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Managing Mangrove Ecosystem Services for Local Livelihoods and Adaptations in Tanzania

Baraka Nyangoko

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Abstract

Recognizing the importance of ecosystem services (ES) for peoples' livelihoods and well-being is important for decision-making processes on conservation. Mangrove ecosystems in Tanzania are protected by law, but they continue to be exposed to degradation and loss, and there is still limited information about the awareness, preferences, status and trends of the ES they provide. This thesis aims to explore the link between mangrove ecosystem services (MES) and community livelihoods, changes in MES and associated drivers of change, adaptation options and their management in Tanzania, using the Rufiji Delta and Pangani Estuary as case studies. A mixed framework of methods including focus group discussions, key informant interviews, household surveys, direct observations, and literature reviews was used to gather data. Provisioning services were the most commonly identified MES, and they were more often reported to be deteriorating than regulating, cultural, and supporting services. Proximity to mangrove forest and residence time were positively associated with communities' awareness of all identified MES. Poles for building, firewood for cooking, coastal protection, and fisheries habitats were perceived as the most important MES for sustaining local livelihoods, though perceptions varied between sites. Reliance on mangrove resources was significantly predicted by household residence time, household main occupation, household size, and the cost of alternative resources to substitute mangrove wood as a source of domestic fuel. Illegal harvesting of mangrove poles, rice cultivation, climate change and inadequate governance and conservation measures were identified as the most critical drivers of mangrove degradation, but differed significantly from place to place. Fishing was perceived as the most impacted livelihood occupation compared to the other groups of occupations. Potential ways to adapt to environmental changes in the study areas included reliance on MES for ecosystem-based adaptation (EbA), switching of occupation, diversifying crops, offshore fishing, and migrating to other areas. This thesis argues that the linkage between MES and human well-being is site-specific, and drivers impacting on mangroves and their associated services vary spatially and is greatly accelerated by anthropogenic disturbances. Raising more awareness about the multifunctionality of mangroves and committing to participatory forest management that involves local people, as well as reforming the current forest policy by incorporating clear legal mechanisms for engaging communities around mangrove management and diversifying livelihood options are re-emphasized as appropriate ways to improve mangrove conservation. Furthermore, investment by providing adequate funding for conservation in long run rather than relying on short-term international donor-funded projects are recommended to government institutions as a basis for sustainable management of mangrove forests in Tanzania.

Keywords: *Mangroves, ecosystem services, mangrove management, livelihoods, ecosystem-based adaptation, Tanzania.*

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Department of Physical Geography

Stockholm University, 106 91 Stockholm

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Cover photos: Traditional fishing in Pangani Estuary (top), women carrying firewood from mangroves on traditional dugout canoes (bottom left) and harvesting of mangrove poles in the Rufiji Delta (bottom right) by Mwita Marwa Mangora

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To my mother
Florence Wagunda, my
lovely wife Lineth
Mikida, and late father
Dr Nyangoko Paul

Abstract

Recognizing the importance of ecosystem services (ES) for peoples' livelihoods and well-being is important for decision-making processes on conservation. Mangrove ecosystems in Tanzania are protected by law, but they continue to be exposed to degradation and loss, and there is still limited information about the awareness, preferences, status and trends of the ES they provide. This thesis aims to explore the link between mangrove ecosystem services (MES) and community livelihoods, changes in MES and associated drivers of change, adaptation options and their management in Tanzania, using the Rufiji Delta and Pangani Estuary as case studies. A mixed framework of methods including focus group discussions, key informant interviews, household surveys, direct observations, and literature reviews was used to gather data. Provisioning services were the most commonly identified MES, and they were more often reported to be deteriorating than regulating, cultural, and supporting services. Proximity to mangrove forest and residence time were positively associated with communities' awareness of all identified MES. Poles for building, firewood for cooking, coastal protection, and fisheries habitats were perceived as the most important MES for sustaining local livelihoods, though perceptions varied between sites. Reliance on mangrove resources was significantly predicted by household residence time, household main occupation, household size, and the cost of alternative resources to substitute mangrove wood as a source of domestic fuel. Illegal harvesting of mangrove poles, rice cultivation, climate change and inadequate governance and conservation measures were identified as the most critical drivers of mangrove degradation, but differed significantly from place to place. Fishing was perceived as the most impacted livelihood occupation compared to the other groups of occupations. Potential ways to adapt to environmental changes in the study areas included reliance on MES for ecosystem-based adaptation (EbA), switching of occupation, diversifying crops, offshore fishing, and migrating to other areas. This thesis argues that the linkage between MES and human well-being is site-specific, and drivers impacting on mangroves and their associated services vary spatially and is greatly accelerated by anthropogenic disturbances. Raising more awareness about the multifunctionality of mangroves and committing to participatory forest management that involves local people, as well as reforming the current forest policy by incorporating clear legal mechanisms for engaging communities around mangrove management and diversifying livelihood options are re-emphasized as appropriate ways to improve mangrove conservation. Furthermore, investment by providing adequate funding for conservation in long run rather than relying on short-term international donor-funded projects are recommended to government institutions as a basis for sustainable management of mangrove forests in Tanzania.

Sammanfattning

Att förstå betydelsen av ekosystemtjänster (ES) för människors försörjning och välbefinnande är viktigt för processer som berör bevarande av och beslutsfattande om länkade social-ekologiska system. Mangroveskogar i Tanzania är skyddade av lagar, men de fortsätter att förstöras, och det finns fortfarande begränsad information om medvetenheten, preferenserna, statusen och trenderna för de ES som dom tillhandahåller. Denna avhandling syftar till att undersöka kopplingen mellan ekosystemtjänster från mangroveskogar (MES) och lokala samhällens försörjningsmöjligheter, förändringar i MES och faktorer som driver dessa förändringar, anpassningsmöjligheter baserat på MES och förvaltning av MES i Tanzania, genom fältstudier i Rufiji-deltat och Pangani-deltat. Flera olika metoder har använts för att samla in data och inkluderar fokuserade grupp-diskussioner, intervjuer med nyckelpersoner och hushåll, direkta fält-observation och litteraturgenomgångar. Försörjande ekosystemstjänster var de MES som flest människor kunde identifiera, och ansågs ofta vara i sämre kondition än reglerande, kulturella och stödjande tjänster. Närhet till mangroveskogar och boendetid i dessa områden, ökade lokalbefolkningens medvetenhet om alla identifierade MES. Byggmaterial, ved för matlagning, kustskydd och fiskhabitat uppfattades som de viktigaste MES till stöd för lokalbefolkningens försörjningsmöjligheter, även om uppfattningarna varierade något mellan olika platser. Befolkningens beroende av resurser från mangroveskogar påverkades signifikant av deras boendetid i området, deras huvudsakliga sysselsättning, hushållets storlek och kostnaden för alternativa bränslen som ersättning för mangrove ved. Olaglig avverkning av mangrove, risodling, klimatförändringar och otillräckliga kontroll och bevarandeåtgärder identifierades som de mest kritiska drivkrafterna till att mangroveskogar förstörs, men skilde sig väsentligt från plats till plats. Fiske uppfattades som det mest påverkade yrket jämfört med andra yrkesgrupper. Möjliga sätt att anpassa sig till miljöförändringar i området inkluderade att använda MES för ekosystembaserade lösningar, byte av yrke, diversifiering av grödor, fiske längre från kusten och att flytta till andra områden. Den här avhandlingen visar att kopplingarna mellan MES och mänskligt välbefinnande är platsspecifika, och att drivkrafter som påverkar mangroveskogar och deras associerade ekosystemtjänster varierar rumsligt och förstärks av mänsklig påverkan. En ökad medvetenhet om mangroveskogarnas multifunktionalitet och ett ökat deltagande av lokalbefolkningen i förvaltningen av mangroveskogar, samt en reformerad skogspolitik med tydliga juridiska mekanismer för att engagera lokalsamhällen kring mangroveförvaltning och diversifierade försörjningsalternativ, framhålls som möjliga sätt att förbättra bevarandet av mangroveskogar. Dessutom rekommenderas investeringar för att tillhandahålla tillräcklig finansiering för bevarande på lång sikt, snarare än att förlita sig på kortsiktiga internationella biståndsprojekt, som en grund för hållbar förvaltning av mangroveskogar i Tanzania.

Thesis content

This doctoral thesis consists of a summary and four appended papers (referred to as Paper I - IV) listed below:

I. **Nyangoko, B. P**., Berg, H., Mangora, M. M., Gullström, M., and Shalli, M. S. (2021). Community perceptions of mangrove ecosystem services and their determinants in the Rufiji Delta, Tanzania. *Sustainability*, 13(1), 63. https://doi.org/10.3390/su13010063

II. **Nyangoko, B. P**., Berg, H., Mangora, M. M., Shalli, M. S., and Gullström, M. (2022). Local perceptions of changes in mangrove ecosystem services and their implications for livelihoods and management in the Rufiji Delta, Tanzania. *Ocean and Coastal Management*, 219, 106065. https://doi.org/10.1016/j.ocecoaman.2022.106065

III. **Nyangoko, B. P**., Shalli, M. S., Mangora, M. M., Gullström, M., and Berg, H. (2022). Socio-economic determinants of mangrove exploitation and management in the Pangani River Estuary, Tanzania. *Ecology and Society*, in Press.

IV. **Nyangoko, B. P**., Berg, H., Mangora, M. M., Shalli, M. S., and Gullström, M. (2022). Community perceptions of climate change and ecosystem-based adaptation in the mangrove ecosystem of the Rufiji Delta, Tanzania. *Climate and Development*, 1-13. https://doi.org/10.1080/17565529.2021.2022449

Author Contributions

The contributions from the listed authors for each paper are described as follows:

I. BPN, HB and MMM conceived and conceptualized the study. BPN and MMM conducted field work. BPN performed data analysis with assistance from HB, and led the writing of the Paper. Both BPN, HB, MMM, MG, and MSS discussed the results, provided critical feedback, edited and revised the Paper.

II. BPN and HB conceived and conceptualized the study. BPN and MMM conducted field work. BPN and HB performed data analysis. BPN led the writing of the Paper, and all authors actively contributed to discussion, writing, editing and revision of the Paper.

III. BPN, MSS and MMM conceived and conceptualized the study. BPN conducted field work, and analysed data with supports of MSS and MMM. BPN led the writing and all authors discussed the results, provided critical feedback, and revised the Paper.

IV. BPN conceived and conceptualized the study, conducted field work, analysed data and led the writing of the paper. Both BPN, HB, MMM, MG, and MSS discussed the results, provided critical feedback, edited and revised the Paper.

LIST OF ACRONYMS

BMU	Beach Management Unit
DFO	District Forest Officer
DFC	District Forest Conservator
DFM	District Forest Manager
ES	Ecosystem services
MES	Mangrove ecosystem services
FGD	Focus Group Discussion
HHQ	Household Questionnaire
KII	Key Informant Interview
LMI	Local Management Institutions
MACEMP	Marine and Coastal Environment Management Project
MNRT	Ministry of Natural Resource and Tourism
NAFORMA	National Forest Resources Monitoring and Assessment
PFM	Participatory Forest Management
TCZCDP	Tanga Coastal Zone Conservation and Development Programme
TFS	Tanzania Forest Services Agency
VNRC	Village Natural Resources Committee

Contents

1. Introduction

1.1 General background

The well-being of humankind is intrinsically tied to the benefits that ecosystems offer (Rivera-Monroy et al., 2017). These benefits are commonly known as ecosystem services (ES) and they are classified as provisioning, regulating, supporting, and cultural services (Millennium Ecosystem Assessment, 2005). Mangroves are among the most important coastal ecosystems that provide a plethora of ES for coastal livelihoods and well-being in tropical and subtropical regions of the world (Himes-Cornell et al., 2018). For example, mangroves directly provide a variety of provisioning ES such as timber, firewood, honey, and traditional medicines, which are locally essential for subsistence and commercial uses (Mangora and Shalli, 2014; Nyangoko et al., 2021). Mangroves' regulating ES are valued for protecting coastal communities from natural hazards (storms and erosion), seizing and storing carbon, which aids in mitigating the impacts of climate change (Wagner and Sallema-Mtui, 2016; Gullström et al., 2021). They also provide a broad range of cultural ES by providing a foundation for religious values, ecotourism, and education (Mangora and Shalli, 2014; Nyangoko et al., 2021), while their supporting ES are exemplified as critical habitats for coastal and marine fisheries (e.g. fish, shrimp, and crabs) (Gajdzik et al., 2014; Kimirei et al., 2016) as illustrated in Figure 1.

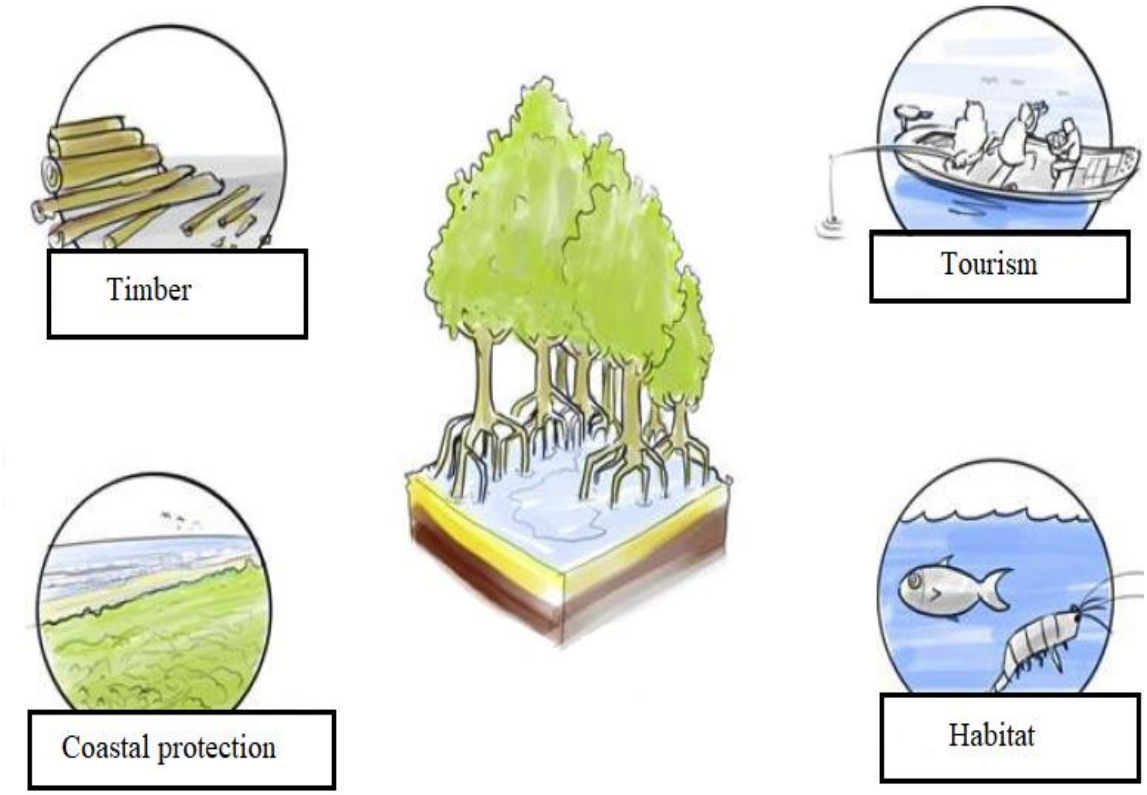

Figure 1. Conceptual schematic presentation of mangroves and some of their multi-functionalities adapted from Worthington et al. (2020).

Despite the values and benefits of mangroves, they are still under threat in many regions where they occur (Goldberg et al., 2020), and their deterioration is alarming, particularly in developing countries where people often rely directly on their ES for livelihoods (Polidoro et al., 2010; Friess et al., 2019; Spalding and Leal, 2021). Human activities (e.g. aquaculture, agriculture and coastal development) and demand for products and services provided by these ecosystems, together with the influence of climate change (e.g. sea level rise and increased temperature) are considered as prime factors for mangrove deterioration (Friess et al., 2019; Goldberg et al., 2020). Almost 607,500 ha (4.3%) of the world's mangrove area has already been lost between 1996 and 2016 (Spalding and Leal, 2021). However, in comparison to 35% of global mangrove losses over the last 50 years (Polidoro et al., 2010), these recent losses indicate that anthropogenic disturbances to mangrove ecosystems have decreased in some way (Goldberg et al., 2020). The reasons for this trend are strongly associated with increased efforts to restore and conserve mangroves and inclusion of their services in the policy domain (Spalding and Leal, 2021; Su et al., 2021). However, mangrove change and the degree of degradation varies geographically, with pressures differing in terms of causes, size and type (Scales and Friess 2019, Maina et al. 2021). For example, while about 80% of mangrove losses in the Asia region in the 20 years preceding 2016 were due to human activities (Goldberg et al., 2020), only a third of mangrove losses in the same period were directly attributed to humans in other regions of the world where mangroves occur (Spalding and Leal, 2021).

Disparities in mangrove degradation rates in the areas where they occur is also explained by the fact that the pattern of goods and ES delivered from mangroves varies over space and time, often in a non-linear fashion (Koch et al. 2009; Renaud et al. 2016), and different segments of communities have diverse perceptions on their ES, depending on local ecological conditions, socio-economic attributes of resource users and legal frameworks instituted to protect them (Martín-López et al., 2014; Pan et al., 2016; Nyangoko et al., 2021). Such variation in public perceptions of mangrove forests provide insights about what matters to the people, and is critical in defining their management and conservation measures (Dahdouh-Guebas et al., 2020). For example, poor marginalized communities, who are residing near mangrove forests and directly rely more on mangrove ecosystem services (MES) for their livelihoods would suffer more when mangroves are lost than those living outside the forests (Nyangoko et al., 2021), and thus appropriate institutions that recognize interest of people in their ecosystems and allow them to participate in management could enhance willingness of local people to respect nature (Nyangoko et al., 2022), and facilitate development of adaptation plans that could reduce impacts of different stressors on ecosystems (Arumugam et al. 2020). In many places, inadequate and unclear policy or legislation has led to contradictory decisions and negative perceptions on conservation of these ecosystems, exposing mangroves to continued degradation and loss (Friess et al., 2016; Suman, 2019). Therefore, a site-specific understanding of the importance and values of ES provided by mangroves, their threats and management, as well as how resource users are affected directly or indirectly by changes in mangrove

ecosystems is crucial for guiding sustainable exploitation and conservation of the remaining mangrove ecosystems (Spalding and Leal, 2021).

1.2 Mangrove ecosystems of Tanzania

Africa has lost almost 55,000 ha of mangroves over a 20-year period, from 1996 to 2016 (Spalding and Leal, 2021), and Tanzania is also affected by mangrove degradation (Mungai et al., 2019; Maina et al. 2021). According to NAFORMA (National Forest Resources Monitoring and Assessment), mangroves are estimated to cover an area of 158,100 ha along Tanzania's mainland coast (MNRT, 2015), with the largest segments found in estuarine-river mouths spanning the country from north to south (Semesi, 1992; Wang et al., 2003). However, in comparison to the estimated mangrove vegetation areas of 115,475 ha in 1992 (Semesi, 1992) and 108,138 ha in 2003 (Wang et al., 2003), the recent estimate by NAFOMA appear to be higher than the previous studies because NAFOMA's assessments included both mangrove vegetation areas and other associated mangrove land areas such as tidal mudflats and salt crusts, and should not be considered as there has been an increase in coverage. Mangroves of Tanzania are recognized by law as forest reserves (von Mitzlaff 1989; Semesi 1992; Wang et al. 2003, Mangora et al. 2016), and the ES they provide to the coastal people have been recognized for many years (Mainoya et al. 1986; von Mitzlaff 1989; Semesi 1992, 1998). However, striking an equilibrium between mangrove resource use and conservation is challenging (Mangora, 2011; Nyangoko et al., 2021). As a result, they are being degraded and lost in different areas of the country where they occur (Wang et al. 2003; Mangora 2011; Njana 2020). For example, Njana (2020) reported that almost 19,000 ha of mangrove area were lost between 1990 and 2015 country wide. Monga et al (2018) also reported that between 1991 and 2015, approximately 9,089 ha of mangroves were lost in the Rufiji Delta only, corresponding to a loss rate of 0.5% per year. Mangrove deterioration is also evident in the Pangani Estuary, where mangrove areas are exploited for timber and firewood (Turpie et al., 2005; Ngomela, 2007).

To reverse the trend of this degradation, collaborative arrangements between government agencies (e.g. Tanzania Forest Services Agency-TFS) and local management institutions (e.g. village natural resource committees-VNRCs), as well as non-governmental organizations are promoted in different parts of country to enhance mangrove conservation (Mangora 2011, Mshale et al. 2017, Nyangoko et al. 2021). As part of an earlier effort to establish a national strategy for mangrove conservation and to reduce the escalating mangrove loss, the Tanzanian government imposed a ten-year ban on mangrove harvesting in 1987, which was followed by a national mangrove inventory and development of a management plan (von Mitzlaff 1989; Semesi 1992). Despite there being a management plan, degradation and loss of mangroves continued unabated, compelling another state ban in 2016, which was lifted in September 2021, but only for the Rufiji Delta and Kilwa mangrove blocks following the revision of respective management plans. While the management plans puts emphasis on community engagement to ensure their effective implementation, the modes for implementing participatory forest management (PFM) approaches are still doubted at the local level owing to stringent legal jurisdictional frameworks that constrain access and use rights, and inadequate capacity to enforce management rules and regulations (Mangora 2011; Beymer-Farris and Bassett 2012;

Mangora et al., 2016; Mwansasu 2016), lack of viable alternative livelihoods and poor harmonization among conservation actors (Nyangoko et al., 2021). This is coupled to the persistent misperception among policymakers, who regard poor mangrove dependent communities as destroyers of mangroves instead of being partners in conservation (Mangora, 2011; Mwansasu, 2016; Nyangoko et al., 2021).

While coastal communities in Tanzania have depended on mangroves for decades to gain livelihoods and well-being (Mainoya etal. 1986, Semesi 1992, 1998, Wang et al. 2003), information about the bundles of ES provided by mangroves to communities and their predictors at the local scale is not well captured (Nyangoko et al., 2021). Many of the reported local studies represent a small selection of ES, such as those traded in markets, with little emphasis on appraising intangible services from mangrove ecosystems, and hence many MES that cannot be quantified monetarily, but are equally important to support well-being of local communities are often overlooked (Nyangoko et al., 2021). In this regard, the values of ecosystems and their associated services in non-monetary units may possibly be more important than the prices they fetch on local/ regional markets. Hence, including a wide range of interactions between humans and mangroves, serve as important entry points for understanding people perspectives about their ecosystems and services they provide for sustainable management strategies. However, the matter of promoting sustainable management and conservation of these ecosystems is further complicated by the emerging phenomenon of climate change and variability (Wagner and Sallema-Mtui, 2016). Analysis on climatic stressors in some areas, such as the Rufiji Delta, has noticed that the health of mangrove ecosystems is being deteriorated not only by human disturbances and mismanagement but also due to the impacts of climate change (Ellison, 2015; Wagner and Sallema-Mtui, 2016). For example, changes in temperature and ocean salinity have affected productivity of coastal mangroves in Tanzania (Punwong, 2013; Rohli et al., 2019). Specifically, fisheries in some areas have declined due to increased degradation of breeding grounds, which is suggestively linked to sea level rise, (Yanda et al., 2019), illegal fishing gear and overfishing along the mangrove swamps (Nyangoko et al., 2022). Increased threats from both human-caused disturbances and climate change often disrupt or interrupt the flow of MES, which in turn adversely impact the well-being of local communities, who rely on mangroves and their related activities for employment and income generation (Nyangoko et al., 2022). Therefore, whether or not mangroves and the ES they provide are threatened by reckless and ruthless human interventions and/or other natural stressors, appropriate management strategies are warranted to manage and protect the existing mangroves and their services from further deterioration. In this regard, a clear understanding about the multi-functionality of mangrove landscapes and their associated ES in relation to human well-being is important for translating and integrating their benefits and preferences into decision making (Nyangoko et al., 2021). This also provide opportunity to identify key threats that affect these ecosystems and how these ecosystems together with other community-based practices can provide options for adaptations to environmental changes (Nyangoko et al., 2022).

1.3 Scope of the thesis

The overall objective of the thesis is to explore stakeholders' perspectives on the link between mangrove ecosystem services (MES) and community livelihoods and well-being, changes in MES and drivers of change, adaptation options and their management in Tanzania, using the Rufiji Delta and the Pangani Estuary as case studies.

More specifically, the thesis had the following objectives:

I. To identify and assess factors that influence on the awareness and importance (demand) of MES to local communities in the Rufiji Delta (Paper I), so as to translate and incorporate their benefits, priorities, and preferences into decision making.

II. To assess the status, change and trends in ES provided by mangroves, associated drivers, and the impacts of these changes on local people's livelihood and well-being in the Rufiji Delta (Paper II), in order to advise managers and policymakers on the need for sustainable management measures.

III. To explore socio-economic determinants of mangrove exploitation patterns, and effectiveness and enforcement of mangrove forest management interventions in the Pangani River Estuary (Paper III), in order to contribute to designing of appropriate mangrove management interventions that would promote common ground for collaborative arrangements with local communities.

IV. To explore how communities in the Rufiji Delta perceive climate change and variability, ecosystem-based adaptation (EbA) strategies based on MES and other societal-based adaptation measures (Paper IV), in order to identify risks associated with climatic stress and feasible opportunities for adaptation.

2. Methods

2.1 Description of the study areas

This study was conducted in two places; the Rufiji Delta and the Pangani Estuary in Tanzania (Figure 2). The Rufiji Delta is situated on the coast of Tanzania and holds nearly 50% of the country's mangrove forests (Monga et al., 2018). The delta is divided into three parts; northern, central, and southern, with several villages situated in and outside the mangroves. The field work (Paper I, II and IV) was carried out in six villages of the Delta, including Mohoro, Mtunda A, and Ruaruke Magharibi, which are relatively distant (>1 km) from mangroves (DM), as well as Ruma, Mbwera Magharibi, and Mbuchi, which are closer to mangroves (CM) (Figure 2). The delta experiences two rainy seasons: long rains from February to May and short rains from October to December, with temperatures from 25 to 41 °C throughout the year (Japhet et al., 2019; Mwansasu, 2016). Agriculture, fishing, small businesses, livestock keeping, and exploitation of mangrove and inland terrestrial forests are the most important livelihood activities carried out by communities in the delta.

However, utilization of mangroves varies depending on proximity to mangrove forests, access to roads and energy, and livelihoods (Nyangoko et al., 2021). The DM villages are comparatively easily accessible by road, electrified, and its local economies are based on farming, small-scale food vending, and exploitation of both inland and mangrove forests. The CM villages are often only reachable by boat through river channels, and occasionally by road, especially during the dry season, non-electrified, and dominated by mangrove-based livelihoods such as fishing and mangrove cutting. The delta is home to a number of indigenous and immigrant ethnic groups (e.g. Ndengereko, Tumbi, Pogoro, and Sukuma), and over 25, 000 people reside in and around the delta (Personal communication, village elders, 2018). The influx of pastoralists and farmers from other regions into the delta to seek pasture and agriculture land has resulted in an increase in population in the delta (Mwansasu 2016; Mshale et al. 2017). Most of the residents in the Delta have informal or primary educational training (Nyangoko et al., 2021).

The Pangani Estuary represents the terminal end of the Pangani River in the Tanga region of northern Tanzania. Here the study involved two communities of Bweni and Pangani Magharibi (Paper III) in the Pangani township (Figure 2). Bweni has a more rural setting, situated on the southern bank, whereas Pangani Magharibi is more urbanized on the northern bank. The estuary is characterized by a temperature range of 18-35 °C throughout the year, and annual rainfall of 1100-1900 mm (Ngomela, 2007). Subsistence rain-fed agriculture and artisanal fisheries are main sources of income in the estuary, followed by food vending and kiosks. Small scale livestock keeping is also carried out in the area. The majority of people who live near the estuary also rely on mangroves to meet their basic socio-economic needs. The total area covered by mangroves in the Pangani District is 3897 ha (Wang et al., 2003), with the Pangani Estuary accounting for nearly 753 ha (Turpie et al., 2005). Apart from mangroves, the estuary is characterized by other common vegetation, which includes coconut trees, shrubs, and dispersed terrestrial trees. The major ethical groups are Zigua, Digo and Sambaa, and the majority of residents in the estuary have attained primary level of education.

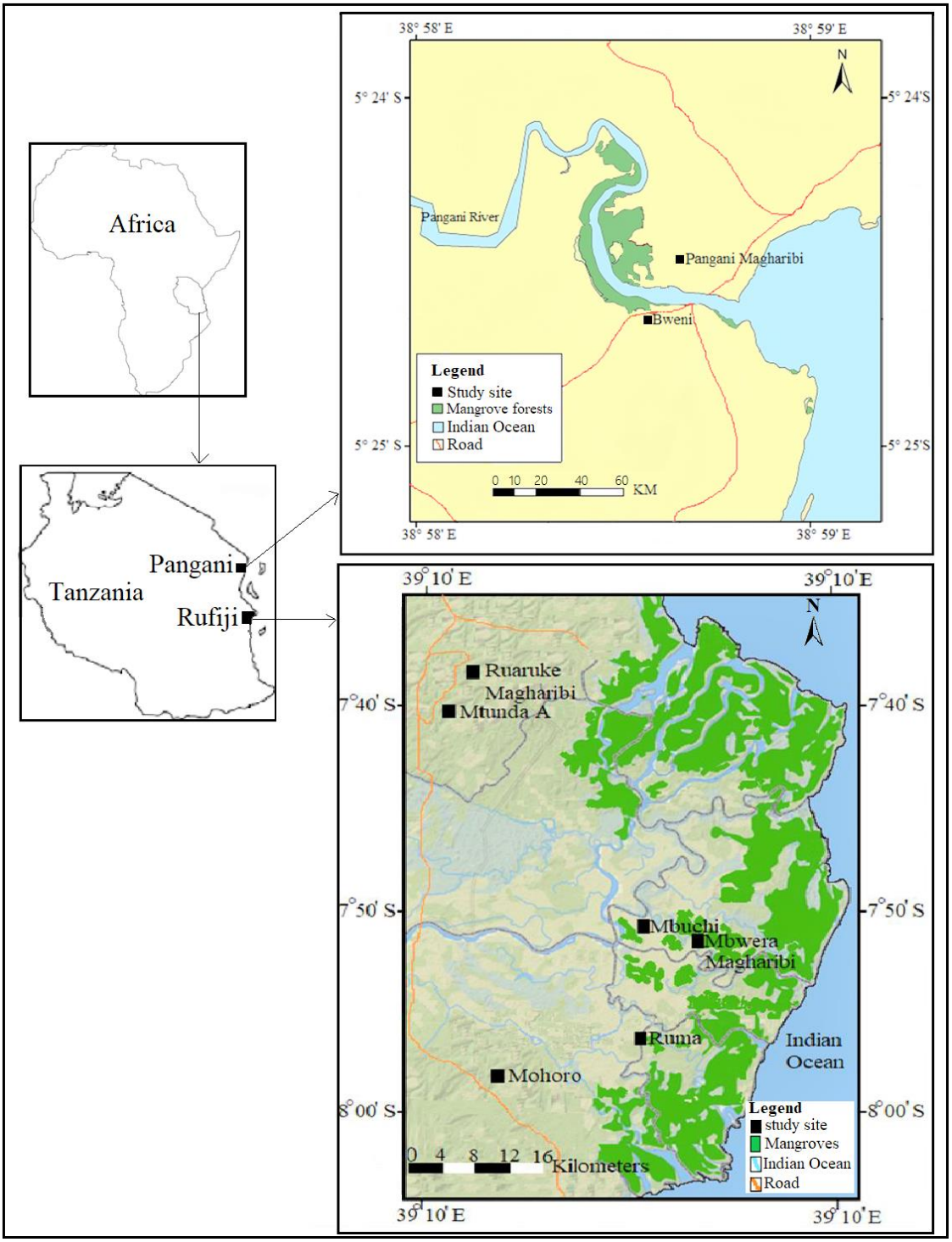

Figure 2. Map of the the Rufiji Delta and the Pangani Estuary showing the location of the study villages Mohoro, Mtunda A and Ruaruke Magharibi, which are located distant to the mangrove forests (DM). Ruma, Mbwera Magharibi, and Mbuchi are situated in close proximity to the mangrove forests (CM). Bweni and Pangani Magharibi are situated on the southern and northern banks of Pangani River, respectively.

2.2 Research design and data collection

This study employed a research design of both qualitative and quantitative nature to triangulate the collected information (Schoonenboom and Johnson, 2017). Data gathered aimed to inform the four studies presented in the four papers, three of which were carried out in the Rufiji Delta and one in the Pangani Estuary. All studies employed focus group discussions (FGDs), key informant interviews (KIIs), household questionnaire surveys (HHQ), direct field observations, and literature reviews. The overview of methods and sample size used in each paper are summarized in Table 1. Two parallel surveys in six villages of the Rufiji Delta (Paper I and II) aimed to identify and assess factors that influence on the awareness and importance (demand) of MES to local communities, as well as exploring changes in MES (status and trends), associated drivers of change in mangrove ES, and the impacts of the changes on local livelihoods and well-being during the last 10 years (2008-2018). Awareness of each MES was mapped based on the benefits that people perceived to receive from mangroves (prior to moderators' discussions with respondents), and during follow-up discussions between moderators and respondents about additional benefits from mangroves, and if they also would agree to these benefits.

The relative importance of the identified MES was determined using a Likert scale, and ranked as: 1 = not important, 2 = least important, 3 = second most important, and 4 = most important. Perceived status of MES was explored based on a four-options Likert scale: 1 = very low, 2 = low, 3 = medium and 4 = high. The perceived trends of MES were assessed as either -1 = decreasing, 0 = no change, or 1 = increasing. Drivers of mangrove change were prioritized on a scale of 1 to 4, as: 1= low importance, 2 = medium importance, 3 = high importance, and 4 = very high importance. The perceived impact of changes in MES on local livelihoods was assessed using a Likert scale: 1= low, 2 = medium, 3 = high, and 4 = very high impacts. In order to establish a first order estimate of the management priority of the identified key MES, a "management index" was calculated based on the household's ratings of the importance score (demand) of ES, and the perceived status (supply) and trend of ES (Management index = [supply + trend]/demand). The index was based on the notion that a high demand for goods and services supplied by ecosystems increases the reliance and pressures on MES, and that the pressure increases even more when the MES are in low supply and in a decreasing trend (cf. Maron et al. 2017).

The survey in the Pangani Estuary (Paper III) explored the socio-economic determinants of mangrove resource exploitation, as well as how people perceive effectiveness and enforcement of mangrove forest management interventions. In order to identify the factors influencing on the use of mangrove resources, local people who listed at least one main resource extracted from mangroves to support their subsidence or commercial needs were classified as mangrove reliant, whereas those who did not extracted any resources were branded as mangrove non-reliant. Effectiveness and enforcement of management interventions were evaluated using mangrove conservation statements, in which respondents were asked to depict a statement and rank their responses as either strongly disagree, disagree, neutral, agree, or strongly agree per given statement.

For paper IV, the study explored how mangrove dependent communities in the Rufiji Delta perceive climate change, ecosystem-based adaptation strategies based on MES, and other societal-based adaptation measures. Local people who had lived in the area for more than 10 years were asked to describe any changes in climatic conditions/events observed between 2009-2019, and their perceived changes were assessed using a Likert scale of 1 (no change), 2 (decreasing), and 3 (increasing). They were also asked to indicate to what extent MES were seen as important for them to adapt to the impacts of climate change, as well as what other social measures they applied to deal with the negative effects of climatic stress. In this regard, participants were asked to rate their responses to predefined statements about the potential benefits of mangroves for climate change adaptation, which were identified during a pilot survey at the community level, as 1 = strongly disagree, 2 = disagree, 3 = agree, or 4 = strongly agree for each given statement.

Table 1. Overview of the research design and methods used in this thesis research papers.

Methodologies	Paper I and II	Paper III	Paper IV
Focus group discussions (FGDs)	2 FGD in each village, with 5-8 participant per group. One focus group included resource users of mixed gender and age, while another included representative from LMI (BMUs and VNRCs)	1 FGD with 8 participants (resource users) of mixed gender and age in each site	1 FGD in each village, with 5-10 participants (resource users) of mixed gender and age who had lived in the area for more than 10 years.
Key informant interviews (KIIs)	1 village leaders and 2 village elders in each village, and 1 TFS manager.	1 village leader, 2 village elders in each village, 6 members of LMI (BMUs and VNRCs), 1 DFO and 1 DFM	1 village leader, 2 village elders, 1 member of LMI in each village, and 1 forest officer in Kibiti District
Household survey	60 household, 10 in each village	60 households, 30 in each village	120 households, 20 in each village
Direct observation	Visit to mangrove area assisted by two local people	Visit to mangrove areas assisted by one local resident	Visit to mangrove area assisted by two natives' residents
Literature review	Literature search on the benefits of mangroves to the community and the causative of mangrove degradation in Tanzania	A review on issues and challenges of mangrove management in Tanzania	Literature search on potential climatic stress and available adaptation measures in mangrove areas

LMI= Local Management Institutions, DFO = District Forest Officer, District Forest Manager (DFM) and Tanzania Forest Services Agency (TFS)

Note: Following Tanzania Forest Services agency (TFS) transformation into a paramilitary agency in 2021 after a period of field surveys, District Forest Officer (DFO) and District Forest Manager (DFM) are currently called District Forest Conservators (DFC).

2.3 Data analysis

Data from the household surveys were sorted using Microsoft Excel, and statistical analyses were carried out using the SPSS statistical software, v 23. A chi-squared test of independence was used to compare respondents' awareness of mangrove-derived ES between DM and CM groups (Paper I). A logistic regression model was used to predict factors associated with respondents' awareness of identified MES (Paper I), as well as to deduce relationships between socioeconomic drivers and mangrove resource exploitation patterns (Paper III). The responses from the studied villages were combined to increase the strength of the link between predictors and response variables in the logit model. One-way ANOVA was used to compare respondents' perspectives on the relative importance of MES for livelihoods between the DM and CM groups (Paper I), the status and trends of MES, the drivers of mangrove change and the impact of the changes on people's livelihood and well-being (Paper II), the extent of perceived climate change, its impacts, and adaptation strategies (Paper IV). Chi-square tests of independence was used to compare perceptions of climate change among respondents between DM and CM groups (Paper IV). Content analysis was used to analyze qualitative data from focus groups, key informant interviews, direct observations, and literature reviews in Paper I, II, III, and IV.

3. Results

3.1 Key findings

Paper I: Community perceptions (awareness and importance) of mangrove ecosystem services and their determinants in the Rufiji Delta, Tanzania

- Among the four categories of mangrove ecosystem services, provisioning services were the most commonly recognized and highest ranked services in support to local livelihoods.
- Community awareness of all identified mangrove ecosystem services was associated with proximity of household homes to mangrove forests and residence time.
- All respondents (100%) living close to mangrove forests (CM) relied on services provided by mangroves for their livelihoods and well-being, while 37% of the respondents in the village distant to mangroves (DM) said that they did not rely on mangroves.
- Poles for building, firewood for cooking, coastal protection, and fisheries habitats were perceived as the most important MES for sustaining local livelihoods, though perceptions varied between communities.

Paper II: Local perceptions of changes in mangrove ecosystem services and their implications for livelihoods and management in the Rufiji Delta, Tanzania.

- Low status and declining trends in provisioning ES were more frequently reported by the respondents than in regulating, cultural, and supporting services.

- Mangroves and their associated ES were threatened by a complex set of anthropogenic and natural factors, with illegal mangrove harvesting, rice cultivation, climate change and variability, and poor management being identified as the most common drivers of degradation, though views differed between communities.
- Reduced fish yields, decreased availability of quality poles, decreased honey production, depletion of firewood, and property damage were the most commonly perceived impacts of mangrove changes on local people's livelihood and well-being.
- In comparison to the other groups of occupations, fishing was perceived as the most impacted livelihood occupation due to changes in mangrove ES.

Paper III: Socio-economic Determinants of mangrove exploitation and management in the Pangani River Estuary, Tanzania

- About 70% of the households in Bweni were mangrove reliant, while 60% in Pangani Magharibi were mangrove non- reliant.
- Reliance on mangrove resources was significantly predicted by household residence time, household occupation, household size, and the cost of alternative resources to substitute mangrove wood as a source of domestic fuel.
- About 56% of the respondents in Bweni agreed that interventions by Beach Management Units (BMUs) enhanced mangrove conditions, whereas only about 16% of the respondents in Pangani Magharibi had similar perceptions.
- Overall, 55% of respondents were dissatisfied with the performance of government institutions in implementing conservation measures for long-term mangrove use.

Paper IV: Community perceptions of climate change and ecosystem-based adaptation in the mangrove ecosystem of the Rufiji Delta, Tanzania

- A general decrease in rainfall, increased temperatures, coastal flooding, and the incidence of sea level rise were identified by local communities as key variables associated with climate change and variability in their area.
- Decline in crop yields, reduced fish yields, and decline of honey production were generally perceived as the main impacts of climate change on livelihoods by mangrove dependent communities, although the perceptions differed across occupational groups.
- Reliance on MES as ecosystem-based adaptation (EbA), switching of occupation, diversifying crops, offshore fishing and migrating to other areas were all potential options for adapting to the impacts of climate change and variability.

3.2 Awareness of MES and their predictors (Paper 1)

Figure 3 summarizes the community's awareness of MES in the study area. People in the CM villages were more aware of these services than those in the DM villages. Provisioning services were the most commonly identified ES, accounting for 80% and 53% of the responses in the CM and DM villages, respectively, followed by regulating (63% in CM and 43% in DM), cultural (53% in CM and 37% in DM), and supporting ES (60% in CM and 30% in DM). Community awareness of all identified MES (i.e. provisioning, regulating, and cultural and supporting services) was greatly enhanced by a decrease in the distance between the household homes and the mangrove forest and by an increase in the residence time (Table 2). The gender of the household heads and the households contact with mangrove management committees also predicted the community awareness of provisioning, regulating, and cultural services (Table 2). Main occupation of households, household income and education levels of household heads had no significant effect on the awareness of MES (Table 2).

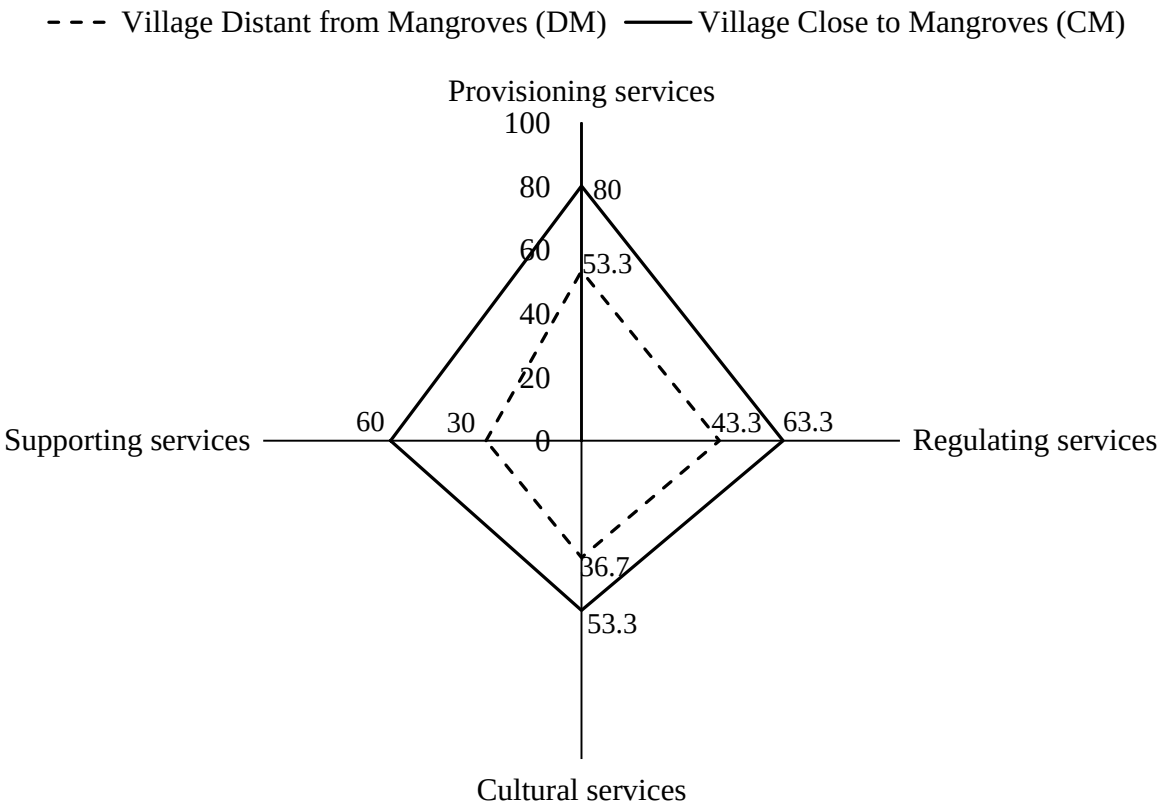

Figure 3. Radar diagram showing the awareness of ecosystem services provided by mangroves by respondents in percentage (%), after the intervention in the study area grouped by categories (n = 30 per grouped village).

Table 2. Factors influencing on respondents' awareness of mangrove ecosystem services in the study area (n = 60).

Variables	Provisioning services			Regulating services			Cultural services			Supporting services		
	B	Sig	Exp(β)	B	Sig	Exp(β)	B	Sig	Exp(β)	B	Sig	Exp(β)
Distance from household homes to mangroves	-0.70	0.04*	0.46	-1.03	0.01*	0.36	-1.10	0.01*	0.33	-0.79	0.01*	0.45
Residence time of household	1.41	0.02*	4.10	1.18	0.03*	3.26	1.11	0.02*	3.04	0.87	0.02*	2.38
Gender of household head	2.68	0.03*	14.62	3.17	0.02*	23.75	2.25	0.01*	9.46	0.24	0.78	1.27
Contact of household with management committee	1.74	0.04*	5.67	2.16	0.02*	8.69	2.73	0.04*	15.23	0.56	0.37	1.76
Main occupation of household	0.41	0.28	1.51	0.15	0.58	1.16	0.58	0.06	0.56	0.04	0.85	1.04
Household income	0.69	0.15	1.99	0.75	0.09	2.12	0.70	0.15	0.49	0.02	0.95	1.02
Age of household head	0.35	0.58	1.43	0.55	0.36	1.73	0.39	0.56	0.68	0.37	0.48	1.45
Household size	0.35	0.62	1.40	0.58	0.35	1.79	0.14	0.82	0.87	0.42	0.38	0.65
Education level of household head	0.42	0.63	1.52	0.22	0.78	1.25	1.81	0.08	6.11	0.21	0.70	0.81
Constant	-7.78	0.06	0.01	-8.64	0.03	0.01	-1.83	0.60	0.16	-0.27	0.91	0.76

* indicates significant factors at $p < 0.05$, β is the coefficient of regression, a negative sign (-) of the coefficient implies that a unit increase in a stated variable will decrease the chance of the community to identify the stated services by a factor of the observed odd (Exp β).

3.3 Relative importance of MES (Paper I), their status, trends and drivers of change (Paper II)

While all respondents (100%) in the CM villages relied on mangroves for their livelihoods and well-being, about 37% of the respondents in the DM villages did not rely on mangroves (Figure 4). Provisioning services, followed by regulating services, were perceived as more important than supporting and cultural services, and there were significant differences in the relative importance of specific ES, between the DM and CM villages (Table 3). The most important MES to support livelihoods and well-being in the studied communities within each category of ES were perceived to be poles for building (provisioning ES), coastline protection (regulating ES), natural beauty (cultural ES), and fishery habitats (supporting ES). A low status and declining trends in the supply of provisioning ES were more frequently reported by the respondents than for regulating, cultural, and supporting services (Table 3). A first order management index for prioritizing the management need of identified ES shows that several provisional services together with habitats for fish (supporting ES) were of high need for improved management, due to their low status/supply, declining trends and high demand (Table 3). The management index indicated a comparatively low and moderate management need for cultural and regulating services respectively, due to their perceived low demand (Table 3). The awareness of these ES categories were also found to be low (Figure 3), and much work remains to be done to enhance community awareness and knowledge about the benefits of these services.

Illegal exploitation of mangrove resources and climate change (e.g. through declined rainfall, increased temperature and salinity, which cause tissue desiccation and die back of some mangrove trees) were identified as major causes of mangrove loss and their associated ES in the CM villages, while rice farming (due to the existence of freshwater flowing towards the northern part of the delta that favour rice production in mangrove areas) and illegal harvest were perceived as major causes of mangrove loss in the DM villages (Figure 5). The introduction of invasive plant species (climbers), which was brought into the delta due to change in direction of river flow, was also reported to damage mangroves and cause degradation by spreading quickly and covering mangrove trees, particularly in areas dominated by fresh water (Figure 5).

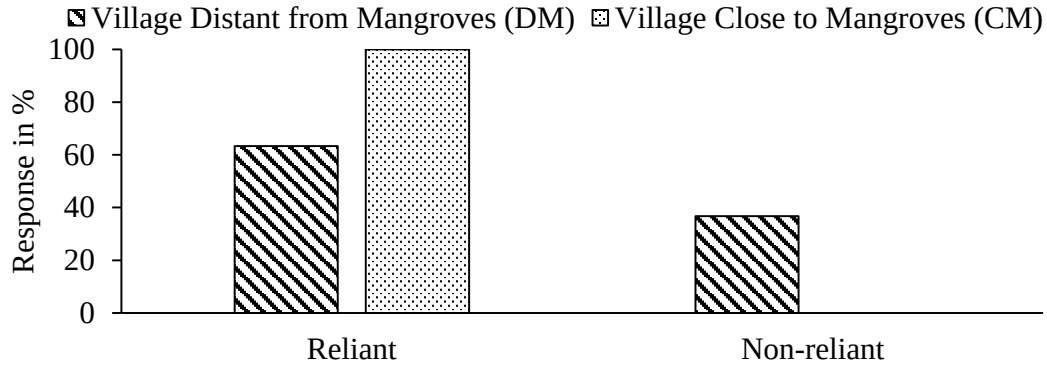

Figure 4. Mangroves reliant and non- reliant communities in the study area (n= 30 per village).

Table 3. Perceived importance score (demand) of specific mangrove ecosystem services and their status (supply) and trend during the last 10 years (2008-2018) in the study area.

Mangrove ecosystem services	Village Distant from Mangroves (DM, n = 30)	Village Close to Mangroves (CM, n = 30)	Overall	Village Distant from Mangroves (DM, n = 30)	Village Close to Mangroves (CM, n = 30)	Overall	Management index
	Mean ± SD (importance or demand)			Mean ± SD (Status and trend)			
Provisioning services (P)							
Poles	3.5 [a] ± 0.6	3.9 [b] ± 0.3	3.7 ± 0.5 H	2.3 [a] ± 0.8 L↓	3.1[b] ± 0.5 M↓	2.7 ± 0.7 M↓	0.5
Firewood	2.6 [a] ± 0.8	3.5 [b] ± 0.5	3.1 ± 0.8 M	1.5 ± 0.5 [a] VL↓	2.4 ± 0.3 [b] L↓	2.0 ± 0.6 L↓	0.3
Honey	2.6 ± 0.6	2.7 ± 0.6	2.6 ± 0.6 M	2.0 ± 0.7 [a] L↓	2.8 [b] ± 0.5 M→	2.4 ± 0.6 L→	0.9
Traditional medicines	1.1 ± 0.3	1.4 ± 0.4	1.3 ± 0.3 VL	3.4 ± 0.4 M→	3.6 ± 0.5 H→	3.5 ± 0.5 M→	2.7
Fodder	1.0 ± 0.2	1.4 ± 0.3	1.2 ± 0.3 VL	3.1 ± 0.3 M→	3.5 ± 0.5 M→	3.3 ± 0.5 M→	2.8
Fruit	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.2 VL	2.9 ± 0.5 M→	3.0 ± 0.5 M→	2.9 ± 0.5 M→	2.6
Average (P)	2.0 [a] ± 0.2	2.3 [b] ± 0.3	2.2 ± 0.2 L	2.5 [a] ± 0.2 L↓	3.1 [b] ± 0.1 M→	2.8± 0.3 M→	1.1
Regulating services (R)							
Coastal protection	2.5 [a] ± 0.9	3.3 [b] ± 0.7	2.9 ± 0.8 M	2.7 ± 0.6 M→	3.1 ± 0.6 M↓	2.9 ± 0.6 M→	1.0
Climate regulation	2.6 ± 0.7	2.4 ± 0.6	2.5 ± 0.6 M	3.2 ± 0.4 M→	3.4 ± 0.5 M→	3.3 ± 0.4 M→	1.3
Sediment trapping	1.1 ± 0.3	1.4 ± 0.4	1.2 ± 0.3 VL	2.0 [a] ± 0.2 L→ *	3.8 [b] ± 0.4 H→	2.5 ± 0.3 M→	2.1
Average (R)	2.1[a] ± 0.3	2.3 [b] ± 0.2	2.2 ± 0.2 VL	2.6 ± 0.5 M→	3.4 ± 0.5 M→	3.0 ± 0.4 M→	1.3
Cultural services (C)							
Natural beauty	1.8 [a] ± 0.5	2.1 [b] ± 0.7	1.9 ± 0.6 L	2.9 ± 0.7 M↓	3.2 ± 0.7 M→	3.0 ± 0.7 M→	1.6
Spiritual belief	1.4 ± 0.5	1.6 ± 0.6	1.5 ± 0.5 VL	3.5 [a] ± 0.5 M→	3.9 [b] ± 0.7 H→	3.7 ± 0.4 H→	2.5
Ecotourism	1.1 ± 0.3	1.3 ± 0.4	1.2 ± 0.4 VL	2.8 ± 0.6 M→	3.1 ± 0.5 M→	2.9 ± 0.5 M→	2.4
Education	1.2 ± 0.4	1.2 ± 0.4	1.2 ± 0.4 VL	3.6 ± 0.5 H↑	3.8 ± 0.4 H↑	3.7 ± 0.5 H↑	3.9
Average (C)	1.4 [a] ± 0.2	1.6 [b]± 0.4	1.5 ± 0.3 VL	3.2 ± 0.3 M→	3.5± 0.2 M→	3.3 ± 0.3 M→	2.5
Supporting services (S)							
Habitats for fish	2.0 [a] ± 0.6	2.7 [b] ± 0.4	2.4 ± 0.5 L	2.2 ± 0.6 L↓	2. 5± 0.7 L↓	2.3 ± 0.6 L↓	0.6
Soil formation	1.0 [a] ± 0.0	1.2 [b] ± 0.3	1.1 ± 0.2 VL	2.7 ± 0.6 M→ *	2.9 ± 0.4 M→	2.8 ± 0.5 M→	2.6
Latrine site	1.0 ± 0.0	1.1 ± 0.1	1.0 ± 0.1 VL	X	3.0 ± 0.0 M→	1.5 ± 0.5 VL→	#
Average (S)	1.3 [a] ± 0.2	1.6 [b] ± 0.3	1.5 ± 0.2 VL	1.6 [a] ± 0.3 L→	2.8 [b] ± 0.7 M→	2.2 ± 0.5 L→	1.3

Means with different superscript letters within rows are significantly different at $p < 0.05$. The importance was estimated with a Likert scale, where; 1 = not important, 2 = least important, 3 = second most important and 4 = most important. A Likert scale for the status and demand of ES was analyzed as: VL (1-1.5 = very low), L (1.6-2.5 = low), M (2.6-3.5 = medium), and H (3.6-4.0 = high). The symbols ↓, → or ↑ indicate declining trend, no change and increasing trend for ES, respectively. SD = Standard deviations. * = The stated service was identified by only one village within the group. X = The stated service was not identified. # = not calculated. The management index for a service was calculate as = (status + trend)/demand. The trend was estimated as 1 = increase, 0 = no change, and -1= decrease. Red (< 1), yellow (1-2), and green (> 2) colors indicate the services with high, medium and low need for management interventions, respectively.

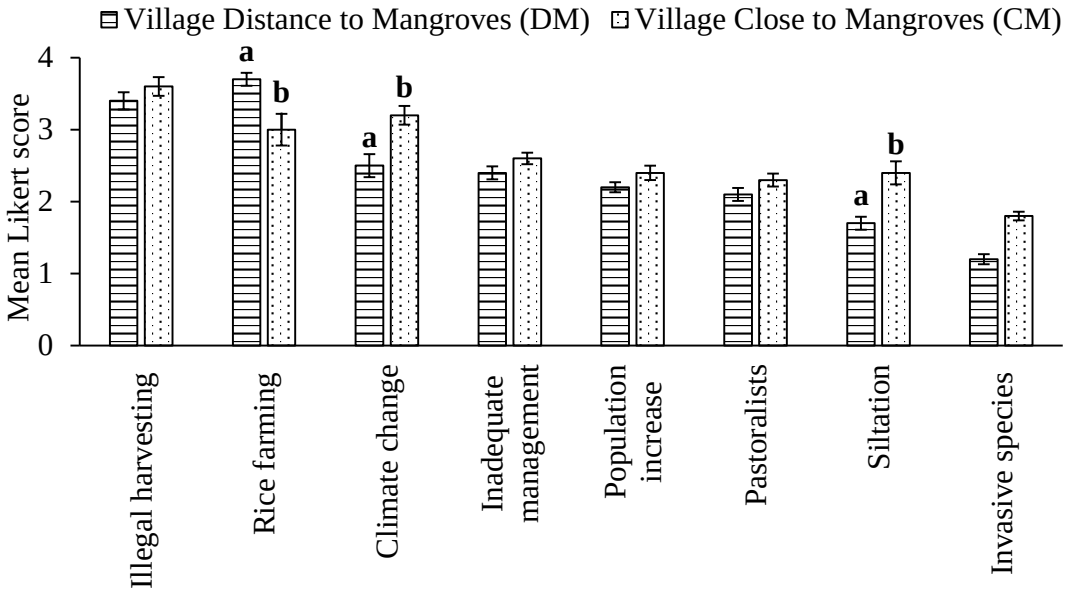

Figure 5: Perceived drivers of change on mangrove ecosystems and their services during the last 10 years (2008-2018) according to the household survey. Bar marked with different letters within the same drivers indicate significant difference at $p < 0.05$. Likert score for 1= low importance, 2 = medium importance, 3 = high importance, and 4 = very high importance. Error bars represent SE.

3.4 Determinants of mangrove exploitation and management (Paper III)

To identify factors that determine the use of mangrove resources, respondents who indicated to extract mangrove resources to sustain their subsidence or commercial needs were classified as mangrove reliant, whereas those who did not extracted any resources were labelled as mangrove non-reliant (Table 4). Of those surveyed, almost 70% of the households were mangrove reliant and 30% were mangrove non-reliant in Bweni, while in Pangani Magharibi 40% and 60% were mangrove reliant and mangrove non-reliant, respectively. In both sites, fishers (30% in Bweni, and 17% in Pangani Magharibi), and farmers (13% in Bweni and 7% in Pangani Magharibi) relied more on mangrove resources compared to other occupants (Table 4). Reliance on mangrove resources was significantly predicted by household residence time, household main occupation, household size, and the cost of alternative resources to substitute mangrove wood as a source of domestic fuel (Table 5). An increase in a unit of these factors contributed to the increase in the number of people who were involved in the extraction of mangrove resources to meet their livelihoods in the studied communities. Surprisingly, level of education did not have a significant impact on mangrove exploitation, indicating that many people, regardless of their educational background, exploited mangrove resources (Table 5).

Table 6 summarizes community opinions on the efficacy of mangrove forest management interventions for sustainable mangrove utilization and conditions in the studies communities. Over half of the respondents (56%) in Bweni agreed (agreed and strongly agreed responses) that interventions by Beach Management Units (BMUs) enhanced

mangrove conditions, whereas only about 16% of the respondents in Pangani Magharibi had similar perceptions (Table 6). Overall, 55% of respondents were dissatisfied with the performance of government agencies (TFS and DFO) in implementing conservation measures for long-term mangrove use (Table 6). The majority of respondents in Bweni (47 %) were also satisfied with the ability of the village council to collaborate with some members of the local community to resolve disputes on mangrove use, whilst only 30% in Pangani Magharibi held similar views (Table 6).

Table 4. Household reliance patterns on mangrove resources by occupation in the study area (n = 30 per site).

Site	Occupations	Mangrove reliant	Mangrove non-reliant	Total
Bweni	Farmers	13.3	6.7	20
	Fishers	30	6.7	36.7
	Civil servants	6.7	6.7	13.4
	Food vendors	13.3	3.4	16.7
	Livestock keepers	3.3	3.3	6.6
	Others	3.3	3.3	6.6
	Total	69.9	30.1	100
Pangani Magharibi	Farmers	6.7	26.6	33.3
	Fishers	16.7	10	26.7
	Civil servants	6.7	10	16.7
	Food vendors	6.7	3.3	10
	Livestock keepers	3.3	6.7	10
	Others	0.0	3.3	3.3
	Total	40.1	59.9	100

Table 5. Binary logistic regression model for socio-economic factors influencing on mangrove resource exploitation in the study area (n = 60).

Drivers	B	SE	Sig	Exp (β)
Gender of household head	1.12	1.55	0.07	3.08
Age of household head	-0.10	0.07	0.14	0.90
Household size	1.12	0.55	0.04*	3.07
Level of education	-0.19	0.28	0.09	0.82
Household Main occupation	3.80	1.78	0.03*	4.67
Residence time of household	1.35	0.15	0.02*	1.42
Cost of alternative resources	1.02	0.02	0.03*	2.02
Household income	-0.03	0.02	0.12	0.96
Constant (Intercept)	-2.77	3.15	0.38	0.06

* indicates significant drivers at $p < 0.05$, SE is standard error, β is the coefficient of regression. A positive sign (+) of the coefficient (β) indicates that a unit increase in a specific variable could increases the number of people involved in mangrove resource extraction by a factor of the observed odd (Exp β), and vice versa for negative sign. Mangrove extraction (dependent variable) was assessed by yes or no responses, where respondents were asked if they had extracted any resources from mangroves for their livelihoods or not.

Table 6. Percentage responses on perceptions of effectiveness and enforcement of mangrove forests management interventions in the study area based on household surveys.

Strategy	Conservation statements	Category	Bweni	Pangani Magharibi	Overall
Establishment and support by BMUs	Improved condition of mangroves	Strongly disagree	0.0	16.7	8.4
		Disagree	16.7	46.7	31.7
		Neutral	26.7	20.0	23.4
		Agree	40.0	10.0	25.0
		Strongly agree	16.7	6.7	11.7
	Facilitation of by-laws and enforcement	Strongly disagree	16.7	20.0	18.4
		Disagree	43.3	30.0	36.7
		Neutral	20.0	26.7	23.4
		Agree	16.7	16.7	16.7
		Strongly agree	3.3	6.7	5.0
Rehabilitation and collaborative arrangements promoted by conservation actors	Effectively engaged community	Strongly disagree	0.0	3.3	1.7
		Disagree	30.0	40.0	35.0
		Neutral	33.3	20.0	26.7
		Agree	13.3	16.7	15.0
		Strongly agree	23.3	20.0	21.7
	Enhanced community willingness	Strongly disagree	10.0	13.3	11.7
		Disagree	3.3	0.0	1.7
		Neutral	23.0	20.0	21.7
		Agree	43.3	46.7	45.0
		Strongly agree	20.0	20.0	20.0
	Enhanced community awareness	Strongly disagree	10.0	6.7	8.3
		Disagree	46.7	43.3	45.0
		Neutral	20.0	30.0	25.0
		Agree	13.3	6.7	10.0
		Strongly agree	10.0	13.3	11.7
Enforcement of laws and decision making by government agencies	In-adequate enforcement measures by TFS and DFO	Strongly disagree	23.3	30.0	26.7
		Disagree	10.0	16.7	13.3
		Neutral	6.7	3.3	5.0
		Agree	56.7	46.7	51.7
		Strongly agree	3.3	3.3	3.3
	Conflict resolution by village council	Strongly disagree	16.7	23.3	20.0
		Disagree	16.7	30.0	23.4
		Neutral	20.0	16.7	18.4
		Agree	26.7	16.7	21.7
		Strongly agree	20.0	13.3	16.7

BMU= Beach management unit, TFS = Tanzania Forest Services, DFO = District Forest Officer

3.5 Perceived impact of climate change, EbA and community-based measures to risks associated with climate change and variability (Paper IV).

Local communities identified a general decrease in rainfall (62% of the responses in CM, and 43% in DM), increased temperatures (47% in CM and 55% in DM), and the incidence of sea level rise (32% in CM and 8% in DM) as key changes associated with changing climate in their area (Figure 6). Although the majority of respondents in DM villages reported a decrease in coastal flooding, many inhabitants in CM villages (52%) felt that occurrence of coastal flooding had increased during the last 10 years in their area (Figure 6). There were no significant differences regarding perceptions on changes in rainfall and temperature among the respondents between CM and DM villages, but the perceived changes in sea level rise ($\chi 2$ =10.954, $p < 0.001$) and coastal flooding ($\chi 2$= 20.095, $p < 0.001$) across the respondents in the study area differed significantly between these two groups (Figure 6). Farming and fishing were perceived to be the most impacted livelihood occupations by climate change and variability (Table 7). Lower rice yields owing to reduced rains, as well as reduced fish yields due to the destruction of fish habitats by sea level rise and other non-climatic stressors, were the most severely impacted mangrove-based livelihoods in the study area (Table 7). Food security, local climate regulation and coastal protection were identified as the most important roles of mangroves in assisting communities to adapt to the impact of climatic change and variability (Table 8). Because of their proximity to mangroves, respondents from the CM village rated the use of MES for EbA as more important than those from the DM villages (Table 8). Interestingly, some responders mentioned the mangrove's role as a carbon sink in the tackling climate change (Table 8). Changing occupations and crop diversification were the most common community-based measures to adapts to the impacts of environmental change, such as climate change and variability in the study area, though perceptions differed depending on household occupations (Table 9). Farmers and fishermen indicated that they had employed more options as ways to reduce the consequences of climate change and variability than other occupational groups in the study area (Table 9).

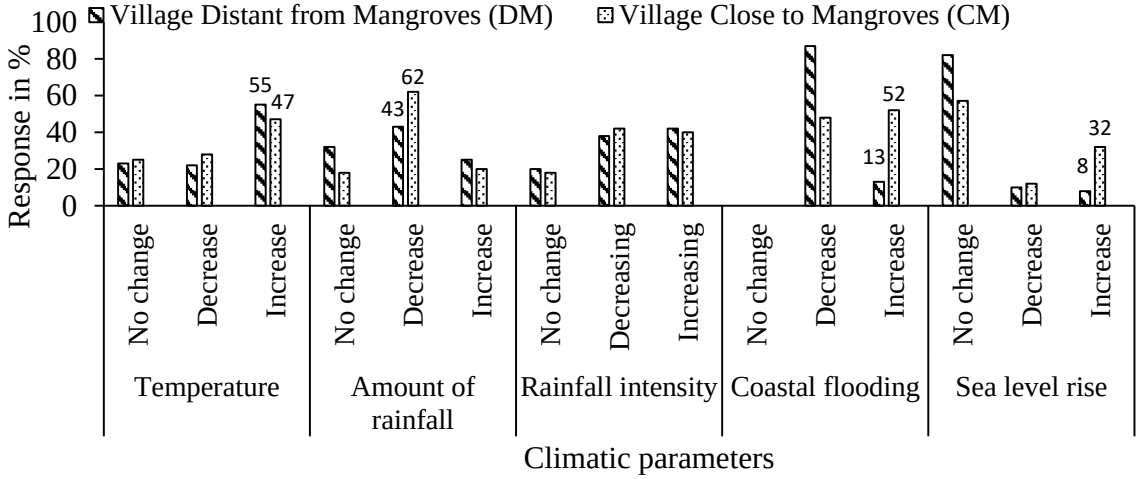

Figure 6. Perceived climate change during the last 10 years (2009-2019) in the study area according to the household survey (n = 60 per village).

Table 7. Perceived impact of climate change on mangrove-based livelihoods during the last 10 years (2008-2018) by occupations in the study area.

Observed impacts	Farmers	Fishers	Mangrove cutters	Small business	Public servants	Others	Total
	(n = 40)	(n = 28)	(n = 11)	(n = 29)	(n = 5)	(n = 7)	(n = 120)
	Mean ± Standard deviation						
Decline in rice yields due to decreased rains	3.8 ^{a} ± 0.6	3.6 ^{a} ± 0.6	3.5 ^{a} ± 0.5	2.3 ^{b} ± 0.3	2.6 ^{b} ± 0.4	3.0 ^{b} ± 0.3	3.1 ± 0.4
Reduced fish yields due to destruction of habitats for fish by sea level rise, and other non-climatic stressors	3.5 ^{a} ± 0.3	3.8 ^{a} ± 0.4	2.8 ^{b} ± 0.7	2.2 ^{b} ± 0.6	2.2 ^{b} ± 0.6	2.6 ^{b} ± 0.7	2.8 ± 0.5
Low production of honey due to prolonged droughts, which distress wild bees for pollination	2.4 ± 0.9	2.2 ± 0.8	2.5 ± 0.8	2.4 ± 0.8	2.2 ± 0.7	2.0 ± 0.7	2.3 ± 0.8
Depletion of firewood for cooking due to mangrove die off by both climate change (dry spell), illegal harvesting and population growth.	2.4 ^{a} ± 0.5	2.6 ^{a} ± 0.4	2.2 ^{a} ± 0.4	1.9 ^{b} ± 0.2	1.0 ^{c} ± 0.0	2.3 ^{ab} ± 0.3	2.1 ± 0.3
Damage of house and property due to flooding	2.3 ^{a} ± 0.6	2.4 ^{a} ± 0.6	1.9 ^{a} ± 0.5	1.8 ^{b} ± 0.1	1.0 ^{c} ± 0.0	1.6 ^{b} ± 0.2	1.8 ± 0.3
Overall	2.8 ± 0.6	2.9 ± 0.6	2.5 ± 0.6	2.1 ± 0.4	1.8 ± 0.3	2.4 ± 0.4	2.4 ± 0.5

Means with different superscript letters within rows are significantly different at $p < 0.05$. Likert scale: 1= low impact, 2 = medium impact, 3 = high impact and 4 = very high impact

Table 8. Perceived importance of mangrove ecosystem services for ecosystem-based adaptation to risks associated with the negative effects from climate change and variability during the last 10 years in the study area.

Perceived benefits	Village Distant from mangroves (DM, n = 60)	Village Close to Mangroves (CM, n =60)	Overall
	Mean ± Standard deviation		
Mangroves provide food security (fish and honey) that are used for subsistence and income source during decreased crops yield.	3.4 [a] ± 0.8	3.7 [b] ± 0.5	3.5 ± 0.6
Mangroves provide shade, influence rainfall and cool temperature (climate regulation).	3.2 [a] ± 0.4	3.5 [a]± 0.3	3.3 ± 0.3
Mangroves provide coastal protection and protect lives from flooding caused by intense rains.	2.4 [a] ± 0. 6	2.9 [b] ± 0.2	2.6 ± 0.4
Flooded alluvial soils in mangrove areas provide suitable site for rice farming in case of increased temperature and drought in upland areas.	2.6 [a] ± 0. 5	2.2 [b] ± 0.3	2.4 ± 0.4
Mangrove store carbon to reduce climate change	2.3 [a] ± 0.6	2.5 [a] ± 0.6	2.4 ± 0.6
Mangrove poles and firewood are used as source of additional income in times of difficulty, such as when agriculture production fails.	1.2 [a] ± 0.9	2.4 [b] ± 0.5	1.8 ± 0.7

Means with different superscript letters within rows are significantly different at $p < 0.05$. Likert scale: 1= strongly disagree, 2 = disagree, 3 = agree and 4 = strongly agree

Table 9. Identified community-based measures to climate change and variability by different occupations in the study area during the last 10 years according to household survey.

Strategies	Farmers	Fishers	Mangrove cutters	Small business	Public servants	Others	Total
	(n = 40)	(n = 28)	(n = 11)	(n = 29)	(n = 5)	(n = 7)	(n = 120)
	Mean ± Standard deviation						
Switching occupations	3.5 ^{a}± 0.7	3.7 ^{a} ± 0.6	3.2 ^{a} ± 0.6	2.9 ^{a} ± 0.7	1.8 ^{b} ± 0.3	3.2 ^{a} ± 0.7	3.1 ± 0.6
Crop diversification	3.9 ^{a} ± 0.2	3.4 ^{b} ±0.8	3.1 ^{b} ± 0.7	3.1 ^{b} ± 0.6	2.0 ^{c} ± 0.5	3.0 ^{c} ±0.4	2.9 ± 0.6
Migration to other areas	2.8 ^{a} ± 0.3	3.5 ^{b} ± 0.5	1.7 ^{c} ± 0.6	2.4 ^{a} ± 0.4	1.0 ^{c} ± 0.7	2.2 ^{b} ± 0.6	2.3 ± ± 0.5
Farming in other regions outside the delta	3.4 ^{a} ± 0.4	3.0 ^{a} ± 0.3	2.0 ^{b} ± 0.6	2.0 ^{b} ± 0.8	1.0 ^{b} ± 0. 7	2.0 ^{b} ± 0.6	2.2 ± 0.5
Offshore fishing	2.3 ^{a} ± 0.6	2.6 ^{b} ± 0.3	2.0 ^{c} ± 0.7	2.0 ^{c} ± 0.8	1.0 ^{c} ± 0.8	2.0 ^{c} ± 0.8	2.0 ± 0.7
Remittance from relative in other towns	2.3 ^{a} ± 0.4	2.5 ^{a} ± 0.5	2.4 ^{a} ± 0.4	2.3 ^{a} ± 0.5	1.2 ^{b} ± 0. 7	1.4^{b} ± 0.6	2.0 ± 0.5

Means with different superscript letters within rows are significantly different at $p < 0.05$. Likert scale: 1= strongly disagree, 2 = disagree, 3 = agree and 4 = strongly agree

4. Discussion

The importance, values and multifunctionality of mangrove ecosystems to local communities is often overlooked or underestimated by policy makers when it comes to conservation and management of these critical coastal-marine ecosystems, resulting in inappropriate decision-making for sustainable management (Mangora, 2011; Malik et al., 2015; Nyangoko et al., 2021). There are strong links between coastal communities and mangroves in Tanzania, and hence building on community perspectives by recognizing diverse preferences for MES among local groups is an entry point for instituting effective management intervention. This could help to avoid unwanted trade-offs in ES, fostering trust among resource users and managers, and create a rationale for resource ownership by communities, identifying potential alternative livelihood activities and making appropriate use of multifunctional mangrove forests that could align with long-term management goals and sustainability of mangrove forests (Nyangoko et al., 2021).

As presented in this thesis, mangroves are perceived as vital ecosystems that provide a myriad of ES (benefits) to the livelihoods and well-being of coastal communities (Paper I), but they are jeopardized by overharvesting and illegal exploitation (Paper II and III), conversion to other land uses and climate variability (Paper II and IV), and thus much work remains to be done to increase public awareness and knowledge of ES provided by mangroves (Paper I). The degradation of mangroves has led to reduced fish yields, decreased availability of quality poles, decreased honey production, depletion of firewood, and property damage (Paper II), and generally erodes the resource bases for many poor mangrove-dependent communities living in these areas and the options for these communities to adapt to future environmental changes, including climate change (Paper IV). Although these impacts are well recognized by the studied communities, the government efforts to promote appropriate management interventions that meet the interests of both resource users and conservation priorities are hampered by significant challenges such as limited information about the multifunctionality of mangrove landscapes and access and user rights (Paper I), insufficient human and financial resources, the lack of feasible alternative livelihoods, which are rooted in traditional and cultural context, inadequate community participation in conservation, miscommunication among management institutions (Paper II and III; Mangora, 2011; Mwansasu, 2016) and poor adaptation strategies to environmental changes (Paper IV). As shown in this thesis, some climate-related effects (environmental changes) are already being felt in some areas including the Rufiji Delta (Paper IV), and the continuous deterioration of these ecosystems (Paper II) will impede their potential capabilities to supply ES that could help local communities to respond to and recover from extreme weather events such as floods and sea level rise (Paper IV).

4.1 Determinants of awareness of MES and mangrove resources exploitation

In this thesis, the link between humans and the benefits provided by mangrove ecosystems shows that coastal communities in Tanzania are more aware of provisioning services than regulating, cultural, and supporting services (Paper I), which is in line with what has been reported from other places (López-Santiago et al., 2014; He et al., 2018; Quevedo et al., 2020). This awareness is closely related to the direct socioeconomic value of provisioning

ES to support local livelihoods and well-being (Gouwakinnou et al., 2019; Nyangoko et al., 2021), as contrasted to other categories of MES that are more intangible and difficult to see or quantify (Paper I). Community awareness of all types of MES was strongly influenced by the proximity of household's home to mangroves, because people living near forests (CM) have stronger ties with mangroves and are more reliant on MES for their livelihoods and well-being, and thus are more aware of MES than those residing far from the forests (DM). Residence time was also a strong determining factor for awareness of all MES, as people who had lived in the area for long time would have superior traditional knowledge and historical experience about a variety of services provided by forests than those who had only lived in the forested area for a short time (Paper I; Nesheim et al. 2006). With this knowledge, long-term local dwellers have the opportunity to know where resources can be found, and hence are partly involved with exploitation of mangrove resources for subsistence purposes or income generation (Paper III), a finding which is similar to the observations by Garekae et al. (2017). Proximity and residence time also had influence on factors such as sense of place (e.g. viewing the beauty of the mangrove environment and symbolic site for traditional related activities such as rituals; Paper I), which increase the awareness of mangrove ES. This is in line with the observation that people's attachment to mangrove ecosystems helps them to recognize what these ecosystems have to offer in terms of historical and spiritual ties that people have with the places they inhabit (Queiroz et al., 2017). As shown in Paper I, gender differences in relation to knowledge about provisioning, regulating, and cultural services are closely linked to disparities between men and women in accessing and using mangrove resources (Paper I; Kibria et al., 2018), with men exploiting more resources than women (Eneji et al., 2015; Mensah et al., 2017). However, this observation should be considered with caution because many people irrespective of their gender, could extract resources from mangroves, and gender was not a determining factor for mangrove resource use in the study area (Paper III). The observed awareness of both men and women of supporting services (e.g. habitat for fish and crabs) revealed in this thesis could be due to their shared experience regarding fisheries related activities through for example engagement in a small scale fishing, which is in conformity with observations by Pearson et al. (2019).

Community awareness of provisioning, regulating, and cultural services was also predicted by the interaction between households and management committees (BMUs and VNRCs). However, the observed difficulty in recognizing supporting services by local residents (Paper I), insinuates that existing local management committees do not disseminate adequate information on all possible values and worth of mangroves (Paper I). This could be attributed by the fact that majority of members, who form local institutions have a low level of education (primary) and lack skill-based training for capacity-building and genuine cooperation with local communities on issues related to mangrove conservation (Paper III), a finding that is consistent with other research elsewhere (Begum et al., 2021). The limited promotion of mangroves' multifunctionality by management institutions could also be a reason why respondents did not recognize carbon sequestration as a regulating ES (Paper I), which is not surprising given its invisible nature, where it is hard for local communities to identify and assign value to such ES. However, with a growing interest in managing and protecting coastal habitats (e.g. mangroves, tidal marshes, and seagrasses) as part of global climate change mitigation policies (Quevedo et al., 2020), close collaboration among state

and non-state actors, particularly at the local levels, where people have direct contact with natural resource (Nyangoko et al., 2022), has the potential to promote more awareness about the importance of mangroves in sequestering and storing carbon (Paper IV).

This thesis also shows that although occupation of household was not associated with awareness of MES (Paper I), it is still strongly linked to mangrove resource use, where for example fishermen relied more on fishery and forest products than farmers and small business operators (Paper III), which is in line with reports from other places (Adhikari et al. 2010). Moreover, household size was noticed to be closely related to mangrove dependency, as larger families have greater livelihood needs (Paper III), and therefore relies more strongly on MES, a finding that is consistent with other research elsewhere (Garekae et al., 2017; Handavu et al., 2019). The cost of purchasing alternative energy sources for cooking also greatly influenced the harvesting of mangroves as a source of cheap wood fuel, which concurs with the assessment that most poor and rural families cannot afford to pay for the price of kerosene or electricity as an alternative source of energy for cooking (Doggart et al., 2020). In this thesis, many of the ES provided by mangroves were recognized by both young and old people (Paper I), but the reliance on mangroves was perceived to decreases with respondent age (Paper III), a result that agrees with other findings elsewhere (Garekae et al., 2017). Household income had no significant effect on the identification of MES (Paper I) because many respondents in the studied sites irrespective of their income levels, to some extent relied on goods and ES provide by mangroves as a source of income to meet their livelihoods. This reliance was linked with a low level of education among the majority of respondents in the study areas (Paper I, II, III and IV), which in turn limited people ability to search for formal employment at the government and private sectors, and hence exert pressure on mangrove resources (Paper III), a finding that is consistent with observation by Okello et al.(2019). However, the observed negative coefficient linked to the variable "household monthly income" tentatively suggests that as income grows, the extraction of mangrove resources tend to fall, as those with higher income could access alternative resources (Paper III; Satyanarayana et al., 2013).

4.2 Relative importance (demand), status (supply) and threats of MES and their management

Among all MES recognized by the local communities, provisioning ES were ranked highest in support of local livelihoods (Paper I). They were also often perceived to be in a declining state (Paper II). This observation is linked to the direct values and importance of these services to human well-being, a finding which show similarities with what has been documented from other communities outside Tanzania (Gouwakinnou et al., 2019; Wangchuk et al., 2021). The thesis also reveals that demand (importance) and supply (status) for various MES vary between communities, due to factors such as village proximity to mangrove forests, management measures, availability of alternative livelihoods, harvesting activities, population growth, and natural factors like climate variability (Paper II and IV). For example, demand for flood control was felt to be high in locations where people were at risk of flooding, while demand for poles was seen in areas where alternative building materials, such as cement and iron sheets, were in limited supply

(Paper I). The noted decline in many mangrove ES, particularly in the CM villages (Paper II), was caused by over-extraction of mangroves to meet people's demand in these villages (Nyangoko et al., 2021). This implies that a high demand of ES often leads to an increased pressure that may lead to a decreasing supply of ES and therefore a need for more urgent management actions as indicated by the management index (Paper II; Maron et al., 2017). The declining trends in MES due to overexploitation by coastal inhabitants as revealed in this thesis are also evident elsewhere (Quevedo et al., 2020). Local residents felt that the conditions (status) of mangrove and their ES could continue to deteriorate or improve depending on management measure undertaken in terms of access rights, participatory forest management (PFM), and availability of alternative livelihoods (Paper II and III; Okello et al., 2019). A good collaboration between local institution such as BMUs and local communities, make people willing to disclose illicit activities as observed in Bweni, whereas in the absence of close cooperation and trust, illegalities persist to cause degradation, as seen in Pangani Magharibi (Paper III).

The thesis also shows that, while Tanzania forest policy calls for PFM with local communities to safeguard mangroves, PFM in Tanzania has never been used as envisioned, and the strategies for shared management responsibilities and partnerships between government agencies and local communities are not clearly defined in the laws (Paper II and III). Poor people who often rely on these resources for a livelihood are viewed by policymakers as drivers of mangrove deterioration rather than being partners in conservation (Mangora, 2011; Nyangoko et al., 2021). All decisions are also made by the government rather than the people who live near the forests (paper III; Beymer-Farris and Bassett 2013, Mwansasu 2016, Mshale et al., 2017). Strict controls, including reintroduced ban measures in 2016, had also incensed and dispossessed a large number of mangrove-dependent households of their livelihoods (Nyangoko et al., 2021). This has exacerbated a disharmony between the government and mangrove-dependent communities, and illegal logging persists to endanger mangroves (Paper II, III, and IV). The threats and pressures that impact on mangroves and their associated services revealed in this thesis are context specific, which concur with observations from other studies (Quinn et al. 2017, Maina et al. 2021). For example, while rice farming was revealed as a causative agent of mangrove loss in communities far from mangrove forests (DM), illegal exploitation and climate change were recognized as main drivers in societies close to mangroves (CM) (Paper II and IV). Conversion of mangroves for rice production had a negative impact not only on the loss of mangrove habitat for biodiversity conservation, but also, to some extent, has deteriorated the supply of other important ecosystem services, particularly those tied to the long-term functioning of the mangrove ecosystem (Paper II; Monga et al., 2018). For example, degradation of mangrove forests due to rice farming and perceived climate change have resulted in changes in natural beauty and availability of pollinating insects, which in turn has adversely effects on bee health and development, making them less likely to reproduce and thus contributing to reported low status and declining trend of honey (Paper II), and undermines the ability of the biophysical environment to support people livelihoods and well-being (Paper IV). In this thesis, it is shown that mangroves are under multiple stresses in the studied areas (Paper II), and that socioeconomic pressures exercised by humans and mismanagement (Paper III), have a greater impact on mangrove

degradation in Tanzania than climate change and variability (Paper II and IV), which is in agreement with the findings of Maina et al. (2021).

4.3 Relevance of MES for EbA and community-based adaptation measures to risk associated with climate change and variability

The findings in Paper IV highlight the importance of mangroves and their associated ES in reducing the impacts of environmental stresses, such as risks associated with changes in climatic parameters. Due to natural fluctuations in winds, humidity, and the dynamic of tropical circulation, climate conditions in Tanzania vary, with some areas having warm temperatures and dry conditions and others experiencing cool temperatures and heavy rainfall (Borhara et al., 2020). For the past decades, warmer temperatures and variability of rainfall with a declining trend are being experienced along Tanzania's coasts (Kashaigili et al., 2014; Kabanda, 2018), which is consistent with the perceptions of local communities, who had noticed an increase in temperature and a decrease in rainfall during the last decade (Paper IV). However, the climatic changes perceived by the studied communities were probably reflecting more on climatic variability over seasons or a year than climate change over more extended periods of time (10 years). Due to the nature of local livelihoods, which often are rooted in local climate seasonality, farmers and fishers more often recognized issues related to change in climatic parameters than small businessmen and public servants (Paper IV). For example, variability in annual rainfall and seasonal floods, which control many activities in the delta, were identified by farmers and fishers as a major cause of inconsistency in agricultural and fisheries yields in the studied communities (Paper IV; Yanda et al. 2019).

Many of the respondents felt that they had been impacted by climatic stress, and mangrove ecosystems was seen as an important way to adapt to the effects of a changing climate through EbA strategies (Paper IV). EbA involves the use of ecosystems and their associated ES in helping people in adapting to the negative effects of climate change and variability (Nalau et al., 2018). Most respondents revealed that MES such as poles, firewood, and fish resources provided important safety nets during periods of agricultural crop failure, due to dry spell and increased climate variability (Paper IV). Respondents' reliance on forest resources to sustain subsistence and economic needs during period of climatic stresses revealed in this thesis has also been reported elsewhere (Pramova et al., 2012; Kupika et al., 2019). However, the potential of using ecosystems and their associated ES as part of EbA strategies depend on geographical setting, the health of the ecosystem and climatic risks that needs to be tackled, as well as policies and institutional arrangement undertaken to implement such adaptation (Huq et al., 2017). For example, CM villages reported more uses of mangroves for EbA strategies to reduce climatic stresses than DM villages, partly due to their proximity to mangroves. During the FGDs in the study areas, some participants stated that an improved clarity on access and use rights to mangrove resources would lead to improved management in the future. This is urgently needed, as recent and ongoing illegal exploitation of mangroves has resulted in mangrove degradation, which in turn has to some extent reduced the mangroves ability to provide ES for EbA strategies to deal with current and future environmental stresses such as climate change. This suggests that, although MES are becoming more widely recognized as a locally relevant means for EbA

to climatic stresses, an excessive dependence on mangroves could also lead to mangrove deterioration, if mangrove uses are not well managed and protected in close partnership with local communities. As shown in this thesis, human pressures (Paper II), have together with climate change accelerated the loss of mangroves in the studied communities, which in turn have adversely impacted on the livelihoods of coastal communities, who directly or indirectly rely on these ecosystems for their well-being and livelihoods (Paper IV). Still, community members have also adapted to climatic risks through social-based measures such as changing occupations, temporarily relocating to other areas to seek alternative livelihoods, or by moving their fishing efforts further offshore, which can help to decrease the pressure on mangrove ecosystems. These results are in line with some findings from previous studies (Amos et al., 2015; Yanda et al., 2019). However, not all communities are able to adapt to the impacts of climate change and variability in a sustainable manner (Nyangoko et al., 2022), and the involvement of government entities in managing these ecosystems is important for developing new sustainable adaptation options (Paper IV). Hence, adaptation strategies should not be promoted in isolation, but EbA strategies and social-based measures should be applied in a complementary and sustainable way, and by considering the heterogeneity of local contexts and equitable partnerships with a variety of actors (government agencies and non-government stakeholders).

5. Conclusion

Mangrove ecosystems and associated ES are perceived as a valuable asset for the livelihoods and well-being of many coastal communities in Tanzania. This thesis validates such views by highlighting the strong link between MES and community well-being and livelihoods. Despite this, many MES are being degraded by a multiple drivers of change, which decreases these social-ecological systems ability to adapt to future stresses, including climate change. These processes and how they are managed were studied using the Rufiji Delta and Pangani Estuary as case study sites. Awareness, importance, and decrease of provisioning services were more commonly reported by communities than for regulating, cultural and supporting services, due to their direct relevance to society. Proximity to mangrove forests and household residence time had a positive influence on local people's ability to recognize mangrove ES. Household residence time, household main occupation, household size, and the cost of alternative resources to substitute mangrove wood as a source of domestic fuel were significant predictors of mangrove resource utilization. Reduced fish yields, decreased availability of quality poles, decreased honey production, depletion of firewood, and property damage were the most perceived impacts of mangrove changes on local people's livelihood and well-being. As shown in the thesis, mangroves and their associated services are deteriorated by both human and natural disturbances, and their strength and impact are site specific, depending on the social-ecological context. Illegal mangrove harvesting, rice cultivation, climate variability, and inconsistent management interventions and enforcement (inadequate governance and conservation measures) are cited as key factors for mangrove degradation in Tanzania. Reliance on MES as a basis for EbA strategies, switching of occupation, diversifying crops, offshore fishing, and migrating to other areas were the most commonly identified adaptation options in the studied communities. Designing appropriate management interventions that recognize and appreciate interests and priorities of local people is crucial in shaping the future of sustainable mangrove management strategies. To efficiently

accomplish this, raising more awareness about the multifunctionality of mangroves, and practical adherence to PFM with clear mechanisms for engaging communities in mangrove managements is reemphasized as way forward for sustainable mangrove management. Reclassification of mangroves as special ecosystems rather than being labelled as forest reserves could also suit the interests of multiple sectors and provide harmonization in their use and management. Diversifying livelihood options and investing in mangrove conservation activities by providing adequate funding for conservation over the long term rather than relying on short-term international donor-funded projects that are often insufficient, site-based, and time-constrained, are also recommended to government institutions as a basis for sustainable management of mangrove forests in Tanzania.

6. Future research

The findings of this thesis have a number of implications for future research on mangrove ecosystems as emphasized below:

- Since the findings of this study are more based on stakeholders' perceptions and literature reviews, additional research using remote sensing and ArcGIS to explore the spatial distribution of mangrove landscapes and the flow of MES over time and in space should be carried out to complement the study.

- The perceived decline in MES noted in this thesis necessitates further research based on the high classification accuracy of remote sensing technique and climate modeling to estimate their recovery rates and trends following climatic and non-climatic disturbances, so as to explore and reveal future potential of mangroves to supply ES.

- Since many of the adaptive measures highlighted in this thesis are based on community perceptions, more studies should also be done on how different conservations actors can support local adaptations in mangrove forested areas and how these can help in shaping sustainable livelihoods. Further research on alternative livelihoods which are locally acceptable by traditional and cultural context of mangrove-dependent communities is also needed, as many conservation actors often come with ready-made alternatives that are often incompatible with local contexts.

- More studies should also be carried out on how the use of approaches such as media, school curricula, workshops, conferences, video and documentary films can promote mangrove ecosystem protection and awareness. This can emphasize and raise more awareness about the social, cultural, economic, and ecological importance of different types of MES for people and the environment, and could increase community willingness to participate in management and conservation of mangroves.

- Following the transformation of TFS into a paramilitary agency in 2021, and the existence of different management strategies in the Rufiji Delta, an assessment of the implications of this transformation is needed, as the use of a paramilitary forces to protect natural resources perhaps could result in contradictory decisions, unjust outcomes for PFM, and negative perceptions about the conservation of these ecosystems.

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