Natural Capital Assessment for Development Corridor Projects

Case study for the Special Agri-Industrial Processing Zone of the Pemba-Lichinga Integrated Development Corridor, Mozambique

2023

Promotion of Green Economy and valuing natural capital in Africa

GGKP | WWF | UN environment programme WCMC | Groupe de la Banque Africaine de Développement / African Development Bank Group

PHOTO CREDIT (FRONT PAGE): Oleksandr / stock.adobe.com.

CITATION: GGKP (2023). Natural Capital Assessment for Development Corridor Projects: Case study for the Special Agri-Industrial Processing Zone of the Pemba-Lichinga Integrated Development Corridor, Mozambique. Geneva: Green Growth Knowledge Partnership.

ACKNOWLEDGEMENTS:

This report was prepared for the Mainstreaming Natural Capital in African Development Finance (NC4-ADF) Initiative led by the Green Growth Knowledge Partnership (GGKP), African Development Bank (AfDB) and World Wide Fund for Nature (WWF) by:

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The UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is a global centre of excellence on biodiversity. The centre operates as a collaboration between the United Nations Environment Programme and the UK-registered charity WCMC.

This study provides scientifically sound evidence of applying natural capital approaches for an infrastructure finance project in Africa as a key output of the NC4-ADF initiative. The NC4-ADF initiative was led under the technical guidance of **Sun Cho** (GGKP), **Innocent Onah** (AfDB) and **Durrel Halleson** (WWF) alongside a team of experts from the three organizations and a joint implementation institution – **Peter Scheren** (WWF), **Koeun Lee** (GGKP), **Nkoanyane Cornelius Sebutsoe** (AfDB), **Tendai Chinho** (WWF), **Koffi Kpognon** (AfDB), **Johannes Kruse** (GIZ) and **Elias Huland** (GIZ). The initiative was supervised under the leadership of the co-chairs **John Maughan**, Coordinator of Secretariat (GGKP), and **Vanessa Ushie**, Acting Director, African Natural Resources Management and Investment Centre (AfDB). Its vision was set up by **Kevin Urama**, Acting Chief Economist and Vice President for the Economic Governance and Knowledge Management Complex (AfDB) as a result of the GGKP Natural Capital Expert Group's collaborative work. The NC4-ADF initiative was implemented and developed with generous support from the MAVA Foundation for Nature and the Federal Ministry of Economic Cooperation and Development of Germany (BMZ), implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

The authors are grateful to **Alima Taju** (WWF Mozambique)**, João Neto** (Embassy of Sweden, Maputo), **Paulo Junior** (Embassy of Sweden, Maputo), **José Hoogervorst** (Netherlands Development Organisation, SNV)**, Hilário Sitoe** (SNV), **Jeffrey Phiri** (SNV), **Patricia Baptista** (AfDB), **Cesar Tique** (AfDB), **John J. Maughan** (GGKP), **Sun Cho** (GGKP), **Koeun Lee** (GGKP)**, Laurent Belanger** (GGKP) and **Ela Mesinovic** (GGKP) for contributing data and input to the report as well as for providing feedback on the preliminary and final drafts of the study. The authors are also grateful to participants of the Capital Natural para uma Economia Verde em Moçambique meeting in Maputo on 29 June 2022 for their feedback on the initial proposal for the case study presented in this report.

The production of this report was supported by the GGKP Secretariat and, in particular, the GGKP Knowledge Generation and Application Programme (KGAP) led by **John J. Maughan**. The production of the report was stewarded by the KGAP team including **Sun Cho, Brittany King** and **Noémie Bricard. Mark Schulman** provided copy editing.

We sincerely thank the authors, contributors and reviewers for making this work possible.

The Green Growth Knowledge Partnership (GGKP) is a global community of organizations and experts committed to collaboratively generating, managing and sharing green growth knowledge. Led by the Global Green Growth Institute (GGGI), Organisation for Economic Co-operation and Development (OECD), United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO) and World Bank Group, the GGKP draws together over 90 partner organizations. For more info, visit www.greengrowthknowledge.org

This study received principal funding from the Federal Ministry for Economic Cooperation and Development (BMZ), implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and financial support from the MAVA Foundation for Nature for its outreach and stakeholder engagement events.

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Table of Acronyms

AC	Aggregation Centres
AfDB	African Development Bank
APH	Agro-industrial Processing Hubs
ATC	Agricultural Transformation Centres
BCR	Benefit Cost Ratio
BII	Biodiversity Intactness Index
CBA	Cost Benefits Analysis
CIESIN	Consortium for International Earth Science Information Network
COVID-19	Coronavirus Disease 2019
DFIs	Development Finance Institutions
ENAMMC	Mozambique National Strategy for Climate Change
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
GCM	General Circulation Model
GDP	Gross Domestic Product
GEAP	Green Economy Action Plan
GER	Green Economy Roadmap
GFDRR	Global Facility for Disaster Reduction and Recovery
GGKP	Green Growth Knowledge Partnership
GIZ	German Agency for International Cooperation
GoM	Government of Mozambique
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
MMF	Morgan–Morgan–Finney
NbS	Nature-based Solutions
NC4-ADF	Natural Capital for African Development Finance
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NHM	Natural History Museum
NPV	Net Present Value

NTFPs	Non-Timber Forest Products
OECD	Organisation for Economic Co-operation and Development
PPE	Personal Protective Equipment
PREDICTS	Projecting Responses of Ecological Diversity in Changing Terrestrial Systems
RCP	Representative Concentration Pathway
REDD+	Reducing emissions from deforestation and forest degradation, conservation of existing forest carbon stocks, sustainable forest management and enhancement of forest carbon stocks
SAPZ	Special Agri-Industrial Processing Zone
SDGs	Sustainable Development Goals
SEEA EA	System of Environmental-Economic Accounting Ecosystem Accounting
SPHY	Spatial Processes in Hydrology
TZS	Tanzanian Shilling
UN	United Nations
UNEP	United Nations Environment Programme
UNEP-WCMC	UN Environment Programme World Conservation Monitoring Centre
USAID	United States Agency for International Development
USD	United States Dollar
WCED	World Council on Environment and Development
WEF	World Economic Forum
WWF	World Wide Fund for Nature

Executive Summary

Nature is at the heart of many economic activities, such as agriculture, forestry and fisheries. It also contributes in many ways to maintaining safe and comfortable environments for people and communities, as well as being important for cultural reasons. However, continuing nature loss under the current economic development pathway is widely acknowledged as a fundamental barrier to sustainable development.

In Africa, the need to mainstream nature (or natural capital) into development planning is recognized in the aspirations of Agenda 2063. The African Union Green Recovery Action Plan (2021-2027) highlights the continental vision of restoring and sustainably managing ecosystems for economic recovery and job creation. In different African nations, investing in natural capital for economic development is also being integrated into national green economy policies, action plans and strategies.

To support green economic transition and a green post-COVID recovery in Africa, there is an urgent need to help financial institutions and governments make more nature-positive investment decisions on a routine basis. Recognizing this, the Green Growth Knowledge Partnership (GGKP), African Development Bank (AfDB) and World Wide Fund for Nature (WWF) launched the Natural Capital for African Development Finance (NC4-ADF) project in 2021.

This report provides a contribution to the NC4-ADF project. The report is targeted at those in financial institutions and national governments in Africa involved in appraising, planning and implementing large-scale development projects. However, it is likely to be of interest to a wider audience concerned with better integration of nature into development planning. The report aims to build a common understanding around natural capital concepts and approaches, which will be new to many. It also presents a state-of-the-art natural capital assessment for the Pemba-Lichinga Integrated Development Corridor in Northern Mozambique (Phase 1), which is funded by AfDB's Special Agri-Industrial Processing Zone (SAPZ) project.

Natural capital assessments quantify, map and, sometimes, value the benefits nature provides. They inform natural capital approaches for development project design and implementation, for example. These are approaches that recognize and mitigate natural capital impacts that lead to unintended economic and social welfare losses. They also identify and capture opportunities for natural capital investments to deliver economic and social benefits. The natural capital assessment for the SAPZ project in northern Mozambique explores possible trade-offs and synergies between cropland intensification as a land-use (project baseline scenario) and investment to reforest riparian croplands and develop agroforestry in existing croplands (natural capital approach scenario).

The natural capital approach scenario for the SAPZ project demonstrates how an integrated landscape management approach can deliver on multiple development objectives. It estimates the increases in benefits from improved dry season water flows, avoided sedimentation of watercourses, climate change mitigation and wood fuel supply in physical and monetary terms under the natural capital scenario, compared to the project baseline scenario. Based on this partial economic analysis, returns from establishing riparian forest and agroforestry ecosystems in current cropland areas are estimated to be $42/ha/year in terms of benefits to Mozambique based on the four ecosystem services valued. This increases to $90/ha/year when global costs of climate change mitigation are included (i.e. when the US social cost of carbon is applied to value climate change mitigation benefits). By way of comparison, studies suggest conventional tillage maize farming in Mozambique generates profits of around $100/ha/year. However, it should be recognized that economic benefits realized through agroforestry crop production are not yet monetized under the natural capital approach scenario.

Additional co-benefits under the natural capital approach scenario include improved pollination (cropland with sufficient pollinators increases by 221 hectares) and increases in biodiversity

(biodiversity intactness index increases by 4%). Additional ecosystem services likely to be supplied under the natural capital approach scenario include wet season flood mitigation, provisioning of non-wood forest products and regulation of pest damage. However, it has not been possible to estimate the magnitude or value of these services without additional, more local data.

The natural capital assessment can be used by SAPZ designers to inform nature-based solutions to agricultural irrigation issues, delivering wider community benefits (e.g. wood fuel security) and achieving national objectives for climate change mitigation and biodiversity. It can also help planners recognize the benefits that better integration of natural capital into agricultural development projects elsewhere in Africa could realize.

Mainstreaming natural capital approaches into these types of development projects can foster transition to green economies, where these projects deliver better outcomes for nature and people in landscapes and seascapes. Development finance institutions will play a key role in delivering this. They can help build the knowledge and capacity for mainstreaming natural capital into development planning in Africa (i.e. by embedding natural capital assessment in project appraisal). Also, by recognizing the additional benefits nature provides in their decision-making, they can create the enabling environment to favour financing nature-positive investments and nature-based solutions. In this way, they can work with government and other partners to overcome some of the barriers to implementing natural capital approaches that many projects face.

1. Introduction

The economic development pathway of the 20th and 21st centuries is characterized by accumulation of produced and human capital, at the expense of natural capital (Dasgupta, 2021; UNEP, 2011). This has created a situation where humanity's demands on nature are now unsustainable. This is affecting the benefits the economy and society receives from nature and pushing it towards tipping points, beyond which sharp declines in benefit flows are expected (WEF, 2020; World Bank, 2021b).

Addressing nature loss in Africa and around the world requires transition to an economic development pathway that redirects substantial financial flows into nature-positive investments, and away from activities that negatively impact nature (Dasgupta, 2021; WEF, 2020). Such a transition can generate many new business opportunities, jobs and well-being benefits. The World Economic Forum (WEF) highlights transitioning to nature-positive food, land and ocean use systems may generate over $3.5 trillion in business opportunities and nearly 200 million jobs by 2030. Transitioning to nature-positive infrastructure and built environments, including using nature-based solutions (NbS), may generate over $3 trillion in business opportunities and over 100 million jobs by 2030 (WEF, 2020).

The African Union Green Recovery Action Plan (2021-2027) highlights the continental vision of restoring and sustainably managing 100 million hectares of land and creating 10 million jobs by 2030, while also contributing to attaining 15 of the 17 Sustainable Development Goals (SDGs) (African Union, n.d.). It sets out priority interventions for biodiversity and NbS, harnessing climate finance and climate-resilient agriculture to support economic recovery. The action plan recognizes the importance of investing in nature for livelihoods and climate change resilience, following the economic impact of COVID-19 on the continent.

There is an urgent need to help financial institutions and governments move from broad plans and commitments to making nature-positive decisions and investments on a routine basis (Ruckelshaus et al., 2022). Recognizing this and the need to better consider natural capital in development planning projects, the Green Growth Knowledge Partnership (GGKP), African Development Bank (AfDB) and World Wide Fund for Nature (WWF) launched the Natural Capital for African Development Finance (NC4-ADF) project in 2021.[1] The project is piloting the mainstreaming of natural capital approaches in the development and financing of African development projects.

This report provides a contribution to the NC4-ADF project by demonstrating a use case of natural capital approaches in an agricultural development project in Africa. This use case is to provide the opportunity to build institutional and political consensus for mainstreaming natural capital in lending practices of African development finance institutions (DFIs), including AfDB. It is intended to build a common understanding around natural capital concepts, which will be novel to many. Drawing on a case study for Mozambique, it also demonstrates to financial institutions and national government partners the benefits of applying natural capital approaches to development projects design, planning and, ultimately, financing and implementation. This applies generally, and for building back better following the COVID-19 pandemic.

1 https://www.greengrowthknowledge.org/initiatives/NC4-ADF

2. Natural Capital Concepts and Approaches

Nature is at the heart of many economic activities, such as agriculture, forestry and fisheries. It also contributes in many ways to maintaining safe and comfortable environments for people and communities, as well as being important for recreation, relaxation and cultural reasons. The need for governments to consider nature in development planning and economic management has been recognized for decades, notably via the Brundtland Commission report from World Council on Environment and Development in 1987 (WCED, 1987). The concepts of natural capital and ecosystem services have emerged as a way of integrating the value of nature into public and private planning.

2.1 Natural capital and ecosystem services

An early definition by Daly (1994) describes natural capital as the "stock that yields a flow of natural services and tangible natural resources". Bateman & Mace (2020) define natural capital as "those renewable and non-renewable natural resources (such as air, water, soils and energy), stocks of which can benefit people both directly (for example, by delivering clean air) and indirectly (for example, by underpinning the economy)".

Broadly, non-renewable natural capital includes abiotic resources such as coal, minerals and oil. Renewable natural capital relates to biotic resources, which may regenerate over time. A common way of characterising biotic resources in landscapes and seascapes is as ecosystem assets. An ecosystem is a community of species and their local, non-living environment acting as a functional unit. The interactions of species (i.e. plants and animals) and non-living components in ecosystems (e.g. water, sediments and topography) drive different functions (e.g. biomass accumulation or slowing passage of water), which lead to the supply of ecosystem services. Formally, ecosystem services are the contributions of ecosystems that lead to benefits for the economy and for human well-being (United Nations et al., 2021). They are organized into the following categories:

- **Provisioning ecosystem services:** Ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems (e.g. wood for timber harvest).

- **Regulating and maintenance ecosystem services:** Ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles (e.g. pollination, carbon sequestration, flood control).

- **Cultural ecosystem services:** The experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits (e.g. recreational settings or cultural practices).

The relationship between "stocks" of ecosystem assets (i.e. the ecosystems themselves), the flows of ecosystem services they supply and the benefits they lead to is illustrated in Figure 1. In Figure 1, the stocks of ecosystem assets (green circle, e.g. a forest) supply a flow of ecosystem services (green arrow, e.g. standing timber for harvesting). Various ecosystem processes lead to supply of the ecosystem service (e.g. photosynthesis). This "ecosystem asset" perspective on natural capital is the one adopted in this report (i.e. non-renewable resources such as coal and minerals are not considered). Ecosystem services contribute to ecosystem service benefits (grey box, e.g. harvested timber) enjoyed by the economy or society.

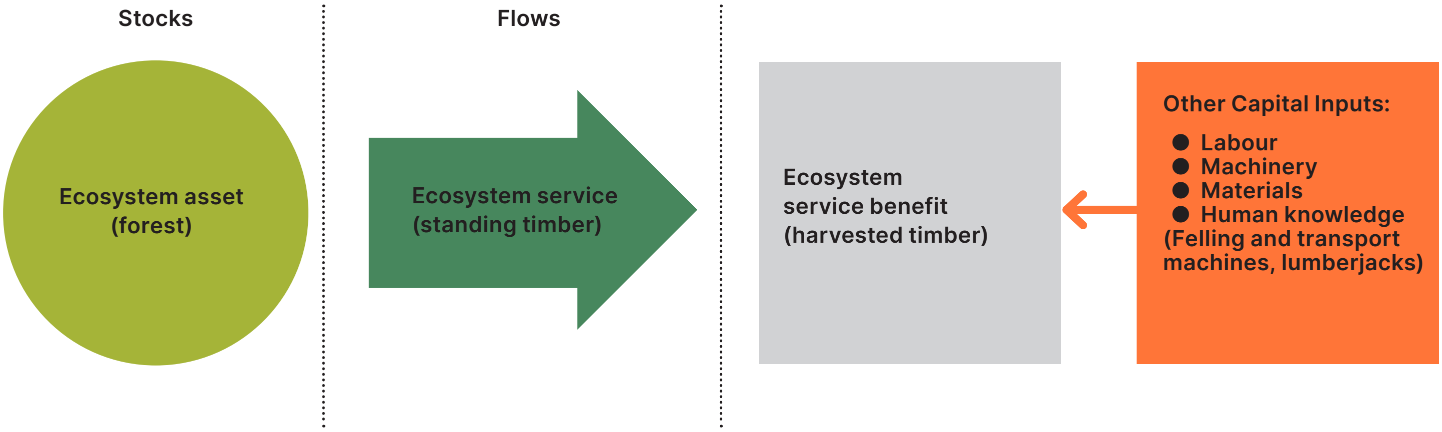

Figure 1: Ecosystem assets and ecosystem services: stocks and flows (Dickson et al., 2014)

As Figure 1 indicates, the ecosystem service benefit may be considered to arise from a joint production process to which ecosystem services contribute to different degrees. As the example in Figure 1 demonstrates, other capital inputs are needed to realize the benefit of harvested timber from a forest (orange box, e.g. machinery, labour and forestry knowledge).

2.2 Biodiversity

Biodiversity is an important characteristic of nature. It essentially reflects the variability and abundance of life at the ecosystem level (the different communities of species in different locations), species level (the number and abundance of different species) and genetic level (the different genetic and other characteristics that exist in species populations). Loss of biodiversity affects ecosystem service supply in different ways. Less ecosystem diversity means there is a smaller portfolio of ecosystem assets in landscapes and seascapes. As such, a narrower range of ecosystem services can be supplied at these scales. Loss of species and genetic level biodiversity can impact the processes and functions that drive ecosystem service supply (as described above). This means ecosystem assets may supply less services and may be less resilient to impacts such as climate change, as they have fewer functional components to keep their processes going.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) identifies that substantial biodiversity loss is occurring across all three levels of biodiversity (Figure 2). The UN Agenda for Sustainable Development recognizes this as a material development concern (UN, 2015). For instance, IPBES (2019) identifies biodiversity loss as undermining progress towards 80% of the SDG Targets.

Maintaining and enhancing biodiversity is critical for ensuring the sustainable supply of ecosystem services. As ecosystems are converted, lose species or otherwise degrade, their functioning and ability to supply ecosystem services becomes impaired. This can lead to reduction in both the range and quantity of ecosystem services supplied. It can also compromise the resilience of ecosystems to shocks and stresses, including climate change. Eventually, tipping points may be reached beyond which there is a collapse in ecosystem services supply (WEF, 2020; World Bank, 2021b). Countries and communities whose economies are more reliant on ecosystem services are the ones most at risk from the effects of these tipping points being breached. The World Bank (2021b) estimates that sub-Saharan Africa would be particularly hard hit by a collapse in ecosystem services supply, experiencing a relative contraction in GDP of 9.7% per year by 2030 (or equivalent to -$358 billion).

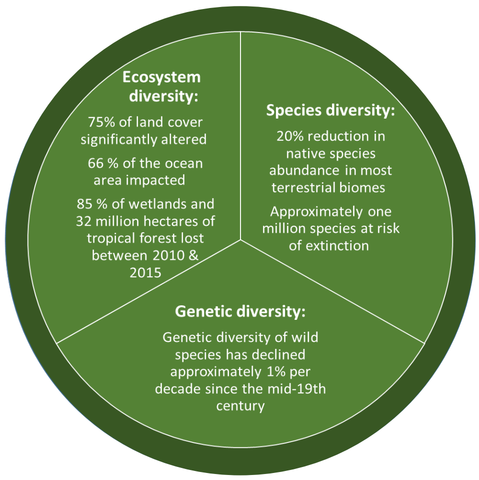

Figure 2: Global loss of the levels of biodiversity (IPBES, 2019)

2.3 Natural capital approaches

Ruckelshaus et al. (2022) describe natural capital approaches as those that drive changes in policy and/or investment decisions by incorporating the values of ecosystem services into decision-making. They are increasingly being implemented by a wide range of actors at various scales. This includes implementing nature-based solutions (e.g. using ecosystem services for climate change adaptation), within single sectors of the economy (e.g. improving ecosystem services related to water supply to agriculture) and across the economy (e.g. green economy transition). For example, China has zoned 51% of the country for boosting ecosystem service supply, targeting payments to over 200 million people for ecosystem restoration (Ouyang et al., 2016)

To inform natural capital approaches, assessments of the stocks of ecosystem assets and the flows of ecosystem services they deliver under different decision-based scenarios is needed. These scenarios may include baseline (or business as usual) scenarios, natural capital improvement, or loss scenarios (e.g. project or policy scenarios) and scenarios that explore future pressures (e.g. in the context of climate change). These "natural capital assessments" are based on quantifying, mapping and valuing ecosystem assets and service flows, and how these are expected to change under these different scenarios. They explore the trade-offs and synergies across different development objectives under different scenarios where natural capital (or ecosystem asset) stocks change. Hence, natural capital assessments can be used to guide more integrated policy, planning, investment and management practices. These are practices that recognize and capture the multiple benefits nature provides, while mitigating unintended impacts on nature and unintended economic and social welfare consequences.

By their nature, natural capital assessments are inter-disciplinary, melding different data, methodologies and perspectives. The increasing availability of readily accessible remote sensing data (e.g. satellite based) is allowing ecosystem assets to be identified and mapped more easily. There are currently a number of models, platforms and applications for estimating ecosystem services, such as the InVEST suite of models from the Natural Capital Project,[2] Costing Nature and related policy support applications[3] and ARIES.[4] GGKP (2020) highlights useful natural capital platforms and tools, additional to a large body of literature on natural capital and ecosystem assessments that now exists to draw on.

A feature of natural capital assessments is the valuation of ecosystem services. IPBES (2022) highlighted the importance of presenting different value perspectives to decision makers via natural capital assessments. For example, monetary valuation of ecosystem services will be helpful to economic planners in evaluating the costs and benefits of different natural capital approaches. However, social planners are likely to be more interested in understanding the bio-physical contributions of ecosystems to food security (e.g. calorific flows), water security (e.g. m^3 water/year) or disaster risk reduction (e.g. reduction in peak flood flows). Environmental managers will be interested in ecological returns from natural capital approaches, such as increases in species habitat and abundance. Therefore, to the degree possible, natural capital assessment should speak to these different perspectives and development objectives, illustrating the synergies and trade-offs that emerge.

2 https://naturalcapitalproject.stanford.edu/software/invest
3 http://www.policysupport.org/home
4 https://aries.integratedmodelling.org

2.4 Natural capital approaches and green recovery in Africa

Africa has a wealth of natural capital. However, as with elsewhere across the world, this is under threat from human activity and climate change (WWF, 2020). A business-as-usual recovery, built on continuing unsustainable production and consumption of nature, poses unacceptable long-term risks to economies, livelihoods and well-being. At the same time, the stocks of ecosystem assets that Africa is endowed with provide a foundation for sustainable economic development and a green recovery from the impacts of COVID-19. In this context, WWF (2020) highlights that investments in natural capital may deliver nine times more in economic benefits than they cost and support long-term livelihoods.

WWF (2020) also highlights a set of key investment opportunities to support transition to nature-positive economies and green and just recovery in Africa. This includes investing in nature-based solutions, which boost ecosystem services relevant to climate change adaptation, water management and nature-based tourism. They also include investing in more sustainable and productive food systems (e.g. via agroforestry and climate-smart agricultural production), as well as applying natural capital assessment to inform climate resilient infrastructure development.

Similar opportunities are highlighted in the African Union Green Recovery Action Plan (2021-2027) (African Union, n.d.). Biodiversity and nature-based solutions feature as a priority intervention area under the plan, due to the opportunity they bring to build back better by delivering on multiple social, environmental, as well as economic, development goals. Sustainable agricultural land management, maintaining ecosystem services essential for agriculture (e.g. pollination and water regulation) and maintaining climate resilient landscapes and livelihood resilience are all important interventions of the plan that natural capital approaches can also contribute to achieving.

The challenge is to move from these high-level commitments to action on the ground. This requires development finance institutions and their government partners to mainstream natural capital approaches in their development planning and financing decisions. A key opportunity for this is via development corridor projects. Following Juffe-Bignoli et al. (2021), development corridor projects are defined as "large, often transnational and linear, geographical areas targeted for investment under a spatially oriented and common economic strategy towards achieving long-term sustainable development". This definition encompasses both infrastructure development projects, as well as agglomeration type projects that provide targeted support to increase economic activity within or across sectors in different localities.

Environmental impact assessments are widely required by governments to assess and mitigate the impact of these development corridor projects on the environment. Finance institutions have also developed environmental standards, such as the International Finance Corporation, which includes a specific Performance Standard related to biodiversity (Performance Standard 6). This aims to ensure that no net loss of biodiversity is incurred with project implementation.

However, ecosystem services and natural capital are very rarely considered in the impact assessment of development corridor projects. In their analysis of peer-reviewed literature on development corridors, Juffe-Bignoli et al. (2021) found that only seven articles out of 271 identified assessed impacts on ecosystem services. Griffiths et al. (2019) highlight this issue in the context of project mitigation actions to achieve no net loss (NNL) of biodiversity, often deployed as a response to an environmental impact assessment. They observe that changing the configurations of biodiversity (including ecosystems) in the landscape via off-setting alters the patterns of ecosystem services supply and use. This may result in third parties becoming worse off after a project than they were before it.

This report provides a spatially explicit natural capital assessment to illustrate how natural capital approaches can be better mainstreamed into development corridor projects. It uses an agricultural development project in northern Mozambique as a case study. It demonstrates how integration of natural capital can better support the project objectives to boost cropland yields, deliver wider benefits for communities, climate change mitigation and adaptation benefits and improved outcomes for biodiversity.

3. Case Study Description

This report uses the Mozambique SAPZ project as its main case study, which aims to enhance agricultural productivity within the Pemba-Lichinga integrated development corridor in the north of the country. While Mozambique has substantial natural resources, these are declining and the country is facing significant development challenges posed by climate change (AfDB, 2015). To respond to these challenges, the Government of Mozambique, together with the African Development Bank and other key development partners, launched a Roadmap for a Green Economy (GER) in 2012.

The GER establishes the national development objective of becoming: "…an inclusive middle income country by 2030, based on protection, restoration and rational use of natural capital and its ecosystem services to guarantee development that is sustainable, inclusive and efficient, within the planetary limits." (AfDB, 2015)

To operationalize the goals of the GER, the Government of Mozambique approved a Green Economy Action Plan (GEAP) in 2013 for the period 2014 to 2019. The GEAP identifies the efficient and sustainable use of natural resources as one of three major interventions necessary for green economic transition. The inter-ministerial steering group identified mapping, valuation and integration of natural capital in national planning as a priority for the GEAP, which should also be reflected in the national development plan (AfDB, 2015). The GEAP was updated for the period 2020 to 2030. The updated GEAP highlights efficient and sustainable use of natural resources as a major intervention. Entry points for natural capital also feature with respect to sustainable infrastructure (e.g. integrated water resources management) and climate change adaption (e.g. disaster risk reduction) (Government of Mozambique, 2020). Therefore, continued natural capital assessment will be key to developing the evidence base to implement the GEAP over the coming years.

3.1 Background

The potential of agriculture to support economic growth, alleviate poverty and address food insecurity is well recognized in Mozambique (AfDB, 2018). In 2020, the agricultural sector in Mozambique contributed around 26% of total national GDP (World Bank, 2022). The main crops cultivated in Mozambique are maize (29%), cassava (13%), sorghum (11%), beans (9%) and rice (5%). Next in importance are cash crops: peanuts, sesame seeds, cotton, tobacco and cashews (AfDB, 2018). However, most income from agriculture is in the form of self-consumption and, to a lesser degree, some sales of production. Only 18% of farmers grow at least one cash crop, and less than half of these sell any of their production in markets (World Bank, 2021a). Nonetheless, the rebound in the agricultural sector, supported by favourable climatic conditions, has helped underpin a timid national recovery from the COVID-19 crisis (World Bank, 2022).

The agricultural sector also provides 71% of total employment in the country (in 2015) (World Bank, 2022). It is the major source of livelihoods in rural areas and is highly dependent on natural resources (World Bank, 2018). About 3.9 million households cultivate around 5.1 million hectares in the country, mostly practicing subsistence farming on small plots that average 1.3 hectares in area (World Bank, 2018). These small holder farmers account for 94% of agricultural production in Mozambique, and 95% of this production occurs on plots less than 1.5 hectares in area (IFAD, 2018).

The productivity of Mozambique's agricultural sector is one of the lowest in the region (AfDB, 2018). This is in part due to limited market access, poor infrastructure and post-harvest losses (AfDB, 2015). The sector is also highly vulnerable to climate change and natural disasters, including droughts and flooding that regularly affect the country and lead to food insecurity (AfDB, 2018).

To improve the performance of the sector, address food insecurity and deliver decent jobs, the Government of Mozambique has identified six development corridors to target investment for improved crop production (AfDB, 2018). One of these is the Pemba-Lichinga corridor in the north of the country (AfDB, 2018), which runs east to west across the Niassa and Cabo Delgado provinces (Figure 3). In both of these provinces, 99% of farms are small (<10 ha) and average crop production is dominated by maize and, to a lesser extent, beans (MADER, 2021).

While agricultural development is important, it needs to be balanced with other national development objectives. This requires integration of agriculture, forestry, water and other sectors in policymaking (AfDB, 2015; World Bank, 2018). For instance, forests provide goods and services to local communities that contribute to almost 20% of cash and 40% of subsistence incomes (World Bank, 2018). Wood fuel supplied by forests accounts for 80% of total household energy consumption in Mozambique (World Bank, 2018). Agricultural production also benefits from the ecosystem services delivered by forests, such as maintaining reliable water flows (World Bank, 2018). The government is also seeking to create a green growth policy framework that protects watersheds, soil fertility and pollinators important for crops of high nutritional and cash value (AfDB, 2015).

Mozambique is also experiencing the adverse effects of climate change, with more frequent and more intense droughts, flooding and tropical cyclones affecting most of the population.[5] These events have significant impacts, resulting in loss of life, property, livelihoods, crops and damage to infrastructure. The impacts on agricultural production may also be significant. Irregular rainfall and the increasingly unpredictable rainfall load and duration of the rainy season could see crop yield reductions of up to 25%. This will result in increased food insecurity and affect the livelihoods of many, particularly the most impoverished (GoM, 2021). Therefore, increasing climate change resilience and reducing climate risks is a key national development priority.

Mozambique has several climate change mitigation and adaptation policies in place, namely the Mozambique National Strategy for Climate Change (ENAMMC), the Technological Action Plan (covers adaptation in agriculture and coastal zones), the Local Adaptation Plans, and the Second National Communication of Mozambique (GoM, 2021). In terms of Mozambique's climate change mitigation objectives, the country has committed to reduce its emissions by about 40 $MtCO_2e$ between 2020 and 2025.[6] In terms of nature-based solutions to climate change mitigation, Mozambique is committed to its REDD+ ambitions with aims to reduce deforestation and increase forest cover (including restoring 1 million hectares under the Bonn Challenge) (GoM, 2016).

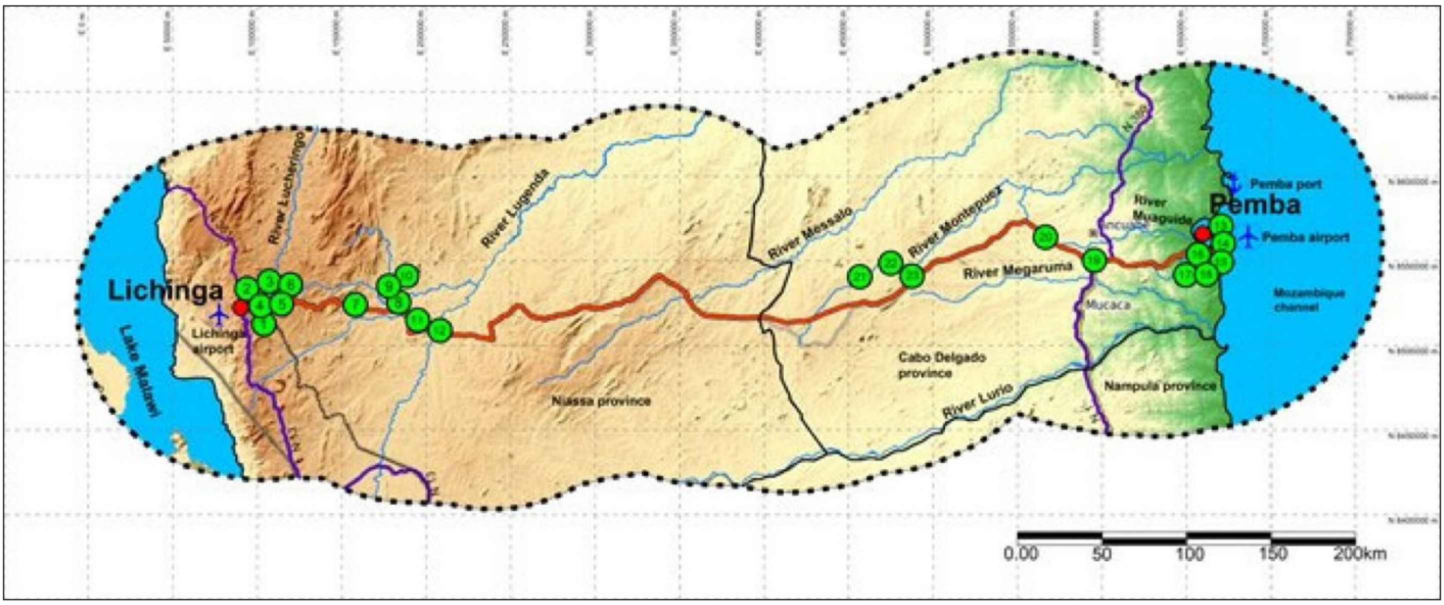

Figure 3: Pemba-Lichinga Corridor in Northern Mozambique (Mahindra Consulting, 2020)

5 https://www.climatewatchdata.org/ndcs/country/MOZ/full
6 https://www.climatewatchdata.org/ndcs/country/MOZ?document=revised_first_ndc

3.2 SAPZ description

The Pemba-Lichinga Special Agro-industrial Processing Zone (SAPZ) project is intended to stimulate a major increase in agricultural production within the Pemba-Lichinga corridor. It broadly aims to bring smallholder farmers out of subsistence and into a competitive and inclusive agribusiness subsector. The SAPZ project is supported by an integrated feasibility study, master plan and business plan produced by Mahindra Consulting Engineers (2020).

The physical scope of the project includes the construction of state-of-the-art agro-industrial processing hubs (APH) in the Niassa and Cabo Delgado provinces. Elsewhere within these provinces, agricultural transformation centres (ATC) and aggregation centres (AC) will be established. These will provide technical support and other services to farmers using a cluster approach. This includes better access to credit and markets. They will also act as collection points for supplying the APH.

In the wider agricultural landscape, the project aims to improve smallholder farm production and establish "captive farming" systems. These are farmland areas to supply required commodities to the APH for value addition activities (e.g. the processing of crops into higher value products). In broad terms, the master plan suggests that interventions at farm level will aim to increase output within the existing cropland footprint (i.e. the project is one of agricultural intensification rather than extensification). ATCs will also provide storage for fertilizer and other agricultural supplies and equipment, thereby improving the accessibility of these inputs to farmers (Mahindra Consulting, 2020).

The Pemba-Lichinga SAPZ project is being implemented over three phases. The first phase focuses on action to boost and improve productivity of the farmers around the Lichinga, Cuamba and Marrupa Districts in Niassa Province. The smallholder agriculture interventions focus on farms of between 0.5 to 10 hectares. At the same time, the SAPZ will rehabilitate the existing feeder mill in Cuamba to an APH. The proposed APH will have a footprint of around 300 hectares and will be located just north of the town of Cuamba. The Cuamba APH is located 13 kilometres from the Muanda River, a tributary of River Lurio. The Muanda River will supply the water for the APH, as the underlying aquifer productivity is very low.

Figure 4 presents indicative or potential locations for the APH and ATCs in the Niassa Province. A second phase of the project will include the development of an irrigation scheme and the full development of the APH in Cuamba, in partnership with a private sector entity. A third phase may focus on the development of the SAPZ in Pemba, subject to a de-escalation of the crisis in the Cabo Delgado province.

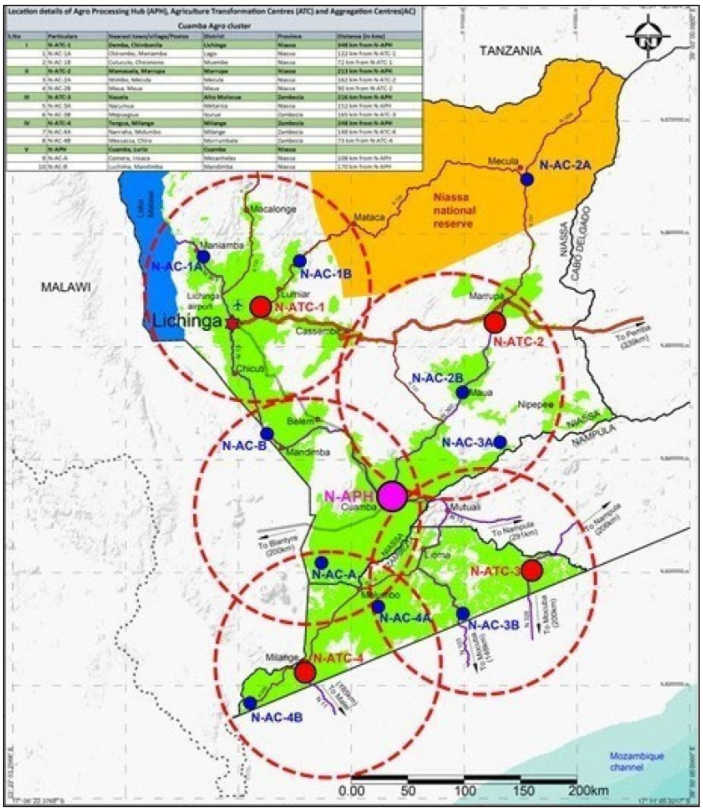

Figure 4: APH in Cuamba (pink dot) and ATCs in Niassa Province (red dots) and their collective zones of influence (red dotted circles) (Mahindra Consulting, 2020)

3.2.1 Land use activities in Niassa Province (Phase 1 SAPZ area)

According to the findings of a report commissioned by the Swedish Embassy and the Swedish International Development Cooperation Agency, maize is grown by virtually all households practicing agriculture in project sites surveyed in Niassa (ORGUT, 2013). While this is mainly for self-consumption, about 25% of households sold some maize during the 2008 season. A relatively wide range of other staple crops are also grown. This includes crops such as cassava, soybeans, banana, macadamia, sorghum and rice, as well as some pulses (beans) and cabbages.

During the 2008 harvest season, 10-20% of households producing maize, and other staple crops such as sorghum, cassava and rice and pulses (beans), sold some portion of their harvest. However, evidence from Cuamba, Lago and Majune indicates many households made "emergency" sales of staple foods to purchase important non-food items (e.g. soap) (ORGUT, 2013). This highlights the need to improve agricultural yields, so households and smallholder farmers can upscale production and generate a regular income for purchasing non-food items. This will be a key social development benefit from the SAPZ project.

Elsewhere in the Niassa, land has been used to establish plantations. However, Overbeek (2010) highlights that foreign plantation investments in the province have typically focused on generating carbon credits. This has not been found to benefit local people, as it limits access to communal lands and increases risks of food insecurity. The report emphasizes the importance of developing smallholder farming and promoting a balanced model with agroforestry, instead of developing large tree plantations that do not encourage sustainable production systems. A natural capital assessment would be helpful to frame these discussions and the various benefits from different land-use options in different locations.

3.3 SAPZ environmental and social impacts and mitigation measures

The environmental and social impact assessment (ESIA) and associated Environmental and Social Management Plan (ESMP) published in September 2021 (MADR, 2021) assesses the SAPZ project in terms of its compliance with Mozambican environmental laws and regulations, and the AfDB's policies and procedures. It also sets out mitigation measures for addressing impacts of the SAPZ in the Niassa Province. All the risks and the mitigation measures have been analysed and discussed through public and private stakeholder consultation processes, involving the stakeholders operating in the agro-industry and ensuring the farming community are at the centre of the discussions. The ESMP sets out the following mitigation measures for identified environmental and social risks associated with the SAPZ:

- **Establishing environmentally friendly agricultural practices:** Integrated pest management systems techniques, incorporating agroforestry (for carbon sequestration, increasing soils health and nutrients for productivity improvement and mitigation of erosion) and efficient waste management systems, as well as nature positive harvest and post-harvest techniques that protect the environment and guarantee food security with reduced crop losses.

- **Environmental measures and sensitization campaigns:** Interdiction (ban) on farming near rivers and around the areas bordering the Niassa Special Reserve (one of the largest protected areas on the continent to mitigate agricultural encroachment).

- **Technical assistance for best farming practices:** Inputs use (i.e. agrochemicals) and measures to manage them safely for the environment, to maximize productivity and efficiency and with appropriate personal protective equipment (PPE) for the health and safety of the farmers.

4. Natural Capital Assessment Methods

The purpose of the natural capital assessment is to identify and quantify the co-benefits in addition to increasing crop production, which could be delivered via an integrated landscape management approach to the SAPZ (i.e. an approach that recognizes there are multiple stakeholders with different objectives for the local landscape). This includes increasing the supply of ecosystem services that can improve the long-term performance of the SAPZ and deliver wider social welfare benefits, climate change mitigation and better outcomes for biodiversity. To achieve this, the natural capital assessment models ecosystem service flows and biodiversity measures under a project baseline scenario and compares them to a natural capital approach scenario. The resilience of selected ecosystem services supply under these two scenarios is then assessed under a climate change scenario.

4.1 Geographical focus of the assessment

Given the large zone of influence of the SAPZ project within the Niassa Province, the focus of the assessment is on the Muanda River Basin, which is around 450,000 hectares in area and drains into the Lurio River (Figure 5). The focus on this geographical area reflects the focus of Phase 1 of the SAPZ, and that the basin is a key watershed for the SAPZ area and the proposed APH. There is also a large endowment of agricultural cropland within the basin area that is likely to be influenced by the APH (see Figure 6). However, the assessment is designed to provide insights into the potential benefits that could be realized from mainstreaming natural capital into the SAPZ project as a whole.

4.2 Rationale for selecting ecosystem services to model

The master plan for the SAPZ project identifies a large extent of potentially irrigable land in the Muanda River Basin, which could be serviced via a Muanda irrigation scheme (Figure 7). The master plan also identified the Muanda River as the preferred source of water for supplying the proposed APH in Cuamba. Finally, the master plan for the

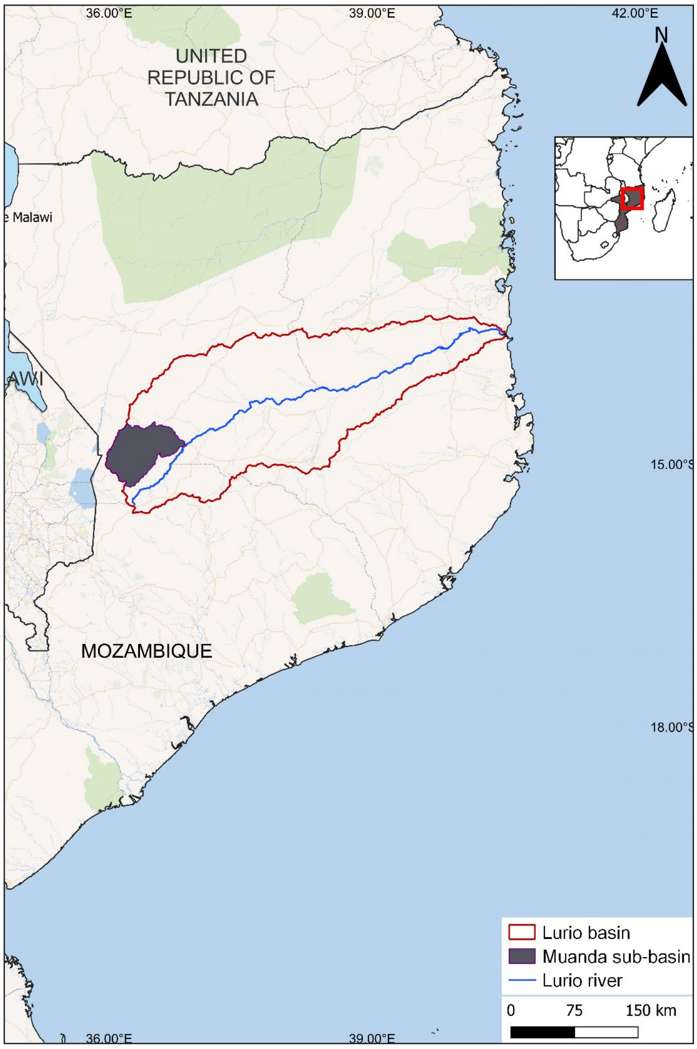

Figure 5: Muanda (dark area) and Lurio (boundary line) river basins

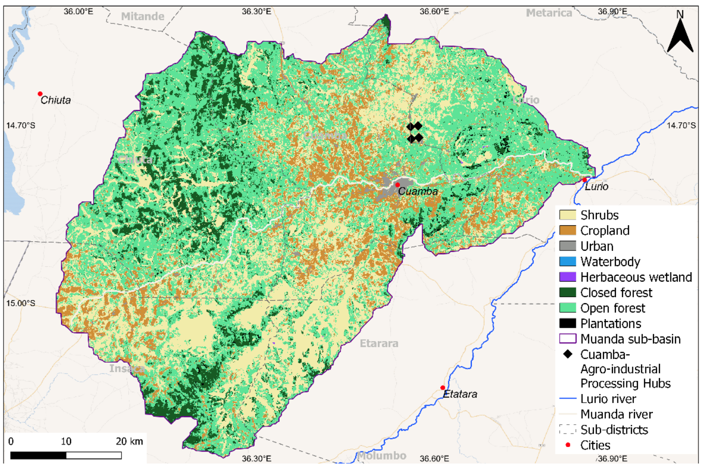

Figure 6: Land cover in the Muanda River Basin (reclassified from (Copernicus 2019)

SAPZ highlights limited access to power supply local to the Pemba-Lichinga corridor and the potential for hydropower in the Lurio River Basin. As such, understanding changes in water quantity supply and water flow regulation ecosystem services in the context of the SAPZ master plan is an important part of the natural capital assessment.

Related to the above, base flow maintenance services are derived from the ability of ecosystems to absorb and store water in wet periods and then release it during dry periods. Where base flows can be maintained in drier months, they can supply more irrigation and APH processing water to the SAPZ project during these months. This can be particularly valuable in mitigating risks of crop failure in unexpected drought conditions.

To supply irrigation water to agricultural land, extension of irrigation coverage is required via the SAPZ project (Mahindra Consulting, 2020). However, sedimentation is a major problem affecting irrigation schemes in sub-Saharan Africa (de Sousa et al., 2019; Gurmu et al., 2022). This leads to inadequacy and inequity in the distribution of irrigation water to crops over time. As such, sediment retention (or erosion control) ecosystems services in the Muanda River Basin will be important to the future performance and maintenance of the SAPZ project's irrigation interventions. It will also reduce water treatment costs at the proposed Cuamba APH.

At the national level, Mozambique has ambitions to both reduce emissions from deforestation and increase forest cover through reforestation and restoration, including the forest restoration commitment of 1 million hectares by 2030 under the Bonn Challenge.[7] Mitigating impacts from the SAPZ project on existing forests, as well as identifying opportunities to introduce forest cover, will contribute to both of these goals. Mozambique's Nationally Determined Contribution (NDC) to climate change mitigation also commits to developing low-carbon agricultural practices, including promoting conservation/climate-smart agriculture and the use of agroforestry (GoM, 2021). Therefore, exploring opportunities for reducing emissions and sequestering carbon within forest and agroforestry areas will be important in improving the co-benefits delivered via SAPZ project interventions. It may also generate additional revenues via emissions reduction purchase agreements.

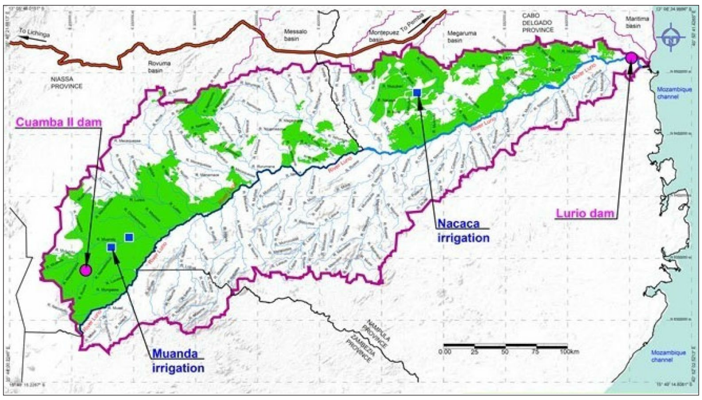

Figure 7: Extent of potentially irrigable land in Lurio River Basin (green areas) (Exhibit No. 12.7, Mahindra Consulting, 2020)

Mozambican households rely heavily on wood fuel for their domestic energy, with wood fuel supplied by forests accounting for 80% of total energy consumption (World Bank, 2018). Rural households rely on wood fuel from their own resources, often collected from nearby areas, and the natural Miombo woodlands are a significant source of household energy requirements (Boucher et al., 2014; FAO, n.d.). Establishing sustainable wood fuel supplies by increasing forest cover through the SAPZ project will increase energy security, reduce pressures on natural wood land and forest ecosystems elsewhere and create diversified livelihood opportunities. As such, important additional benefits can be realized by increasing wood fuel provisioning services. Increasing forest cover would also provide non-wood forest products to local communities. The World Bank (2018) estimates provisioning services from forest ecosystems contribute to almost 20% of cash and 40% subsistence incomes in rural areas.

Increasing agricultural output and productivity are a key focus of the SAPZ project. In many parts of Africa, the most important cash crops including coffee, cocoa, sesame, cotton and many pulse and oil crops are pollinator-dependent and these often constitute leading export products, providing employment and income for many (Kumsa & Ballantyne, 2021). For smallholder farms (< 2ha), Garibaldi et al., (2016) identify increasing pollinator populations reduced the yield gap between high and low output farms of pollinator-dependent crops by 24%. In their study of nutrient deficiency risks in Zambia, Uganda and Mozambique, Ellis et

7 https://www.bonnchallenge.org/pledges

al., (2015) found that up to 56% of the population would become at risk of nutrient deficiency if pollinator populations declined. Therefore, ensuring sufficient pollinator habitat is essential to ensuring the ongoing production of important cash and nutritional crops. Increasing pollinator habitat will also improve the resilience of key pollinator species under climate change.

4.3 Modelling ecosystem services and biodiversity in physical terms

The set of ecosystem services to be modelled based on the rationale presented in Section 4.2 is listed below. The natural capital assessment models the flows of these ecosystem services in physical and, where possible, monetary terms under different scenarios. The first step is always to model ecosystem services delivered in physical terms. The list below highlights the different spatially explicit models employed (the modelling methods are described in detail in Annex I):

- **Water quantity (supply) and water flow regulation (dry season supply):** Spatial Processes in HYdrology (SPHY) model (Terink et al., 2015).

- **Sediment retention (or erosion control services for irrigation/water courses:** Spatial Processes in HYdrology (SPHY) model (Terink et al., 2015) with Morgan–Morgan–Finney erosion model (Eekhout et al., 2018).

- **Carbon sequestration and storage:** UNEP-WCMC model based on InVEST approach.

- **Wood fuel provisioning services:** UNEP-WCMC bespoke model.

- **Pollination:** UNEP-WCMC model based on Chaplin-Kramer et al. (2019) approach.

In addition to the above ecosystem services, the natural capital assessment also models the spatial distribution of biodiversity in the Muanda basin using the Biodiversity Intactness Index (BII). BII is defined as the average abundance of a taxonomically and ecologically broad set of species in an area relative to their abundances in an intact reference ecosystem (i.e. what would be expected under near natural conditions) (Scholes & Biggs, 2005). Considering the spatial distribution of biodiversity in the assessment is important for designing a SAPZ that can deliver on conservation objectives. It is also important because areas of high biodiversity will also be more resilient to shocks and stresses (as described in Section 2.2). This means ecosystems are more likely to be able to continue to function and supply current levels of ecosystem services under different impact scenarios, including climate change. As such, the spatial distribution of biodiversity can also be considered as an indicator of the sustainability of the range of ecosystem services supplied from different locations.

4.4 Modelling ecosystem services in monetary terms

Where financial decision makers are faced with several different development expenditure options, one way to make the case for implementing a natural capital approach is using an economic perspective (see examples in Ruckelshaus et al., 2022). Estimating the monetary value of benefits realized from implementing a natural capital approach to the SAPZ project can help make a financial case for investing in this scenario. Following the UN System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA), these monetary values are estimated by multiplying the measures of ecosystem services supplied in physical units by an appropriate price per unit, or marginal value (United Nations et al., 2021). This marginal value should reflect the value of the ecosystem service contribution to some final benefit enjoyed by an economic unit (e.g. government, business, or household).

Marginal values for ecosystem services can be estimated using available market prices, bespoke valuation studies (based on surveys of individuals, their purchasing decisions, etc.) or using benefits transfer approaches. The benefit transfer approach is based on estimating the values for ecosystem services by transferring information and values from studies completed in another, similar location or context to a policy or project context. While original valuation studies remain the ideal option, the time and budget constraints associated with this natural capital assessment mean that benefits transfer is the only feasible option for valuation of the ecosystem services modelled. To the degree possible, marginal values have been obtained from studies local to Mozambique or in sub-Saharan Africa.

4.4.1 Marginal values for water supply

Improved supply of irrigation water is a key mechanism to improve agricultural output via the SAPZ. D'Odorico et al. (2020) estimate marginal values for the contribution of irrigation water to agricultural production for major crops across the world. Their analysis is based on the increases in farm revenue associated with meeting irrigation water requirements. For maize, they estimate that the global mean average value of withdrawn irrigation water to agricultural production is $0.16/m³, with a 25th percentile of $0.08/m³ and 75th percentile of $0.21/m³ (see D'Odorico et al., (2020) supplementary materials). Their analysis suggests that for sub-Saharan Africa, the value is close to the 25th percentile value. As such, a value of $0.08/m³ is adopted as the marginal value of additional water supply in the dry season for the natural capital assessment. It is assumed that water supply exceeds demand during the wet season.

4.4.2 Marginal values for sedimentation retention service

High sediment loads in watercourses feed into irrigation systems, get deposited and block up these systems and need to be regularly removed for irrigation systems to function effectively (Gurmu et al., 2022). This incurs high maintenance costs, which can be avoided by retaining more sediment within landscapes. One way to estimate a marginal value for sediment retained is using dredging costs incurred in other water bodies, as these are avoided costs realized via the sedimentation retention ecosystem service.

Shrestha et al. (2021) identify a unit cost of dredging of $3/m³ from their review of the literature to value sediment retention services (avoided sedimentation of watercourses) in southern Laos. This is the value proposed by the World Bank in their report on extending reservoir life (Annandale et al., 2016). This is broadly in line with Diwedar et al. (2022) who use a cost equivalent to $2.26/m³ for removing sediment from water courses in Egypt. Elsewhere, slightly higher values have been proposed. Guerrero et al. (2013) identify an actual cost of dredging of $4.48/m³ for the removal of sediment from the Parana River in Argentina. Reflecting on these different unit costs, a reasonable value to assume for avoided sedimentation of the Muanda River, local irrigation systems in the basin and downstream is $3/m³ (i.e. the mode average of the three marginal values). Reducing sediment loading will also reduce water treatment costs at the Cuamba APH.

4.4.3 Marginal values for carbon sequestration

There are two approaches that can be used for valuing carbon sequestration services. From a social welfare perspective, the appropriate price for avoided carbon emissions is the avoided social damage costs associated with greenhouse gas emissions. These are based on the aggregate economic impacts predicted for the emission of a tonne of CO_2e (carbon dioxide equivalent) to the atmosphere, usually to 2050 (e.g. as per the US Interagency Working Group on Social Cost of Greenhouse Gases, 2021). These social costs of carbon are used when governments undertake economic assessment of policies, especially with respect to climate change mitigation. Broadly, the social cost can be considered indicative of the global economic damage costs that are avoided via carbon sequestration services. In the United States, a social cost of carbon of $51/tonne of CO_2e has been proposed by the US Interagency Working Group on Social Cost of Greenhouse Gases (2021).

The traded carbon market price is usually substantially lower than the social cost of carbon. This is the price that has been paid for carbon sequestration or avoided emissions by organizations and individuals purchasing carbon mitigation services (e.g. carbon off-setting). Mozambique was the first country to receive payments for emissions reductions from the Forest Carbon Partnership Facility (FCPF).

Mozambique has an emissions reduction purchase agreement with the FCPF for a further reduction of 10 million tonne CO_2e (up to $50 million) through to 2024 in the Zambezia province (World Bank, 2021c). This reflects a marginal value of $5/tonne CO_2e. This is very similar to the value in voluntary carbon markets, where the average price for carbon offsets generated via forestry and land use projects was $5.60/tonne CO_2e in 2020 and $4.73 tonne CO_2e in 2021 (Forest Trends' Ecosystem Marketplace, 2021).

Accounting for the above, a marginal value for the social costs of carbon of $50/tonne CO_2e and a market price that could be attained from selling carbon credits of $5/tonne CO_2e is considered appropriate for the natural capital assessment. Using the US social cost of carbon in this context is considered broadly appropriate, given climate regulation ecosystem services deliver global benefits and increasing the supply of these services can be linked to global climate finance initiatives. The market price of $5/t$CO_2e$ is also appropriate as it is a price that has been agreed in Mozambique and wider evidence indicates it is a price that is realistic in voluntary carbon markets.

4.4.4 Marginal values for wood supply

Wood fuel is the main source of domestic energy in Mozambique, accounting for 80% of total energy consumption (World Bank, 2018). However, the wood fuel sector in Mozambique is characterized as being unsustainable (Techel et al., 2016; World Bank, 2018), indicating there is need to increase supply.

In their analysis of the Mozambique wood fuel sector for the World Bank, Techel et al. (2016) find the marginal value of a tonne of charcoal sold at the roadside to be 85 $/tonne. In rural areas, raw wood is typically used for fuel (World Bank, 2018). Based on analysis from nearby Malawi, Zulu (2010) suggests this achieves around a quarter of the price of charcoal, implying a marginal value for fuel wood of little in excess of $20/tonne ($0.02/kg) close to the point of collection.

By way of corroboration, in their valuation of non-timber forest products (NTFPs) in the United Republic of Tanzania, Balama et al. (2016) identify a mean annual collection of 443.3 head loads of firewood per household per year for subsistence and trade. The mean value of the annual firewood collected at point of use or sale was estimated at TZS 881,200. Balama et al. (2016) suggest that the mean mass of firewood per headload to be 16.55 kg (+/- 3.33 kg). This implies a value of collected firewood of approximately TZS 120/kg (based on TZS 881,200/443.3 head loads/16.55 kg per headload). Or approximately $0.06/kg at the point of use (rather than collection) using the same conversion factor of $1 = TZS 2077.5 applied by Balama et al. (2016).

Accounting for the above, a marginal value for fuel wood of $20/tonne is considered appropriate for valuing wood provisioning services from forests at the point of collection.

4.5 Modelling scenarios

The natural capital assessment models change in ecosystem service supply and use under a project baseline and natural capital approach scenario. This is achieved by adjusting parameters and data within the ecosystem service models to reflect the scenarios described below. It also models how ecosystem service supply changes under predicted climate change impacts. This is to help evaluate the resilience of ecosystem services supply to climate change under the different scenarios.

4.5.1 Project baseline scenario

The project baseline scenario assumes current land cover remains unchanged, that agricultural output is increased purely by intensification within the existing cropland footprint. The scenario also assumes that agricultural intensification is supported via training, access to finance and access to better agricultural equipment and inputs. As such, the cropland type modelled in the scenario is all considered to be represented by the established cropping pattern of maize and bean production, with agroforestry absent. This is acknowledged as a simplifying assumption. However, cropland used to grow other non-agroforestry crops will also be characterized with the same parameters as cropland grown for maize and bean in the ecosystem service models used. The project baseline scenario does not consider the environmental mitigation measures of the ESMP for the SAPZ project as they postdate the SAPZ master plan.

It is noted that the project baseline scenario does not consider natural capital impacts associated with infrastructure footprint and other on-the-ground interventions. This is because the exact locations of infrastructure to be developed via the SAPZ, such as the APH and ATCs, remain uncertain. Given the relatively small footprint of these facilities (e.g. the Cuamba APH is likely to be around 1.75km x 1.75km), it is believed they are unlikely to have a substantial impact on ecosystem services supply at landscape scale. Nonetheless, inappropriate siting of these facilities could have significant local impacts on ecosystem services supply and social welfare.

4.5.2 Natural capital approach scenario

The natural capital approach scenario demonstrates the additional flows of ecosystem services a more natural capital orientated approach to the SAPZ could realize. The natural capital approach scenario models the natural capital interventions in the following ways:

- **Increasing agroforestry in existing cropland:** This intervention relates to increasing tree cover in cropland areas. This entails planting trees at regular spacing (e.g. 10 metres apart), with crops grown in between. Agroforestry systems improve soil stability, limit soil crusting and increase ground litter and water infiltration. These processes prevent soil erosion and reduce runoff water that can carry nutrients and sediment from agricultural production areas into nearby water bodies. Increased tree cover can also serve to regulate water flows in surface waters nearby. Trees also improve carbon sequestration and storage in cropland and the crops provided by those trees will generate extra revenues. For instance, the cashew industry in Mozambique is well developed, and contributes significantly to the economy, specifically in the rural northern regions, such as Niassa. Agroforestry is also recognized as a solution to improve food security and adapt agriculture to predicted climate change impacts (e.g. mitigating local temperature) in Africa (Mbow et al., 2014; Thorlakson & Neufeldt, 2012).
- **Afforestation in riparian cropland:** This intervention relates to establishing natural forest (closed forest or Miombo forest) in riparian croplands. This will protect rivers from run-off from croplands, including soils and fertilisers, thereby protecting water sources. Increased tree cover can also serve to regulate water flows in surface waters nearby. Increased tree coverage will also improve wood fuel suppliers, carbon sequestration and storage and forest biodiversity.

It is highlighted that the natural capital approach integrates some of the recommendations of the ESMP for the SAPZ project. These are not included in the baseline scenario as they were proposed after the original master plan design. The natural capital approach scenario is also not intended to be indicative of an optimal SAPZ project design. Rather, the intention is to illustrate natural capital approaches that may deliver additional development benefits (beyond increased crop provisioning services) when implemented at a landscape scale as part of the SAPZ, or as part of similar development projects in Africa.

4.5.3 Climate change scenario analysis

Under climate change, temperatures are predicted to rise by 1.5-3°C between 2046 and 2065 across Mozambique (GoM, 2021). Most of Mozambique's agricultural production is small-scale and rainfed, making the sector particularly vulnerable to changes in precipitation, with increased drought and flooding events resulting in crop losses (USAID, 2012). Climate change may increase water demand for crops, impact crop suitability, reduce production capacity and challenge the long-term viability of the SAPZ project.

The duration of the rainy season may also become harder to predict, with the difference between the “official start” and “real start” of the agricultural campaign increasing, which may result in a reduction in current yields in the order of 25% in some regions (GoM, 2021). The Government of Mozambique (2021) indicates that the main crops for food security are at risk of a 20% yield reduction. This poses a substantial threat to efforts that aim to reduce poverty in the country due to decreased yields and increased food insecurity. Therefore, measures that promote adaptation and resilience to climate change are a key component of Mozambique’s development plan (GoM, 2021).

The climate change scenario assessment aims to understand the adaptation benefits of a natural capital approach to the SAPZ. This is achieved by modelling the impact of climate change on ecosystem services delivery under the natural capital approach and the project baseline scenarios and comparing the differences. Potential impacts of climate change are modelled for water quantity and flow regulation, as well as sedimentation retention (erosion control) ecosystem services. This is achieved using daily downscaled data from a multi-model mean of General Circulation Model (GCM) outputs for the 2050s period to drive the hydrological and soil erosion models. This climate model data was based on the Representative Concentration Pathway (RCP) 8.5 scenario, representing plausible emission levels up to mid-century (Schwalm et al., 2020). The RCP 8.5 scenario is one that results in emissions that deliver global warming at an average of 8.5 watts per square metre across the planet.

5. Natural Capital Assessment Results

The natural capital assessment provides a baseline understanding of ecosystem assets and the delivery of selected ecosystem services within the Muanda River Basin. It reveals how the supply of these services is improved under the natural capital approach scenario, in both physical and monetary terms. This can support economic analyses of natural capital intervention options and exploration of synergies and trade-offs between crop provisioning and other ecosystem services. Returns with respect to biodiversity objectives are also assessed, as this is important to both conservation objectives and the sustainability of ecosystem services supply. The natural capital assessment also reveals how both the project baseline and natural capital approach scenarios perform under projected climate change impacts, with respect to water and sediment retention related ecosystem services supply only.

5.1 Project baseline scenario

The project baseline scenario provides the counterfactual against which to assess changes in ecosystem services delivery and biodiversity under the natural capital approach scenario. Hence, this is broadly a business-as-usual scenario. The assumptions underpinning the parameterization of this scenario reflect current land-use activities and configurations and are described in Section 4.5. It is highly likely that the SAPZ project will have natural capital impacts on the ground. However, without detailed design plans, it is not possible to evaluate these at this stage.

5.1.1 Water quantity and flow regulation

Figure 8 shows the relative importance of different areas (pixels) of the Muanda River Basin to downstream beneficiaries of water supply. The darker blue colours represent areas contributing relatively higher amounts of water. In these areas, higher quantities of precipitation either run-off on to neighbouring land or infiltrate to deeper groundwater stores, contributing to baseflow within the river system. Essentially, these areas play a more important role in the maintenance of the hydrological system of the Muanda River. As would be expected, these are more prominent in the western headwater areas, where more rainwater is intercepted. Figure 9 shows how the rainfall collected within the Muanda River Basin area collects within the hydrological system. As figures reveals, water feeds into the headwaters and accumulates in the main stem of the Muanda River, accumulating as it flows downstream to meet the Lurio River at the outflow of the Muanda River Basin.

Having modelled the behaviour of the Muanda River system, it is possible to calculate and characterise the water yield from the hydrological system at its outflow (i.e. where the Muanda River joins the Lurio River). This is shown in Figure 10, which reveals high outflows from the Muanda River during the wet season and low outflows during the dry season.

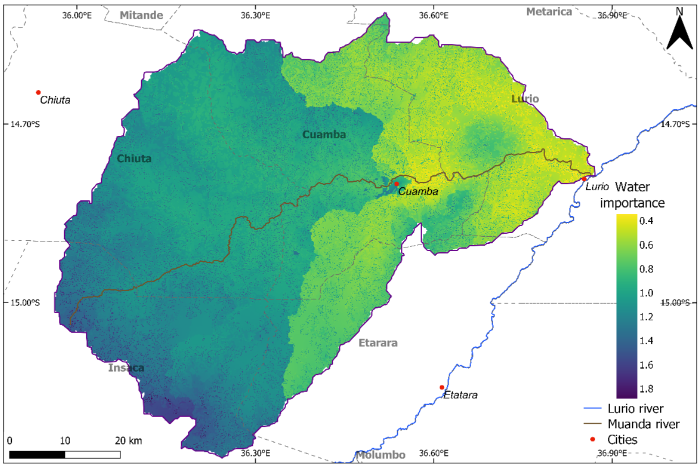

Figure 8: Map of the relative contribution of different areas of the Muanda River Basin to downstream beneficiaries

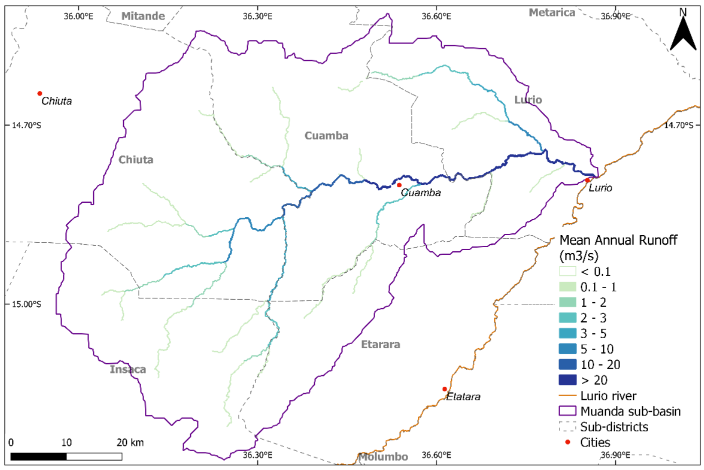

Figure 9: Modelled annual baseline runoff (m^3/s) of the Muanda River Basin

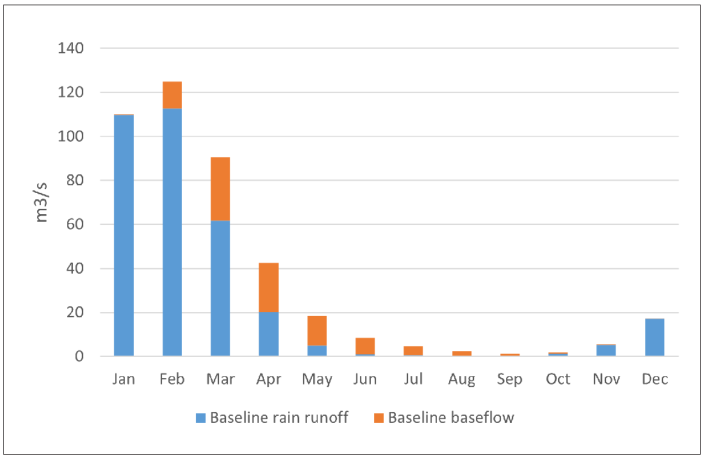

Figure 10: Annual baseline rain runoff and baseflow at outflow of the Muanda River Basin (Average monthly flow, m³/s)

The dry season is considered to be the period from May to September (World Bank, 2019). During these months, water is shown to be very scarce, with the baseflow (orange part of the graph) playing the main role in providing any supply. Baseflow represents the flow into the river from groundwater migration from the surrounding land. Consequently, increasing groundwater storage and slowing its release rate can contribute to higher surface water flows within the Muanda River during the dry season.

5.1.2 Avoided sedimentation of water courses

Rainfall and surface water run-off across the landscape leads to erosion of surface soils. Figure 11 reveals where the soil erosion is highest within the Muanda River Basin. Close inspection of Figure 11 reveals small areas of very high soil erosion throughout the river basin area (>100 t/ha/yr, purple areas) which tend to be areas with steeper slopes. More generally, moderate rates of soil erosion are identified by the dark green areas in Figure 11. These green areas clearly represent the pattern of cropland in the river basin (see Figure 6). This serves to highlight soil loss is associated with this land use, which needs to be managed given soil is essential for sustainable agriculture. These green areas clearly represent the pattern of cropland in the river basin (see Figure 6). This serves to highlight soil loss is associated with this land use, which needs to be managed given soil is essential for sustainable agriculture.

Having modelled the soil erosion in a spatially explicit way, sediment delivery ratios can then be calculated for the land surface across the basin (on a pixel-by-pixel basis). These reflect the proportion of sediment that is projected to enter the hydrological system. Figure 12 presents this information as a monthly time series, which represents the sediment yield (or outflow) from the river basin (i.e. into the Lurio River). The total annual sediment yield from the Muanda River Basin area amounts to 162,400 tonnes per year. As expected, most of this is generated during the wet season, driven by rainwater erosion of surface soils.

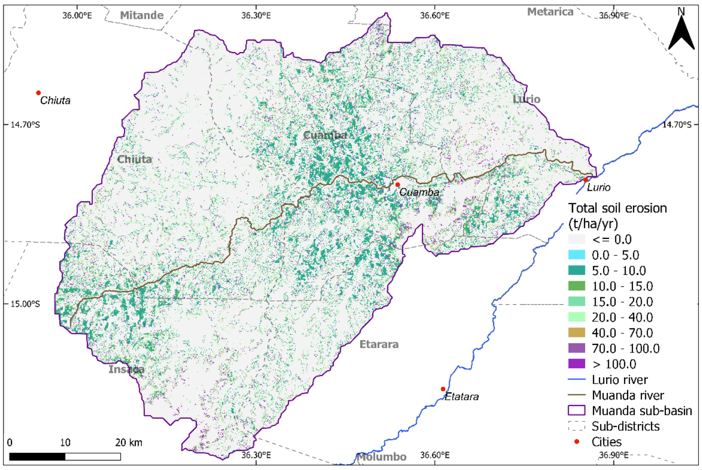

Figure 11: Soil erosion from rainfall and run-off in the Muanda River Basin (t/ha/year)

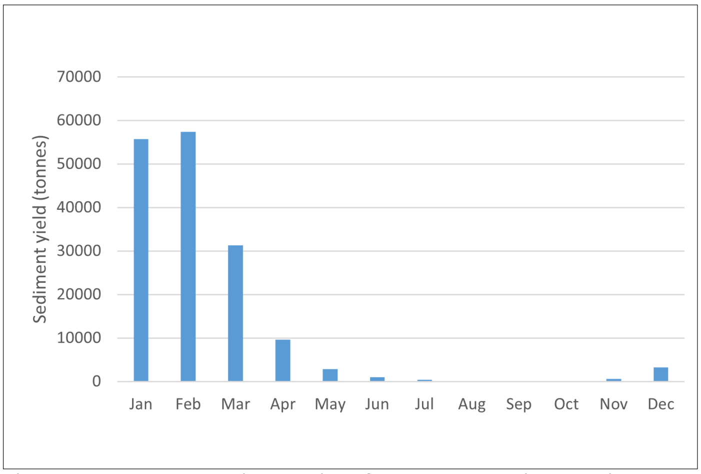

Figure 12: Monthly sediment yield from Muanda River Basin (tonnes)

5.1.3 Carbon storage and sequestration

Carbon stocks and carbon sequestration (i.e. the net carbon captured by ecosystems via photosynthesis) was mapped by linking different land use and land cover classes to different storage and sequestration rates, based on literature values. Figure 13 maps the carbon stocks for the Muanda River Basin. As would be expected, relatively higher stocks (orange/brown areas) are associated with areas of tree cover in the basin (see Figure 6). The total carbon stock under the baseline project scenario is 27,412,751 tonnes C, with a mean carbon stock across the Muanda River Basin area of 61.5 tonnes C/ha. The highest carbon stock is found in closed forest (87.4 tonnes/ha) and the lowest in croplands (excluding urban areas and water bodies).

Figure 14 maps carbon sequestration rates across the Muanda River Basin in terms of tonnes of carbon sequestered per ha per year. Tonnes of carbon can be converted to tonnes of CO_2 equivalent (tCO_2e) using a molecular weight ratio of 3.67. This provides a better insight into climate change regulation services supplied by ecosystems. The mean carbon sequestration rate across the Muanda River Basin is 1.56 tCO_2e/ha/yr. The highest values of carbon sequestration are found in plantations (6.2 tCO_2e/ha/yr) and lowest values are found in croplands. The high rates in plantations reflect observations by Overbeek (2010) that this land use has been targeted for climate change mitigation outcomes in the Niassa Province. However, as Overbeek (2010) observes, this has often come at significant opportunity cost to local communities. These plantations trees are often chosen due to their fast initial growth rate. However, ultimately, they typically fail to achieve the same carbon stocks seen in natural Miombo forests.

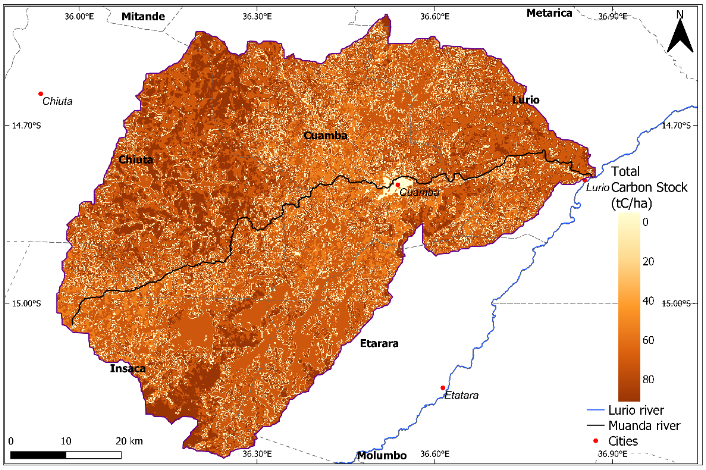

Figure 13: Carbon stock (t/C/ha)

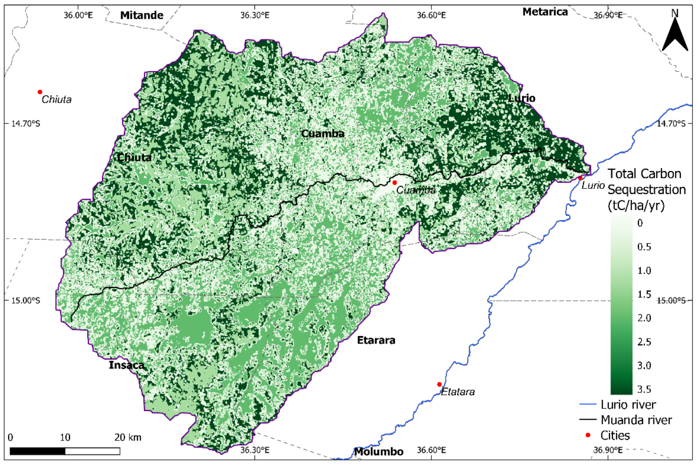

Figure 14: Carbon sequestration (tC/ha/year)

5.1.4 Wood fuel provisioning services

Figure 15 maps the supply and use of wood fuel collected from forest that can be sustainably maintained. The model maps sustainable supply, subject to accessibility and there being a population to demand the wood fuel nearby. Across the forests of the Muanda River Basin, a total sustainable supply and collection of 138,367 tonnes of wood fuel per year is possible with current land use and population density configurations. As Figure 15 reveals, the supply and use of wood fuel is low in the forested areas in the northwest of the river basin, due to inaccessibility and small populations meaning low demand.

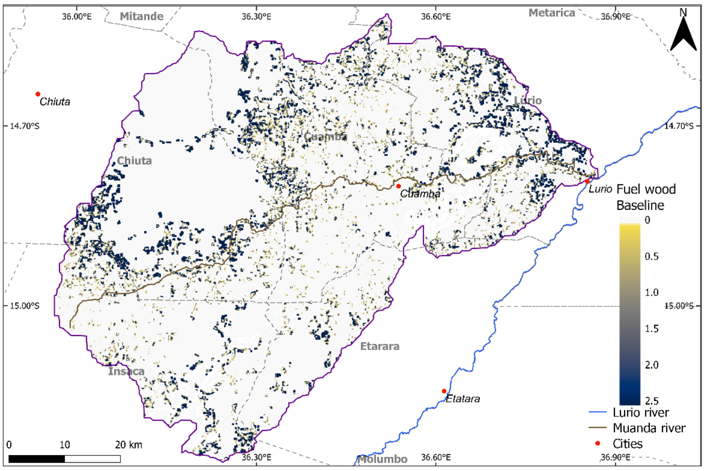

Figure 15: Wood fuel supply and use (tonnes/ha/year)

5.1.5 Pollination

Figure 16 presents the distribution of cropland within the Muanda River Basin with access to sufficient pollinators (mainly insects and birds). This is important for producing nutritious crops, often of high cash and export value, which also provide important employment and income support opportunities.

Dark green areas represent those with sufficient pollinator habitat for pollinator dependent crops. This is assumed to be the case if at least 30% of land cover within 2km of the cropland is natural land cover (following Chaplin-Kramer et al., 2019). The values <1.00 represent the proportion of the 30% natural land cover required within 2km of cropland to secure sufficient pollinator ecosystem services that is present. This means that the orange values imply <7.5% of land cover within 2km of that cropland area is natural land cover (i.e. <0.25 * 30%).

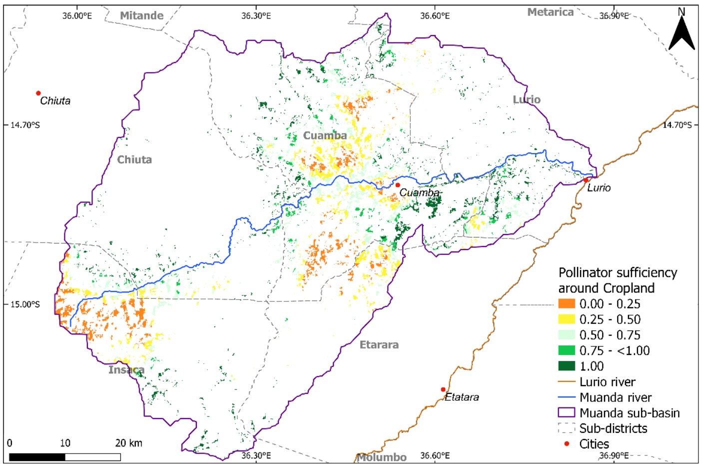

Figure 16: Distribution of cropland with access to pollinators under project baseline scenario; pollinator sufficiency is assumed if 30% of land within a 2km of cropland is natural land cover (values of 1 on the map)

Around 30% (17,785 ha) of the cropland within the Muanda River Basin is sufficiently supplied by pollinators (i.e. pollinator sufficiency = 1.00 in Figure 16). It is important that the natural habitats close to these croplands are conserved. Loss of such habitat will narrow options for crop production to wind or self-pollinating crops. It is also possible that the yields of these crops would be reduced, as pollinators often improve yields of these crops too (Elisante et al., 2020). The corollary of this is increasing natural habitat around croplands with insufficient supply of pollination ecosystem services would expand and boost crop production possibilities. As Figure 16 reveals, such areas are identified to the west of Cuamba and in the west of the Muanda River Basin area (orange areas).

5.1.6 Biodiversity

The overall status of species-level biodiversity in the Muanda River Basin area is modelled using the Biodiversity Intactness Index (BII). The BII was conceptualized by Scholes & Biggs (2005) and is defined as the average abundance of a diverse group of organisms, relative to reference levels under minimally disturbed (or near natural) conditions. The BII can provide an overarching view of the biodiversity status and outcomes, which can help design more biodiversity inclusive development projects.

BII values range from 0% to 100%, with 100% representing a diversity of organisms equal to that expected to be found in minimally impacted, near natural land conditions. If the BII is 90% or more, the area has enough biodiversity to support resilient and well-functioning natural ecosystems. If the BII is under 90%, biodiversity loss means some ecosystems functions may be impaired. If the BII is 30% or less, the area's biodiversity has been depleted and ecosystem functioning could be at risk of collapse (NHM, 2021).

Figure 17 presents the BII for the project baseline scenario (urban area of Cuamba excluded). The minimum BII score in the Muanda River Basin area is 36% and the maximum 100%. The mean BII across the Muanda River Basin under the project baseline scenario is estimated to be 65%. As per NHM (2021), this average BII suggests some ecosystem functions may be impaired, but the area's biodiversity has not been depleted to such an extent that there is substantial risk of collapse in ecosystem function. As would be expected, the lowest values (purple areas in Figure 17) are generally associated with areas of cropland (see Figure 6).

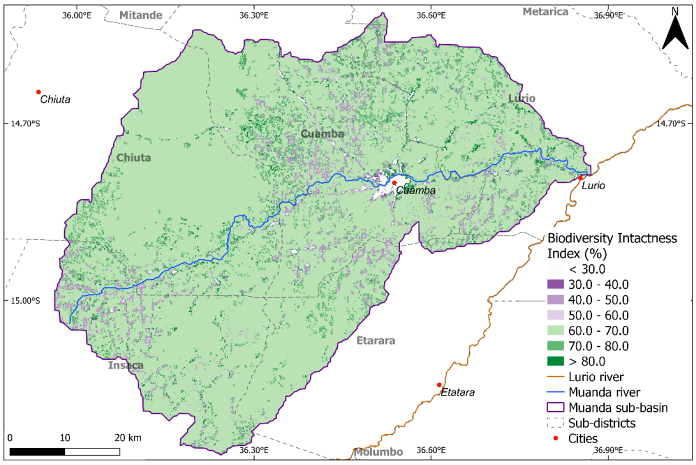

Figure 17: BII for project baseline scenario

5.2 Natural capital approach scenario

The natural capital approach scenario was created by targeted conversion of key areas of cropland to agroforestry and forestry. Cropland areas important for water (Figure 8) or with high soil erosion rates (Figure 11) were selected for conversion to agroforestry to boost infiltration and stabilise soil movement. A total of 4,460 ha of cropland were converted to agroforestry in this selection process. In addition, cropland within 500 metres of larger river stretches was reforested to natural forest (closed forest or Miombo forest). This intervention delivers benefits from those areas' close watercourses, where farming is banned under the Environmental and Social Mitigation Plan for the project. This resulted in a total of 10,513 ha of current cropland around rivers being replanted as natural forest.

Under the natural capital approach scenario, 25% of total cropland in the Muanda River Basin is converted to either agroforestry (7.4% of current cropland) or natural forest in riparian areas (17.6% of current cropland). This is considered viable on the basis of low productivity in existing cropland that characterizes the sector in Mozambique (AfDB, 2018). As such, the impact of reducing cropland extent on yields can be offset by sustainable intensification else where via the SAPZ project. It is also the case that livelihood opportunities can be provided from agroforestry and forestry ecosystems. Figure 18 shows the natural capital scenario land use map with the additional class of agroforestry. Figure 19 shows the land use change transitions under this scenario. Figure 19 reveals that most ofthe changes from cropland to agroforestry arein the headwaters in the west of the Muanda River Basin area.

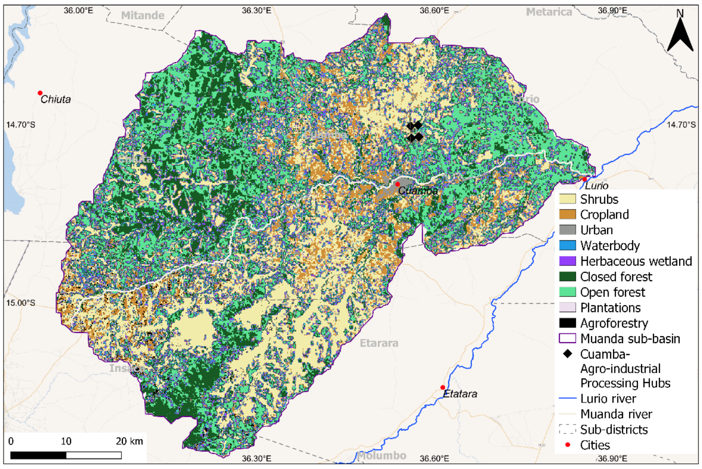

Figure 18: Land cover in the Muanda River Basin under the natural capital approach scenario

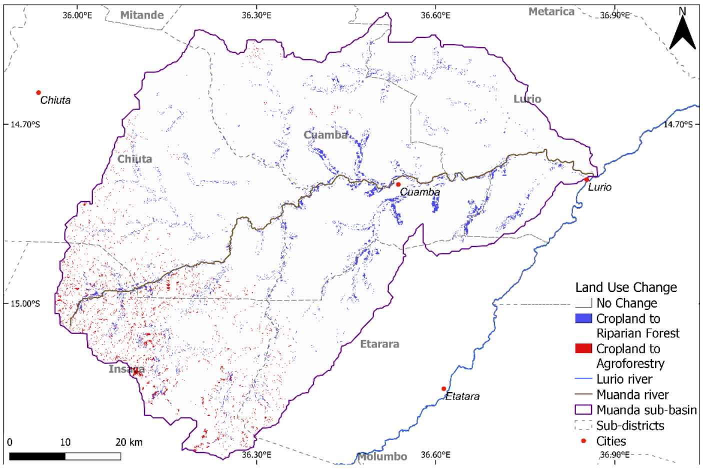

Figure 19: Land use change transition between baseline and natural capital approach scenario

5.2.1 Water quantity and flow regulation

Figure 20 shows the difference in how water collects within the Muanda River hydrological system under the natural capital approach scenario, compared to the project baseline scenario. As the figure shows, there is an overall annual decrease in water in the river system. This is to be expected given the additional vegetation that is established, and its associated water use, under the natural capital scenario.

However, the role of additional forests and agroforestry in regulating water flows is important. As Figure 21 reveals, under the baseline scenario, water enters the hydrological system and the Muanda River more rapidly during the wet season, compared to the natural capital approach scenario; noticeably during the November to March period. This difference results from both additional water use by vegetation and additional storage in groundwater due to increased infiltration in the additional forest and agroforestry ecosystems of the natural capital approach scenario. This could create a buffer to peak flows and supply flood mitigation services in the river basin, where flooding has been a wet season issue in the Cuamba area (GFDRR, 2015). More detailed modelling employing local hydrological, topographical and geological data would be needed to understand how to best configure additional forest and agroforestry ecosystems to boost the supply of this potential ecosystem service.

Figure 21 clearly shows the increasing importance of baseflow to the river system during the dry season months. These are the orange and yellow parts of the bars in Figure 21. Figure 22 reveals the difference in dry season surface water flows within the Muanda River under the project baseline (blue bars) versus natural capital approach (green bars) scenarios. Because the forest and agroforestry ecosystem store more water within their soils, this water tends to get released more slowly following the wet season months. This provides a valuable regulation service by increasing water supply during the dry season months, when it is more scarce (Oates et al., 2015). This is important for maintaining dry season agriculture, as well as the Cuamba APH operations and other downstream water uses from the Lurio River.

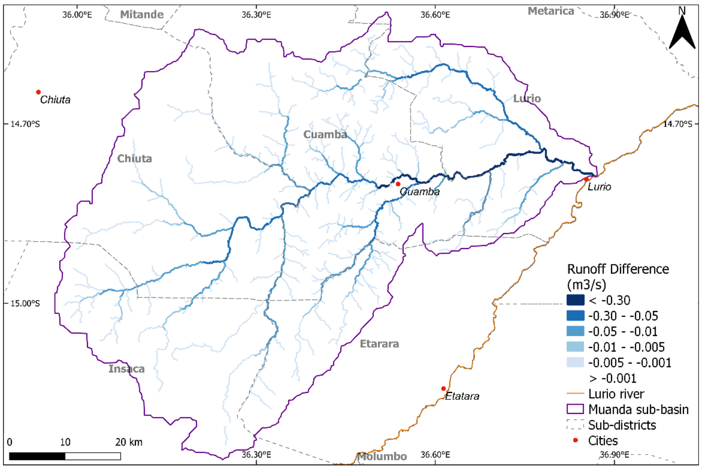

Figure 20: Difference in mean annual runoff between the project baseline and natural capital approach scenarios

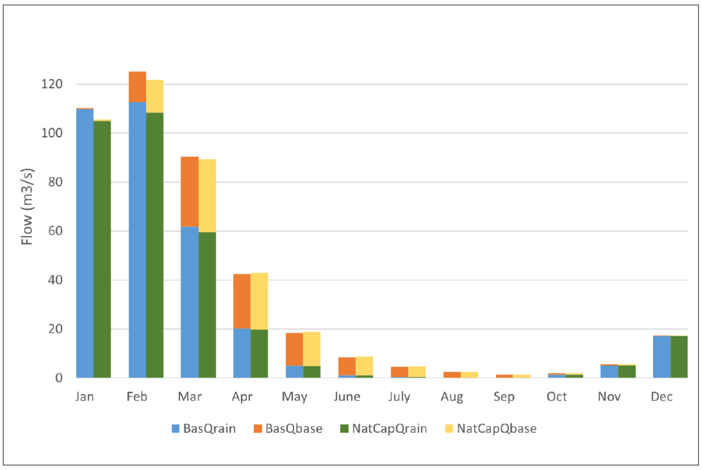

Figure 21: Comparison of total mean monthly flows (rainfall runoff and baseflow) between baseline and natural capital approach scenario at basin outflow

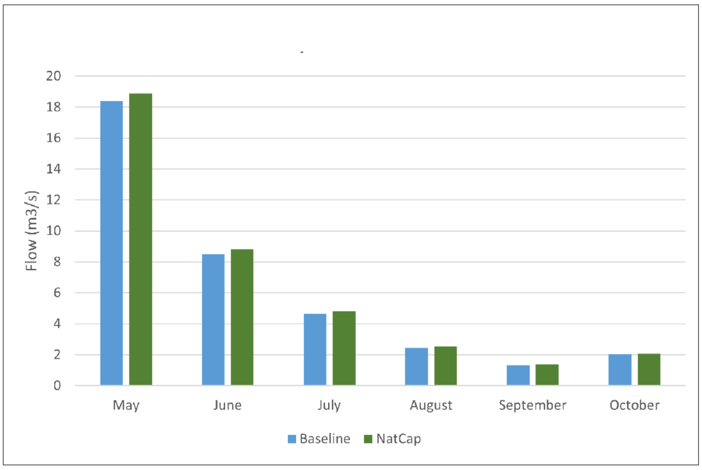

Figure 22: Mean average monthly dry season flow for project baseline and natural capital approach scenario (m3/s) at basin outflow

Under the natural capital scenario, overall water quantity in the Muanda River is reduced. Mean annual flow decreases from 35.7 m^3/s to 35.1 m^3/s (-1.7%). This is equivalent to a 19.6 mm^3 (million m3) reduction in flow quantity per year. However, in the dry season mean flows in the river increase from 7.06m^3/s to 7.28 m^3/s (average flow May to September) under the natural capital approach scenario. **This is equivalent to an increase in dry season flow to support irrigation agriculture of 2.850 Mm^3.** As Oates et al. (2015) identify, due to water scarcity farmers are prepared to pay a premium of 56% more for irrigation withdrawals during the dry season, reflecting importance of boosting supply during this part of the year.

In their review of the literature on the effectiveness of nature-base solutions in Africa, Acreman et al. (2021) also find evidence to support this pattern of decreased water quantity, but increased dry season flow from increasing native forest cover. Similarly, WWF (2021) finds that while native forests in Africa can reduce total water production from a watershed, they often increase water availability in the dry season. WWF (2021) highlights this can be more important to water users than total annual production.

5.2.2 Avoided sedimentation of water courses

Figure 23 maps the differences in sediment erosion across the Muanda River Basin between the project baseline and natural capital approach scenarios. This is a function not only of the additional erosion control from increasing tree cover in existing cropland areas, but also the knock-on effect this has in reducing the sediment delivery ratios of nearby areas, as they receive less incoming sediment in run-off themselves.

As would be expected, high soil erosion is associated with heavy rainfall experienced during the wet season months. Figure 24 shows the difference in sediment entering the Muanda River system under the project baseline (blue bars) and natural capital approach (green bars) scenarios. **Under the natural capital scenario, the annual sediment yield of the basin reduces by 21,655 tonnes per year (-13.3%).** This change is achieved by targeting agroforestry to cropland areas that have very high soil erosion rates and were driving the total soil losses from cropland within the Muanda River Basin under the project baseline scenario. Reforestation of riparian areas also substantially reduces the sediment delivery ratios of these areas.

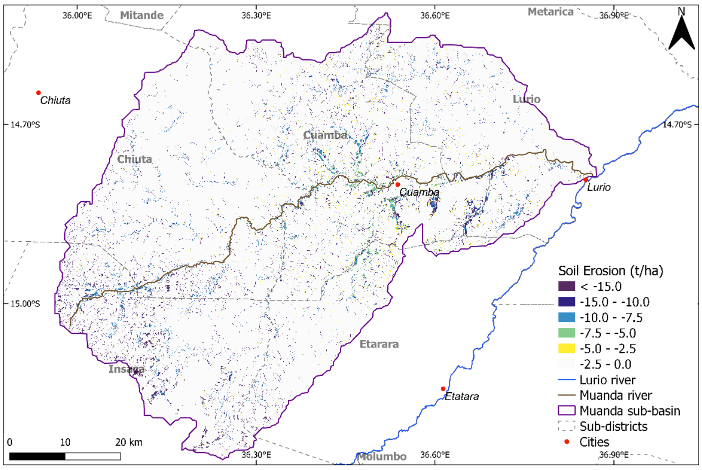

Figure 23: Difference in soil erosion in the Muanda River Basin between the project baseline and natural capital approach scenario (tonnes/ha)

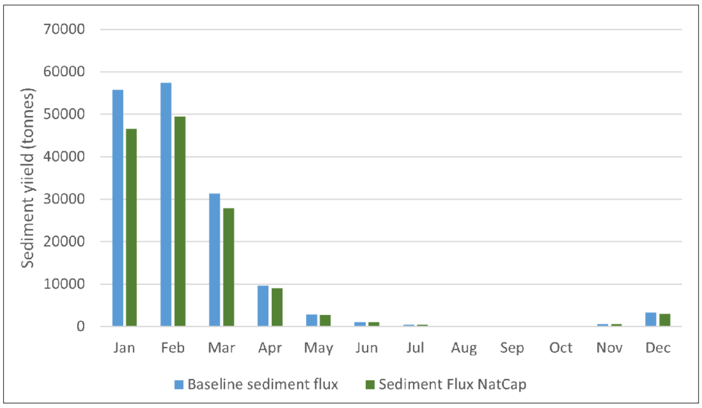

Figure 24: Monthly sediment yield under the project baseline and natural capital approach scenarios (tonnes)

5.2.3 Carbon storage and sequestration

Figure 25 presents the difference in carbon stocks between the project baseline and natural capital approach scenarios. These represent differences that would be expected once trees in natural forests in riparian areas and agroforestry reach maturity. Ameja et al. (2022) suggest such natural Miombio forests can be regenerated in 15 to 20 years. At this point, carbon stocks under the natural capital approach scenario total 27,951,466 tonnes, an increase of 538,715 tonnes compared to the project baseline scenario. Natural forest established in riparian areas represents most of the increase.

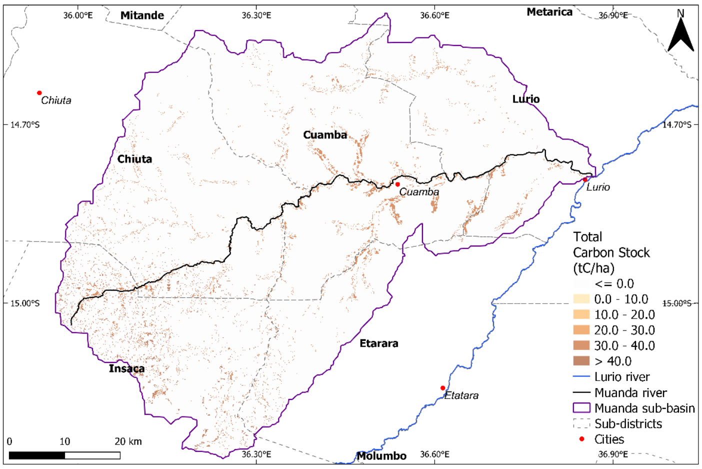

Figure 25: Difference in carbon storage between project baseline and natural capital approach scenario (tC/ha)

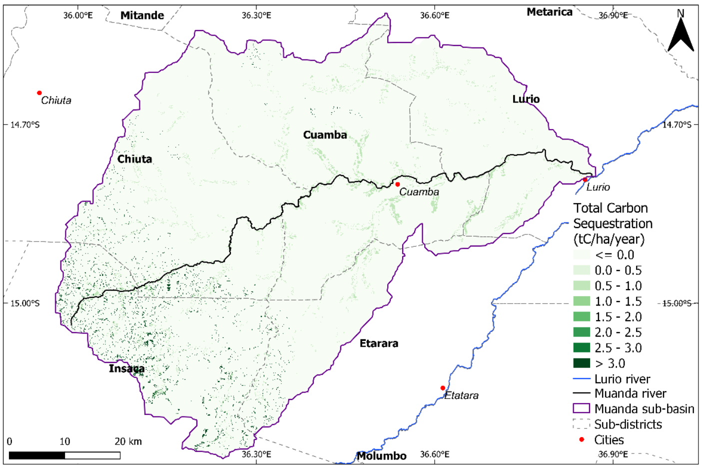

Figure 26: Change in carbon sequestration between project baseline and natural capital approach scenario (tCO$_2$e/ha/yr)

The IPCC (2006) suggests that carbon dynamics remain influenced by land cover change for around 20 years. Hence, forests (including agroforests) would be considered mature after this period, which is broadly in line with Ameja et al. (2022). Carbon sequestration rates provide an indication of the pathway to achieving these increased carbon stocks. Figure 26 maps the change in tonnes of carbon sequestered under the natural capital approach scenario, compared to the project baseline scenario. Applying the conversion factor of 3.67, this reflects a total carbon sequestration per year of 1,052,901 tCO^{2}e/year across the Muanda River Basin. **This is an increase of 16,720 tCO^{2}e/yr from the project baseline.** This sequestration rate is broadly consistent with achieving an increase of 538,715 tonnes of carbon stored over 10-20 years

5.2.4 Wood fuel provisioning services

The increase in wood fuel provisioning ecosystem services is mapped in Figure 27. This reveals substantial increases in supply in the western areas of the Muanda River system, linked to both agroforestry and reforestation of riparian areas. Increases in the wood fuel provisioning services are also noted in the central area of the Muanda River systems, linked more to reforestation of riparian areas.

It is important to note that this is based on a wood fuel supply from mature agroforestry and natural forest trees. As such, it will take some time for these trees to establish and generate the level of wood fuel returns presented in Figure 27. As previously highlighted, Ameja et al. (2022) suggest such natural Miombio forests can be regenerated in 15 to 20 years.

Under the natural capital approach scenario, the delivery of the wood fuel provisioning service in the Muanda River Basin is 149,853 tonnes per year, compared to 137,366 tonnes under the project baseline scenario. **This is an increase of 12,487 tonnes per year in sustainable wood supply.**

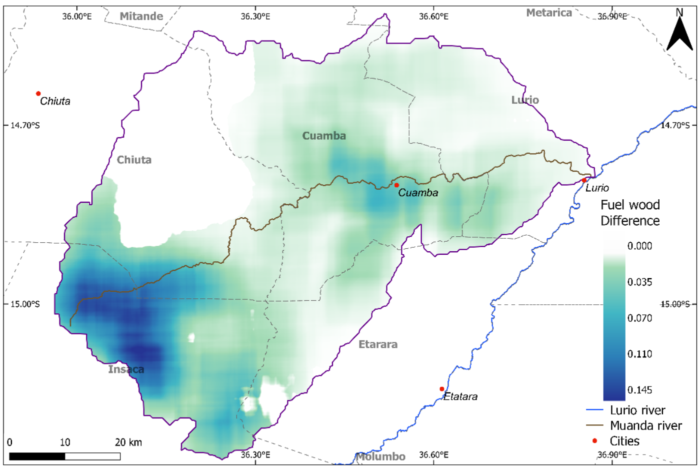

Figure 27: Change in wood fuel provisioning services between the natural capital approach and project baseline scenario (tonnes/ha/year)

5.2.5 Pollination

The pollination sufficiency under the natural capital scenario is shown in Figure 28. Under this scenario, 18,006 hectares of all cropland has a sufficient supply of pollinators. In absolute terms **this is an increase of 221 hectares of cropland being supplied with sufficient pollinator ecosystem services,** compared to the project baseline scenario. While this is a modest 1.2% increase, it should be noted that overall extent of cropland in the Muanda River Basin is reduced by 25% under the natural capital approach scenario. This means that the remaining stock of cropland ecosystems are much better supplied with pollinator ecosystem services under the natural capital approach scenario.

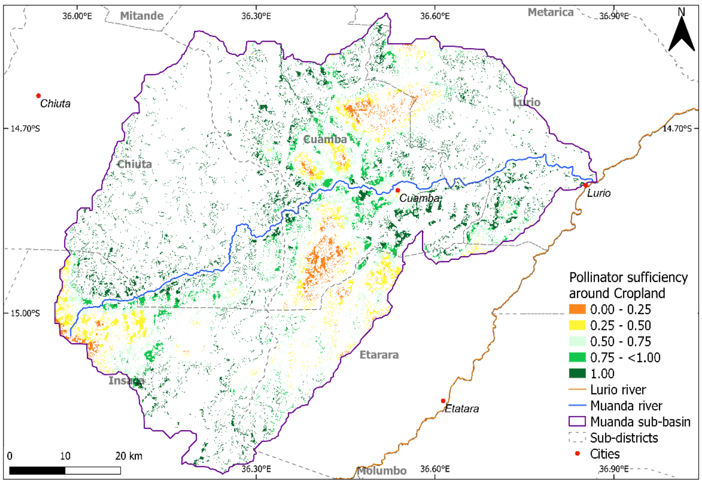

Figure 28: Distribution of cropland with access to pollinators under natural capital approach scenario

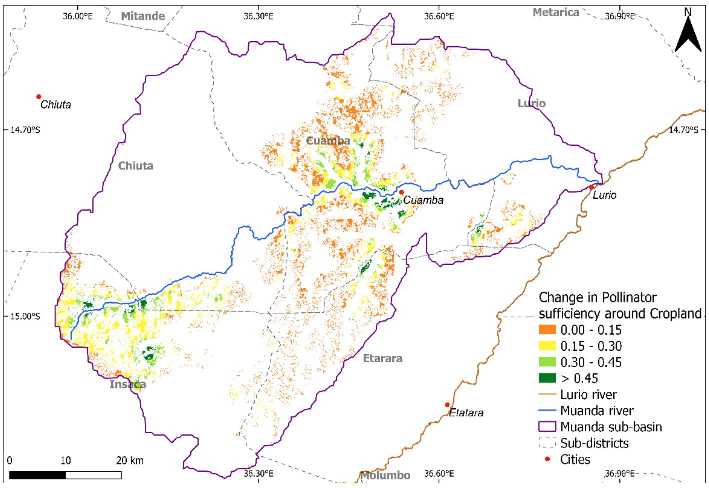

Figure 29: Change in distribution of cropland with access to sufficient pollinators between project baseline and natural capital approach scenario

In relative terms, 30% of cropland has sufficient supply of pollinators under the project baseline scenario and this increases to 40% under the natural capital approach scenario. This supports the notion that the natural capital approach scenario can support intensification of cropland production and more diversified, resilient and higher value crop production patterns.

As Figure 29 reveals, increases in pollinator sufficiency are found for croplands around areas that have been converted from cropland to riparian forests and in areas converted to agroforestry, as the increased habitats provided by these interventions increase the supply of this ecosystem service. Figure 29 shows these gains are most substantial in the cropland areas to the west of Cuamba and in the western area of the Muanda River Basin.

5.2.6 Biodiversity

Figure 30 presents the distribution of BII values for the Muanda River Basin under the natural capital approach scenario. In comparison with Figure 17, there is an increase in the occurrence of dark green areas with relatively high BII values. As a result, the BII for the basin area under the natural capital scenario **increases from 65% under the project baseline scenario to 69% under the natural capital approach scenario**.

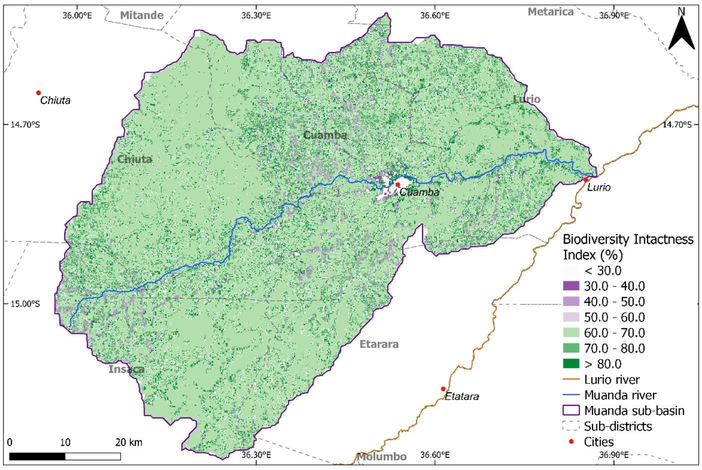

Figure 30: BII for the natural capital approach scenario

5.3 Analysis of ecosystem service returns from implementing a natural capital approach

Based on the physical modelling results summarized in Section 5.2 and the marginal values presented in Section 4.4, Table 1 provides a partial economic analysis of the returns in ecosystem services delivery under the natural capital approach scenario, compared to the project baseline scenario. As Table 1 reveals, the aggregate value of increased ecosystem service delivery under the natural capital approach scenario is $626,305/year, compared to the project baseline scenario. It should be noted this is based on using a market price for carbon credits to value the carbon sequestration related ecosystem service. If a social cost of carbon is applied, aggregate value of increased ecosystem services delivered rises to $1,378,705/year.

The natural capital approach scenario is based on converting 10,513 hectares of existing cropland to forestry and 4,460 hectares to agroforestry. This is approximately 15,000 hectares of land in total. This implies that the natural capital interventions return around $42/ha when market prices for carbon are employed. This doubles to around $90 when social costs of carbon are employed.

These returns can be compared against the value of crop production activities to better explore trade-offs and synergies for the final design of the SAPZ and to maximize the return of different benefits from across the Pemba-Lichinga landscape. At this stage, the economic returns in terms of increased crop output are not explicitly set out in the existing master plan for the SAPZ project. However, by way of comparison, in their survey of 638 smallholder farmer plots in Mozambique, Kidane et al. (2019) estimate a net return from conventional tillage maize farming of $104/ha. Although, this increases to $195/ha when direct seeding practices were employed (a non-tillage approach entailing placing a seed in a hole made by a planting stick).

Table 1 provides only a partial analysis of ecosystem services returns. Important additional ecosystem services returns that could be realized from implementing the natural capital approach also include: flood mitigation services during wet season months; pollination services linked to increased agricultural output; provisioning of non-wood forest products (nuts, honey, etc.); and regulation of pest damage from forests/agroforestry ecosystems (e.g. see Sheppard et al., 2020) It is highlighted that economic returns from agroforestry crop production are also omitted in Table 1 and would be realized under the natural capital approach scenario.

Table 1: Economic benefits analysis of increases in selected ecosystem services delivered under a natural capital approach for the SAPZ

Ecosystem service	Units/year	Difference in delivery	Marginal value ($/unit)	Total value ($/year)
Water flow regulation (dry season supply)	m^3	2,850,000	0.08	228,000
Sediment retention services	m^3	21,655	3	64,965
Carbon sequestration*	tCO_2e	16,720	5	83,600
Fuelwood supply	tonnes	12,487	20	249,740
Total				**626,305**

*Based on traded price of carbon in voluntary markets

5.4 Climate change scenario

The potential impacts of climate change on water and sediment retention related ecosystem services were assessed by running simulations with the Spatial Processes in Hydrology (SPHY) model for project baseline and natural capital approach scenarios with climate inputs based on NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)[8] for the Representative Concentration Pathway (RCP) 8.5 climate change pathway (i.e. one that results in emissions that deliver global warming at an average of 8.5 watts per square metre across the planet). This climate change scenario results in an increase in mean annual precipitation of 16 mm over the Muanda River Basin area, with some changes in seasonality; for instance, higher rainfall between February and August and lower rainfall between September and December. Under the climate change scenario mean temperatures are also projected to increase by 1.6°C.

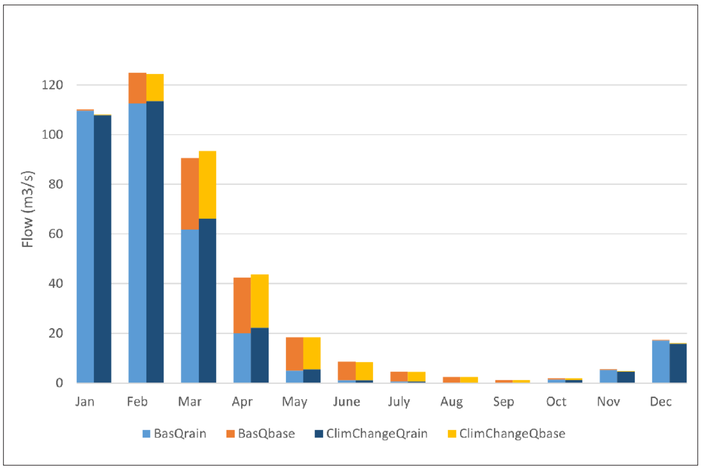

Figure 31: Mean monthly rain runoff and base flow for baseline and climate change scenario at basin outflow

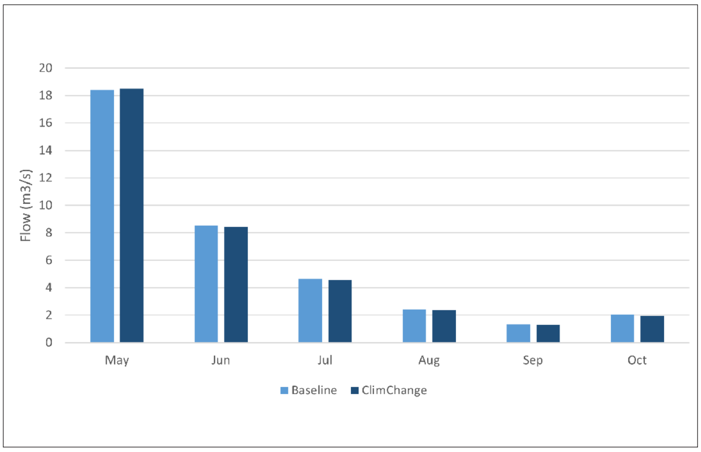

Figure 32: Dry season monthly mean flow for baseline and under climate change scenario at basin outflow

8 https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp

5.4.1 Water quantity and flow regulation

Projected climate change under the RCP 8.5 scenario leads to a small annual reduction in water flow in the Muanda River (-1.3 mm³/yr). While rainfall increases under predicted climate change conditions, due to higher temperatures, increased evaporation in the landscape means less water enters the river system. However, as shown in Figure 31, some seasonal changes are also observed, with slightly higher flows in the river predicted for the months March to May and reduced flow in all other months. Figure 32 shows the changes in dry season monthly flows in more detail. These flows are projected to reduce, with mean flows between May and September reducing from 7.06 m³/s to 7.04 m³/s. While these are small changes overall, a reduction of -0.39 Mm³ in dry season flow could have implications for an already water stressed system. In particular, if increased water demands for irrigation and the Cuamba APH are to be met.

Under the combination of the natural capital approach scenario with climate change, lower flows compared to the project baseline under climate change are projected for five out of 12 months (Figure 34), leading to an overall net annual water loss of 20.6 Mm³ (or -1.8%). In contrast to the project baseline scenario under climate change, a natural capital approach under climate change leads to slight increases in dry season flow across dry season months (Figure 34). In total, 0.16 Mm³ more water is estimated to be available during the dry season in the Muanda River for the natural capital approach scenario under predicted climate change conditions. **This shows that the natural capital scenario performs better than the project baseline scenario under predicted climate change impacts with respect to maintaining dry season water flows.**

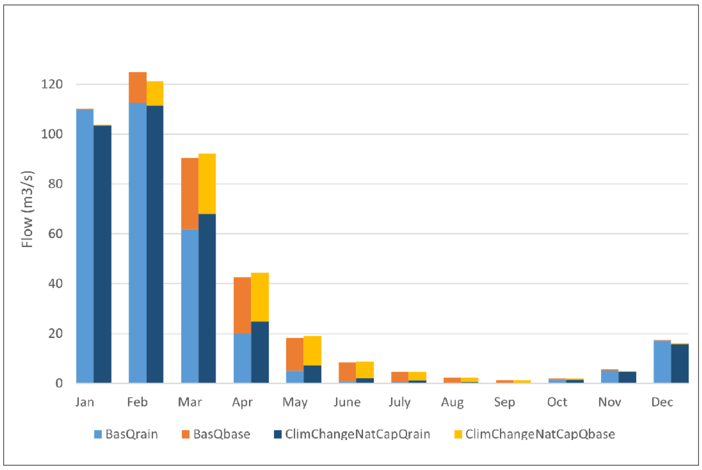

Figure 33: Mean monthly rain runoff and base flow for baseline and natural capital approach under climate change scenario at basin outflow

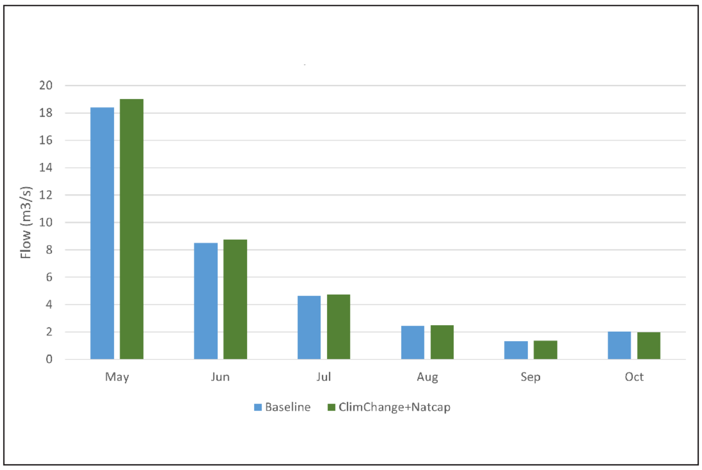

Figure 34: Dry season monthly mean flows for baseline and under natural capital approach with climate change scenario at basin outflow

5.4.2 Avoided sedimentation of water courses

For the project baseline scenario, under climate change annual average total sediment loads entering the Muanda River reduce slightly due to reduced rainfall and resulting runoff (i.e. because of the reduced overall annual surface water runoff to the river as projected under climate change, Figure 31). However, as revealed by Figure 35, sediment loads to the river increase between March and May, linked to higher runoff under climate change during these particular months (dark blue bars in Figure 31). Overall, the annual total sediment load to the Muanda River reduces by 1,218 tonnes (-0.75%) under climate change.

Figure 36 shows the distribution of the changes in sources of soil erosion entering the Muanda River system for the project baseline scenario under climate change. Small increases are widespread, but slightly more prevalent in the south of the river basin. Decreases are more often observed in the north.

Under the natural capital approach with climate change, sediment yield reduces for all months (green bars in Figure 37). The total annual decrease of sediment entering the Muanda River system is 22,758 tonnes, compared to the project baseline scenario under climate change. This is higher than the difference of 21,655 tonnes per year between these scenarios without climate change (as per Section 5.2.2). The spatial distribution of the changes of the sources of soil erosion entering the Muanda River under the natural capital approach scenario under climate change is presented in Figure 38.

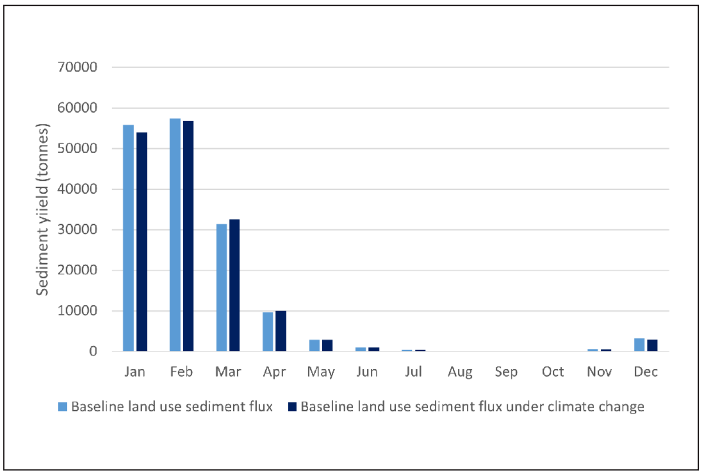

Figure 35: Monthly sediment yield under project baseline scenario and with under climate change scenario

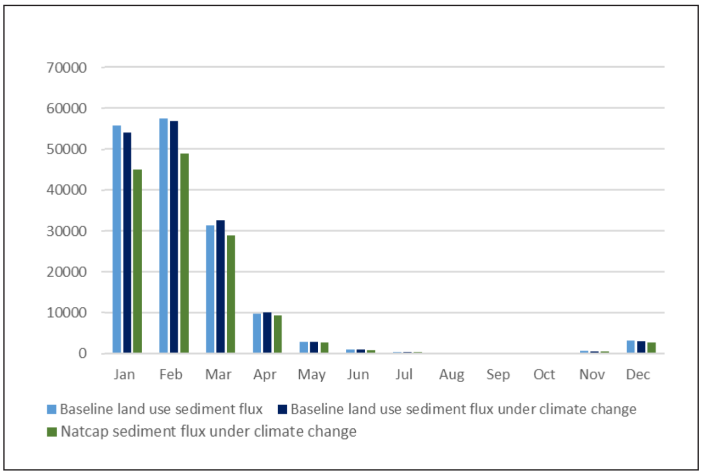

Figure 37: Difference in soil erosion between the project baseline and climate change scenario

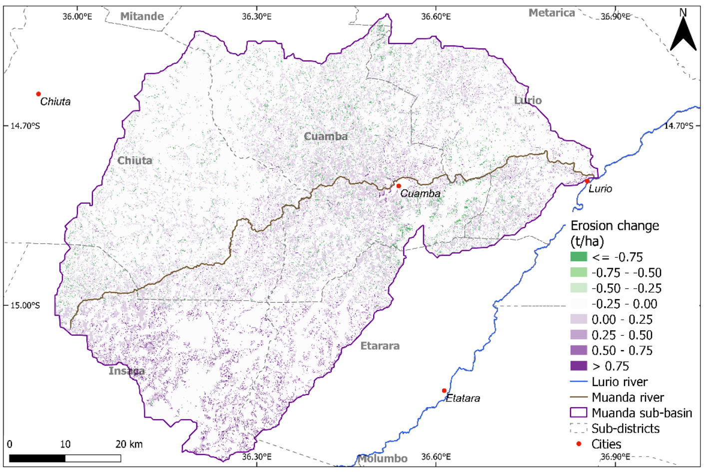

Figure 36: Monthly sediment yield under the project baseline and natural capital approach with climate change

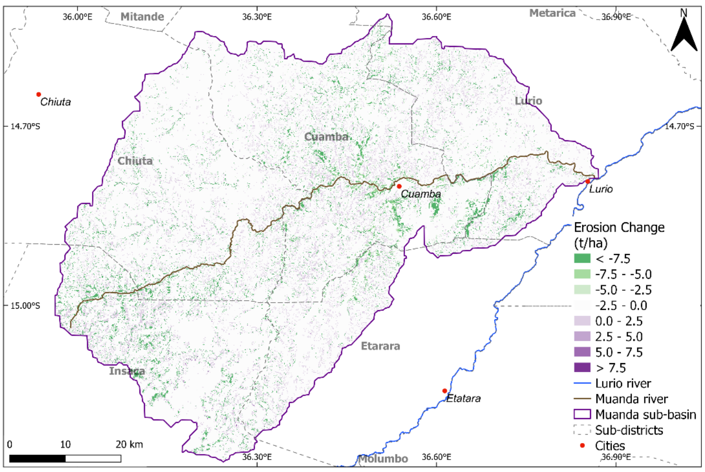

Figure 38: Difference in soil erosion between the project baseline and natural capital approach with climate change

6. Using, Developing and Mainstreaming Natural Capital Assessment

Natural capital loss is widely acknowledged as a fundamental barrier to sustainable development. The importance of sustainable use of natural capital for long-term social and economic development is recognized through the Sustainable Development Goals (SDGs). The UN Decade on Ecosystem Restoration also serves to highlight the urgent need for large-scale investment in ecosystem restoration and conservation of these critical natural capital assets.

Natural capital assessments that map, quantify and value ecosystem assets and ecosystem service flows under different development scenarios allow for natural capital to be integrated into development corridor and infrastructure project planning. This allows the multiple benefits from nature to be recognized by development planners and financing institutions. This is fundamental to capturing the synergies across environmental, social and economic development objectives, which effective development planning should aspire to. It also allows explicit consideration of trade-offs that may emerge in the context of land use activities that may deliver short-term economic gains at the expense of the long-term supply of ecosystem services and maintenance of biodiversity.

6.1 Mozambique case study

The natural capital assessment for the Special Agro-Industrial Processing Zone (SAPZ) project provides an integrated assessment of the possible trade-offs between cropland development (project baseline scenario) and other landscape ecosystem investment options (natural capital approach scenario). Specifically, it demonstrates how targeted interventions to increase tree cover in cropland and reforesting riparian cropland areas can improve ecosystem services supply and deliver on multiple development objectives via an integrated landscape management approach.

As such, the assessment supports the implementation of the Mozambique Roadmap for a Green Economy and its national development objective for the protection, restoration and rational use of natural capital and ecosystem services; in particular, the Mozambique Green Economy Action Plan to 2030 by helping to inform sustainable use of natural resources at a landscape scale. It also responds to the inter-ministerial request for mapping, valuation and integration of natural capital in planning as a priority for the GEAP to 2019.

The natural capital approach scenario demonstrates multiple returns for investing in ecosystems. The partial analysis estimates the aggregate value of four ecosystem services to be in the region of $42/ha in terms of benefits that could accrue to Mozambique. This increases to $90/ha when global avoided social costs of climate change mitigation are included. These monetary estimates allow for the relative costs and benefits of different landscape development options to be compared. They serve to demonstrate to development financers and governments that ecosystem investments do deliver economic returns.

Beyond direct economic benefits, increased delivery of ecosystem services under the natural capital approach scenario will also support the longevity of the SAPZ project, deliver important social welfare benefits and contribute to climate change mitigation and biodiversity conservation objectives. As such, the natural capital assessment supports a more integrated landscape development approach by:

- **Informing nature-based solutions to support the SAPZ:** Targeted agroforestry and afforestation under the natural capital approach scenario directly supports the SAPZ project by improving the potential for dry season irrigated agriculture (increasing dry season river flow by 2.85 Mm^3) and mitigating sedimentation risk of irrigation channels (reducing sediment entering the river system by 21,65 m^3/yr). This will also support the operation of the Cuamba APH. The natural capital assessment can help scope and locate these nature-based solutions to support the SAPZ. For instance, where to establish agroforestry and afforestation to protect soils and watercourses. This can support the updated GEAP on its objectives for sustainable infrastructure and integrated water resources management. These interventions also increase the extent of cropland with sufficient access to pollinators by 221 hectares in the Muanda River Basin. While this is a small increase in absolute terms, the stock of cropland supplied with sufficient pollinator increases by 10% under the natural capital approach scenario.

- **Delivering wider social benefits:** The natural capital approaches scenario highlights how the SAPZ could improve energy security in the Muanda River Basin by generating an additional sustainable supply of wood fuel of 12,487 tonnes/year. Although some time would be needed for trees to mature and deliver this level of wood fuel supply (around 15-20 years, following Ameja et al., 2022). The additional tree and forest cover will also support communities by providing non-wood forest products, such as nuts, fruits and honey.

- **Delivering climate change mitigation:** Mozambique has committed to reduce its emissions by about 40 $MtCO_2eq$ between 2020 and 2025.[9] Carbon sequestration services that could be realized via the natural capital approach scenario could contribute around 16,000 tCO_2eq per year towards such a target.

- **Delivering better biodiversity outcomes:** The natural capital approach scenario illustrates interventions that can be integrated in the SAPZ to deliver on biodiversity objectives. The natural capital approach scenario establishes over 10,000 hectares of natural forest in riparian areas, contributing to national biodiversity objectives and progress towards SDG Target 15.1. This would also lead to a tangible increase on species level biodiversity, increasing the Biodiversity Intactness index for the Muanda River Basin area from 65% to 69%. This shows interventions in the landscape under the SAPZ natural capital approach are likely to be nature-positive.

9 https://www.climatewatchdata.org/ndcs/country/MOZ?document=revised_first_ndc

The results of the natural capital assessment for the Muanda River Basin also highlight the potential benefits that could be realized elsewhere from adopting a natural capital approach within the SAPZ zone of influence. The assessment demonstrates that selectively increasing tree cover in croplands can contribute to better dry season flows, address erosion, improve energy security and deliver better outcomes for biodiversity where these are most needed. This can help inform a more integrated programme of work for the SAPZ as a whole, based on mainstreaming natural capital and ecosystem service benefits into the project design. This can support the government in creating a green growth policy framework that protects watersheds, soil fertility and pollinators important for crops of high nutritional and cash value. The natural capital assessment can also inform discussions to unlock different sources of financing. This includes leveraging climate and conservation finance to support integrated landscape development via the SAPZ project.

The monetary value of ecosystem service returns per ha highlighted above ($42-90/ha) may be lower than profits from crop production activities in cash terms (e.g. $104/ha from conventional tillage maize farming). However, this does not infer the natural capital approach comes with an opportunity cost. First, the value of ecosystem service returns does not include the revenue generated from agroforestry crops. Once these are included, returns are likely to exceed those for maize farming. Second, the reforestation of riparian croplands under the natural capital approach is also in line with the SAPZ environmental and social impact assessment. This places a ban on farming in proximity to rivers. As such, afforestation of these areas does not necessarily reflect an opportunity cost under the natural capital approach.

Finally, it is highlighted that additional ecosystem services will be realized under the natural capital approach scenario, which were beyond monetary calculus within the resources available to this assessment. These include: potential flood mitigation services in wet season months; pollination services; provision of non-wood forest products; and pest regulation services. When all these factors are considered, the natural capital approach could be the socially preferable scenario. Demonstrating this would require further development of the assessment, likely requiring additional local data collection.

6.1.1 Climate change resilience and adaptation

Increasing climate change resilience and reducing climate risks is a key national development priority for Mozambique. The natural capital assessment for the SAPZ demonstrates the natural capital approach remains resilient to climate change and delivers some adaptation advantages in comparison to the project baseline scenario. During the dry season, water quantity in the Muanda River is estimated to be 0.16 Mm^3 higher under the natural capital approach scenario, with predicted climate change conditions. It is also noted that peak flows in the Muanda River for January and February are higher in the project baseline scenario under climate change, compared to the natural capital approaches scenario in these, the wettest, months of the rainy season.

More generally, the increase in forest and agroforestry ecosystems are also likely to support more diversified livelihoods, which will also deliver social resilience to climate change. Agroforestry is recognized as an effective climate change adaptation strategy for the agricultural sector in Africa, as it can mitigate extreme local temperatures, improve food security and deliver diversified sources of income. Without agroforestry and other climate change adaptation interventions in the SAPZ, it is possible that any increases in crop yield may be short lived and lost when the impacts of climate change manifest in the agricultural sector in this part of Mozambique.

6.1.2 Developing the SAPZ assessment

It should be noted that the assessment presented is intended to be indicative and has been largely completed using readily available global data. As with the intervention measures proposed in the feasibility study, master plan and business plan (Mahindra Consulting, 2020), detailed design of natural capital intervention measures is needed. This will likely require the use of more detailed data, including on-the-ground survey data, to calibrate the models employed to local conditions. Further engagement with those practicing agroforestry in Mozambique and other countries in the region is also needed to better quantify returns from this land use option. This includes gaining a better understanding of the ecosystem services agroforestry supplies, including with respect to pest regulation services. It will also help to understand how agroforestry can be best deployed as a climate change adaption strategy for the SAPZ project.

The water quantity modelling reveals that wet season peak flows in the Muanda River are mitigated under the natural capital approach scenario. This derives from the ability of forest and agroforestry ecosystems to absorb and store water from high rainfall events, then release it more slowly. The Global Facility for Disaster Reduction and Recovery (GFDRR) (2015) highlights the vulnerability of smallscale farmers in the central and northern parts of Mozambique to flooding events. Investing in local data will help inform interventions to increase the extent of forest and agroforestry ecosystems where they could best deliver important flood mitigation services, including for Cuamba city, as well for agricultural land.

Local household surveys can also help to characterise the income streams that local people obtain from sustainable forest use. This will allow potential incomes and value addition possibilities linked to non-wood forest products to be better estimated. Farm level surveys will also be important to better estimate the importance and value of increasing pollinators under the SAPZ project and where interventions to do so would be best located.

It is also highly likely that the SAPZ project will have natural capital impacts on the ground that will affect ecosystem services supply, and this should be better considered in the assessment. For instance, where industrial agricultural intensification is implemented or, more locally, associated with the footprint of infrastructure development associated with the project. Once more detailed plans on agricultural land use changes and infrastructure are available, their impact on ecosystem services supply and social welfare at landscape and local scales should be assessed.

It is also essential that any final natural capital interventions options are designed in an inclusive, participatory fashion with local communities to ensure they will meet their development needs. For example, establishing plantation forests for climate mitigation benefits has been shown to have negative impacts on local communities in the Niassa Province (Overbeek, 2010). Community engagement is essential to avoid these unintended social welfare impacts from natural capital interventions. Although, it should be noted that the interventions proposed under the natural capital approach are anticipated to off-set any such impacts in aggregate.

6.1.3 Moving to full cost-benefit analysis (CBA) for the SAPZ

The scope of the SAPZ natural capital assessment aims to highlight the additional benefits that applying a natural capital approach to the project can deliver. To develop a fully integrated assessment, the benefits derived from crop provisioning services also need to be included. Once a detailed design for the land use and cropping patterns under the SAPZ project is proposed, these impacts and values can be better assessed and integrated. This should also include the provisioning services associated with agroforestry under the natural capital approach.

As development finance decision makers are faced with many different expenditure options, they will be interested in understanding how the full value of the benefits realized via the SAPZ compare against costs under different implementation approaches. This economic appraisal of environmental (and other project) interventions is commonly implemented through a cost-benefits analysis (CBA) (OECD 2006).

In the context of the SAPZ, the CBA approach would be based on comparing both the monetary costs and benefits associated with implementing the natural capital approach or the project base line scenarios compared to a "do not do the project" scenario over a given time period. Future costs and benefits are evaluated and discounted over this time period. They are discounted using a discount rate that reflects the productivity of capital and the time preferences of society for consuming benefits and meeting costs associated with the project. As an example, in their CBA of agroforestry interventions in Mali, Sidibé et al. (2014) employ a 25-year time period and 5% discount rate. If the overall net present value (NPV) – the discounted benefits minus costs over the time period – of implementing the project scenario is positive, it is economically rational to implement the project, as the benefits exceed the costs of not doing so. However, there may also be strategic or other reasons to implement the project.

Where multiple investment options are possible, such as the natural capital approach or project baseline scenarios for the SAPZ, a CBA allows the identification of the "best value for money" solution. This can be achieved by comparing the NPVs directly and selecting the highest. However, other summary statistics are often derived from a CBA to support investment appraisal. These include calculating to ratio of discounted benefits to costs (the benefit cost ratio or BCR which provides an indicator of returns on investment) and the internal rate of return (for comparing against other investment options). Typically, investors will consider these economic indicators against benchmarks or thresholds, given the CBA is based on multiple assumptions of a project costs and future benefits.

To proceed with such a CBA, the SAPZ project implementation proposal needs to be fully costed, as do interventions under any proposed natural capital approach scenario. As a starting point, literature values for afforestation and establishing agroforestry may be used to better inform the cost of implementing the natural capital approach. With monetary benefit values from cropland and agroforestry provisioning and wider ecosystem services, net present values of future benefits and costs for the SAPZ project under the natural capital approach and project baseline scenarios could then be determined. This environmentally extended approach to a CBA would then provide development finance decision makers with a more complete set of economic information to base their investments on. German development agency GIZ (2013) provides a useful overview of the CBA approach, although there is plenty of guidance and examples that can be drawn on.

6.2 Role for natural capital accounting

Natural capital accounting essentially comprises of undertaking repeated natural capital assessments to generate a time series of consistent information on the state of ecosystems and flows of ecosystem services for an accounting area. National statistical offices are increasingly implementing this at national and sub-national scales, using the System of Environmental Economic Accounting Ecosystem Accounting (SEEA EA) framework (United Nations et al., 2021). The SEEA EA supports the mainstreaming of natural capital approaches across development and economic planning at different levels of government in a coherent way. Government implementation of the SEEA EA could directly support natural capital assessment of development projects like the SAPZ in the following ways:

- The SEEA EA sets out consistent terms and classifications for information on ecosystems. This would include an agreed national ecosystem typology, ecosystem condition indicators and priority ecosystem services. This would establish a framework to enhance consistency across natural capital assessments and make them more coherent with national ecosystem measurement approaches.

- Compilation of SEEA EA accounts requires maps (or spatial data) on ecosystems to be organized. This provides a public good for informing natural capital assessments across all scales, thereby reducing the resources required and time taken to complete them.

- Methods established via the SEEA EA process (e.g. with respect to ecosystem services modelling) at the national level could be implemented for project level natural capital assessments. This would also reduce resource requirements, improve consistency across assessments and make project level decisions more coherent with national policy objectives.

- Helping to identify broad opportunities for natural capital investment that more detailed natural capital assessments could target to generate a pipeline of bankable natural capital projects.

6.3 Better uptake by governmental and financing institutions

This report and the SAPZ natural capital assessment are intended to build the capacity of those in government and development finance institutions to understand concepts related to natural capital, so they can better mainstream them into their decision-making. The report seeks to build a common understanding on natural capital concepts, which this community can work from. The SAPZ case study demonstrates how these concepts can be implemented to support more integrated development planning that can capture the multiple benefits different ecosystems deliver and link these to different development objectives. Ultimately, this can deliver more effective and better integrated planning, where development corridor and infrastructure projects serve as a catalyst for green economy transition.

To these ends, development finance institutions can support mainstreaming of natural capital into public and financing decisions by:

- **Building and institutionalizing knowledge on using natural capital approaches in Africa.** Support countries to build knowledge on natural capital approaches, the stocks of natural capital countries are endowed with and how these can be harnessed to support green economic development. This includes supporting natural capital assessment and natural capital accounting to build a more coherent knowledge base and a pipeline of bankable natural capital projects across Africa.

- **Supporting and engaging with existing networks on mainstreaming natural capital.** Collaborate with existing networks that advance the uptake and use of natural capital approaches in development corridor and infrastructure projects and in wider decision-making contexts.

- **Leading the way on implementing natural capital approaches.** Be a knowledge leader and apply these tools routinely in evaluation of development corridor and infrastructure projects and mainstream natural capital into their design. Integrate monetary and non-monetary values of ecosystem services realized from natural capital approaches into their investment decisions. Call for natural capital assessments to be part of the process for designing development projects in an integrated way, which delivers on multiple development objectives.

- **Promoting of nature-based solutions.** Build natural capital knowledge to promote nature-based solutions as viable development options. Prioritize these over "grey" (human-made) infrastructure solutions where possible, to capture the additional benefits they realize and use natural capital approaches to help shift financial flows from actions that degrade natural capital towards long-term stewardship of nature.

- **Enabling the financing for implementing natural capital approaches.** Help countries to overcome high upfront investment and long-term maintenance costs often associated with implementing natural capital approaches. For example, by playing a convening role in bringing funders together to overcome some of these costs given their different objectives in landscapes. Also by assisting countries to implement financing mechanisms to help overcome these costs. These may include credit enhancement, long tenures, quasi equity loans (i.e. loans based on projected future cash flows rather than collateral) and credit guarantees to make natural capital approaches and nature-based solutions more affordable, and mitigate risks associated with their more widespread adoption. It may also include helping to establish payments for ecosystem services mechanisms to meet long-term maintenance costs.

7. Conclusions

In Africa, the need to mainstream natural capital into development planning is recognized in the aspirations of Agenda 2063. The African Union Green Recovery Action Plan (2021-2027) highlights the continental vision of restoring and sustainably managing ecosystems for economic recovery and job creation. In countries across Africa, mainstreaming natural capital for green economic development is being recognized in national green economy policies, action plans and strategies.

There is an urgent need to help financial institutions and governments to make more nature-positive decisions and investments on a routine basis to support these plans to transition to green economies. Natural capital assessments that quantify, map and value natural capital and ecosystem service flows provide essential knowledge to mainstream natural capital into these decisions. This includes identifying where restoring natural capital can make positive contributions across

social, economic and environmental challenges, thereby supporting more ecologically sustainable and inclusive development.

The natural capital assessment for the Special Agro-industrial Processing Zone (SAPZ) project in the Muanda River Basin responds to this need by providing an integrated assessment of trade-offs between cropland and other ecosystem investments. While agricultural development for Mozambique is important, it needs to be balanced with other national development objectives. This requires integration of agriculture, forestry, water and other sectors in policymaking. This is recognized in the national Green Economy Action Plan (GEAP), which also identifies mapping, valuation and integration of natural capital in national planning as a priority (AfDB, 2015).

The natural capital assessment of SAPZ provides a tangible demonstration of the long-term co-benefits that can be realized via natural capital approaches. Under the natural capital approach scenario, dry season water flows in the Muanda River increase by 2.85 Mm^3/year and sediment loading to the river from local soil erosion decreases by 21,655 tonnes/year. This can support the long-term success of the SAPZ project by increasing water available for dry season agriculture, avoiding sedimentation of irrigation channels and improving water quality for agro-processing activities. The natural capital approach delivers improved local energy security for local communities, increasing sustainable wood fuel supplies by 12,487 tonnes per year. It also delivers global climate change mitigation benefits of 16,720 tCO_2e/year.

The aggregate value of the benefits realized under the natural capital approach, compared to the project baseline scenario for the SAPZ, is $42/ha/year. This increases to $90/ha/year when social costs of carbon are used to estimate climate change mitigation co-benefits. Additional co-benefits from improved pollination (cropland with sufficient pollinators increases by 10%) and biodiversity are also realized (biodiversity intactness index increases by 4%). Additional ecosystem services whose supply is likely to be increased under the natural capital approach include wet season flood mitigation, provisioning of non-wood forest products and regulation of pest damage. However, additional data is needed to quantify the potential supply of these services and to value them.

Natural capital assessments, such as those presented for the SAPZ project, can be undertaken for many other development or infrastructure projects, to highlight returns in investing in ecosystems for nature-based solutions, social welfare benefits, climate change mitigation and improved biodiversity outcomes. Such assessments can foster a transition away from traditional development approaches that address development issues such as poverty, economic growth, climate change and biodiversity conservation on an individual basis. Towards a more integrated planning response, which recognizes the multiple benefits nature provides, captures these benefits and mitigates unintended trade-offs from natural capital impacts. This is essential if countries are to transition to green economies, where national development is both socially just and in balance with nature.

Development finance institutions and their government partners will play a key role in delivering this green economic development vision. They can drive the natural capital mainstreaming agenda by developing the knowledge base on natural capital and its role in sustainable development and green recovery in Africa. By applying this knowledge to project design and investment planning, they can lead the way for better and more integrated planning that recognizes the many benefits nature provides to the people of Africa and its economy. By working together, they can help to overcome some of the cost barriers to implementing natural capital approaches that many projects face. In this way, development projects can be a catalyst for building natural capital stocks in landscapes and seascapes.

Glossary

Biodiversity: The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity. Art. 2: Use of Terms, 1992).

Climate change: A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period (IPBES, 2019a).

Climate change adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (Masson-Delmotte et al., 2018).

Climate change mitigation: A human intervention to reduce emissions or enhance the sinks of greenhouse gases (Masson-Delmotte et al., 2018).

Ecosystem: An ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity. Art. 2: Use of Terms, 1992).

Ecosystem services: The contributions of ecosystems to the benefits that are used in economic and other human activity (United Nations et al., 2021).

Nature-based solutions: Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits (UNEA, 2022).

Natural capital: Those renewable and non-renewable natural resources (such as air, water, soils and energy), stocks of which can benefit people both directly (for example, by delivering clean air) and indirectly (for example, by underpinning the economy) (Bateman & Mace, 2020). A common way of characterising this biotic component of natural capital in landscapes and seascapes is as ecosystems that supply ecosystem services. This is the perspective on natural capital adopted in this report.

Natural capital approaches: Approaches that drive changes in policy and/or investment decisions by incorporating the values of ecosystems to people, aiming to improve human well-being (Ruckelshaus et al. 2022).

Natural capital assessment: Quantifying, mapping and valuing natural capital and ecosystem service flows and how these are expected to change under different scenarios (Ruckelshaus et al. 2022).

Natural capital accounts: A set of objective data on the stocks of natural resources (including ecosystems), how they contribute to the economy (e.g. via the supply of ecosystem services) and how the economy affects natural resources that are compiled on a regular and consistent basis (adapted from Vardon et al., 2017).

Tipping point: A set of conditions of an ecological and/or social-ecological system where further perturbation will cause rapid change and prevent the system from returning to its former state (IPBES, 2019a).

Annex I: Detailed Methods for Ecosystem Services Modelling

Water quantity (supply) and water flow regulation

To calculate the water flow regulation services, we used the SPHY (Terink et al., 2015) hydrological model at daily time step at a resolution of 100 metres for the full study area. The SPHY hydrological model is a spatially distributed leaky bucket type of model, applied on a cell-by-cell basis. The model includes two upper soil storages and a third groundwater storage. For each cell, precipitation interception and evaporation by vegetation is calculated. Remaining precipitation is transformed into surface runoff and infiltration into soil, depending on soil properties and vegetation. Soil moisture is subject to evapotranspiration and remaining water either laterally flows from the first soil layer or percolates into the deeper groundwater store from where it contributes to baseflow.

Since there was no local climatological data available for the study area, we used the highest resolution daily remote sensing-based dataset available for temperature, CHIRTS (Verdin et al., 2020), which provides daily minimum and maximum temperatures for the period 2003-2016. For precipitation inputs, we used the CHIRPS daily precipitation data based on infrared remote sensing combined with station observational data (Funk et al., 2015). These data are available at ~5km resolution. All climate data were then resampled to 100-metre resolution using bilinear resampling. For land use, we used Copernicus 2019 (Buchhorn et al., 2020) land use dataset available at 100 metres. Soil properties data were derived from the 250 metre resolution HiHYDROSOILS data (Simons et al., 2020) and OpenLandMap[10] soil datasets, both resampled to approximately 100-metre spatial resolution for modelling. The model was run for the period 2012-2016, using the first year for model spin-up.

Potential impacts of climate change were modelled using the SPHY hydrological model but driven with General Circulation Model (GCM) derived climatological data for the RCP 8.5 emission pathway (Riahi et al., 2011) for the 2050s. Daily precipitation and temperature anomalies were derived from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), which provide data for 21 GCMs for RCPs 8.5 and 4.5 for the period 1950-2100 at 25 x 25 km resolution. Daily anomalies between the periods 2010-2020 and 2050-2060 were calculated for the study region using Google Earth Engine and a mean for all 21 models. Anomalies were then applied to the daily high resolution baseline climatology for the period 2012-2016.

Avoided sedimentation of water courses

To map the avoided sediment of water courses service, we used the Morgan–Morgan–Finney (MMF) erosion model that is integrated with the SPHY hydrological model (Eekhout et al., 2018). This model includes a complete representation of key soil erosion processes such as surface runoff generation, dynamic vegetation development, and sediment deposition which makes this model particularly suitable for evaluating inter- and intra-annual impacts of environmental change on soil erosion and sediment yield at large spatial and temporal scales The model runs at the same timestep (daily) as the hydrological model and receives input from the SPHY model, such as effective precipitation (throughfall), runoff and canopy cover for calculation of erosion and deposition processes. Parameters for the MMF model were estimated based on literature values.

Pollination

The pollination ecosystem service was mapped using a similar approach as Chaplin-Kramer et al. (2019), which assumes there are sufficient pollinators when there is at least 30% natural habitat within 2 kilometres of cropland. Using a moving window of 2 kilometres, the total area of natural land (shrub, herbaceous woodland, closed, open forest and agroforestry) around cropland pixels were calculated. These values were then normalized and all values above 0.3 were set to 1 and values between 0 and 0.3 were rescaled between 0 and 1.

10 www.openlandmap.org

Carbon sequestration and storage

Carbon stock and sequestration services for project baseline and natural capital approach scenario were mapped based on land use and land cover and carbon stored or sequestered in different pools based on literature values (Tables A.1 and A.2) using a similar approach as the InVEST carbon storage model (Sharp et al., 2020). For the natural capital approach scenario, no changes in existing classes were assumed but values were added for the additional class of agroforestry.

Table A.1
Carbon sequestration in land use classes

Land cover class	Aboveground biomass (tC/ha/year)	Belowground biomass (tC/ha/year)	Total biomass (tC/ha/year)	Soil carbon (tC/ha/year)
Shrubs	1.49	0.55	2.04	1.77
Herbaceous wetland	0.48	0.2	0.68	0.42
Cropland	0.37	0	0.37	1.02
Urban	0	0	0	0
Waterbody	0	0	0	0
Plantations	4.835	1.39	6.225	1.46
Closed forest	1.15	0.16	1.31	0
Open forest	2.01	1.5	3.51	0.88
Agroforestry	3.145	0.59	3.735	1.58

Table A.2
Carbon stock in land use classes

Land cover class	Aboveground biomass carbon stock (tC/ha)	Belowground biomass carbon stock (tC/ha)	Soil carbon stock (tC/ha)	Deadwood carbon stock (tC/ha)	Total carbon stock (tC/ha)
Shrubs	12.935	8.304	43.170	5.145	69.554
Herbaceous wetland	2.700	0.700	68.280	0.300	71.980
Cropland	2.375	0.600	50.250	0.450	53.675
Urban	0.000	0.000	0.000	0.000	0.000
Waterbody	0.000	0.000	0.000	0.000	0.000
Plantations	27.815	7.650	36.235	0.400	72.100
Closed forest	35.025	13.810	37.030	1.600	87.465
Open forest	25.480	9.670	33.105	0.120	68.375
Agroforestry	17.700	7.150	73.500	1.760	100.110

Wood fuel provisioning services

To map wood fuel provisioning ecosystem services, we developed a wood fuel model based on mapping total supply from total biomass in accessible forest pixels, where forest with slope over 15% (general definition of a 'steep slope') were excluded within a 10-kilometre radius. Total supply represents the mean annual increment in wood fuel biomass that would be expected once forests had reached maturity. Similarly, total wood fuel demand was calculated for a 10-kilometre radius by multiplying the number of people with the per capita demand for wood fuel based on literature values (set at 1.52 tonnes/person/year; Balama et al., 2016). Total realized supply was then calculated as the supply minus demand for each pixel or total supply in case of greater demand.

Biodiversity conservation

In this study, due to paucity of primary information for the biodiversity of the Muanda River Basin, the PREDICTS (Projecting Responses of Ecological Diversity in Changing Terrestrial Systems) database (Hudson et al., 2014) was used to calculate the BII. The database includes ~54,000 species that encompass diverse floral and faunal groups (plants, fungi, birds, mammals, reptiles, amphibians and invertebrates). The BII is estimated by combining two statistical models executed using R statistical software (R Development Core Team, 2021). The first is the site-level organismal abundance model, and the second model is on compositional similarity to a site still having primary vegetation. Since the data is derived from various regional datasets, these are performed as mixed-effects models that are controlled for study origin and methods.

For the BII estimates, the species data were filtered by regional biomes and those that closely represent the land use class and currently practiced land use intensities in the Muanda River Basin. The model results that were generated were mapped with the land use class of the basin with the PREDICTS land use class and intensity as shown in Table A.3. After mapping, the models were then projected onto the baseline land use scenario and the proposed natural capital scenario along with the anthropogenic pressures that includes land use intensity and the Human Population Density (CIESIN, 2018) of the basin and is represented in terms of percent.

Table A.3:
Mapped PREDICTS land use for the Muanda River Basin

Muanda land cover	PREDICTS land use – intensity
Shrubs	Primary vegetation
Cropland	Cropland – intense
Urban	Urban
Waterbody	Mask layer
Herbaceous wetland	Primary vegetation
Closed forest	Primary vegetation
Open forest	Primary vegetation
Plantations	Plantation forest – other
Agroforestry	Plantation forest – minimal

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GGKP

GGKP Green Policy Platform

GGKP Green Finance Platform

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