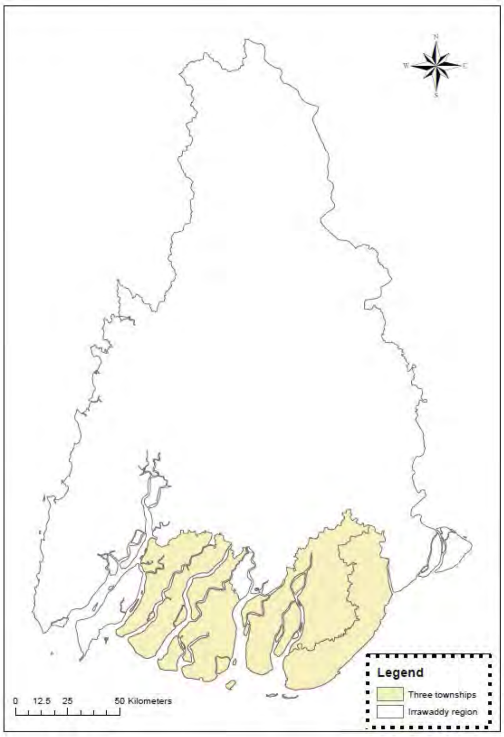

Figure 2.
Study area in the lower Ayeyarwady Delta, Myanmar

4.2 Stakeholders

Analyses of the management activities associated with mangroves required identification of the range of stakeholders in the study area. We identified stakeholders involved in value chains of different mangrove products. Based on information from surveys of the study area we considered actors involved with main mangrove products and main aquaculture and agricultural activities: fuelwood, crab fattening, shrimp production, and rice production.

• For fuelwood from mangroves, the key stakeholders are the households in the mangrove region. Most of the families in three research townships use mangrove fuelwood for domestic cooking. The second consumer of fuelwood in the Delta are the fishers who use bamboo rafts (kyar phaung) for drying fish from the simple on-shore fishing sector. Government authorities, particularly the Forest Department, is the key law enforcement for mangrove management and protection. Until an alternative cooking fuel, which is cheaper and/or which local residents can afford, becomes readily available, fuelwood collected from mangrove will remain the key domestic energy source for local people. Alternative fuels could include national electricity, gas or fuel from agriculture by-products (e.g. rice husk briquettes),

• For crab-fattening products, the major stakeholders are collectors of juvenile crabs, local mangrove landholders (who grow out crab larvae), middlemen in villages (who buy and transport the product), the Department of Fishery, and consumers, including restaurants in the larger cities.

• Shrimp production actors include the collectors of wild shrimp fry (larvae), shrimp farmers, the Department of Fishery, and local buyers who sell products at the wholesale market to exporters and consumers.

• In the agriculture sector, the major stakeholders are the owners of rice fields, rice farmers, and the Department of Agriculture, Livestock and Irrigation. Large areas within the government-managed mangrove Reserve Forest (RF) boundaries were converted from natural mangroves to rice fields (Webb et al. 2014). These areas have high risks of soil acidification and saline water intrusion. Irrigation of rice is not highly developed in the study area, and therefore farmers usually grow only one rice crop per year with relatively low rates of productivity.

05 Valuation phase

Valuing ecosystem services reveals the importance of ecosystem functions and is an essential component for devising management activities. Ecosystem services do not just generate products and raw materials, but also provide the primary productivity and vital life support services that are critical to human well-being and to the functioning of economies. Ecosystem services are categorized into provisioning, regulating, supporting, and cultural services (MEA 2003).

The Millennium Ecosystem Assessment Framework disaggregates the total ecosystem service value (TEV) into two categories: use values and non-use values (Figure 2 and 3). The use value refers to the value of ecosystem services used by humans for consumption or production purposes. It includes tangible and intangible services of ecosystems that are either currently used directly or indirectly or that have a potential to provide future use values. These have been further refined in the Final Ecosystem Goods and Services Classification System (FEGS CS, Landers and Nahlik 2013), which provides a structured framework that avoids double counting of services. The non-use values are known as existence value (or, sometimes, conservation value or passive use value). Humans ascribe value to knowing that a resource exists, even if they never use that resource directly. Valuation methods vary, mostly based on the nature of the goods and services of the ecosystem. However, the conventional valuation methods rely on quantification of ecosystem functions only.

The major ecosystem services from natural capital in the study area were identified through literature review, expert consultation, and baseline survey in the study area. In this report, we focussed on valuing a subset of the direct use (wood, fish) and indirect use (carbon sequestration, storm protection) ecosystem services provided by mangroves.

Based on the 3Returns Framework, we estimated the potential natural, financial, social and human capital returns associated with the implementation of mangrove restoration projects and variation in management arrangements. Changes in natural, financial, social & human capital with different mangrove management and restoration scenarios were quantified and monetized (where possible), while acknowledging key data gaps and the pitfalls of ecosystem services valuation methods (Himes-Cornell et al. 2018).

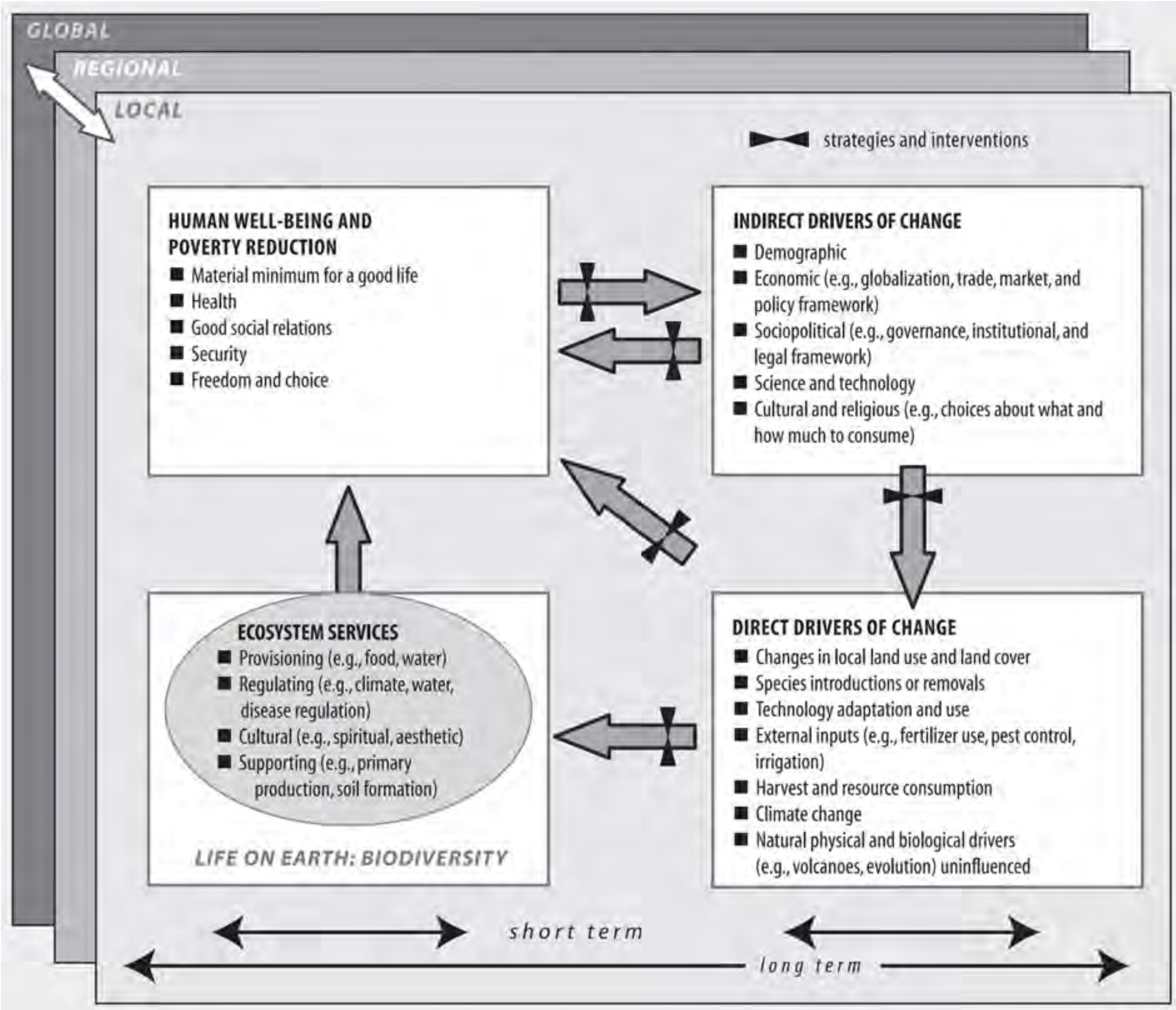

Figure 3.
Millennium Ecosystem Assessment Conceptual Framework (Millennium Ecosystem Assessment, 2003).

5.1 Mangrove area and carbon sequestration

Mangrove carbon stocks, which enable calculation of the value of projects that avoid degradation of mangroves and associated emissions, and carbon sequestration of mangroves during restoration were obtained from plot survey data and modelling of mangrove tree growth in the delta. The University of Queensland is in the process of analysing sediment profiles from the delta mangroves to estimate carbon sequestration in soils of restored mangroves. Before these results are available, the IPCC Tier 1 default value for soil carbon gain from mangrove restoration was used to estimate soil carbon sequestration (IPCC 2013). Values were expressed as megagrams (1 Mg = tonne) of CO2 equivalents per unit area per year which are converted to a value by assuming a carbon price per Mg of CO2 (e.g. US$/ha per year). Multiplying the unit value by the area of land cover provided a total value of carbon sequestration at the landscape level.

We surveyed 328 mangrove sites in the study area. Data collection included variation in species, tree stocking density, growth, regeneration, and soil carbon. In over 40 sites, the data and samples were collected in different adjacent land uses in order to evaluate impacts of land use changes on carbon sequestration and other soil properties. We also conducted an inventory of 215 mangrove plantations. Data collected included the source of investments in mangrove plantations, plantation species, age, investment cost norms, management practices (mainly based on community involvement), tree density, plantation type (mixed or monoculture), details of whether plantations were in or outside ponds, and location (by GPS coordinates). Additionally, distance to the closest water body was calculated and bioclimatic variables and total suspended matter in water bodies were obtained from secondary sources. Bioclimatic data are extracted from the WorldClim Bioclimatic 5-minute dataset (http://www.worldclim.org/bioclim) (Fick and Hijmans 2017). Total suspended matter (TSM) in the water column at a 4-km resolution was collected from http://hermes.acri.fr/. We used Google Earth to measure and verify distances from the plots to the nearest open water bodies, sea, rivers, and creeks. Other variables that might comprise other unknown sources of variation at each site (for example past land-use), and which might influence plantation performance, were also assigned in the dataset. Each plot was assumed as a single site. Using this data, we conducted statistical analyses (boosted regression tree analysis, Elith et al. 2008) to identify the most significant factors affecting mangrove plantation success. Growth data of surveyed plantations was used to model basal area, diameter and volume growth of mangroves in the delta. According to studies in similar regions, the natural regeneration of mangroves would achieve similar biomass carbon to natural mangroves in 20-30 years (Nam et al. 2016, Salmo et al. 2013).

5.2 Coastal protection

Coastal protection services at the landscape level were determined based on secondary data and the literature. The assessment of coastal protection in this report is not a spatially explicit analysis as the underlying data required are not sufficiently robust to estimate coastal protection at the landscape level. Therefore, we based our estimate of the value of mangrove storm protection from studies in Myanmar and nearby countries.

An important study in this field was conducted by Barbier (2007), who estimated the value of mangroves in Thailand by summing the value of the forest products they provide, the value of their enhancement of fisheries, and the value of their coastal protection. The total value of ecosystem services of mangrove ranged between US$ 10,158–12,392 ha−1, of which US$ 8,966–10,821 ha−1 (~87%) was attributed to storm protection services between 1996–2004. More recently, the value of the storm protection function of mangroves was shown to lead to more resilient economies, where communities with protective mangrove areas suffered lower economic losses due to intense storms and recovered more rapidly compared to those with limited mangrove cover (Hochard et al. 2019). Estoque et al. (2018) estimated coastal protection value of mangroves in Myanmar using avoided expenditures on physical reclamation and replenishment and obtained a value of US$1,369 ha-1 year-1. A recent study conducted by Akber et al. (2018) estimated storm protection services of mangrove for Sundarbans Bangladesh against the super-cyclone Sidr. Quantifiable monetary loss associated with cyclone Sidr in Bangladesh averaged US$ 1,025 per household in the villages sheltered by mangrove, whereas those not sheltered by mangrove sustained an average cost of US$ 1,963. However, in both cases villages were protected by an embankment. With no embankment and no mangrove, the cost was US$ 2,302. Based on similarities among studies (within the region and with a broadly similar setting) we estimated the value of the storm protection services of mangroves in Myanmar from Estoque et al. (2018) (i.e. US$1,369 ha-1 year-1).

5.3 Climate change, including sea level rise

Many climate change factors are likely to influence the Ayeyarwady Delta including sea level rise, changes in rainfall and river flows, changes in storm intensity and frequency, and changes in wind and wave climates, all which increase the likelihood of coastal hazards (IPCC 2019). Here we focus on increases in sea level, which are expected with high confidence (IPCC2019). Sea level rise (SLR) is a global risk to nations with low elevation coastal land because of increased inundation, storm surge, erosion, and saltwater intrusion (Nicholls and Cazenave, 2010). In addition, the impacts of sea level are predicted to be particularly negative for developing nations (Dasgupta et al., 2011), with negative economic consequences for rice production (Chen et al., 2012). Sea level rise is also expected to increase the damage caused by storm surges (Fritz et al., 2009). Mangroves provide coastal protection from storms and other waves (Hochard et al., 2019), yet they are also at risk from SLR if increases in tidal inundation and erosion exceed rates of accretion of shores, which results in mangrove loss (Lovelock et al., 2015). Here we provide a brief review of the likely impacts of SLR on mangroves in the Ayeyarwady Delta of Myanmar.

Detailed modelling of the impacts of sea level rise require accurate digital elevation models as well as knowledge of sediment supply, wave exposure, and vertical and horizontal accretion of shorelines (Minderhoud et al., 2019). Without detailed site level data and modelling, projections of the impact of SLR are likely to have large errors. Therefore, in order to estimate effects of SLR on the mangroves of the Ayeyarwady Delta we use recent analyses from global models instead of detailed spatial analyses for which data are unavailable and which would require more substantial research efforts.

Coastal wetlands sea level rise can result in erosion of shorelines. However, where coasts are gently sloping and coastal squeeze is avoided, SLR may also lead to mangrove expansion landward. The term 'coastal squeeze' describes the reduction in the space for coastal vegetation because of the prevention of landward movement of ecosystems by infrastructure (e.g. seawalls, bunds, dykes) along with the loss of ecosystems on the seaward edge if they are overwhelmed by inundation. Recent global models indicate that SLR may have a positive effect on carbon sequestration in mangroves and saltmarsh (Rogers et al., 2019) and that impacts on the cover of coastal wetlands can be positive if coastal squeeze is limited (Schuerch et al., 2018).

The model of Schuerch et al. (2018) is based on the DIVA model, which assessed the impacts of SLR on segments of the global coastline that are 30-50 km in length. DIVA model coastal segments are assigned parameters describing local rates of SLR, the geomorphology, and human population density. We used the SLR scenario of Representative Concentration Pathway 8.5 (0.6 – 0.8 m by 2100, IPCC 2018) and two coastal squeeze scenarios (one is High coastal squeeze – low adaptation, where landward migration of mangroves is prevented at population densities of 5-20 persons/km2; and the other is Low coastal squeeze – high adaptation, where landward migration of mangroves is prevented at 300 persons/km2). Results indicated that in the High coastal squeeze – low adaptation scenario, mangrove losses of 1,200 km2, which is approximately 15 km2 per year (0.29% per year) could occur. In the Low coastal squeeze – high adaptation scenario, mangrove area may increase by 2,200 km2 or at 27.5 km2 per year (0.54% per year). Losses and gains in cover are likely to be spatially variable. We use these potential proportional annual losses and gains over our study area to make first order estimates of the changes in the potential value of mangroves over time with sea level rise (Table 1).

Table 1.
Scenarios of mangrove cover change with sea level rise.

	Coastal Squeeze Scenarios	
	High coastal squeeze - low adaptation (P5)	Low coastal squeeze - high adaptation (P300)
Initial cover (km^2)	5,100	5,100
Cover 2100 (km^2)	3,900	7,300
Change in mangrove cover (km^2)	-1,200	2,200
%Change	-24%	43%

The impacts of climate change on agriculture include high temperatures, changing patterns of precipitation, and saltwater intrusion with sea level rise, which are likely to reduce the productivity of agriculture in the deltas of the world (Wassmann et al. 2009, Dam et al. 2019). Saltwater intrusion may accelerate with increasing incidence of intense storms, which may increase the magnitude of agricultural losses. Management of the effects of climate change and saltwater intrusion in Myanmar include development of high temperature and salt tolerant rice varieties and modified agricultural practices e.g. irrigation based on lunar calendar (low tides) and double cropping (Thein 2015). However, these may not be sufficient to counteract the effects of sea level rise (Deb et al. 2016). Although the impacts of climate change are likely to vary, models for Bangladesh suggest a ca. 33% reduction in rice yields to 2100 (Karim et al. 2012), which we annualize as a reduction in production of 0.4% per year. This reduction rate was applied for rice cropping in mangrove Reserve Forests in the three research townships. Changes in agricultural productivity are likely to vary spatially and may be non-linear; however, there are insufficient analyses to provide spatially explicit changes in agricultural production with climate change for the Ayeyarwady Delta.

5.4 Targeted mangrove products derived from aquaculture, crab culture and fuelwood harvesting

The assessment of Return on Investment from different products derived from mangroves (at a project scale) were determined using the 3Returns Framework. This provided novel ways of visualizing the impact of management interventions within the production systems connected with related ecosystem services.

For their livelihoods, a significant number of landless farmers depend on catching crabs in the mangrove areas. This makes it an important activity in coastal rural areas in the delta. We therefore include this product in our 3Returns analysis for mangroves in the delta.

In the three townships in the project area, one of the highest incomes is derived from mangrove aquaculture ponds, which local farmers build in mangrove areas. Aquaculture is largely extensive with limited semi-intensive ponds. Typically, farmers build low earthen walls around their mangrove area. The walls are constructed in the processes of digging ditches in the mangroves, which make shallow ponds for aquaculture. The farmers tend to keep mangroves in the remaining platform area within the pond walls, although often the mangroves are degraded or can die due to the altered hydrology, as water levels are maintained at higher than normal levels for shrimp/fish, which reduces mangrove growth (Lewis et al. 2015). The ponds are periodically flushed with tidal water, which provides wild shrimp, crab and fish larvae into the pond. To increase productivity, many farmers also put additional shrimp fingerlings and juvenile crabs into ponds. Because the farmers do not feed the fish in the ponds, the crabs, shrimp and fish depend on natural food that is carried in river water and from adjacent mangrove.

In the current typical mangrove aquaculture system, farmers use polyculture systems that include crab, shrimp and other fish cultured together. This polyculture diversifies products but may have significant negative impacts on the productivity of crabs and shrimp, which are two major products of this system. Although seabass is a popular product with farmers in the brackish water ponds in the delta, it is a major predator of crabs and shrimp. We consider that crabs and shrimp are the key aquaculture products from mangrove areas. In the future, mangrove aquaculture systems could increase productivity and income from ponds by removing unwanted species like seabass, before growing crabs and shrimp.

Fuelwood is the major energy source for domestic cooking in mangrove areas and buffer zones in the Delta. In Pyapon township, it also provides the energy used for drying fish on bamboo racks on the shore. In this regard, harvesting timber for charcoal and fuelwood for cooking and drying, is a main cause of mangrove deforestation and degradation in the Delta. Fuelwood is a significant income source for local people even though most of fuelwood is illegally logged from Reserve Forest and National Parks in the Delta. Thus, another product we consider for 3R analysis is fuelwood from mangroves.

In addition to products obtained from the mangrove, mangrove areas have been converted to rice agriculture. There are over 60,000 hectares of rice fields within the Reserve Forest boundaries. This is an important income source for farmers. These areas, particularly low elevation fields, are vulnerable to saline water intrusion and soil acidification. Considering its current vimportance, we include rice production in our analyses. The major impact of sea level rise on rice land and livelihoods associated with rise production was incorporated as described above by assuming a constant reduction in productivity over time (section 5.3).

06 Methodology

6.1 Mangrove status, fuelwood and carbon sequestration

6.1.1 Mangrove survey

We conducted several field campaigns to survey the mangroves of the delta. Overall, over 500 plots were established on mangroves and adjacent land uses. Plots were located inside and outside mangrove aquaculture ponds, and in natural and planted mangroves. We identified tree species, measured tree diameter, height, biomass, understory vegetation, and regeneration. Plot coordinates were recorded with a hand-held GPS, and 04 photos were taken from the centre of the plot at cardinal directions. Soil core samples were collected from over 300 plots in mangroves and alternative land uses for analyses of soil carbon and impacts of land use change on soil carbon and other soil properties. The plot level data was also used for satellite image interpretation and for producing mangrove forest status and land use maps for the study area.

6.1.2 Satellite image interpretation and mapping

The objective of the satellite image interpretation was to produce mangrove status and land use maps in three townships. Planet Earth images were analysed for producing maps (Planet team 2017). The results were validated by Google Earth and Spot 5 images. A semi-supervised image classification approach was used.

The nature of land uses in areas of high-density population and agriculture and aquaculture production, like the coastal region of the Ayeyarwady Delta, is complex. Thus, only semi-automatic classification was used for analysis of satellite images. We used manual digitalizing for most of the ponds because it was not possible to auto-classify pond walls as was done for agriculture land and/or other land uses.

6.1.3 Timber growth and carbon sequestration

The forest growth data on permanent sample plots in mangroves in Myanmar are not available. Due to limited time, budget and mature plantation trees, we could not conduct tree ring analyses. The growth and dynamic of mangroves were based on measured plantations where we knew the date of planting and other silviculture practices. Basal area, biomass, and mean annual increment of basal area (MAI), were calculated from plantation survey data.

To estimate growth rates of natural mangroves, we assumed that natural mangrove stands have similar growth rate as plantations if they have similar basal area, as has been demonstrated in terrestrial forests.

6.1.4 Socio-economic, fuelwood, mangrove Aquaculture and crab-catching surveys

We surveyed livelihoods, land tenure, and rights for ecosystem-based land use planning through interviews with stakeholders in the study area, based on guidance from The practical guidelines for socio-economic surveys by CIFOR – CIRAD (Liswanti, Shantiko et al. 2013). Detailed questions relating to mangrove aquaculture activities, crab catching, and fuelwood harvesting were also developed. The questions asked in socio-economic surveys and aquaculture value chain surveys, were translated into Myanmar for use by field staff during interviews. This socio-economic research was approved by the Australian Human Research Ethics Committee at The University of Queensland (No. 2018000480).

07

Mangrove management scenarios

Management of mangroves largely depends on the institutional arrangements within countries. In Myanmar, the political reforms over last decade, which followed 50 years of economic and political isolation, have affected the forest management strategies. We developed a range of mangrove management scenarios in order to assess and compare the potential outcomes (including ROI and other metrics) of different management strategies. Table 2 summarizes the scenarios for community-based mangrove management and mangrove rehabilitation/restoration, which are described in detail below. The scenarios include a BAU, a scenario where the current MRRP is fully enforced (MRRP+) and a range of scenarios that assess increased allocation of mangroves to community forestry (CF), either through increasing the area allocated to the Community Forestry User Groups (CFUGs) or through increase in area of village woodlots (VW). These two community forestry arrangements differ in the access that they provide for landless people in the study area to fish and collect wood within the mangrove. A range of other improvements for forest management and aquaculture is also included.

A. Business as usual (BAU)

Table 2.
Description of impact drivers, impacts, impact consequences, and dependencies in the BAU scenario on the study area.
Outcomes in red text are negative, orange are neutral and those in green are positive for some stakeholders.

Impact Drivers	Expected impact on study area	Impact consequences and dependencies
Law enforcement on mangrove management	*Weak law enforcement, continuous and repeatedly illegal logging of fuelwood and timber from mangroves; and mangrove resources are degraded*	*- Mangrove forest structure and dynamics are degraded. Dominance of unwanted species which limits recovery of mangroves* *- Mangrove biomass carbon and timber loss. Mangrove biomass productivity significantly reduced* *- Reduce habitat for wildlife, especially birds and mammals* *- Conflict between meeting needs of local landless people and Government's target to maintain and improve mangrove forests* *- Limited outcome for Government mangrove rehabilitation program because of illegal logging and unregulated management activities*
Community Forestry and mangrove aquaculture practices	*Intensive fuelwood harvesting for cash and more intensive farming is likely preferred*	*- Simple forest structure comprised of pioneer, fast growing species. Only young trees remain in the mangrove stands* *- Extensive aquaculture productivity directly linked to pond surface area; thus CF farmers tend to keep less trees and dig more ponds if possible, reducing mangrove area* *- Water levels are kept high most of the time in the ponds resulting in unsuitable hydrological regimes for mangroves* *- Rapid cash return for mangrove aquaculture pond owners from fuelwood and aquaculture contributions to livelihoods*
Mangrove restoration	*Limited mangrove restoration given limited government budget; some unsuitable plantation establishment techniques*	*- Mangrove restoration achieves only about 2/3 of the target set by the MRRP program* *- Unsuitable plantation establishment techniques have negative ecological impacts (e.g. burning vegetation before planting)* *- Low investment in capacity building within local Forest Department staff* *- Healthy seedlings from nursery contribute to the higher survival rate of planted trees*
Management of village common woodlot (VW)	*Ineffective management due to insufficient capacity building and low investment*	*- Micro institutional village frameworks are not sufficiently strengthened through capacity building and investment* *- Illegal logging still occurs in the VW areas* *- People have free access to mangroves for catching crabs*
Sea level rise	*Soil acidification and saline water intrusion*	*- Soil which was previously mangrove habitat has been acidified and become toxic resulting in low or very low rice productivity* *- Saline water intrusion in low elevation rice fields. Farmers have no or little rice harvest in about 10 % of the rice area. On average, rice yields reduced by 0.4 % per year.*

Key:
Red = Negative impacts expected **Orange = Mild positive / Negative impact** **Green = Positive impact**

i) All rice field and aquaculture ponds converted from mangrove remain in the present converted condition;

ii) 11% of mangroves are allocated to communities (based on CF certificates) and are managed by the local through CFUGs for timber, non-timber forest products, and aquaculture; 3% of mangroves allocated to villages as VW by 2019;[1]

iii) Approved forest management plan for CFUG allows thinning every 3 - 5 years;

iv) Law enforcement in RFs and mangrove management remain at current levels;

v) Mangrove restoration in three townships through development of plantations by the government and other donors' projects/programs is approximately 1,130 ha annually;

vi) Climate change impact on rice productivity results in declines of 0.4 % productivity per year due to saline water intrusion. Mangrove expands landward by 0.5% per year with SLR.

[1] The current annual rate of increase in areas of CFUGs and VWs were used as estimates of the annual increase in CFs over time.

Scenario 1: MRRP+ describes the scenario where Government law enforcement is improved in Non-CF areas and CF management is improved

i) All rice field and aquaculture ponds converted from RF's mangroves remain in their present condition;

ii) 11% of mangroves allocated to communities (based on CF certificates and community plantations without certificates) and are managed by the local community; 3% of mangroves allocated to villages as CF's common VWs by 2019.[2]

iii) Forest management plan for CF users allows for thinning every 3 - 5 years (unchanged);

iv) Improved law enforcement as the government sees fit, decreased illegal logging compared to BAU scenario (reduced by 85%);

v) Mangrove rehabilitation in three townships is 1,820 ha annually as the government sees fit, but the successful area is only 1,000 ha annually due to limited involvement of communities in plantation management and therefore some illegal fuelwood collection occurs;

vi) Climate change impact on rice productivity results in declines of 0.4 % productivity per year due to saline water intrusion. Mangrove expands landward by 0.5% per year with SLR.

Table 3.
Key aspects of Scenario 1. Description of impact drivers, impacts, impact consequences, and dependencies associated with Scenario 1 in the study area. Outcomes in red text are negative, orange are neutral and those in green are positive for some stakeholders.

Impact Drivers	Expected impact on study area	Impact consequences and dependencies
Law enforcement	*Law enforcement improved for RFs, NP and CFUGs. Less illegal logging of mangroves and reduced thinning time of CF mangroves*	*- Decreased illegal logging of mangroves helps to recover mangrove areas and their quality - Increased forest quality in CFUGs mangroves - Increased habitat for fish, crab and additional wildlife - Reduced illegal logging at the expense of livelihoods losses for fuelwood collectors Increased disputes between local landless people and Forest Department authorities over mangrove protection*
CF mangrove aquaculture practices	*Higher compliance with approved CF management plan*	*- Increased quality of mangroves within the CFUG ponds - Increased value of ecosystem services and timber production of CF mangroves - Increased resilience and sustainability of extensive mangrove aquaculture - Increased income for CF pond owners - Decreased crab and shrimp productivity due to increases in the forest canopy resulting in declines of open water surface area - Decreased cash return for CF farmers in the first few years when they need income to cover capital and operational investment for the ponds (extreme cash shortage is a major problem for the poor in Myanmar)*
Mangrove restoration	*Investment meets MRRP targets*	*- Achieve mangrove restoration targets set by the MRRP program - Unsuitable plantation establishment techniques have negative ecological impacts (e.g. burning vegetation before planting) - Healthy seedlings from nurseries contribute to the higher survival rate of planted trees*
Management of common village woodlots	*Higher law enforcement in VW. Increased area and quality of access to public mangroves*	*- Micro institutional village frameworks are not sufficiently strengthened through capacity building and investment - Illegal logging continues but less occurs in the VW areas - All people have free access to mangroves for crab catching - Income from crab catching and fuelwood collection in open access mangroves and VWs is increased*

Continued on next page

[2] Increase of CFUG and VW area to 2026 as planned by national MRRP.

Table 3 (continued)

Impact Drivers	Expected impact on study area	Impact consequences and dependencies
Sea level rise	*Soil acidification and salt water intrusions*	*- Soils in areas that were previously mangroves are affected by acidification and become toxic. This results in low or very low rice productivity* *- Saline water intrusion in low elevation rice field. Farmers have no or little rice harvest from about 10 % of rice area. On average, rice yields reduced by 0.4 % per year.*

Key:
Red = Negative impact expected **Orange = Unknown or mild positive / negative impact expected** **Green = Positive impact expected**

C. Scenario 2: MRRP+ VW/CFUG: In this scenario increased area of mangroves are allocated equally to Community Forestry User Groups and Village Community Woodlots and mangrove restoration and improved aquaculture occurs.

i) 25 % of RF area is allocated for communities with certificates under CFUGs;

ii) 25 % of RF area is allocated for communities with certificates under VW;

iii) Plantation establishment 1,820 ha per year, but the successful area is 1,500 ha;

iv) At least 50% of funding for restoration allocated to CF areas.

v) All bare, saline land rehabilitated;

vi) CF Forest management plan **changed**[3] to thinning in every 5-6 years leaving 200 – 400 maternal trees per hectare, thereby improving coastal protection, blue carbon sequestration and biodiversity;

vii) Existing mangrove aquaculture ponds (crabs and shrimp) remain in the landscape but production techniques are improved;

viii) Additional aquaculture is introduced into CFUG areas in the project area;

ix) Climate change impact on rice productivity results in declines of 0.4% productivity per year due to saline water intrusion. Mangrove expands landward by 0.5% per year with SLR.

3 The existing forest management plan for community certified mangroves allow heavy thinning and clear cutting which is the primary cause for mangroves degradation. A new forest management plan will be proposed to meet both local mangrove product needs and ecosystem services.

D. Scenario 3: MRRP+CFUG. This scenario describes enhanced allocation of mangrove area to CFUGs, mangrove restoration and improved aquaculture practices.

i) 3 % of RF area allocated for communities under VW and no change in this area;

ii) 47 % of RF area is allocated for communities under CFUG by 2026, reaching 50% area of RF area for VW and CFUGs;

iii) Plantation establishment 1,820 ha per year, but the successful area is 1,500 ha;

iv) At least 50% of funding for restoration is allocated to CF areas.

v) All bare, saline land rehabilitated;

vi) CF Forest management plan **changed**[4] to thinning in every 5-6 years, leaving 200 – 400 maternal trees per hectare, thereby improving coastal protection, blue carbon sequestration and biodiversity;

vii) Existing mangrove aquaculture ponds (crabs and shrimp) remain in the landscape but production techniques are improved;

viii) Additional aquaculture is introduced into CFUGs in the project area;

ix) Climate change impact on rice productivity results in declines of 0.4 % productivity per year due to saline water intrusion. Mangrove expands landward by 0.5% per year with sea level rise.

Table 4.
. Key aspects of Scenario 2,3 and 4. Description of impact drivers, impacts, impact consequences and dependencies on the study area for Scenarios 2, 3, and 4. Outcomes in red text are negative, orange are neutral and those in green are positive for some stakeholders.

Impact Drivers	Expected impact on study area	Impact consequences and dependencies
Law enforcement	*Law enforcement improved for RF, NP and CFUGs. Less illegal logging from mangroves and reduce thinning time of CF mangroves*	*- Decreased illegal logging of mangroves leads to recovery of mangrove areas and quality* *- Increased forest quality in CFUGs and VWs mangroves* *- Increased habitat for fish, crabs and additional wildlife, particularly in public RFs and NP mangroves* *- Reduced illegal logging at the expense of livelihoods of fuelwood collectors, particularly in Scenario 3* *- Increase disputes between local landless people and Forest Department authorities over mangrove protection particularly in Scenario 3.*
CF mangrove aquaculture practices	*Forest management plan changed towards more sustainable actions*	*- Increased quality of mangroves within the CFUGs ponds* *- Value of ecosystem services and timber production of CF mangroves are improved* *- Large maternal trees are protected and provide essential habitat for wildlife* *- Maternal trees provide seeds for natural regeneration* *- Increased resilience and sustainability of extensive mangrove aquaculture* *- Higher economic return from larger timber size classes to meet future high demand for logs in the Delta* *- Decreased crab and shrimp productivity due to the increase in forest canopy and declines in open water surface area* *- Lower cash return for CF farmers in the first few years when they are in need of income to cover capital and operational investment for the ponds (extreme cash shortage is a major problem for the poor in Myanmar)*

Continued on next page

[4] The existing forest management plan for community certified mangroves allow heavy thinning and clear cutting which is the primary cause for mangroves degradation. A new forest management plan will be proposed to meet both local mangrove product needs and ecosystem services.

Table 4 (continued)

Impact Drivers	Expected impact on study area	Impact consequences and dependencies
Mangrove restoration	*Investment meets MRRP targets* *Potential additional investments from additional investors*	*- Mangrove restoration achieves targets set by the MRRP program* *- Increased mangrove restoration rate due to increased investment* *- Unsuitable plantation establishment techniques have negative ecological impacts (e.g. burning vegetation before planting) in Government mangrove rehabilitation projects* *- Healthy seedlings from nurseries contribute to the higher survival rate of planted trees*
Micro-institutional strengthen for VWs	*Significant new areas allocate to villages as common woodlots, many new VWs established*	*- Micro institutional village frameworks strengthened through capacity building and investment* *- Illegal logging reduced in the VW areas* *- People have free access to VW for crab catching particularly in Scenario 2* *- Creation of additional income for crab catching and fuelwood collection on open access mangroves and VWs*
Rehabilitation of ponds without mangrove	*50 % of ponds without mangrove will be restored*	*- Increased mangrove area for ecosystem services* *- Increased resilience and sustainability of extensive aquaculture ponds* *Investment from the government, donors and pond owners is required*
Capacity building	*Decreased vulnerability to climate and socioeconomic shocks* *Aquaculture practices improved*	*- Resilient ecosystems are more sustainable and provide less volatile income* *- Decrease impacts of climate and socioeconomic perturbations on ecosystems and communities* *Increased income for CF pond owners*
Sea level rise	*Soil acidification and saline water intrusion*	*- Soils which were previously mangroves are affected by acidification and become toxic. This results in low or very low rice productivity* *- Saline water intrusion in low elevation rice fields. Farmers have no or little rice harvest in about 10 % of rice area. On average, rice yields reduced by 0.4 % per year.*

Key:
Red = Negative impact expected **Orange = Unknown or mild positive / negative impact** **Green = Positive impact expected**

E. Scenario 4: MRRP+VW – Enhanced allocation to village community woodlots, mangrove restoration and improved aquaculture

i) 11 % of RF area allocated for CF with certificates under CFUGs with no increase in CFUG area;

ii) 39 % of RF area is allocated for communities with certificates under VW by 2026, reaching a total of 50% RF area allocated to CFUG and VW.

iii) Plantation establishment of 1,820 ha per year, but the successful area is 1,500 ha;

iv) At least 50% of funding for restoration is allocated to CF areas.

v) Forest management plan **changed**[5] to thinning in every 5-6 years, leaving 200 – 400 maternal trees per hectare, thereby improving coastal protection, blue carbon sequestration and biodiversity;

vi) Existing mangrove aquaculture ponds for crab and shrimp remain in the landscape but production techniques are improved;

vii) Additional mangrove friendly aquaculture is introduced into project area within CFUG areas;

viii) Climate change impact on rice productivity results in declines of 0.4 % productivity per year due to saline water intrusion. Mangrove expands landward by 0.5% per year with SLR.

[5] The existing forest management plan for community certified mangroves allow heavy thinning and clear cutting which is the primary cause for mangroves degradation. A new forest management plan will be proposed to meet both local mangrove product needs and ecosystem services.

Table 5.
Summary of different scenarios considered in this report. Cells coloured light blue have no change in area of land allocated to community forestry (VW or CFUGs), while green cells have changes in area of land allocated to community forestry. MRRP is the Myanmar Reforestation and Rehabilitation Program.

	Business as Usual (BAU)	**Scenario 1. Enhanced MRRP+**	**Scenario 2. MRRP + VW/CFUG (balanced between CFUG and VWs)**	**Scenario 3. Enhanced MRRP + CFUG**	**Scenario 4. Enhanced MRRP + VW**
Rice and aquaculture	All rice field and aquaculture ponds remain in the present converted condition	All rice field and aquaculture ponds remain in the present converted condition	Area of aquaculture ponds remain the same, but production techniques are improved (crabs and shrimp). Production is improved in all mangrove area, including CF area.	Area of aquaculture ponds remain the same, but production techniques are improved (crabs and shrimp). Production is improved in all mangrove area, including CF area.	Area of aquaculture ponds remain the same, but production techniques are improved (crabs and shrimp). Production is improved in all mangrove area, including CF area.
Allocation to community forestry	**11 %**[6] of mangroves area within Reserve Forests are allocated and managed by CF user groups (CFUGs). Reserve Forests and National Parks - no access to communities 3.0 % of mangrove habitat areas allocated to Village woodlots (VCF) Annual increase, maximum CF area is about 35 % of RF area	**11 %** of mangroves are allocated and managed by CF user groups (CFUGs) Annual increase of CF VW. According to MRRP plan, annual area of - 689 ha (1,700 acres) to 2026. Maximum CF mangrove area is about 35 % of RF area	**25 %** of mangroves are allocated and managed by communities (CFUGs) and **25 %** VW by 2026.	**47 %** of mangroves are allocated and managed by communities (CFUGs) and **3 %** for VW by 2026.	**11 %** of mangroves are allocated and managed by communities (CFUGs) and **39 %** VW by 2026.

[6] CF mangrove area by 2018 is 7,895 ha within 65,599 ha of mangroves and mangrove land in the Delta

Table 5 (continued)

	Business as Usual (BAU)	Scenario 1. Enhanced MRRP+	Scenario 2. MRRP + VW/CFUG (balanced between CFUG and VWs)	Scenario 3. Enhanced MRRP + CFUG	Scenario 4. Enhanced MRRP + VW
Community Forest management plan implementation	Despite the intention in the MRRP/CFUG Management plan of only allowing thinning for fuelwood production practices every 5 years and no clear cutting, the reality is 2-4 years thinning and clearcutting every 7yrs.	**With increased investment in enforcement of the MRRP/CFUG Management plan**, CF users will limit thinning for fuelwood production practices in every 5 years and ban clear cutting. Costs related to the control of thinning every 5 years are considered.	**With increased investment in enforcement of the MRRP/CFUG Management plan**, CF users will limit thinning for fuelwood production practices in every 5 years and ban clear cutting. Costs related to the control of thinning every 5 years are considered. **Improvement of ecological health of CFs, particularly focus on protection of maternal trees age class and species diversity (keeping 300 maternal trees of 03 different species on the stand).**	**With increased investment in enforcement of the MRRP/CFUG Management plan,** CF users will limit thinning for fuelwood production practices in every 5 years and ban clear cutting. Costs related to the control of thinning every 5 years are considered. **Improvement of ecological health of CFs, particularly focus on protection of maternal trees age class and species diversity (keeping 300 maternal trees of 03 different species on the stand).**	**With increased investment in enforcement of the MRRP/CFUG Management plan,** CF users will limit thinning for fuelwood production practices in every 5 years and ban clear cutting. Costs related to the control of thinning every 5 years are considered. **Improvement of ecological health of CFs, particularly focus on protection of maternal trees age class and species diversity (keeping 300 maternal trees of 03 different species on the stand).**

Table 5 (continued)

	Business as Usual (BAU)	Scenario 1. Enhanced MRRP+	Scenario 2. MRRP + VW/CFUG (balanced between CFUG and VWs)	Scenario 3. Enhanced MRRP + CFUG	Scenario 4. Enhanced MRRP + VW
Government law enforcement	Current level of investment of law enforcement in Reserve Forests and National Parks	Improved investment in law enforcement in Reserve Forests and National Parks	Improved investment in law enforcement in Reserve Forests and National Parks Improvement of ecological health, particularly focus on protection of maternal trees age class and species diversity (keeping 300 maternal trees of 05 different species on the stand) in CFUGs areas.	Improved investment in law enforcement in Reserve Forests and National Parks Improvement of ecological health, particularly focus on protection of maternal trees age class and species diversity (keeping 300 maternal trees of 05 different species on the stand) in CFUGs areas.	Improved investment in law enforcement in Reserve Forests and National Parks Improvement of ecological health, particularly focus on protection of maternal trees age class and species diversity (keeping 300 maternal trees of 05 different species on the stand) in CFUGs areas.
Restoration effort	Mangrove restoration effort from the Government is 1,130 ha[7] annually. Some CFUG area are rehabilitated by enrichment planting	Mangrove restoration effort from the Government is planting 1,820 ha annually (MRRP plan). 37.8 % of planted areas will be transferred to local communities.	Mangrove restoration effort from Government/Donors/ Impact Investors is 1,820 ha annually (MRRP). 1,500 ha of planting are successful. All new CF areas will be rehabilitated by plantations and enrichment planting. At least 50% of funding for restoration allocated to community forestry areas.	Mangrove restoration effort from Government/ Donors/ Impact Investors planting 1,820 ha annually. 1,500 ha of planting are successful. New CF areas, CFUGs, will be rehabilitated by plantations and enrichment planting. At least 50% of funding for restoration allocated to community forestry areas.	Mangrove restoration effort from the Government is 1,820 ha annually. 1,500 ha of planting are successful. New CF areas, CFUGs, will be rehabilitated by plantations and enrichment planting. At least 50% of funding for restoration allocated to community forestry areas.
Climate change	0.4% per year decline in rice production; 0.54% annual increase in mangrove area; -0.29 annual decrease in mangrove area.	0.4% per year decline in rice production; 0.54% annual increase in mangrove area; -0.29 annual decrease in mangrove area.	0.4% per year decline in rice production; 0.54% annual increase in mangrove area; -0.29 annual decrease in mangrove area.	0.4% per year decline in rice production; 0.54% annual increase in mangrove area; -0.29 annual decrease in mangrove area.	0.4% per year decline in rice production; 0.54% annual increase in mangrove area; -0.29 annual decrease in mangrove area.

[7] Data estimated from interviews with donors, experts & communities

08
Findings

8.1 Activity 1: Identifying potential impacts

Mangroves in the Ayeyarwady Delta support critical natural resources and rural livelihoods. Mangroves support inshore and offshore fisheries, which are a major livelihood activity in the region. Fuelwood collection from mangrove is an important source of biomass energy required for coastal communities. As the most carbon-rich forest system in the world, mangroves are important for their carbon sequestration capacity. The delta also provides coastal protection to a region that is highly vulnerable to tropical cyclones and coastal flooding. The major ecosystem services considered from the mangrove of study site (Pyapon, Bogale and Labutta townships) includes:

a) Carbon sequestration

b) Coastal protection

c) Selected mangrove compatible products: shrimp farming, crab cultivation and fuel wood collection. These products are selected for investigation because they are currently the major products from mangroves and mangrove aquaculture systems in the Delta. They provide the majority of livelihood benefits derived from mangroves for local communities. Harvesting these products from mangroves has highly significant consequences for mangrove resources in the Delta.

8.1.1 Carbon sequestration

8.1.1.1 Major impacts on success of mangrove rehabilitation

We used boosted regression analysis, a machine learning technique, to analyse the impacts of different predictors (environmental parameters, silviculture practices and law enforcement – management indicator) on mangrove growth performance. The results indicated that mangrove age (43%), planted species (20%), and site condition (15%) are among the most significant variables determining the performance of mangrove plantations. Variables included in the model that had less significant impacts were soil carbon, plantation coordinates, rehabilitation project and bioclimatic variables. These results indicate that protecting plantations for as long as possible prior to harvest, as well as species selection, are the most important silviculture practice when rehabilitating mangroves by planting in the delta.

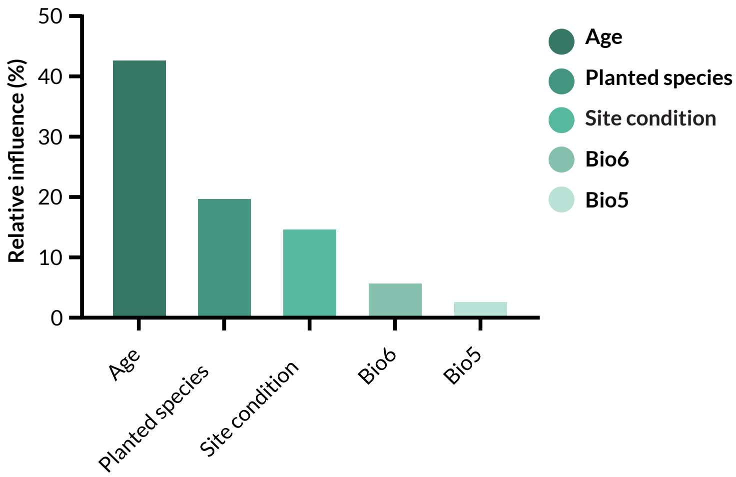

Figure 4.
Results of a boosted regression analysis for factors influencing the growth performance of rehabilitated mangrove plantations in the Ayeyarwady Delta, Myanmar. The figure shows the relative influence (%) of different explanatory factors included in the analyses which indicates that plantation age has the largest influence on mangrove growth performance, accounting for 43% of the variation in the field data. Bio6 is the minimum temperature of the coldest month, and Bio5 is the maximum temperature of the warmest month.

We found some evidence that rehabilitated mangroves managed by communities and households performed better than adjacent mangroves that were directly under management of Forest Department. However, there was no statistically significant difference in forest performance among the different managed types (P=0.12) because of low replication of the number of surveyed mangroves which were managed by CFUGs (only 11 replicates). Interestingly, the cost norms of mangrove restoration did not have a major impact on mangrove performance, particularly in the long term. The cost norms of plantations established by JICA projects, Worldview and FREDA were higher than cost norms of the Government and individual households (Phan, Lovelock 2019 unpublished data). Plantations established by JICA projects, Worldview and FREDA usually had higher success rates than other programs/projects in the initial years of the plantations. However, the established plantations of JICA, Worldview and FREDA will be transferred to the Forest Department for management, similar to other programs/projects, with the exception of community certified mangroves that remain under the management of communities. Thus, in the long-term JICA projects, Worldview and FREDA mangroves will be under similar law enforcement practices and consequently may suffer similar degradation as other Forest Department managed mangroves (e.g. unplanned and continuous fuelwood cutting).

8.1.1.2 Mangrove growth rates

We modelled mangrove growth using simulation models. In this report, we used a simple approach by applying an average growth rate for each plantation species estimated from our survey data.

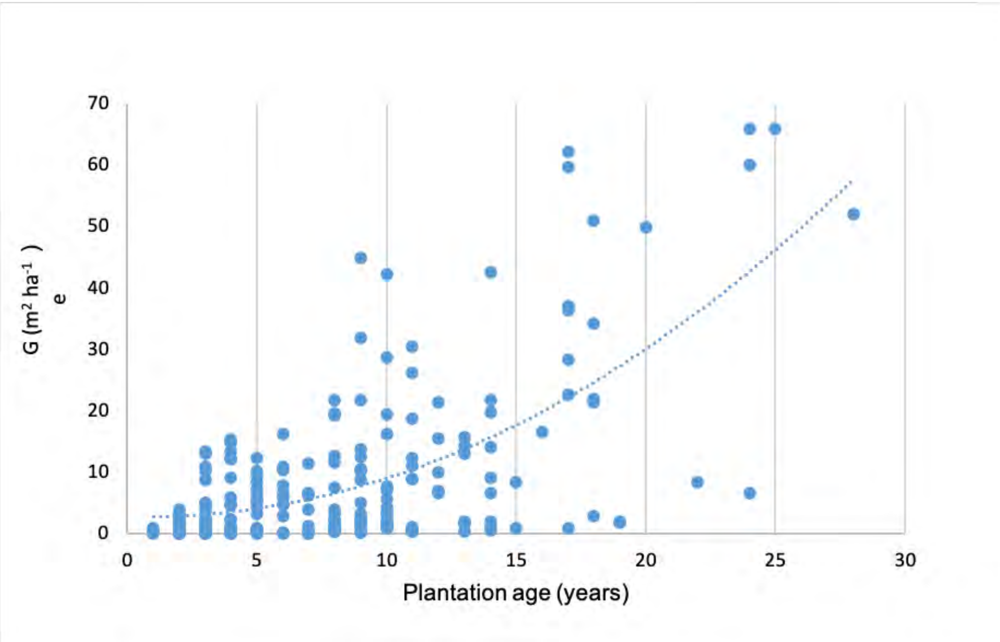

Figure 5.
Basal area growth of different aged mangrove plantations in the Ayeyarwady Delta. The equation is of the form G (G stands for basal area, A is age of plantation, b1, b2, b3 are equation parameters). Variation about the relationship is high due to variation in environmental factors and management, including levels of tidal inundation, fertility, rates of thinning and other factors, which were not assessed or where data was not available. The dashed line illustrates the growth trend over time.

The average basal area growth rate by species was estimated for different species. These growth rates were used to estimate mangrove plantation growth rates in the delta. The detailed basal area growth rates of mangrove tree species are as below:

Table 6.
Average basal area growth rate of different plantation species in the Ayeyarwady Delta, Myanmar. Units are area of mangrove stems (m2) per hectare per year.

Species	Botanical name	Average basal area growth rate (m^2 ha^{-1} $year^{-1}$)	Stde*
Aa	Avicennia alba	0.42	0.25
Ac	Aegiceras corniculatum	0.13	0.04
Am	Avicennia marina	1.09	0.99
Ao	Avicennia officinalis	1.05	1.17
Bc	Bruguiera cylindrical	0.21	0.11
Bg	Bruguiera gymnorrhiza	0.50	0.34
Bs	Bruguiera sexangula	0.94	0.71
Cd	Ceriops decandra	0.17	0.01
Ct	Ceriops targal	0.11	0.0003
Ea	Excoecaria agallocha	1.74	0.98
Hf	Heritiera formes	1.18	0.92
Ll	Lumnitzera littorea	0.81	0.46
Lr	Lumnitzera racemosa	0.95	0.26
Pp	Pongamia pinnata	0.29	0.14
Ra	Rhizophora apiculata	0.15	0.01
Rm	Rhizophora mucronata	0.75	1.45
Sg	Sonneratia griffithii	0.38	0.34
Xm	Xylocarpus mekongensis	1.39	0.23

**Stde: standard deviation of the mean*

A universal equation relating tree biomass and basal area was developed using survey data and other data available in the literature for mangroves in the Ayeyarwady Delta in Myanmar. The equation is:

Biomass = 2.6453*G1.1255
(R2 = 0.9894) (1)

In which Biomass (Mg ha-1) is biomass of vegetation (mangroves) per hectare (fully dried); G is total tree basal area (m2 ha-1)

From equation (1) it is straightforward to estimate biomass of different species from their basal area growth rate (G). Biomass increments were then converted to carbon sequestration using conversion factor from the IPCC Wetland Supplement (2013).

To estimate growth rates of natural mangroves we assumed that growth rates were similar to mangrove plantations that had similar tree basal area per hectare. Based on the 215 survey plots within plantations in the delta, we estimated a growth rate of different natural mangrove stands in different status categories as below:

- Degraded secondary and regenerating mangrove. These have growth rates similar to poor performing plantations (low tree stocking). These types of mangroves have growth rates of 2 Mg biomass per hectare per year.

- Mangrove plantations and natural mangroves in good condition. Growth rates were assumed similar to plantations with tree density of greater than 1500 trees per hectare and with mean growth rates of 5 Mg biomass per hectare per year.

- Regenerating mangroves. These have basal area and growth rates similar to new mangrove plantations (1-3 year-old) and have growth rates of 2 Mg biomass per hectare per year.

Table 7.
Mangrove growth rate analysed from surveyed plantations

Mangrove status	Mean tree basal area (m2 ha-1)	Mean tree biomass increment of similar stocking plantation (Mg ha-1 year-1)	N (number of plots)	Stde*
Degraded secondary and regenerating mangrove	16.3	2.6	24	0.59
Mangrove plantations and natural mangroves in good condition	52.1	6.2	31	1.14
Regenerating mangroves	9.0	1.9	98	0.34

**Stde: standard deviation of the mean*

8.1.1.3 Soil carbon

Beside collecting biomass data, we also conducted soil carbon survey in the Delta. Soil samples were collected on different adjacent land uses in 35 sites across the Delta. Table 8 below presents soil carbon per hectare of the layer from 0 – 50 cm of different land uses.

Table 8.
Total soil carbon of the layer 0 – 50 cm of different land uses in the Delta

Land uses	Average of soil carbon layer 0 – 50 cm (Mg C ha-1)	Stde* (Mg C ha-1)	Note
Grass, shrubs & few regenerating trees - open	165.4	40.1	
Agriculture land	166.8	50.2	
Aquaculture pond (without mangrove)	139.2	38.6	$p < 0.05$**
Bared land	175.6	44.5	
Mangrove in pond	172.6	38.7	
Mangrove plantation	172.2	39.5	
Mangrove plantation in pond	159.0	22.9	
Natural mangrove - open	175.7	46.3	

**Stde: standard deviation of the mean*

$p < 0.05$**: significant different to other land uses

The results reveal that soil carbon at the top 0 – 50 cm layer of different land uses, except aquaculture pond without mangrove, is not significant different. Conversion of mangrove into aquaculture pond without mangroves causes significantly soil carbon loss.

Our analysis has considered a strictly stop to conversion of mangroves to pure aquaculture ponds (without mangroves). It has also considered the rehabilitation of existing aquaculture ponds with mangrove plantations within the ponds. Considering the evidence that indicates that there are no significant differences in soil carbon between land uses in mangrove habitat areas (except ponds without mangrove), soil carbon was excluded in the carbon sequestration analysis for mangroves and associated land uses in the Delta.

8.1.1.4 Mangrove forest statust

Satellite images were interpreted using gound surveys to establish mangrove status maps for the three township areas. In general, most of existing mangroves were within the Reserve Forests and/or National Parks in the region. We produced detailed maps for this region, shown below.

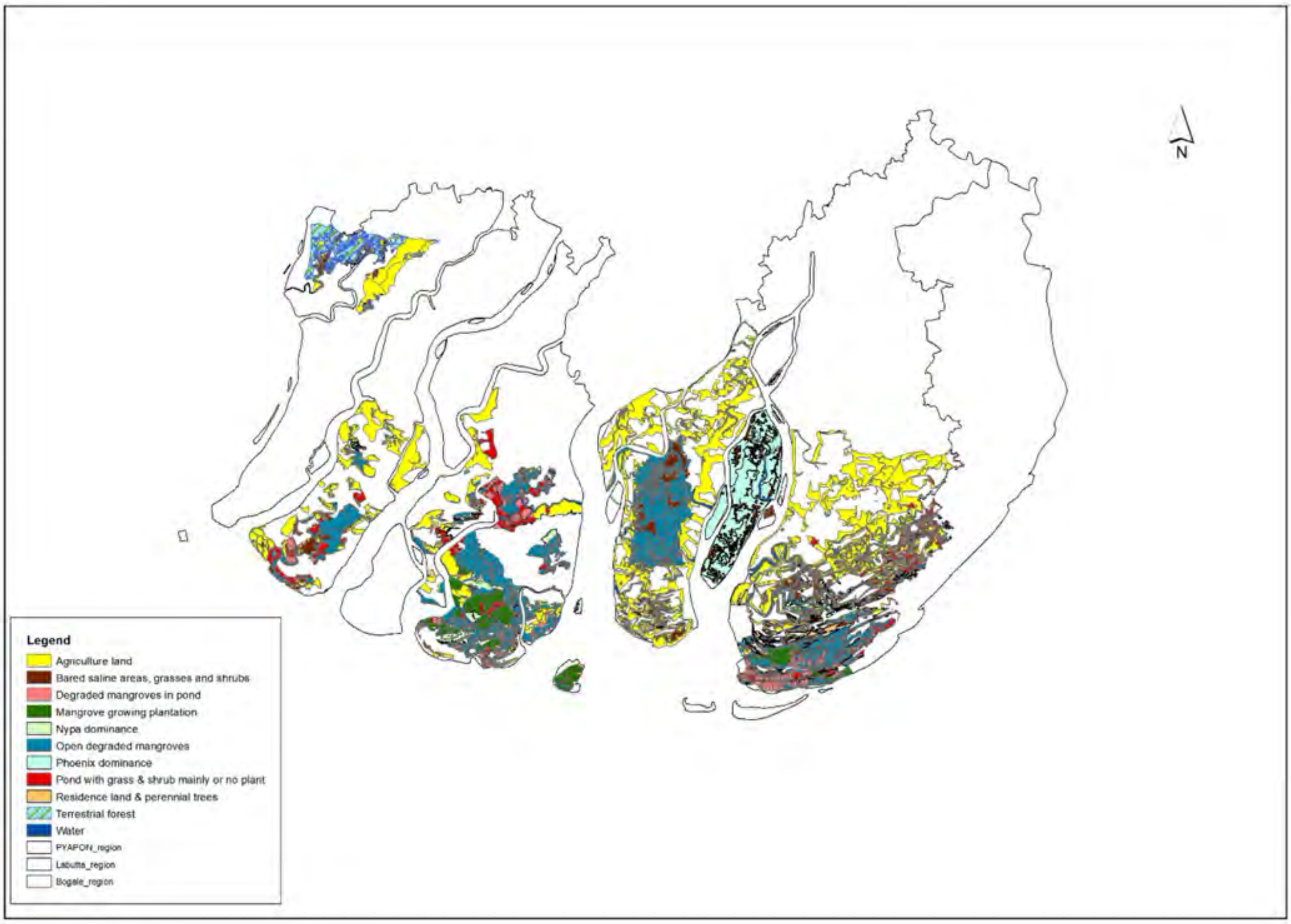

Figure 6.
Mangrove forest status map in Reserve Forests and National Park in three research townships.

Table 8.
Total soil carbon of the layer 0 – 50 cm of different land uses in the Delta

Land use and mangrove status	Bogale	Labutta	Pyapon	Grand Total
1. Mangrove habitat	**28,424**	**34,548**	**22,461**	**85,432**
1.1 Open mangrove habitat	**28,191**	**26,146**	**13,550**	**67,887**
Mangrove plantation		4,293	1,177	5,470
Mangroves, main cover by Nypa	795	3,653	2,471	6,919
Mangroves, main cover by Phoenix Paludosa	11,611	137		11,748
Secondary and restored mangrove	8,873	14,374	5,866	29,113
Young regenerating mangrove	761	1,019	208	1,988
Grass and shrubs with few regenerating mangrove trees	5,630	2,137	3,219	10,986
Open, bare and saline wetland	521	533	609	1,664

Table 8 (continued)

Land use and mangrove status	Bogale	Labutta	Pyapon	Grand Total
1.2 Pond mangrove habitat	**233**	**8,402**	**8,911**	**17,545**
Pond with grass and shrub with few regenerating mangrove trees		293	1,699	1,992
Pond with mangroves	84	4		88
Pond with secondary and restored mangrove		964	3,097	4,062
Pond with young regenerating mangrove	12	1,931	677	2,620
Pond without mangroves	137	5,209	3,438	8,784
2. Agriculture land, other terrestrial land uses and water	**6,351**	**27,764**	**15,531**	**79,646**
Plantation forest		2,753		2,753
Natural forest		840		840
Agriculture land	31,734	20,452	10,599	62,785
Bare land	45	8		53
Unvegetated land with sandy soil	11	225		236
Residents, offices, schools, pagodas	18	95	191	305
Perennial trees	694	194	2,000	2,888
Roads		8		8

Data from the mapping (Figure 6) and Table 8 reveal that the total land which can currently be considered as mangrove land in Reserve Forests and National Parks in the delta only comprises about 85,432 ha. Most plantations were recently established by the Forest Department and other organizations. These projects are within the Young regenerating mangroves and Secondary and restored mangrove classifications, which are among the best quality mangroves in the delta. The total area of young regenerating, secondary, and restored mangroves, and plantations is about 30,000 ha. Thus, there is about 55,000 ha of degraded land that is suitable for mangrove restoration. Of this, over 11,000 ha is within the Meinmahla National Park. This estimation is based on sattelite image interpretation.

The analyses also revealed that over 17,000 ha of mangroves have been used for aquaculture ponds (Figure 7) within mangrove habitats in Reserve Forest and National Park. Nearly two thirds of the mangrove pond areas in Reserve Forests are without mangroves (10,776 ha of the total 17,545 ha of mangrove ponds) suggesting that these lands are severely degraded and that it is very likely that they need hydrological repair to restore mangroves (Brown et al. 2015).

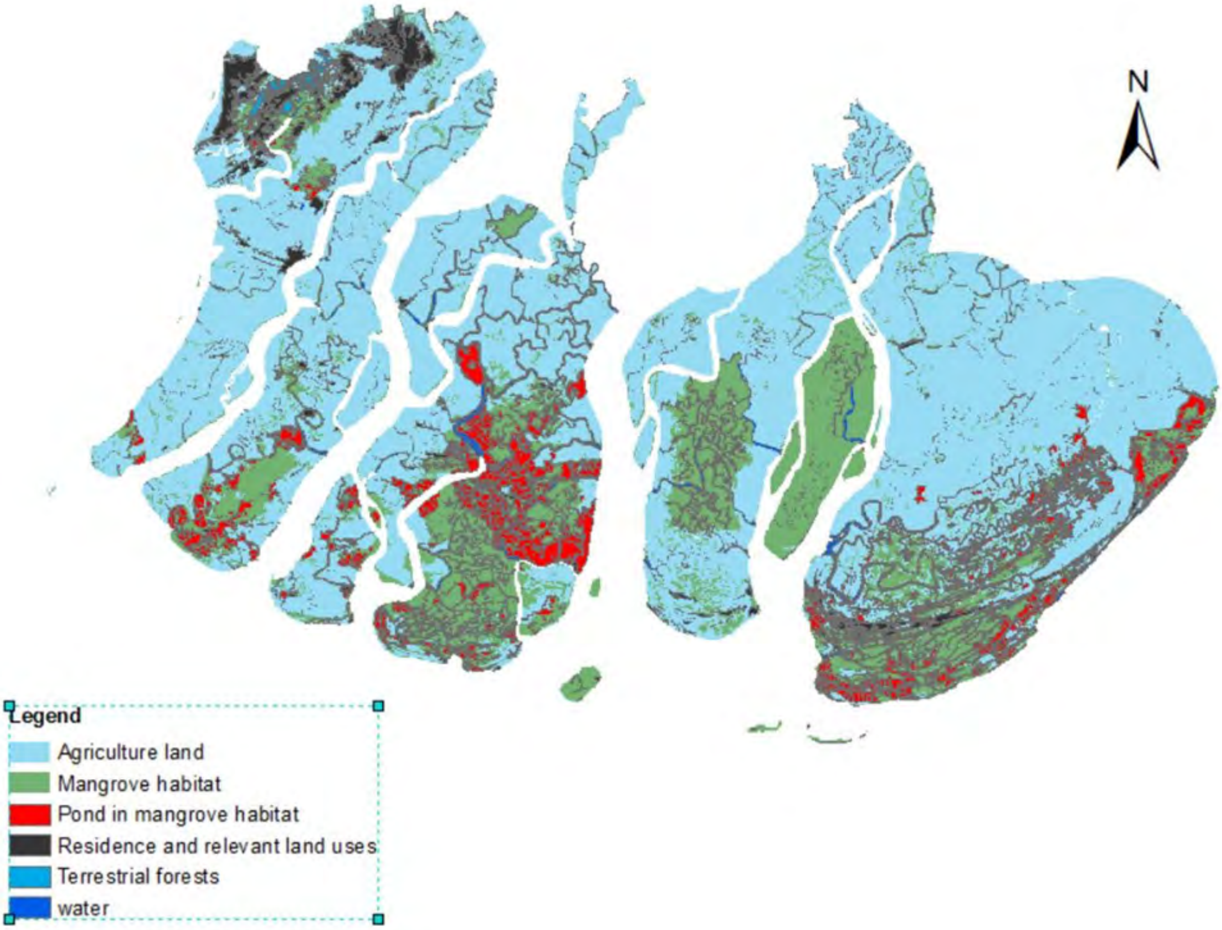

Figure 7.
Open mangrove habitat and pond mangrove habitat in Reserve Forests and National Park

The total mangrove habitat associated with the three townships including Reserve Forests and National Parks is 147,459 ha (Table 9). This area is significantly larger than areas within Reserve Forests and the National Park. These areas are potential areas for mangrove restoration associated with livelihood improvement for local people. However, we did not use the total mangrove habitat in the three townships for the investment scenarios because the legal and institutional frameworks for managing mangroves outside Reserve Forests and National Parks are not clear. This means that there are high risks in developing green development projects on those areas until legal frameworks for managing those mangroves are clarified.

Table 10.
Mangrove status and land uses in three townships (hectares)

Land use and mangrove status	Bogale	Labutta	Pyapon	Grand Total
1. Mangrove habitat	**41,973**	**67,081**	**38,405**	**147,459**
1.1 Open mangrove habitat	***41,510***	***46,017***	***21,883***	***109,409***
Grass and shrubs with few regenerating mangrove trees	6,328	3,725	4,077	14,131
Mangrove plantation		4,673	1,248	5,921
Mangroves, main cover by Nypa	11,821	13,837	3,669	29,328

Table 10.
Mangrove status and land uses in three townships (hectares)

Land use and mangrove status	Bogale	Labutta	Pyapon	Grand Total
Mangroves, main cover by Phoenix Paludosa	12,397	137		2,534
Secondary and restored mangrove	9,579	20,376	9,683	39,638
Young regenerating mangroves	821	2,142	851	3,814
Open, bare and saline wetland	563	1,126	2,354	4,043
1.2 Pond mangrove habitat	***463***	***21,065***	***16,522***	***38,050***
Pond with secondary and restored mangrove		1,525	4,057	5,583
Pond with young regenerating mangrove	12	3,578	952	4,542
Pond with grass & shrub with few regenerating mangrove trees		353	2,323	2,677
Pond with mangroves	163	4		167
Pond without mangroves	289	15,604	9,189	25,082
2. Agriculture land, other terrestrial land uses and water	**161,536**	**183,858**	**106,084**	**451,478**
Natural forest		1,464		1,464
Open land on sandy soil	153	1,232		1,385
Agriculture land	149,035	155,439	88,944	393,419
Bare land	45	9		54
Perennial trees	2,864	3,280	6,603	12,747
Plantation forest		9,237		9,237
Residents, offices, schools, pagoda	1,388	2,106	4,121	7,615
Water	8,051	11,091	6,416	25,558

8.1.1.5 Land uses and community forestry in mangrove areas in the delta

The Myanmar Constitution defines that land ultimately belongs to the state. Although farmers do not have ownership of agricultural cropping land, their land use rights allow them to transfer the land, use it as collateral, and to pass it on via inheritance. A large proportion of mangroves in the delta are within the Reserve Forests and National Park systems of the state. Under the law, these areas are directly and fully under control of Forest Department. After several decades of encroachment onto mangrove land, people have occupied large areas of mangroves and ponds established within the mangroves. The Government has accepted the legality of these ponds. To encourage better land management, local farmers were encouraged to group together and submit applications for community forestry (CF) land certificates for mangroves around their homes and villages. Community Forestry User Groups (CFUGs) have the right to set up aquaculture ponds within their land areas as long as they comply with the rule that less than 10 % of the land is water surface for use for aquaculture purposes. Mangroves are required to be rehabilitated in the remaining areas of the ponds.

According to Forest Department's data, by 2018, 69 CF certificates were issued to 1,606 members (households) in the Myaungmya Forestry District. Most of the CF groups are located in Pyapon, Bogale and Labutta townships (60 CF groups). A total of 7,958 ha (19,665 acres) of mangroves and mangrove land were allocated to CFUGs (Annex 1). This accounts for 9.2 % of total mangrove land area of Reserve Forests in the three townships. Our interviews with different forestry authorities indicated that the Government does not limit the number of CF certificates for local communities. However, significant resources are needed to obtain these certificates. The preparation of a Forest management plan, demarcation of boundaries, mapping etc., take substantial human and financial resources and the Government has limited staff and budget to support the process. Thus, most CF certificates have been issued in the regions with significant support from Overseas Development Aid (ODA) projects such as RECOFTC, JICA and FREDA. Additionally, some Forest Department officers are sceptical about CF mangrove management and are reticent to discuss opportunities to allocate more mangroves to communities.

In addition to CFUGs, villages are also allocated fuelwood plantations, called village woodlots. Only members of the villages have right to harvest timber and fuelwood from village woodlots according to the villages' approved forest management plans. However, these areas are open to the public for NTFP collecting, notably crab catching.

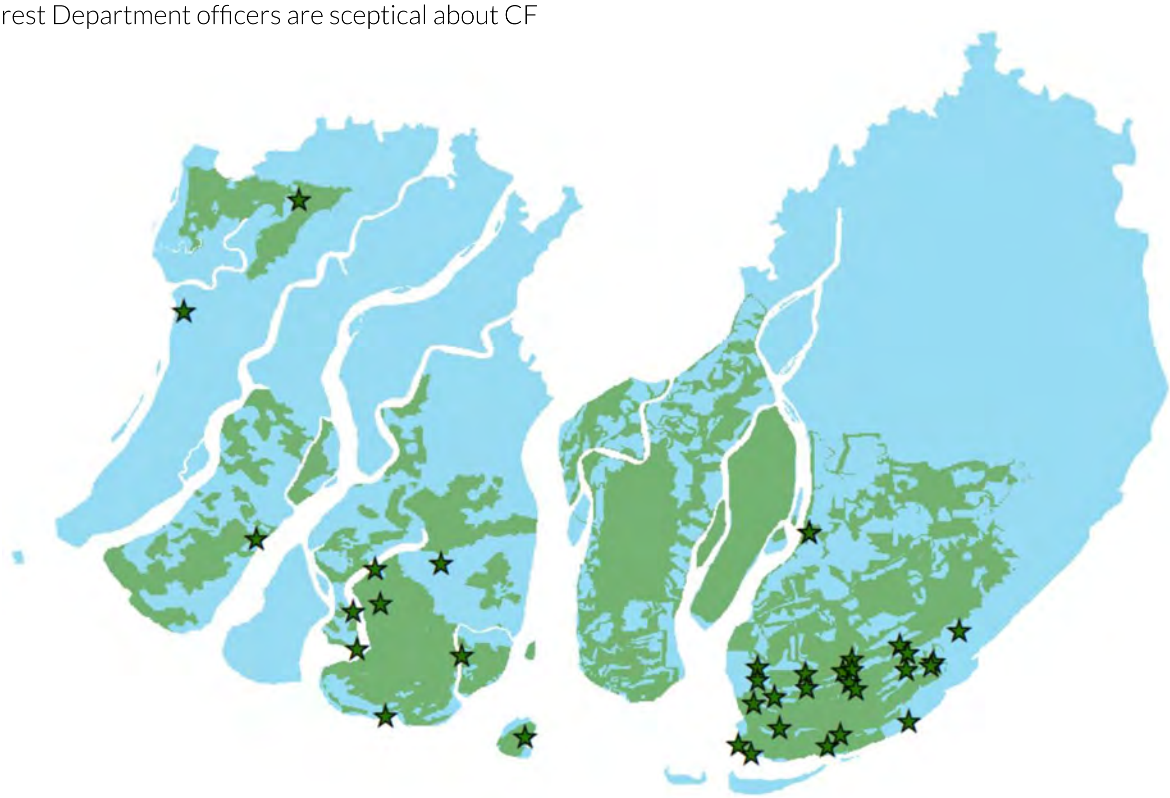

Figure 8.
Community forestry villages in three townships and their locations in the Reserve Forest.

The village CF map indicates that most of mangrove CF villages are in Pyapon township. There are over 10 CF villages in Labutta but only 3 CF user groups in Bogale. Our satellite image classification and ground survey results also indicate very limited pond areas in the mangroves in Bogale township (Figure 8). However, the level of degraded mangrove in Bogale township is similar to the other two townships.

8.1.1.6 Mangrove rehabilitation in the delta

Since the catastrophe of Cyclone Nargis (2008), a range of organizations, especially the Myanmar Government, has made substantial investments in mangrove rehabilitation in the delta. All mangroves which have been planted in the last decade are within Reserve Forests and National Parks. In addition to mangrove rehabilitation for ecological restoration, about 20 – 40% of the mangroves planted by the state are fuel wood plantations for communities. Table 10 shows the area of mangrove plantation established in the most recent years in the delta.

Table 11.
Mangrove rehabilitation by planting by the Government of Myanmar over the last 10 years in three research townships. Values are reported in acres as this unit is used by the Forestry Department and converted to hectares in the final line of the table.

Township	Year (acres)										Total (acres)
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Labutta	800	600	300	300	150	100	150	1,000	1,000	1,000	5,400
Bogalay	750	600	300	400	150	200	400	1,400	1,355	1,400	6,955
Pyapon	500	300	200	100	0	100	150	400	400	400	2,550
Total (acres)	2,050	1,500	800	800	300	400	700	2,800	2,755	2,800	14,905
Total (hectares)	830	607	324	324	121	162	283	1,133	1,115	1,133	6,032

Source: Myanmar Forest Department

Donors such as FREDA, WorldView International, JICA and others also support the restoration by planting of mangroves in the region. The exact planted area data annually has not been recorded. However, estimations from experienced mangrove restoration staff in the region suggest that there are about of 100 – 200 hectares of mangroves planted in three townships annually. Overall, about 2,000 hectares of plantations were established during 2010 – 2019 by organizations other than the Forest Department. Farmers also planted mangrove trees in their ponds. This is required under the Forest Management Plans for CFUGs; if it is not done, the Forest Department has the right to withdraw the CF certificates. Thus, for the purposes of the Returns on Investment analysis we considered the scenario that all mangroves allocated to CFUGs are restored.

If we sum up the total plantation areas established by Government programs, donor projects and by CF farmers, a large area of mangroves (16,000 ha or about 40,000 acres), have been restored in the last 10 years. However, the main pressure on mangroves in the delta still exists, which is the strong demand for fuelwood for domestic cooking and fish processing. Mangroves within the CF ponds generally recover biomass rapidly due to the protection provided by owners. However, the current Forest Management plans allow mangrove aquaculture pond owners to thin the mangroves over very short time periods without leaving significant numbers of maternal trees to maintain key ecosystem services (e.g. coastal protection) and propagule (seed) sources that support regeneration. This practice, in general, does not contribute to the rehabilitation of mangroves; however, it does help farmers to provide fuelwood rapidly as well as cash income for pond owners.

8.1.2 Coastal Protection

Coastal protection service at the landscape level were determined based on secondary data and the literature from studies in Myanmar and nearby countries. The expenditure for restoration for different scenarios explored in the Returns on Investment Analysis provided the cost data for the different scenarios explored. The assessment of coastal protection was not spatially explicit, as data were not sufficiently detailed to estimate coastal protection at the landscape level. We estimated the storm protection value ranging between US$ 1,120 – 1,369 ha-1 year-1 based on the results of Barbier (2007) and Estoque et al. (2018). We estimated the total value of storm protection by multiplying the area of mangrove with the value per ha (US$ 1,120 – 1,369 ha-1 year-1). The net present value of coastal protection for the mangrove was determined as 81,851 million MMK in BAU, and 170,721 million MMK in Scenario 4 by 2026, and varied up to 668,735 MMK in 2079 under the scenarios with the highest mangrove area.

8.1.3 Selected mangrove compatible products

The following are descriptions of the value chains of the targeted mangrove compatible products from mangrove-associated aquaculture (shrimp and crabs) and fuelwood use.

8.1.3.1 Shrimp from mangrove pond aquaculture

The shrimp value chain involves the wild shrimp fry (larvae) collectors, shrimp farmers and local buyers. The collectors of wild larval shrimp collect the larvae from mangrove-lined creeks and channels. They use nets (of local design and manufacture) and boats. Shrimp farmers buy shrimp larvae at a price of about 8-15 MMK per larvae, which they grow out in ponds dug within the mangrove and surrounding areas and contained within earthen walls. Usually they do not provide any additional food and other input for their ponds. The shrimp grow under mainly natural conditions without pond aeration or other management practices. Although the price of the shrimp depends upon size and quality, the average selling price to the local buyer (farm level buyer) is around 16,000 – 17,000 MMK/viss (about 10,000 MMK per kg, 1 viss = 1.6 kg). When the shrimp are transferred to the wholesale market, the farm level buyer incurs the cost of storage and transportation. The selling price of the local buyer to the wholesale market is about 17,000 MMK/viss. The wholesale market has a range of buyers, including exporters and restaurants from the capital city. Although we know that there are other actors involved in the buying, selling, processing and transportation of the shrimp to exporters and restaurants, detailed information was not available. A major portion from the wholesale market also goes to the local retail market.

Due to limited data available on the volume of shrimp production and export from the delta, we were not able to provide a comprehensive shrimp value chain at this stage. However, from our field surveys some limitations within the value chain were noted and thus we have identified several processes which may help to improve the shrimp value chain in the delta. These include the following:

- Currently, the mangrove ponds and other shrimp aquaculture ponds mainly depend on wild larval sources for shrimp fingerlings to stock the ponds. There is high uncertainty about the productivity and sustainability of shrimp aquaculture in the delta. For instance, in 2018, pond owners were not able to buy wild-caught fingerlings due to the low availability of natural larval stocks. There are some shrimp hatcheries in Pathein and Yangon, but they are inactive. In the long term, for the development of shrimp aquaculture in the delta, shrimp hatcheries, particularly small-scale ones, should be developed.

- The productivity of shrimp in mangrove aquaculture ponds in the delta is only about 50 kg per hectare per year. This can, for example, be contrasted with Vietnamese farmers, who achieve 250 – 300 kg per hectare per year. Thus, productivity could be increased (although at higher costs and with potentially negative environmental consequences, Boesma et al. 2012). In addition to the more highly developed aquaculture techniques, particularly the availability of cheap tiger prawn fingerlings in Vietnam, the water surface ratio of mangrove aquaculture ponds in Vietnam is usually 40 – 60 %. We do not suggest that Myanmar increases the permitted water surface of mangrove aquaculture ponds, because of the high risk to mangrove resources within the ponds. While most mangroves within the ponds in Vietnam are monocultures of Rhizophora apiculata, mangrove communities with ponds in Myanmar are more diverse. More productive Myanmar aquaculture should be developed which supports highly diversified and productive mangrove communities within the ponds.

• Myanmar people consume large quantities of dry fish, especially dry shrimp. This is a cheap and safe food storage approach. However, the drying process in Myanmar occurs mainly in open air, which has low hygiene, and which produces a low-quality dried product. To improve the dried shrimp value chain, both for aquaculture and for wild caught shrimp, the introduction of improved drying facilities, such as the use of solar domes, would be highly beneficial.

Our interviews with 50 mangrove aquaculture pond owners in three townships revealed that farmers can obtain 662,000 MMK ha-1 year-1 (268,000 MMK acre-1 year-1) from shrimp. The typical aquaculture rotation of mangrove pond is 9 months, with three months reserved for maintaining and cleaning the ponds. The current extensive mangrove aquaculture practice in Myanmar is to keep all-natural larvae from brackish river water in the ponds. This includes some fish, which are predators of shrimp and crabs, for instance, the seabass, which is popular in the delta. Thus, growing seabass with crabs and shrimps likely reduces survival rate and productivity. Improved aquaculture practices, such as avoiding the culture of seabass together with shrimp and crab in their early stages, would improve productivity and income for farmers.

8.1.3.2 Crab from mangrove pond aquaculture

Crab trapping and fattening are very profitable activities in the region. At the local level, the value chain of crab involves crab trappers, local collectors at the village-level, fatteners, local buyers, and traders. Traders sell the product to exporters, retail markets, and restaurants. Crab trappers use traps to catch wild juvenile crabs from the mangrove creeks and channels. They harvest these naturally available crabs and sell them mostly to village-level buyers (collectors). Collectors sell the crabs to the crab fatteners as well as to the village- or township-level buyers. Crab fatteners also sell their products to the township-level buyers. In some cases, crab trappers can also directly sell product to the township-level buyers depending on the size of the naturally available crabs. From the local market, crabs go to the traders in Yangon and Labutta. Almost 90% of these crabs are exported to China, with 8% going to local soft-shell crab producers. Only 2% of the crabs are sold to retailers. Soft-shell crab producers mostly export and sell to hotels/ restaurants in the capital city.

On average, from 50 mangrove aquaculture ponds in the delta, a farmer can get 914,289 MMK per hectare (370,000 MMK from crabs on one acre) of mangrove aquaculture pond per year. Crab rotation is usually the same as the pond cycle, namely 9 months.

Another kind of crab fattening activity occurs where farmers establish ponds for crab aquaculture. This practice is very popular in higher elevation mangroves, which are usually further from the creek/rivers. The income from this kind of pond is less than that obtained from polyculture ponds. However, the survival rate of crabs is usually greater than in polyculture farms.

Our cost and benefit analysis of mangrove aquaculture ponds revealed a very high return on investment ratio. Benefit to cost ratio was 1.186 and the internal rate of return (IRR) reaches 44 %. On average, pond owners can earn net incomes of nearly 7.14 million MMK per hectare (3 million MMK per acre) from mangrove aquaculture ponds for a five-year cycle.

However, many farmers, particularly those who occupy the land without a legal certificate, clear all the mangroves and make ponds over the whole of their mangrove area. This practice is considered unsustainable and many ponds in other nations have been abandoned after aquaculture has failed due to disease or low water quality (Kauffman et al. 2017).

8.1.3.3 Fuelwood

According to our survey, a fuelwood collector collects fuelwood equivalent to 137,500 MMK per month, of which typically 20% is self-consumed and 80% is sold to different actors in the value chain. These include local shops, middlemen, bamboo raft owners (for smoking fish), and traders. Of the portion they sell, almost half is sold to the local shops in the village and local middlemen. Both of these actors sell again to traders, who own boats and who sell to bamboo raft owners. In some instances, fuelwood collectors also directly sell wood to traders or even bamboo raft owners. Through this network, wood is also distributed to other parts of the country. Mangrove fuelwood is also used for charcoal production; however, this is only a small portion of the amount of fuelwood that is directly used for cooking.

Our surveys in 36 villages within Reserve Forests and in the buffer zone of Reserve Forests, indicated that a fuelwood collector can collect 1.5 – 4.5 Mg of air-dry fuelwood per month and earn about 144,000 – 201,000 MMK (150 MMK per air dry fuelwood viss). In one surveyed village, 43 fuelwood collectors (full time and part time) collected wood for sale. We assume that landless people from villages close to the Reserve Forests and the National Park (probably no more than 1 km distant), cut mangroves within the Reserve Forests and National Parks to sell as firewood to support their livelihood. In total there are 360 villages within the Reserve Forests and the 1km buffer zone, and thus livelihoods of over 15,500 fuelwood loggers in three townships depend on illegal logging of mangroves in mangrove areas under the direct management of the Forest Department. There are costs incurred by the fuel wood loggers. In our surveys, 80 % of interviewed people indicated that loggers pay 1,000 – 2,000 MMK to patrol authorities each time they meet them in the field (Table 11).

Table 12.
Fuel wood logging from mangroves in the delta

	Unit	Average amount	Stde*
Number of household per village	household	252	225
Number of fuel wood logger working as full-time per village	logger	17	15
Number of fuel wood logger working as part-time per village	logger	26	21
Income earned per month for full-time logger	MMK	221,000	28,000
Income earned per month for part-time logger	MMK	145,000	42,000
Expenditure for fuelwood collecting per month (excluding labour cost) for full-time logger	MMK	32,000	12,000
+ Patrol payment (normally each time 1,000 MMK)	MMK	5,000	3,000

**Stde: standard deviation of the mean*

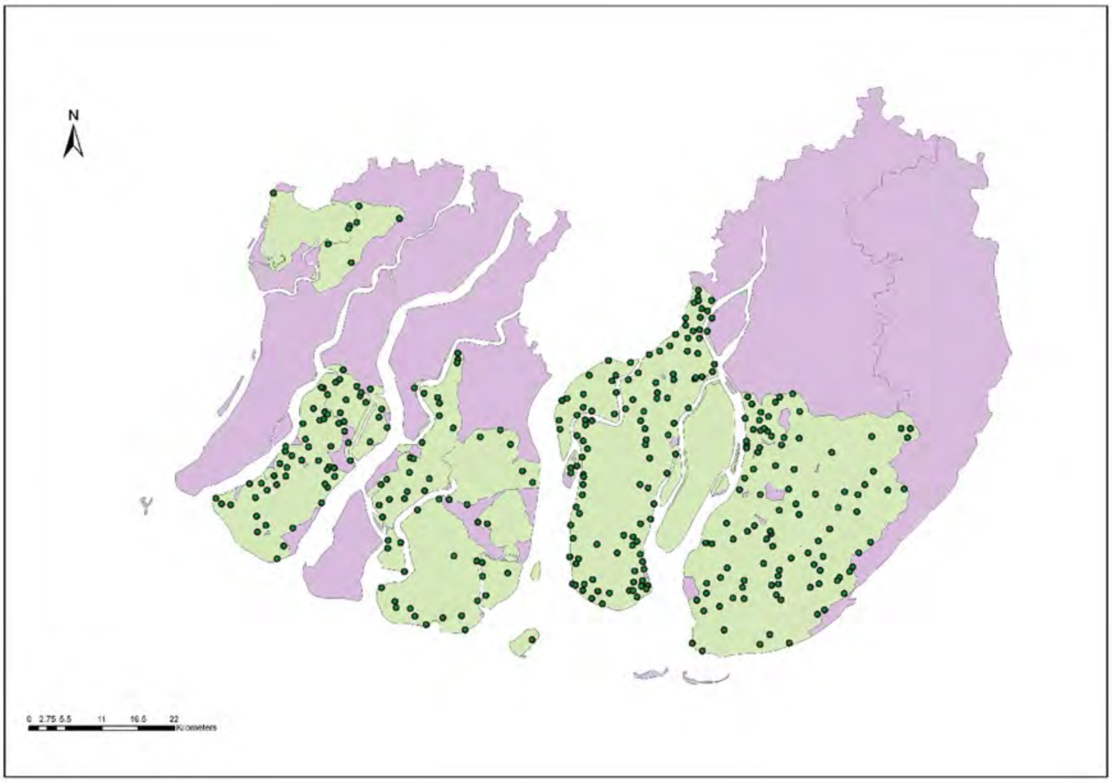

Figure 9.
Villages in reserve forests and their 1 km buffer zone in three research townships

Most households in the Reserve Forest and within the 10 km buffer zone use mangrove fuelwood for domestic cooking. There are 108 village tracks located in Reserve Forest and within a 10 km buffer zone (Figure 10 below and Annex 2). The number of households is 134,731 (population census 2014). On average, a household in this region uses about 700 - 800 kg of fuelwood per year for domestic cooking. Most households collect fuelwood from mangroves and their garden to reduce costs. The average ratio of fuelwood from mangrove and other source is 65% to 35%. Thus, we calculate that over 75,000 Mg of mangrove fuelwood is collected and used annually in the delta for domestic cooking.

Figure 10.
Map of the Reserve Forests and the 10 km buffer zones around the Reserve Forests

In Pyapon township, a popular fishing technique is to position bamboo rafts on the shore for about 8 months of the year to catch fish from them. Due to limited access to ice, bamboo raft fishers use mangrove fuelwood for cooking fish on the sea. We interviewed 30 bamboo raft owners and learnt that on average one bamboo raft uses 5 – 6 viss of fuelwood per day (8.0 - 9.6 kg). Thus, a total of 2,500 bamboo rafts would consume 20 Mg of fuelwood per day and in 240 days (8 months) they would use 4,800 Mg of mangrove fuelwood.

8.1.3.4 Crab catching from public RFs and NP mangroves

According our socio-economic surveys of 12 villages of the 3 townships, 73% of families are landless people. Landless people's livelihoods include fishing, crab catching, fuelwood collection and casual work for agriculture and aquaculture land-owners. Our surveys in 20 villages in three township (Pyapon: 9 villages; Bogale: 8 and Labutta: 3) indicate that there are 30 – 150 crab catchers in a village (Table 12). On average, about 60 crab catchers in the villages catch crabs in the mangroves. 72% of crab catchers are considered to be full-time catchers where catching crab is their main income. The average income for a full-time catcher is about 244,000 MMK per month, while part-time catchers earn about 171,000 MMK per month, on average. We assume that landless people in the villages located within the Reserve Forests or in 5km buffer zone of Reserve Forests (see Figure 12) have livelihoods that mostly depend on mangrove resources.

Table 13.
Crab catching from public mangroves within Reserve Forests and National Park in the delta[8]

	Unit	Average amount	Stde*
Number of households per village	Households	231	199
Number of full-time crab catchers per village	Person	43	32
Number of part-time crab catchers per village	Person	26	18
Average number of crabs caught per day by crab catchers	Crabs	20	4
Average weight of crabs caught per day by crab catchers	Kg	2.1	0.9
Average income of full-time crab catcher per month	MMK	237,000	62,000
Average income of part-time crab catcher per month	MMK	164,000	60,000
Average money that crab catchers borrow from middleman (as advanced payments)	MMK	120,000	81,000

**Stde: standard deviation of the mean*

There are 550 villages within the Reserve Forest areas and 5 km buffer zones. Overall, we calculate that over 32,400 people and their families have livelihoods depending on crab catching in public mangroves in the Delta. However, their livelihoods are threatened by significant reduction of the mangrove area and increases in the pond areas where they cannot catch crabs.

[8] Some areas of mangrove reserve forests were allocated to community forestry user groups. These mangroves are not open for public for collecting NTFP including crab catching.

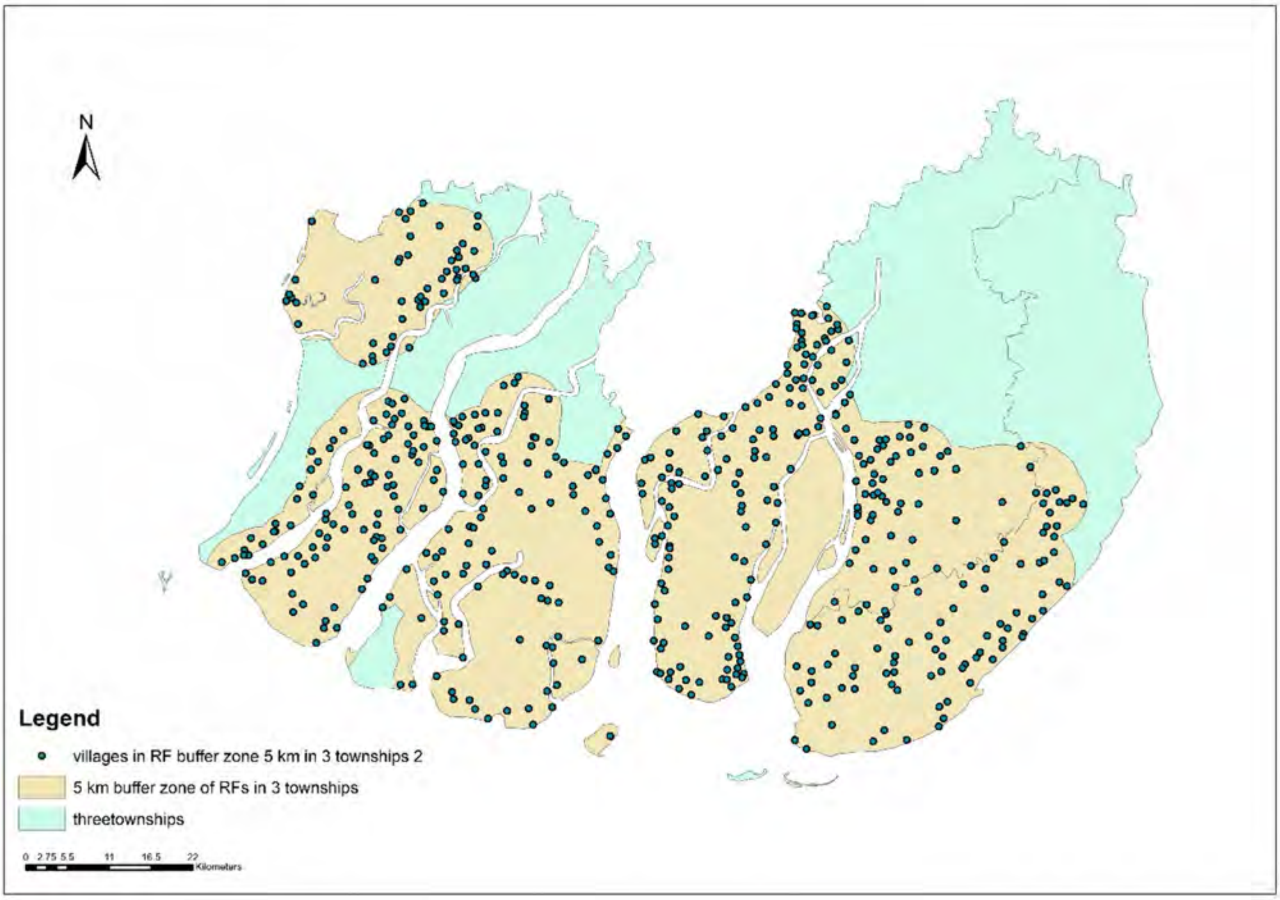

Figure 11.
Villages in reserve forests and their 5 km buffer zone in three research townships

8.2 Activity 2: Return on Investment Analysis of community-based mangrove management improvements and mangrove rehabilitation.

We used the basic principles and methodology of cost and benefit analysis to unpin a Return on Investment Analysis following the 3Returns Framework. The monetary value of prioritized Ecosystem Services (ES) at the landscape level and investment at the project level were quantified, including for net present value (NPV), benefit to cost ratio (BCR) and return of investment (ROI) of different scenarios and mangrove ecosystem states.

Table 14.
Cost and 3Return Framework benefits for the different scenarios explored based on estimated parameters. Note: FR = Financial capital returns, SR = Social & human capital returns, NCR = Natural capital returns

	Business as usual (BAU)		Scenario 1, 2, 3, 4 (Enhanced law enforcement and mangrove management) Million MMK attainable from mangrove aquaculture	
	Cost	3Returns	Cost	3Returns
Carbon sequestration	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
Coastal protection	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
Product A (shrimp)	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
Product B1 (aquaculture crab)	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
Product B2 (crab catching)	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
Product C	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
(fuelwood)	MILLION MMK$/ year	FR + SR + NCR (MILLION MMK$/year)	MILLION MMK$/year	FR + SR + NCR (MILLION MMK$/year)
NPV	MILLION MMK$/year		MILLION MMK$/year	
BCR	Ratio - dimensionless		Ratio - dimensionless	
ROI	Ratio - dimensionless		Ratio - dimensionless	

The results of the Return on Investment analyses, which considered the value of coastal protection and carbon sequestration in three typical investment scenarios, are shown in Table 16.

Table 15.
Key data and assumption applied in the Return on Investment analysis. GIS = Global Information System; RF = Reserve Forest; NP = National Park.

Parameter	Value	Source
General parameters and assumptions		
Land use area		
Total area of RF and NP in three townships	165,078 ha	GIS layer provided by Forest Department (2019)
Total mangrove habitat in the RF and NP in three townships	85,452 ha	Satellite image interpretation (2019) & ground truthing
Degraded mangrove areas in RF and NP in 03 townships	56,537 ha	Satellite image interpretation (2019) & ground truthing
Shrub, grasses and bare saline land in RFs and NP	23,425 ha	Satellite image interpretation (2019) & ground truthing
Pond area in mangrove habitat in RFs and NP	17,545 ha	Satellite image interpretation (2019) & ground truthing
Pond area without mangroves or with shrubs and grasses	10,776 ha	Satellite image interpretation (2019) & ground truthing
Mangrove plantation	5,470 ha	Satellite image interpretation (2019) & ground truthing
Social and financial data		
Number of households in villages living in RFs, NP and their 10 km buffer zone	134,731 households	Mimu data – national population census 2014 & RFs & NP map layer 2019 (assumption: mangrove fuelwood utilization zone))
Number of villages in RFs, NP and their 5 km buffer zone	550 villages	Mimu data – national population census 2014 & RFs & NP map layer 2019 (assumption: crab catching for livelihooods)
Number of villages in RFs, NP and their 1 km buffer zone	360 villages	Mimu data – national population census 2014 & RFs & NP map layer 2019 (assumption: fuelwood cutting for livelihooods)
Total CF user group mangrove areas in 2018	7,895 ha	Forest Department data (2019)
Current Government forestry management staff in three townships	60	Estimated from 03 townships
Fuelwood used for bamboo raft owners per year	4,800 Mg $year^{-1}$	(2,500 bamboo rafts) x (08 months on the river) (x 8kg per bamboo raft per day) (Mg/year) – Project survey
Fuelwood used by local residents in RFs, NP and their 10 km buffer zone	75,449 Mg $year^{-1}$	134,731 households x 0.8 Mg per year x 70 % fuelwood from mangroves
Average capital investment for building ponds	1,366,463 MMK ha^{-1}	Project survey data 2019
CF pond owner investment - operation costs (yearly)	1,161,370 MMK $year^{-1}$	Project survey data 2019
Mangrove plantation establishment costs	3 million MMK ha^{-1}	Project survey data 2018, 2019
Government costs for 1 staff – on average	500,000 MMK per staff	Estimation from staff salary and other costs, survey 2019
Mangrove crab catching in public mangrove income per person (full time)	237,000 MMK per month	Average estimation from surveys of 20 villages
Mangrove crab catching in public mangrove income per person (part time)	164,000 MMK per month	Average estimation from surveys of 20 villages
Number of full-time crab catchers per village	43	Average estimation from surveys of 20 villages

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Table 15 (continued)

Parameter	Value	Source
Social and financial data		
Number of part time crab catchers per village	25	On average estimation from surveys of 20 villages
Fuelwood collection in open mangrove, income for full time collectors	221,000 MMK	Average estimation from surveys of 36 villages
Fuelwood collection in open mangrove, income for part time collectors	145,000 MMK	Average estimation from surveys of 36 villages
Number of full-time fuelwood collectors per village	17	Average estimation from surveys of 36 villages
Number of part time fuelwood collectors per village	25	Average estimation from surveys of 36 villages
Jobs created and maintained from rice production	1 full-time job per 04 ha	It is estimated that 04 ha of rice cultivation needs an equivalent 01 full time job
Carbon price	10 USD Mg^{-1}	Estimation from ongoing carbon sequestration projects
Discount rate	10 %	10 % . This rate is between the commercial rate, 12 – 15 %, and social rate of 8 %
Operational and capital cost rates increase per year	1 %	Our assumption is that the cost rate will increase 1 % per year due to inflation and other factors
Income rate is stable	0 increase or decrease rate	We applied a conservative assumption that the income rate is stable during the investment period
Mangrove biomass, growth, and utilization		
Tree biomass growth per year from plantations and natural mangroves in good condition (Mg)	6.2 Mg ha^{-1} $year^{-1}$	Project inventory. Assumption: natural forest growth rate is similar to plantations with same tree basal area
Tree biomass growth per year from young regenerating mangroves (Mg)	1.9 Mg ha^{-1} $year^{-1}$	Project inventory. Assumption: natural forest growth rate is similar to plantations with same tree basal area
Tree biomass growth per hectare per year in degraded mangroves (Mg)	2.6 Mg ha^{-1} $year^{-1}$	Project inventory. Assumption: natural forest growth rate is similar to plantations with same tree basal area
Average tree biomass/ha of degraded mangroves in RFs (Mg ha^{-1})	0	Similar in BAU and all other scenarios
Increase of average biomass per ha of mangrove plantations, young rehabilitated mangroves and healthy natural mangroves in Scenario 1, 2, 3, and 4 (Mg ha^{-1} $year^{-1}$)	1 Mg ha^{-1} $year^{-1}$	Due to improvement of mangrove forests in Scenario 1, 2, 3 and 4, the average biomass per hectare of three types of mangroves: established plantations, young rehabilitated mangroves and healthy natural mangroves increase 1 Mg ha^{-1} $year^{-1}$.
Average increase in tree biomass per hectare per year (Mg ha^{-1} yr^{-1}) of degraded mangrove	0	No change in degraded mangroves
Average increase in tree biomass growth rate per hectare per year (%) of healthy mangrove, establised plantations and young rehabilitated mangroves in Scenario 1, 2, 3, and 4	1 % increase per year	Due to improvement of mangrove forests in Scenario 1, 2, 3 and 4, the biomass growth rates is improved.
Average increase in tree biomass per hectare per year (Mg ha^{-1} yr^{-1}) of young regenerating mangrove (increase annually in Scenario 1, 2, 3, and 4)	1 % increase per year	Due to improvement of mangrove forests, its productivity is improved.

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Table 15 (continued)

Parameter	Value	Source
Mangrove biomass, growth, and utilization		
Plantation harvest annually	*Surplus planting area*	*Assumptions: A maximum of 40,000 ha of mangrove plantations and 40,000 ha of healthy natural mangroves are planned in the RFs and NP in three townships in both the non and low coastal squeeze scenarios (Table 1). In high coastal squeeze scenario, the maximum area of mangrove plantations and healthy natural mangroves is 30,000 ha due to a decrease in mangrove habitat. We assumed that any surplus planting will result in harvesting the same amount of mature plantation for timber and fuelwood.*
Climate change and sea level rise scenarios		
Rice productivity decrease annually	0.4 %	Rice productivity decreases due to saline water intrusion and climate change
High coastal squeeze – low adaptation	-0.29 % per year	Mangrove habitat declines at 0.29 % per year
Low coastal squeeze – high adaptation	0.54 % per year	Mangrove habitat increase 0.54 % per year, this results in decline in the area of rice fields, which is the land-use with second lowest elevation
BAU scenarios		
Number of Community Forest user group (CFUG) increase per year (01 CFUG equal to 40 households and 134 ha of mangrove allocated – average number)	1 CFUG	No ongoing investment to help establish CF user groups. CFUGs and VWs area reach about 35 % of total RF area
300 ha of VWs increase annually, equal VW area for 1 village.	300 ha	CFUGs and VWs area reach about 35 % of total RF area
Agriculture and other non-mangrove habitat	79,646 ha	Assumption: unchanged
Degraded mangrove area	56,537 ha	Assumption: unchanged due to continuous unregulated fuelwood logging
Mangrove plantation annual increase in area	300 ha	Assumption and estimated: with more investment from MRRP program, it is expected 300 ha of plantation will be in good condition annually.
Shrub, grasses and bare saline land reduced yearly	500 ha	Assumption and estimated: Mangrove rehabilitation MRRP program and efforts of pond owners
Government law enforcement staff	No change	Assumption: unchanged
Public and CF mangrove reduced due to increase of CFUGs	estimation	Estimation from current trend
Jobs from CF aquaculture farm	Survey data	Estimated from survey data
Jobs from crab catching in public RFs and NP mangroves	Estimated and lost 1 % a year due to declining crab resources	Gradually reduced due to decrease of open access public mangrove (CFUGs increase) and 1 % of jobs lost annually due to declines in crab resources

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Table 15 (continued)

Parameter	Value	Source
BAU scenarios		
Unregulated jobs from fuelwood collection in public RFs and NP mangroves	Estimated	Gradually reduced due to decrease of open access public mangrove (CFUGs increase)
Scenario 1 MRRP+ (Government law enforcement in Non-CF areas and CF management improved)		
Number of Community Forest user group (CFUG) increase per year (1 CFUG equal to 40 households and 134 ha of mangrove allocated – average number)	1 CFUG	No ongoing investment to help establish CF user groups. CFUGs and VWs area reach about 35 % of total RF area.
Increase in village's common woodlot (VW) annually	689 ha	Estimated based on MRRP plan: 689 ha of established plantation allocated to local villages. CFUGs and VWs area reach about 35 % of total RF area.
Agriculture and other non-mangrove habitat	79,646 ha	Assumption: unchanged
Annual increase in healthy mangrove	1,000 ha	Assumption: law enforcement improvement contributes to increased healthy mangrove areas
Annual increase in mangrove plantation	1,000 ha	MRRP plan 1,820 ha per year, but successful area over the long term is expected to be 1,000 ha only
Shrub, grass and bare saline land decreases annually	1,500 ha	Due to new planting and improved law enforcement
Other young rehabilitated mangroves (in ponds or outside ponds)	Increased	Increased due to law enforcement
Common mangrove areas lost for public crab catching and fuelwood collection due to allocation to CFUGs	Estimated	Estimated from CFUGs area increase
Capacity building (training and pilot model development)	1.5 times of BAU	It is expected that if the Government adhere to the MRRP capacity building is 1.5 times than BAU
Law enforcement force strengthened	3 times of BAU	High pressure on livelihoods and fuelwood consumptions require significant increase of government authorities for law enforcement for mangrove protection.
Illegal fuelwood harvesting reduced	85 %	With substantial investment of the Government in mangrove law enforcement, the illegal fuelwood cutting is expected to be reduced by 85 %, which results in a reduction of 85 % wood harvesting jobs.
Jobs from crab catching in public RFs and NP mangroves	Estimated	Gradually reduced due to decrease of access to public mangrove (CFUGs increase)
Unregulated jobs from fuelwood collection in public RFs and NP mangroves	Estimated	Reduced due to decrease of open access public mangrove (CFUGs increase) and improved law enforcement, 85 % in 3 years and then a decrease of 100 jobs annually
Biomass for carbon sequestration	50 % of biomass growth	Assumption: 50 % of biomass growth is for fuelwood and 50 % is for carbon sequestration – remaining in the stand
Jobs from crab catching in public RFs and NP mangroves	Estimated	Reduced due to decrease of access to public mangrove (CFUGs increase)

(Continued on next

Table 15 (continued)

Parameter	Value	Source
Scenario 2 MRRP + VW/CFUG (balanced between CFUG and VWs)		
Agriculture and other non-mangrove habitat	79,646 ha	Assumption: unchanged
Annual increase in healthy mangrove	1,500 ha	Assumption: law enforcement improved and changed forest management plan contribute to increase in healthy mangrove areas
Annual increase in mangrove plantation	1,500 ha	Actual planting target is 1,820 ha but estimated about 1,500 ha will reach canopy closed plantations and will not be further degraded
Shrub, grass and bare saline land reduced yearly	3,000 ha	Due to new planting, improved law enforcement and improved forest management plan
Increase in young rehabilitated mangroves (in ponds or outside ponds)	500 ha	Increased due to improved law enforcement and new planting
Common mangrove areas lost for public crab catching and fuelwood collection due to allocation to CF user groups	Estimated	Estimated from increase in CFUGs area
CFUG area increased annually to 2026	1,460 ha	Increase of 1,460 ha of CFUG annually to 2026 to reach about 25 % of RFs area. Total CFUGs and VWs area will be 50 % of RF area by 2026
Increase in village's common woodlot (VW) annually	2,273 ha	Increase 2,273 ha of VWs annually to 2026 to reach 25 % of RFs area. Total CFUGs and VWs area will be 50 % of RF area by 2026
Capacity building (training and development of pilot projects)	2 times of BAU	Significant increase of capacity building is needed for the success of community of forestry
Law enforcement force strengthened	1.5 times of BAU	50 % of RF allocated to CFUGs and VWs and these communities manage/protect their mangroves by themselves. Thus, investment in law enforcement is lower than Scenario 1.
Biomass for carbon sequestration	50 % of biomass growth	Assumption: 50 % of biomass growth is for fuelwood and 50 % is for carbon sequestration – remaining in the stand
Jobs from crab catching in public RFs and NP mangroves	Estimated	Reduced due to decrease of public access mangrove (CFUGs increase)
Unregulated jobs from fuelwood collection in public RFs and NP mangroves	Estimated	Reduced due to decrease of public access mangrove (CFUGs increase) and improved law enforcement.
Aquaculture pond increased productivity (shrimp and crabs)	40 %	Introduced best practices: e.g. gates; removed unwanted species
Aquaculture pond fish income	Almost zero	Removed unwanted fish species to improve shrimp and crab productivity
Scenario 3 Enhanced MRRP + CFUG		
Agriculture and other non-mangrove habitat	79,646 ha	Assumption: unchanged
Annual increase in healthy mangrove	1,500 ha	Assumption: law enforcement improvement and changed forest management plan contribute to increase in healthy mangrove areas
Annual increase in mangrove plantation	1,500 ha	Actual planting target is 1,820 ha but estimated about 1,500 ha will reach closed canopy plantations and won't be further degraded

(Continued on next

Table 15 (continued)

Parameter	Value	Source
Scenario 3 Enhanced MRRP + CFUG		
Annual reduction in shrub, grass and bare saline land	3,000 ha	Due to new planting, improved law enforcement and improved forest management plan
Annual increase in young rehabilitated mangroves (in ponds or outside ponds)	500 ha	Increased due to law enforcement
Annual increase in area allocated to CFUGs	3,733 ha	To reach target of 50 % of mangroves allocated to VWs and CFUGs by 2026
Annual increase in village's common woodlot (VW)	0 ha	Area remains 2,200 ha (the same as 2019)
Common mangrove areas lost for public crab catching and fuelwood collection due to allocation to CFUGs	Estimated	Estimated from CFUGs area increase
Capacity building (training and development of pilot projects)	2 times of BAU	Significant increase of capacity building is needed for the success of community forestry
Law enforcement force strengthening	1.5 times of BAU	50 % of RF is allocated to CFUGs and VWs and these communities manage/protect their own mangroves. Thus, investment in law enforcement is lower than Scenario 1.
Biomass for carbon sequestration	50 % of biomass growth	Assumption: 50 % of biomass growth is for fuelwood and 50 % is for carbon sequestration – remaining in the stand
Number of jobs from crab catching in public RFs and NP mangroves	Estimated	Reduced due to decrease of open access public mangrove (CFUGs increase)
Number of unregulated jobs from fuelwood collection in public RFs and NP mangroves	Estimated	Reduced due to decrease of open access public mangrove (CFUGs increase) and improved law enforcement
Increase in aquaculture pond productivity (shrimp and crabs)	40 %	Introduced best practices: e.g. gates; removed unwanted species
Aquaculture pond fish income	Almost zero	Removed unwanted fish species to improve shrimp and crab productivity
Scenario 4 Enhanced MRRP + VW		
Agriculture and other non-mangrove habitat	79,646 ha	Assumption: unchanged
Annual increase in healthy mangrove	1,500 ha	Assumption: law enforcement improvement and forest management plan change contribute to increase healthy mangrove areas
Annual increase in mangrove plantation	1,500 ha	Actual planting target is 1,820 ha but estimated about 1,500 ha will reach the stage of closed canopy plantations and won't be further degraded
Annual reduction in shrub, grass and bare saline land	3,000 ha	Due to new planting, improved law enforcement and improved forest management plan
Other young rehabilitation mangroves (in ponds or outside ponds)	500 ha	Increased due to law enforcement
Annual increase in area allocated to CF user groups (CFUG)	0	CFUG remain the same (about 11 % - 7,895 hectares of RFs area)
Annual increase in village's common woodlot (VW)	3,720 ha	To reach target 50 % of mangroves allocated VW and CFUG by 2026

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Table 15 (continued)

Parameter	Value	Source
Scenario 4 Enhanced MRRP + VW		
Common mangrove areas lost for public crab catching and fuelwood collection due to allocation to CFUGs	Estimated	Estimated from CFUGs area increase
Capacity building (training and development of pilot projects)	2 times of BAU	Significant increase of capacity building is needed for the success of community forestry
Law enforcement force strengthening	1.5 times of BAU	50 % of RF is allocated to CFUGs and VWs and these communities manage/protect their own mangroves. Thus, investment in law enforcement is lower than Scenario 1.
Biomass for carbon sequestration	50 % of biomass growth	Assumption: 50 % of biomass growth is for fuelwood and 50 % is for carbon sequestration – remaining in the stand
Number of jobs from crab catching in public RFs and NP mangroves	Estimated	Reduced due to decrease of public access mangrove (CFUGs increase)
Number of unregulated jobs from fuelwood collection in public RFs and NP mangroves	Estimated	Reduced due to decrease of public access mangrove (CFUGs increase) and improved law enforcement
Increase in aquaculture pond productivity (shrimp and crabs)	40 %	Introduced best practices: e.g. gates; removed unwanted species
Income from aquaculture of fish	Estimated as zero	Removed unwanted fish species for improving shrimp and crab productivity

Table 16.
Results of the Return on Investment Analysis for different intervention scenarios to 2026 following the 3Returns Framework.

Relevant Actions	BAU	Scenario 1 MRRP+	Scenario 2 MRRP+CFUG/VW	Scenario 3 MRRP+CFUG	Scenario 4 MRRP+VW
Aquaculture	Remain in the same condition	Remain in the same condition	Production techniques improved	Production techniques improved	Production techniques improved
Rice	Remain in the same condition	Remain in the same condition	Remain in the same condition	Remain in the same condition	Remain in the same condition
Community Forest User Group (CFUG)	Rate as current practice	Rate as planned by national MRRP plan	25 % to 2026	47 % to 2026	11 % to 2026
Village common woodlot (VW)	Rate as current practice	Rate as planned by national MRRP plan	25 % to 2026	3% to 2026	39 % to 2026
Community Forest Management Plan	Thinning 2 years and clear cutting	Thinning 3-5 years, no clear cutting	Thinning 5 years, no clear cutting, and keepingv (300) maternal trees	Thinning 5 years, no clear cutting, and keeping (300) maternal trees	Thinning 5 years, no clear cutting, and keeping (300) maternal trees
Law Enforcement	Law enforcement remains the same	Improved enforcement to reduce illegal logging	Forest managements is enforced to increase the area of CF	Forest managements is enforced to increase the area of CF	Forest managements is enforced to increase the area of CF
Restoration effort	300 hectares of successful mangrove plantations annually	1000 ha of successful mangrove rehabilitation under implementation target (under MRRP plan)	1500 ha of successful mangrove rehabilitation under implementation target	1500 ha of successful mangrove rehabilitation under implementation target	1500 ha of successful mangrove rehabilitation under implementation target

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Table 16 (continued)

Relevant Actions	BAU	Scenario 1 MRRP+	Scenario 2 MRRP+CFUG/VW	Scenario 3 MRRP+CFUG	Scenario 4 MRRP+VW
Benefit (monetary) - millions MMK in Present Value (PV)					
Value of fuelwood cutting in open public mangrove	153,035	72,036	72,036	72,036	72,036
Value of fuelwood cutting from village common woodlots	10,970	15,241	32,243	7,846	47,774
Value of aquaculture	82,907	82,907	144,611	225,023	93,840
Value of fuelwood cut in mangrove aquaculture ponds	29,347	29,593	43,827	68,224	28,423
Value of clear-cutting surplus plantation area	0	0	0	0	0
Value of free-open fishing in public mangroves	430,965	444,065	423,261	387,605	445,775
Value of agriculture (rice production)	142,961	142,961	142,961	142,961	142,961
Value of biomass carbon sequestration	5,706	16,391	18,111	18,111	18,111
Value of coastal protection	81,851	137,806	170,721	170,721	170,721

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Table 16 (continued)

Relevant Actions	BAU	Scenario 1 MRRP+	Scenario 2 MRRP+CFUG/VW	Scenario 3 MRRP+CFUG	Scenario 4 MRRP+VW
Operational expenditure (OPEX) - millions MMK in PV					
Forest Department staff operational expenditure	1,979	4,983	2,805	2,805	2,805
Mangrove aquaculture pond operational costs	53,024	53,007	78,898	123,244	50,893
Rice cultivation operational costs	79,742	79,742	79,742	79,742	79,742
Open mangrove fuelwood collection costs	97,227	45,176	45,176	45,176	45,176
Fuelwood collection labour costs for village woodlots (PV)	6,786	9,459	20,102	4,830	29,824
Fuelwood collection costs for mangrove ponds	18,080	18,232	27,143	42,415	17,498
Open fishing labour costs	247,887	255,553	243,377	222,508	256,556
Other operational expenditures *(carbon marketing)*	285	820	906	906	906
Capital expenditure (CAPEX) - millions MMK in PV					
Mangrove restoration by planting **NC**	18,639	30,020	30,020	30,020	30,020
Capacity buildig (CF & forestry staff) **S&HC**	907	1,347	1,814	1,814	1,814
Mangrove pond establishment costs **FC**	1,006	1,006	9,322	23,576	0
Concrete gates for improving aquaculture **FC**	0	0	26,155	46,416	9,539
Financial Indicators					
PV Total Benefits	937,741	941,000	1,047,771	1,092,526	1,019,641
PV Operational Expenditures	505,010	466,972	498,148	521,625	483,400
PV Capital Expenditures	20,552	32,373	67,312	101,827	41,374
NPV	412,179	441,655	482,311	469,074	494,867
BCR	1.78	1.88	1.85	1.75	1.94
ROI	21.06	14.64	8.17	5.61	12.96

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Table 16 (continued)

Relevant Actions	BAU	Scenario 1 MRRP+	Scenario 2 MRRP+CFUG/VW	Scenario 3 MRRP+CFUG	Scenario 4 MRRP+VW
NPV in million USD					
PV Total Benefits (million USD)	625	627	699	728	680
PV Operational Expenditures (million USD)	337	311	332	348	322
PV Capital Expenditures (million USD)	14	22	45	68	28
NPV (million USD)	275	294	322	313	330
Non-monetary benefits					
Cumulative biomass carbon sequestration (after deduction of fuelwood cutting)	573,586	1,682,620	1,883,445	1,883,445	1,883,445
Green jobs maintained	30,898	39,912	44,569	41,407	46,582
Total number of jobs from livelihoods and restoration activities within RFs and NP maintained	65,008	58,308	62,965	59,803	64,978
CF tree species diversity (Shannon Index)	0.195	0.588	0.588	0.588	0.588
Capitals' Status					
Natural Capital - good mangrove areas (natural mangroves and plantations which have stocking > 2,000 trees per hectare and tree volume > 50 m3 per hectare)	8,670	20,570	27,570	27,570	27,570
Social & Human Capital - people involved in community forestry and capacity building	11,818	15,958	38,656	23,987	48,618
Financial Capital - ponds and concrete gates (millions MMK in PV)	1,006	1,006	35,447	69,992	9,539

Table 16 summarizes the results of the Return on Investment analysis for different intervention scenarios to 2026 following the 3Returns Framework, which is the date the current MRRP program of the Myanmar Government finishes. In general, improved and decentralized mangrove management increases the total net present value (NPV) of resources in the landscape within Reserve Forests and National Parks in the delta. Values between 2019 to 2026 increase from 275 million USD in the Business as Usual scenario to 329 million USD for Scenario 4, which allocates most of CF mangroves to villages as village woodlots and included enhanced CF management and production. Highly decentralized mangrove management would provide 1.2 times the monetized returns from mangrove resources compared to the BAU scenario by 2026, with even greater returns evident over longer time frames.

Allocation of a larger area of mangroves for CFUGs, as has been practiced in Myanmar for the last two decades, would contribute to improve livelihoods of families in the region. However, increases in the CFUGs areas would be at the expense of jobs and livelihoods of many other landless people who collect crabs from the mangrove. Thus, we strongly suggest that the Myanmar Government and investors should support community forestry in village woodlots where all community members are permitted to catch crabs under the current fishery regulations.

Our analysis finds that the mangroves in RFs and NP in the three townships provide jobs for several tens of thousands of landless people in the delta. We estimate that over 200,000 people's livelihoods depend significantly on mangrove resources. All in all, mangrove natural resources and financial investments provide over 60 thousands jobs for people in the delta. Currently, most of the jobs are from harvesting natural mangrove resources such as crab catching and fuelwood collection. Many current jobs are not sustainable or environmentally friendly because they lead to over exploitation of the natural resources. Intensive and frequent unplanned logging and crab catching under weak law enforcement has resulted in deforestation and degradation of natural resources in mangrove areas in the delta. Our analysis indicates that more investment in community forestry, especially developing village woodlots and capacity building, would result in a higher proportion of green jobs[9] associated with mangrove resources. Green jobs[9] from sustainable crab catching, fuelwood cutting from CF village woodlots, and mangrove restoration increase from about 31,000 in the BAU scenario to about 46,500 jobs in the Scenario 4 (MRRP+VW) by 2026.

Other essential indicators of Green Growth Investment are improved under green investment scenarios (Scenarios 2 – 4). The areas of healthy mangroves and plantations (natural capital), increased from only about 9,000 hectares (mainly plantations) in the BAU to over 27,500 hectares in the intervention scenarios 2, 3 and 4. Cumulative carbon sequestration in mangroves in 8 years, 2019 - 2026, which accounts for half of total biomass growth of mangroves in the delta, increased from just over 573,000 Mg CO2 in BAU to over 1,883,000 Mg CO2 in Scenario 4. Additionally, species biodiversity of CF mangroves, reported as the Shannon index, increased from 0.195 to 0.588, if CFUG pond owners and village woodlot managers keep at least 300 maternal trees of 3 different species on their land.

[9] A job to be classified as 'Green Job' requires meeting the ***decent job*** criteria. Decent working should include one or more of the following: (a) adequate monthly wage, (b) work stability and security, (c) occupational hazard level involved, (d) decent working hours, and (e) availability of social protection scheme (e.g. social security). Work that uses child labor and bounded labor do not qualify for decent work. Example sectoral areas in AFOLU that have large green employment creation potential include the following: Sustainable forestry activities – tree plantation, forest certification, national voluntary certification; sustainable production practices – organic agriculture, bee-keeping, climate smart agricultural practices; sustainable tourism – ecotourism. (GGGI, 2020).

We also conducted analyses of the different scenarios over longer time scales, although uncertainties are high with such projections. Table 17 summarizes the key results of all scenarios to 2079 (60 years from data collection and analyses in 2019). The modelling results reveal that green capital investments have significantly higher impacts on the NPV, natural capital, social & human capital, cumulative biomass carbon sequestration, number of jobs and number of green jobs (Table 17). In the longer term the return of investment (ROI) of green investment scenarios increased over time while the Business as Usual's ROI declines. Our analysis suggests that conventional and current BAU practice is not sustainable as it reflects a decrease in benefits when there is limited reinvestment or replenishment of capitals. (Figure 12 and Figure 13). After 50 years (by 2069), the ROI of Scenario 4 exceeds the ROI of BAU.

Table 17.
Key results of financial analyses and other outputs of different scenarios in selected years to 2079

Financial Analysis	2026					2039					2069					2079				
	BAU	Scen*.1 + MRRP+	Scen. 2 MRRP+ CFUG/ VW	Scen. 3 MRRP+ CFUG	Scen. 4 MRRP+ VW	BAU	Scen.1 + MRRP+	Scen. 2 MRRP+ CFUG/ VW	Scen. 3 MRRP+ CFUG	Scen. 4 MRRP+ VW	BAU	Scen.1 + MRRP+	Scen. 2 MRRP+ CFUG/ VW	Scen. 3 MRRP+ CFUG	Scen. 4 MRRP+ VW	BAU	Scen.1 + MRRP+	Scen. 2 MRRP+ CFUG/ VW	Scen. 3 MRRP+ CFUG	Scen. 4 MRRP+ VW
BCR	1.78	1.88	1.85	1.75	1.94	1.74	1.97	2.04	1.96	2.11	1.70	2.05	2.27	2.17	2.35	1.70	2.05	2.27	2.18	2.35
ROI	21.06	14.64	8.17	5.61	12.96	19.61	15.96	12.05	9.08	16.35	18.50	17.14	15.17	11.74	19.94	18.42	17.23	15.35	11.82	20.04
PV Total Benefits (million USD)	625	627	699	728	680	1,011	1,101	1,285	1,358	1,239	1,161	1,351	1,681	1,771	1,625	1,167	1,365	1,698	1,788	1,641
PV Operational Expenditures (million USD)	336.7	311.3	332.1	347.8	322.3	559.0	521.3	569.6	609.8	544.2	655.6	617.3	675.3	726.6	642.7	659.9	621.9	680.3	732.2	647.4
PV Capital Expenditures (million USD)	13.7	21.6	44.9	67.9	27.6	23.1	36.3	59.4	82.4	42.5	27.3	42.8	66.3	89.0	49.2	27.5	43.1	66.3	89.3	49.6
Total NPV (million USD)	274.8	294.4	321.5	312.7	329.9	429.4	543.3	656.3	666.1	652.4	478.3	691.0	939.9	955.5	932.7	479.4	700.0	951.3	966.7	943.7
Other outputs																				
Social & Human Capital	11,818	15,958	38,656	23,987	48,618	11,818	15,958	38,656	23,987	49,658	26,178	33,078	38,656	23,987	52,858	26,178	33,078	38,656	23,987	52,858
Natural capital - Healthy mangrove	8,670	20,570	27,570	27,570	27,570	12,570	46,570	66,570	66,570	66,570	24,570	81,000	81,500	81,500	81,500	24,570	81,000	81,500	81,500	81,500
Cumulative biomass carbon sequestration **(thousand Mg)**	574	1,683	1,883	1,883	1,883	1,614	6,103	7,170	7,170	7,170	5,601	32,874	35,365	35,365	35,365	5,601	32,874	35,365	35,365	35,365
Green jobs	30,898	39,912	44,569	41,407	46,582	30,898	39,912	44,569	41,407	46,582	17,416	52,744	59,569	56,407	61,582	17,416	52,744	59,569	56,407	61,582
Total number of jobs	65,008	58,308	62,965	59,803	64,978	65,008	58,308	61,665	58,503	63,678	53,606	68,441	75,265	72,103	77,278	53,606	68,441	75,265	72,103	77,278

*Scen.: Scenario

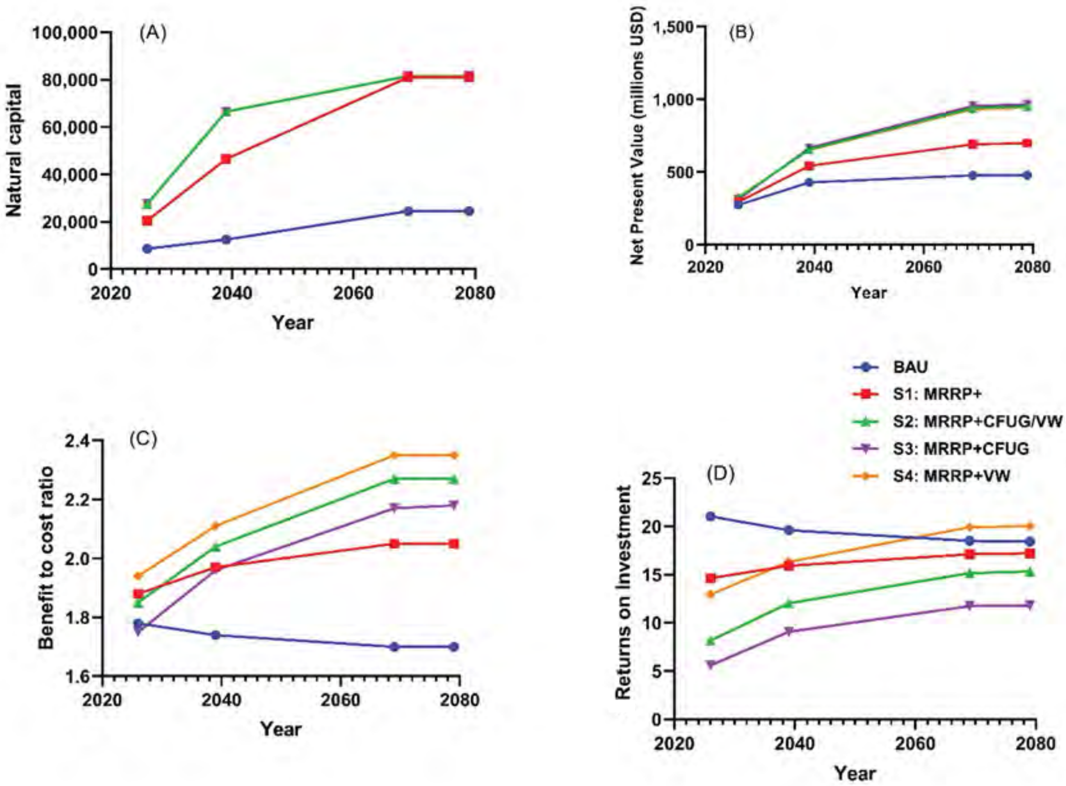

Figure 12.
Changes of key financial indicators of different Green Investment Scenarios over time. (A) Changes in Natural Capital; (B) Changes in NPV; (C) Benefit to Cost Ratio; and (D) Return on Investment (ROI - Ratio – dimensionless). Similar Natural Capital and NPV between three Scenarios 2, 3 and 4 because of similar changes in mangrove resources

Allocation of a greater area of mangroves for local communities, especially as village woodlots, significantly increases the social & human capital of coastal communities in RFs and NP in the delta. While the total number of jobs in all scenarios is similar to the BAU, the proportion of green jobs is much higher in Scenarios 2-4 (70-80% of all jobs). The number of local people participating in community forestry and capacity building increases from about 14,000 people in the BAU to over 71,000 people in highly decentralized forest management scenario by 2079 (Figure 13).

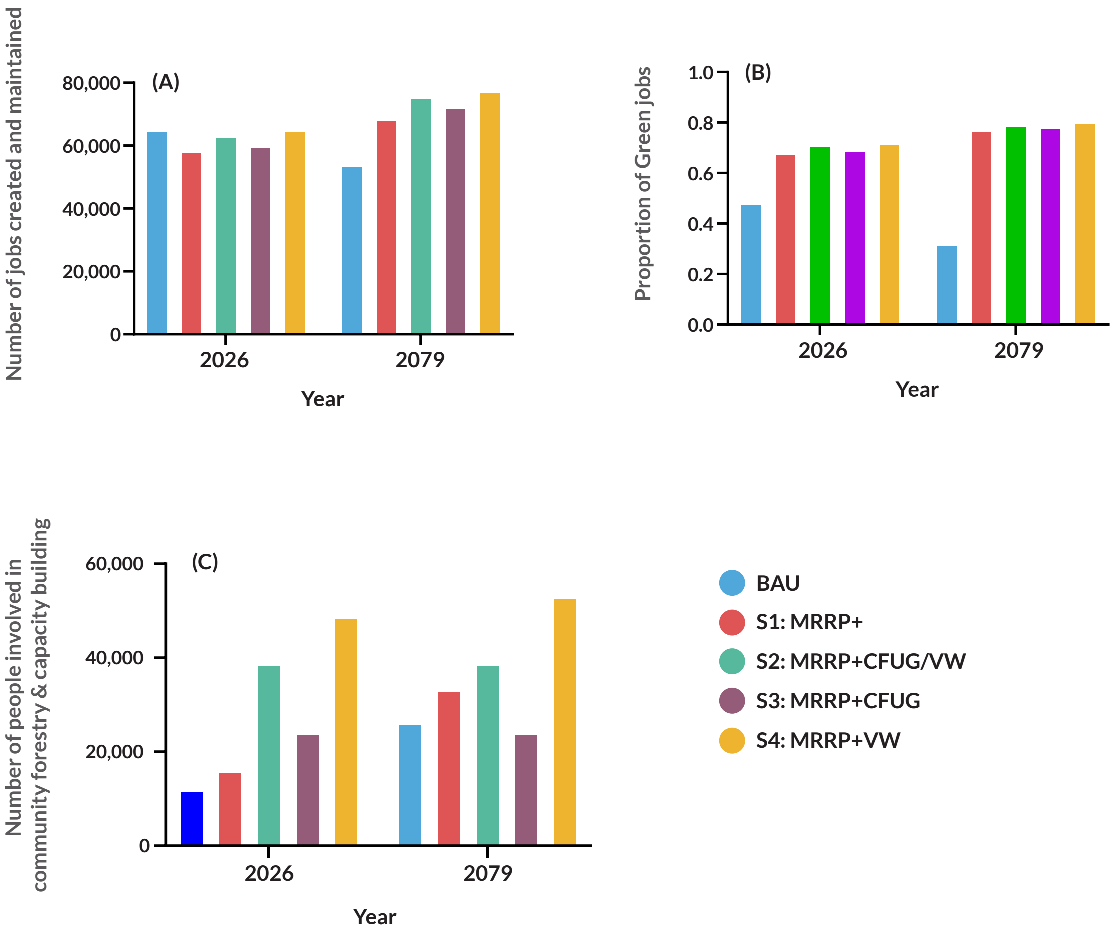

Figure 13.
The number of jobs created in 2026 and 2079 in a range of management scenarios (A) and the proportion of green jobs (B). The figure (C) shows the number of people involved in community forestry and capacity building in the BAU and other modelled scenarios in 2026 and 2079. Due to increase of CFUGs and VWs areas in the BAU by 2079 the number of people involved in community forestry increases

8.3 Sea level rises and climate change impacts

In the financial analyses of different scenarios, the impact of saline water intrusion and climate events on rice productivity was applied as an annual decline in productivity of 0.4 %. Further sea level rise scenarios that considered the impact of coastal squeeze were analysed which included a high coastal squeeze – low adaptation scenario where a loss of -0.29 % mangrove area per year was used and Low coastal squeeze – high adaptation scenario where the mangrove area increased by 0.54 % per year.

Table 18.
Analyses of the influence of coastal squeeze with sea level rise on Returns on Investment in BAU and alternative scenarios following the 3Returns Framework.

Financial Analysis	Results in 2079 - no influence of SLR					Results in 2079 - High Coastal Squeeze,-0.29%					Results in 2079 - Low Coastal Squeeze, 0.54%				
	BAU	Scen*.1 + MRRP+	Scen. 2 MRRP+C FUG/VW	Scen. 3 MRRP+C FUG	Scen. 4 MRRP+V W	BAU	Scen.1 + MRRP+	Scen. 2 MRRP+C FUG/VW	Scen. 3 MRRP+C FUG	Scen. 4 MRRP+V W	BAU	Scen.1 + MRRP+	Scen. 2 MRRP+C FUG/VW	Scen. 3 MRRP+C FUG	Scen. 4 MRRP+V W
BCR	1.70	2.05	2.27	2.18	2.35	1.69	2.10	2.35	2.25	2.43	1.71	2.05	2.27	2.17	2.35
ROI	18.42	17.23	15.35	11.82	20.04	18.05	17.6	15.98	12.28	20.78	19.11	17.70	15.67	12.08	20.46
PV Total Benefits (million USD)	1,167	1,365	1,698	1,788	1,641	1,150	1,374	1,729	1,816	1,667	1,199	1,406	1,741	1,836	1,681
PV Operational Expenditures (million USD)	660	622	680	732	647	653	612	669	719	638	673	642	702	757	667
PV Capital Expenditures (million USD)	28	43	66	89	50	28	43	66	89	50	28	43	66	89	50
Total NPV (million USD)	479	700	951	967	944	469	719	993	1,008	980	498	721	973	990	964
Other outputs															
Social & Human Capital	26,178	33,978	38,656	23,987	52,858	26,178	33,078	38,656	23,987	52,858	26,178	33,078	38,656	23,987	52,858
Natural capital - Healthy mangrove	24,570	81,000	81,500	81,500	81,500	24,570	65,000	65,500	65,500	65,500	24,570	81,000	81,500	81,500	81,500
Cumulative biomass carbon sequestration **(thousand Mg)**	5,601	32,874	35,365	35,365	35,365	5,236	28,734	30,321	30,321	30,327	5,971	34,089	37,067	37,067	37,067
Green jobs	17,416	52,744	59,569	56,407	61,582	13,869	46,273	52,485	48,052	55,306	25,077	64,210	71,747	70,062	72,820
Total number of jobs	53,606	68,441	75,265	72,103	77,278	52,600	65,686	71,898	67,465	74,720	55,691	75,156	82,693	81,007	83,766

**Scen.: Scenario*

Results in Table 18 reveal that coastal squeeze scenarios with sea level rise have significant impacts on rice cultivation jobs due to reduction in the productivity and area of rice fields. Nearly 5,000 jobs are gained in the low coastal squeeze scenario while over 8,000 jobs are lost in the highest coastal squeeze scenario. However, the loss of agricultural jobs was compensated by jobs created from increase mangrove habitat, associated with fishing and fuelwood collection in public access mangroves. Overall, sea level rises had linear impacts on the area of mangrove habitats as well as environmental and social & human returns on green investments (Table 17). Overall, the impacts of coastal squeeze as a consequence of sea level rise are likely to be more complex and interact with other factors (climate, storms, land-use) than modelled here. SLR with low coastal squeeze may increase mangrove habitat, but acceleration of coast erosion could also occur which could result in a decrease of coastal land. Further analyses should be conducted to estimate SLR's impacts on mangroves and associated land uses and communities in the delta.

8.4 Policy implications for Green Growth Investment

Landlessness of a large proportion of the population is a major problem for socioeconomic sustainable development in the delta. Thus, allocation of mangroves to communities for restoration and sustainable utilization is a win-win solution for Government and local people. However, despite the success of many CFUGs, particularly where the CF farmers have sufficient resources to invest into their mangrove aquaculture ponds, many CF user groups are not successfully managing their forests to achieve significant livelihood benefits from their CF mangroves. We conducted a matrix analysis (Table 18) to identify the main barriers to achieving improved mangrove management in the delta and how to enable green growth investment for mangrove restoration and community livelihood improvement in the delta. The table emphasizes a range of policy and institutional characteristics that could be considered.

Table 19.
Policy barriers and enablers matrix for green growth development.

	Key Issues	Proposed Policy Intervention	Expected Outcome
Policy for communities	Unclear land use right for village woodlots (VW) and community forestry user groups (CFUGs)	Properly land use rights for VW and CFUGs	Land use rights enable land deposit for loans, Inheritance and transfer rights for long term and sustainable investment on CFUGs farm activities
	Investment needed for mangrove restoration and economic activities associated with mangroves	Increase and diversion of public investments, particularly from ODA and impact investors to CF activities	Continuous and sufficient investments for CF activities to increase quality in livelihoods for landless people and mangrove rehabilitation
Policy for government	Mangrove resources improved in quantity and quality; sustainable management of CF mangroves	Clear and high-quality mapping and zoning of mangroves for management and monitoring purposes	By decentralizing mangrove resources and management to communities, the government does not have to invest more resources to achieve mangrove rehabilitation and management targets
	Effective management of mangrove		
	Improve livelihoods for mangrove CF communities	Diversion of budget for development of community forestry	
	Include ecosystem services and 3Returns assessment of mangrove resources to develop government policy	Support to develop green growth policies	Government has solid foundation for development of green growth policies

Table 19 (continued)

	Key Issues	Proposed Policy Intervention	Expected Outcome
Policy for impact investor	Regulatory issues	Payment for ecosystem services (PES); benefit sharing between multi stakeholders in the Reserve Forests	Clearer expected outputs for finance and impacts from investment projects
	Business/ Financial Risks: Uncertainty in prices of ecosystem services	Government could secure buyer(s) for ecosystem services and could set up a national mechanism for paying for essential services	Reduce risks

8.5 Sharing the project outcomes

The outcomes of this research were shared with stakeholders for validation of the project outcomes (the Return on Investment provided by mangrove restoration at scale) to support policy development and to inform public and private investment in mangrove restoration projects. During 2019 and 2020, GGGI and UQ held several meetings with relevant Myanmar Government authorities, NGOs and CSOs (civil society organizations) in Myanmar to share information and for validation of scenarios and data.

09

Conclusion and way forward

Mangroves in the Delta provide vital livelihoods derived from the natural resources of the mangroves for thousands of landless people. Over 70% of people within mangrove Reserve Forest areas and buffer zones are landless; therefore, any mangrove management strategy and planning need to prioritize consideration of this issue when developing policy. Our green investment scenarios indicate that decentralized mangrove management and increased investment in community common woodlots, which still allow landless people to harvest non-timber forest products, achieve higher livelihoods, equality for the poor and landless people in the delta compared to other investment and management scenarios.

One of the major difficulties for management of mangrove forests and adjacent other land uses in Myanmar is the inadequate mapping and GIS system. Disputes between different land users and management authorities due to unreliable maps and records have occurred. The Forest Department and investors should invest resources in land zoning, demarcation and mapping to create a transparent, suitable and reliable database for long term mangrove restoration, management and livelihood development in the delta.

People in remote rural coastal areas in the delta are very poor and do not have enough capital to invest in economic activities. Although some communities or CF user groups were allocated CF mangroves, the managers were not able to access formal loans due to the ineligible status of their ownership and use rights. The Government could identify policy measures to improve this situation and thereby allow farmers to access fairly priced and formal loans from the banks for their livelihood activities on CF mangroves rather than informal, highly expensive loans, which are currently their only option.

Our community mangrove study indicated that significant CF areas have not been successfully managed. Their mangroves were not improved. The main reason for failure is that the communities lack capacity to conduct CF activities. Capacity building and continuous support from the Government, NGOs and other investors is essential for the success of CF forests. Most of current CF areas have little support after CF certificates are granted to the communities.

Currently, mangrove aquaculture is a lucrative farming practice for CF pond owners due to its utilization of natural capital from mangrove resources. However, mangrove aquaculture in the delta has low productivity, and is volatile due to dependency on wild caught larvae. Additionally, advanced mangrove aquaculture techniques such as the use of concrete gate, fish stock management, control of pond water quality and diseases, which have been developed in neighbouring countries (e.g. Bangladesh, Thailand and Vietnam), are still not widely used in Myanmar. An aquaculture extension system and investment in best practices for sustainable forms of aquaculture that are compatible with high mangrove cover are needed for improving this important income-generating activity.

Expanding commercially viable, high productivity and profitable forms of agriculture and fisheries (including processing) is needed to develop the agriculture and fishery sectors. The Government could prepare clear sector planning for land uses in mangrove regions to accommodate development in the delta. Long term, clear and transparent zoning for semi-intensive and extensive aquaculture could contribute to reduce intrusion of aquaculture into mangrove areas and their conversion, as has occurred in other deltas of the world, which has led to environmental degradation and vulnerability to climate change (Ahmed, 2013; Giosan, 2014).

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Annex 1. Community forest certificates in the Myaungmya Forestry District

The Community Forestry Certificates issued list of Forest Department Myaungmya District										
No.	Township	Village	Location		Community Forestry			No. Of Member	Chairman Name	Date of Issue
			RF	Compartment	Permit area	Plantation acre	Total			
1	Myaungmya	Phayangatto Shansu	kyaukkone	1	50.0	50.0	50.0	5.0	U Soe Win	10/06/2001
2	Myaungmya	Phayakone	kyaukkone	1	2.8	2.8	2.8	6.0	U Than hlaing	31-12-2015
3	Myaungmya	Phayangatto	kyaukkone	1,2	5.4	5.4	5.4	5.0	U Than Myint	13-6-2016
4	Myaungmya	Bayakone	kyaukkone	1	19.2	5.1	19.2	15.0	U Kan Myint	26-4-2016
5	Myaungmya	Maytadar	kyaukkone	2	24.2	24.2	24.2	27.0	U Myint Than	7/03/2017
6	Myaungmya	Maytadar	kyaukkone	1	4.8	4.8	4.8	5.0	U Myo Aung	7/03/2017
7	Myaungmya	Maytadar	kyaukkone	2	9.0	9.0	9.0	7.0	U Tin Win	7/03/2017
8	Myaungmya	Phayangatto	kyaukkone	1,2	14.7	14.7	14.7	24.0	U Mg Mg Aung	8/12/2018
9	Myaungmya	Mokesokwin	kyaukkone	1,2	8.6	8.6	8.6	20.0	U Htun Oo	8/12/2018
10	Myaungmya	Konethar	kyaukkone	1,2	17.8	17.8	17.8	34.0	U Htun Oo	8/12/2018
	Myaungmya Township Total				**156.3**	**142.3**	**156.3**	**148.0**		
11	Bogalay	Shwepyithar	Pyindaye	8,9	50.0	50.0	50.0	106.0	U Than Soe	24-9-2012
12	Bogalay	Mingalar yaekyaw	Pyindaye	5	20.0	20.0	20.0	7.0	U Myint Sein	7/06/2017
13	Bogalay	Htawpaing	outside RF	-	15.0	15.0	15.0	10.0	U Thaung Aye	8/09/2018
	Bogalay Township Total				**85.0**	**85.0**	**85.0**	**123.0**		
14	Labbutta	Byankgyikone	Pyinalan	76	506.0	506.0	5,006.0	98.0	U Tar Balar Htoo	17-8-1998
15	Labbutta	Yaetwinchaung	Pyinalan	75,76	375.7	375.7	375.7	83.0	U Maung Shwe	17-8-1998
16	Labbutta	Kwinpauk	Pyinalan	64	155.0	155.0	155.0	14.0	U Aung Chit	21-4-2001
17	Labbutta	Kwinpauk	Pyinalan	64	170.0	170.0	170.0	14.0	U Aung Chit	2/05/2002
18	Labbutta	Kaingthaung	Pyinalan	77	290.0	290.0	290.0	58.0	U Kyin Thaung	2/05/2002
19	Labbutta	Painnaekone	Pyinalan	70	780.0	780.0	780.0	156.0	U Than Htay	4/05/2002
20	Labbutta	Tharyakone	Pyinalan	75,57	1,051.0	1,051.0	1,051.0	59.0	U Saw Htoosay	31-7-2012
21	Labbutta	Nyaungtapin	Pyinalan	57,58	693.0	693.0	693.0	68.0	U Myint Soe	31-7-2012
22	Labbutta	Kwakwalay	Kyakankwinpauk	22,26	202.0	202.0	202.0	39.0	U Sein Aung	31-7-2012
23	Labbutta	Ayataw	Pyinalan	50	190.0	190.0	190.0	22.0	U San Min	6/06/2014
24	Labbutta	Yaetwinseik	Pyinalan	50	100.0	100.0	100.0	17.0	U Kyi Soe	6/06/2014
25	Labbutta	Alaechaung	Pyinalan	52	100.0	100.0	100.0	23.0	U Thaung Ye	6/06/2014
26	Labbutta	Kanchaung	Pyinalan	50	100.0	100.0	100.0	22.0	U Myo Win	6/06/2014
27	Labbutta	Taungyargyisu	Laepyauk	11,14	54.0	54.0	54.0	7.0	U Aung Win	30-8-2018
	Total of Labutta Township				**4,766.6**	**4,766.6**	**9,266.6**	**680.0**		

Annex 1. Community forest certificates in the Myaungmya Forestry District

The Community Forestry Certificates issued list of Forest Department Myaungmya District										
No.	Township	Village	Location		Community Forestry			No. Of Member	Chairman Name	Date of Issue
			RF	Compartment	Permit area	Plantation acre	Total			
28	Pyapon	Kharchin	Pyindaye	57	150.0	150.0	150.0	20.0	U Khaing Win	16-2-2001
29	Pyapon	Okphokwinchaung	Pyindaye	49	175.0	175.0	175.0	33.0	U Tin Myint	16-2-2001
30	Pyapon	Kanyinkone	Pyindaye	56	400.0	400.0	400.0	71.0	U Sein Maung	16-2-2001
31	Pyapon	Kyaetae	Pyindaye	58	309.0	309.0	309.0	38.0	U Kyaw Win	16-2-2001
32	Pyapon	Mahmwekwin	Pyindaye	59	237.0	237.0	30.0	30.0	U Myint Kyi	16-2-2001
33	Pyapon	Warkone	Pyindaye	56	250.0	250.0	250.0	45.0	U Tin Aung	16-2-2001
34	Pyapon	Taepinseik	Pyindaye	56	150.0	150.0	150.0	18.0	U Tin San	16-2-2001
35	Pyapon	Ashaepya	Pyindaye	65	100.0	100.0	100.0	20.0	U Tin Yee	29-7-2013
36	Pyapon	Ashaepya	Pyindaye		160.0	160.0	160.0	25.0	U Than Shwe	29-7-2013
37	Pyapon	Htaunggyitan	Pyindaye	66	157.0	157.0	157.0	63.0	U Ba Myaing	29-7-2013
38	Pyapon	Gawdu	Pyindaye	64	50.0	50.0	50.0	83.0	U Mya Hlaing	29-7-2013
39	Pyapon	Htaunggyitan	Pyindaye	65	188.0	188.0	188.0	5.0	U Aung Myo Lwin	14-2-2015
40	Pyapon	Htaunggyitan	Pyindaye	65	157.0	157.0	157.0	6.0	U Thein Htun	14-2-2015
41	Pyapon	Htaunggyitan	Pyindaye	64	205.4	205.4	205.4	7.0	U San Win	14-2-2015
42	Pyapon	Thamainpalae	Pyindaye	64	218.8	218.8	218.8	6.0	U Myint Win	14-2-2015
43	Pyapon	Thamainpalae	Pyindaye	65	200.4	200.4	200.4	6.0	U Khin Soe	14-2-2015
44	Pyapon	Thamainpalae	Pyindaye	64	149.8	149.8	149.8	6.0	U Khin Chaw	14-2-2015
45	Pyapon	U Pe	Pyindaye	62,63	358.0	358.0	358.0	6.0	U Kyaw Khaing	14-2-2015
46	Pyapon	Ashaepya	Pyindaye	64,65	265.0	265.0	265.0	5.0	U Hla Myint	14-2-2015
47	Pyapon	Bawathit (3)	Pyindaye	55	400.0	400.0	400.0	58.0	U Thein Han	15-5-2017
48	Pyapon	Lay Pin Chaung	Pyindaye	52,53	110.0	110.0	110.0	22.0	U Kyaw Khaing	15-5-2017
49	Pyapon	Warkone	Pyindaye	56	100.0	100.0	100.0	20.0	U Soe Than	15-5-2017
50	Pyapon	Ashaemayan	Pyindaye	56	47.0	47.0	47.0	32.0	U Kan Myint	15-5-2017
51	Pyapon	kangyibaayekone	Pyindaye	54	800.0	800.0	800.0	34.0	U Hinnaye Hlaing	15-5-2017
52	Pyapon	Thamainpalae	Pyindaye	62,63,64	1,321.0	1,321.0	1,321.0	124.0	U Khin Mg Nyo	15-5-2017
53	Pyapon	Padaukpinseik	Pyindaye	55,61,,62	742.0	742.0	742.0	50.0	U Thein Shwe	15-5-2017
54	Pyapon	Bawathit (2)	Pyindaye	50,53,54	800.0	800.0	800.0	153.0	U Hla Naing	15-5-2017
55	Pyapon	U Pe	Pyindaye	61	810.0	810.0	810.0	49.0	U Min Thein	15-5-2017
56	Pyapon	Bobakone	Pyindaye	46,47	807.1	807.1	807.1	60.0	U Tin Shein	15-5-2017

Annex 1. Community forest certificates in the Myaungmya Forestry District

The Community Forestry Certificates issued list of Forest Department Myaungmya District										
No.	Township	Village	Location		Community Forestry			No. Of Member	Chairman Name	Date of Issue
			RF	Compartment	Permit area	Plantation acre	Total			
57	Pyapon	Aung kone	Pyindaye	52	169.6	169.6	169.6	27.0	U Maung Gyi	10/10/2017
58	Pyapon	Wapanar	Pyindaye	62	1,078.0	1,078.0	1,078.0	57.0	U Myint kyaw	10/10/2017
59	Pyapon	Phoe Htoo Taung Yar	Pyindaye	47	365.2	365.2	365.2	42.0	U hngawe Thein kyaw	10/10/2017
60	Pyapon	Tawtot	Pyindaye	47,48	134.4	134.4	134.4	15.0	U Than Htike Aung	10/10/2017
61	Pyapon	Ka Nyin kone	Pyindaye	56	356.7	356.7	356.7	17.0	U Lin Maung	24-10-2017
62	Pyapon	Anuckmayan	Pyindaye	49,50,55,56	543.0	543.0	543.0	68.0	U Myint Zaw	24-10-2017
63	Pyapon	Okpho	Pyindaye	31,31,48,49	282.0	282.0	282.0	28.0	U San Hlaing	24-10-2017
64	Pyapon	Kannakwin	Pyindaye	53,62	415.0	415.0	415.0	45.0	U San Aye	11/10/2017
65	Pyapon	Kyaetae	Pyindaye	58	344.0	344.0	344.0	45.0	U Than Naing	11/10/2017
66	Pyapon	Mahmwekwin	Pyindaye	59	251.0	251.0	251.0	58.0	U Thaw Tar Htun	11/10/2017
67	Pyapon	Htanpinkone	Pyindaye	60,61	183.0	183.0	183.0	35.0	U Hlaing Min Htun	11/10/2017
68	Pyapon	Nga Dan Sae	Pyindaye	59,61	218.0	218.0	218.0	39.0	U Kyaw Win Aung	11/10/2017
69	Pyapon	Bawathit (3)	Pyindaye	55,56	500.0	500.0	500.0	35.0	U Tin Win	30-6-2018
	Total of Pyapon Township				**14,657.4**	**14,657.4**	**14,450.4**	**1,606.0**		
	Total of Myaungmya District				**19,665.3**	**19,665.3**	**19,665.3**	**2,546.0**		

Annex 2. List of village tracks and population in mangrove reserve forests and their 10 km buffer zones

DT	DT_PCODE	TS	TS_PCODE	VT	houseH	Population
Pyapon	MMR017D006	Pyapon	MMR017023	Let Pan Pin	1087	4655
Pyapon	MMR017D006	Pyapon	MMR017023	Kyon Ka Dun	1682	7333
Pyapon	MMR017D006	Pyapon	MMR017023	Auk Ka Bar	507	2065
Pyapon	MMR017D006	Pyapon	MMR017023	Byaing Ka Hpee	421	1674
Pyapon	MMR017D006	Pyapon	MMR017023	Kyet Hpa Mway Zaung	935	3588
Pyapon	MMR017D006	Pyapon	MMR017023	Day Da Lu	5069	23165
Pyapon	MMR017D006	Pyapon	MMR017023	Daw Nyein	5682	26061
Pyapon	MMR017D006	Pyapon	MMR017023	Myo Kone	1420	6428
Pyapon	MMR017D006	Bogale	MMR017024	Ka Don Ka Ni	451	2117
Pyapon	MMR017D006	Pyapon	MMR017023	Ba Wa Thit	4950	22518
Pyapon	MMR017D006	Bogale	MMR017024	Aye Yar	2180	9126
Pyapon	MMR017D006	Pyapon	MMR017023	Tei Pin Seik	3915	17415
Pyapon	MMR017D006	Pyapon	MMR017023	Boe Ba Kone	792	3598
Pyapon	MMR017D006	Pyapon	MMR017023	Kyaung Kone	667	3119
Pyapon	MMR017D006	Pyapon	MMR017023	Seik Ma	1500	6665
Pyapon	MMR017D006	Bogale	MMR017024	Kha Naung	407	1621
Pyapon	MMR017D006	Bogale	MMR017024	Nyi Naung Wa	716	3062
Pyapon	MMR017D006	Bogale	MMR017024	Chaung Hpyar (Nyi Naung)	295	1232
Pyapon	MMR017D006	Bogale	MMR017024	Ma Lawt	1159	4858
Pyapon	MMR017D006	Bogale	MMR017024	(Kyun Nyo Gyi) Kyun Hteik	1370	5752
Pyapon	MMR017D006	Bogale	MMR017024	Pa Da Myar Kone	544	2220
Pyapon	MMR017D006	Bogale	MMR017024	Mya Thein Tan	634	2769
Pyapon	MMR017D006	Bogale	MMR017024	Hay Man	2867	12245
Pyapon	MMR017D006	Bogale	MMR017024	Thone Htat	363	1501
Pyapon	MMR017D006	Bogale	MMR017024	Tha Zin Kone	884	3792
Pyapon	MMR017D006	Bogale	MMR017024	Pyin Boe Gyi	619	2467
Pyapon	MMR017D006	Bogale	MMR017024	Pet Pye	489	1832
Pyapon	MMR017D006	Bogale	MMR017024	Set San	5235	23734
Pyapon	MMR017D006	Bogale	MMR017024	Byu Sa Khan	516	2154
Pyapon	MMR017D006	Bogale	MMR017024	Ka Ma Ka Lu	771	3334
Pyapon	MMR017D006	Bogale	MMR017024	Tha Pyay Kan	407	1609
Pyapon	MMR017D006	Bogale	MMR017024	Paung Htei	304	1260
Pyapon	MMR017D006	Bogale	MMR017024	Nga Pyay Ma	808	3402
Pyapon	MMR017D006	Bogale	MMR017024	Ga Yan	714	2855
Pyapon	MMR017D006	Bogale	MMR017024	Daunt Gyi	3613	16706
Pyapon	MMR017D006	Bogale	MMR017024	Chaung Gyi Wa	352	1469
Pyapon	MMR017D006	Bogale	MMR017024	Kyein Chaung Gyi	4266	17031
Pyapon	MMR017D006	Bogale	000	Forest	0	0
Pyapon	MMR017D006	Bogale	MMR017024	Kyun Thar Yar	2812	10648
Pyapon	MMR017D006	Pyapon	MMR017023	Amar	777	3358
Pyapon	MMR017D006	Bogale	000	Forest	0	0
Pyapon	MMR017D006	Pyapon	MMR017023		0	0
Pyapon	MMR017D006	Bogale	MMR017024	Paik Sa Lat	562	2456
Pyapon	MMR017D006	Bogale	MMR017024	Aye	727	3012

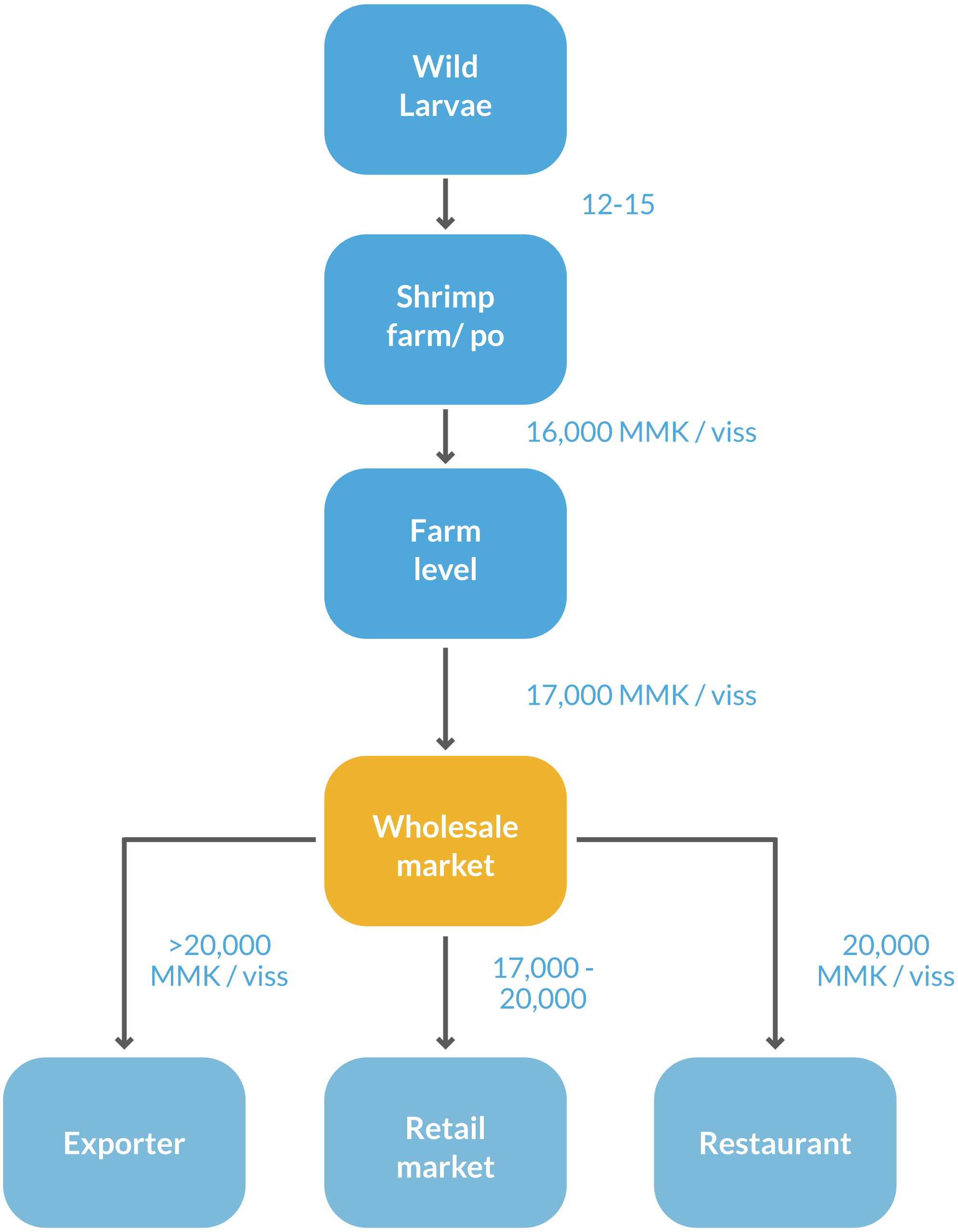
Annex 2. List of village tracks and population in mangrove reserve forests and their 10 km buffer zones

DT	DT_PCODE	TS	TS_PCODE	VT	houseH	Population
Pyapon	MMR017D006	Bogale	MMR017024	Ma Gu	2820	11315
Labutta	MMR017D004	Labutta	MMR017016	Labutta	7203	31174
Labutta	MMR017D004	Labutta	MMR017016	Kyein Kone Gyi	672	2876
Labutta	MMR017D004	Labutta	MMR017016	Bay Pauk	897	3912
Labutta	MMR017D004	Labutta	MMR017016	Kyauk Hmaw	1403	5880
Labutta	MMR017D004	Labutta	MMR017016	Nyaung Lein	992	3801
Labutta	MMR017D004	Labutta	MMR017016	La Put Ta Loke (North)	724	2712
Labutta	MMR017D004	Labutta	MMR017016	La Put Ta Loke (South)	778	3015
Labutta	MMR017D004	Labutta	MMR017016	Sar Kyin	1378	5540
Labutta	MMR017D004	Labutta	MMR017016	Ka Nyin Kone	894	3354
Labutta	MMR017D004	Labutta	MMR017016	Ah Mat	903	3456
Labutta	MMR017D004	Labutta	MMR017016	Kyun Chaung	772	3378
Labutta	MMR017D004	Labutta	MMR017016	Tha Nat Hpet	623	2355
Labutta	MMR017D004	Labutta	MMR017016	Ohn Ta Pin (Aung Hpone)	716	2948
Labutta	MMR017D004	Labutta	MMR017016	Tat Kwin	185	786
Labutta	MMR017D004	Labutta	MMR017016	Bone Gyi Kone	1244	5083
Labutta	MMR017D004	Labutta	MMR017016	Htin Pon Kwin	1215	4934
Labutta	MMR017D004	Labutta	MMR017016	Kan Bet	1745	8049
Labutta	MMR017D004	Labutta	MMR017016	Kyein Kwin	1049	4434
Labutta	MMR017D004	Labutta	MMR017016	Kone Gyi	672	2876
Labutta	MMR017D004	Labutta	MMR017016	Kyee Chaung	885	4267
Labutta	MMR017D004	Labutta	MMR017016	Bi Tut	1915	7978
Labutta	MMR017D004	Labutta	MMR017016	Maung Nge	1230	5448
Labutta	MMR017D004	Labutta	MMR017016	Myit Pauk	2093	8379
Labutta	MMR017D004	Labutta	MMR017016	Shaw Chaung	1596	6949
Labutta	MMR017D004	Labutta	MMR017016	Tei Pin Taing	628	2608
Labutta	MMR017D004	Labutta	MMR017016	Sar Chet	2128	9482
Labutta	MMR017D004	Labutta	MMR017016	Yae Twin Seik	1456	6446
Labutta	MMR017D004	Labutta	MMR017016	Da Ni Seik	1591	6868
Labutta	MMR017D004	Labutta	MMR017016	Yway	516	2194
Labutta	MMR017D004	Labutta	MMR017016	Gant Eik	684	2469
Labutta	MMR017D004	Labutta	MMR017016	Sa Lu Seik	1592	6396
Labutta	MMR017D004	Labutta	MMR017016	Hlwa Zar	1784	6583
Labutta	MMR017D004	Labutta	MMR017016	Kyauk Tan Ka Lay	332	1358
Labutta	MMR017D004	Labutta	MMR017016	Baing Daunt Chaung	2462	9628
Labutta	MMR017D004	Labutta	MMR017016	Koke Ko	1402	5065
Labutta	MMR017D004	Labutta	MMR017016	Sin Chay Yar	787	2977
Labutta	MMR017D004	Labutta	MMR017016	Thin Gan Gyi	936	3201
Labutta	MMR017D004	Labutta	MMR017016	Kant Ba Lar	488	1880
Labutta	MMR017D004	Labutta	MMR017016	Ka Nyin Kaing	0	0
Labutta	MMR017D004	Labutta	MMR017016	Tha Pyu Kone	1657	6336
Labutta	MMR017D004	Labutta	MMR017016	Kyar Kan	998	3875
Labutta	MMR017D004	Labutta	MMR017016	Kyauk Hpyu Pein Hne Taung	1133	4232
Labutta	MMR017D004	Labutta	MMR017016	Ka Tha Paung	820	3510
Labutta	MMR017D004	Labutta	MMR017016	Kyauk Tan Gyi	1317	5499

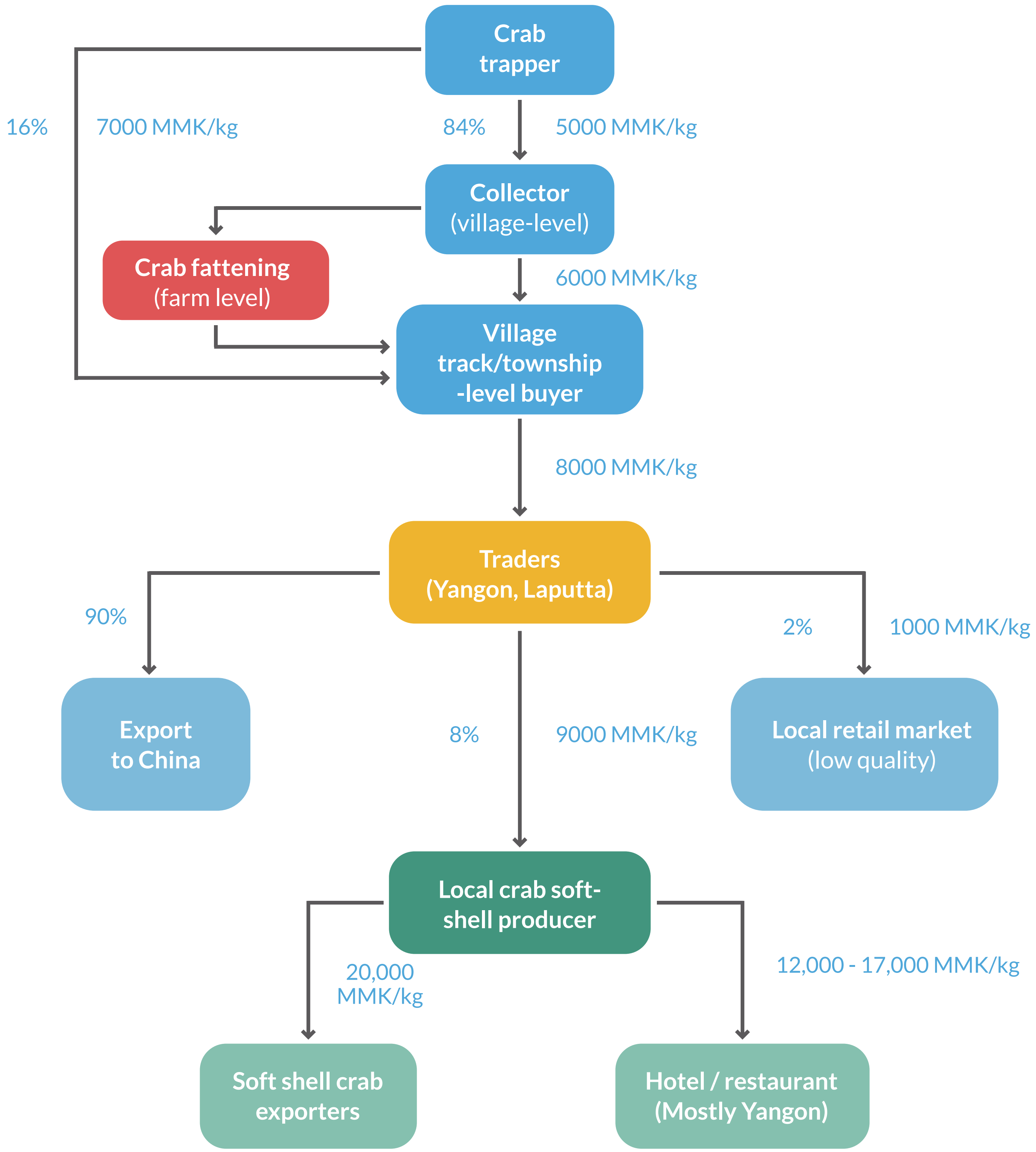
Annex 2. List of village tracks and population in mangrove reserve forests and their 10 km buffer zones

DT	DT_PCODE	TS	TS_PCODE	VT	houseH	Population
Labutta	MMR017D004	Labutta	MMR017016	Nyan Kwin	332	1578
Labutta	MMR017D004	Labutta	MMR017016	Pan Tone Kwin	498	1956
Labutta	MMR017D004	Labutta	MMR017016	Bar Thar Kone	147	656
Labutta	MMR017D004	Labutta	MMR017016	Min Bu Su	555	2559
Labutta	MMR017D004	Labutta	MMR017016	Maung De	987	4128
Labutta	MMR017D004	Labutta	MMR017016	La Put Pyay Le Pyauk	566	2240
Labutta	MMR017D004	Labutta	MMR017016	Tha Yet Kone Le Pyauk	544	2272
Labutta	MMR017D004	Labutta	MMR017016	Thar Li Kar Kone	271	1132
Labutta	MMR017D004	Labutta	MMR017016	Mway Hauk	822	3667
Labutta	MMR017D004	Labutta	MMR017016	Hlaing Bone	790	3219
Labutta	MMR017D004	Labutta	MMR017016	Nyaung Chaung	969	4182
Labutta	MMR017D004	Labutta	MMR017016	Tu Myaung	1484	6241
Labutta	MMR017D004	Labutta	MMR017016		0	0
Labutta	MMR017D004	Labutta	MMR017016	Ka Ka Yan	1339	6064
Labutta	MMR017D004	Labutta	MMR017016	Tha Pyay Chaung	0	0
Labutta	MMR017D004	Labutta	MMR017016	Yae Saing	2138	8943
Labutta	MMR017D004	Labutta	MMR017016	Pyinsalu	501	2229
Labutta	MMR017D004	Labutta	MMR017016	Pyin Ah Lan/ Poe Laung	2004	9364
					134731	571842

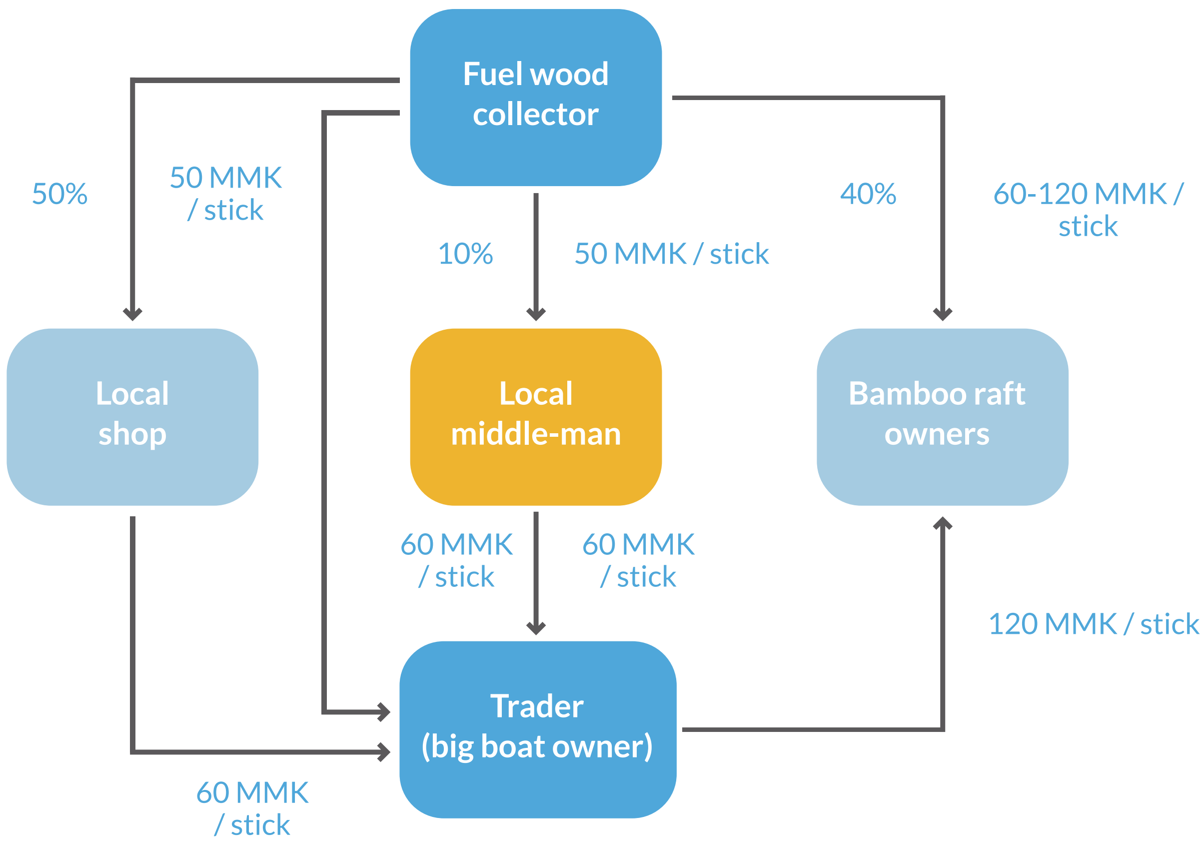
Annex 3. Shrimp value chain in the Ayeyarwady Delta, Myanmar



Annex 4. Crab value chain in the Ayeyarwady Delta, Myanmar



Annex 5. Fuelwood value chain in the Ayeyarwady Delta, Myanmar



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