Assessing benefits and opportunities of tree planting in the Southern Agricultural Growth Corridor of Tanzania

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Abstract

Ecosystem restoration is seen as essential for conserving forests, preserving biodiversity, and addressing climate change. However, achieving effective and equitable restoration requires integrating social considerations to better understand and manage trade-offs that arise from these interventions. This thesis addresses the need for a more inclusive approach to tree-cover restoration by examining methods that incorporate local perspectives and preferences into restoration planning.

Firstly, I map the global evidence on participatory scenarios in ecological restoration to understand their role in assessing trade-offs across restoration outcomes. The findings suggest that participatory scenarios enable the integration of diverse knowledge types and methods, yet their impact on restoration planning remains unclear. Then, through participatory scenarios with smallholder farmers and a sentiment analysis, I explored farmers' preferences and attitudes toward tree-cover restoration in Tanzania's Kilombero Valley. Farmers' desired outcomes diverge from current restoration policies and plans that emphasise exclusionary protected areas, underscoring the importance of participatory planning approaches that align with local aspirations. Lastly, I investigate how homegarden agroforestry and sugarcane contract farming contribute to household resilience to climate change. Both farming strategies can positively and negatively affect livelihood resilience as smallholders grapple with trade-offs from limited land, costs of planting and maintaining, and risks to livelihood outcomes. Farmers have cleared trees from their plots for sugarcane, leading to a concentration of farmers' trees within homegardens, suggesting that homegardens may be important for ensuring the direct benefits of trees for smallholders and conserving aboveground carbon stocks.

Overall, this thesis argues that agroforestry offers a promising strategy to enhance livelihood diversity and resilience. However, achieving equitable restoration requires recognising and addressing the trade-offs and preferences of all stakeholders. I advocate for a broader methodological approach that combines diverse data types and participatory methods to ensure that tree-cover restoration efforts align more closely with the needs and values of local communities.

Preface

This thesis examines the trade-offs faced by stakeholders involved in tree-cover restoration, drawing on diverse methods and data from both social and natural sciences. It begins with a systematic mapping of global studies using participatory scenarios to explore trade-offs, then narrows its focus to the Kilombero Valley in Tanzania, analysing the specific trade-offs for smallholder farmers implementing agroforestry.

My motivation for this research stems from a desire to understand how to evaluate trade-offs in tree-planting initiatives, to help mitigate negative impacts and enhance the effectiveness and equity of restoration efforts. I also aim to bridge social and ecological perspectives, recognising that the field of restoration has traditionally been dominated by ecological approaches. My MSc degree, which emphasised social sciences, introduced me to the importance of inclusive, participatory decision-making—a principle that has guided my approach throughout this research. This background fuelled my commitment to amplifying smallholder perspectives and incorporating participatory methods where possible. However, logistical, cultural, and linguistic challenges sometimes limited the full realisation of these ideals within the constraints of my PhD project. Below, I reflect on how my academic and personal experiences shaped the research direction and informed the methodological choices made in this thesis.

My personal identity has significantly influenced my approach to research. Firstly, as a white British woman from a middle-class background, I acknowledge the privileges that have contributed to my opportunities and shaped my path to this position. My mum was born and raised in Kenya because my grandad was an engineer on oil tankers and worked at Mombasa port. This greatly influenced my desire to visit East Africa because I heard about it a lot as a child. After I finished school, I took a year off and spent three months living in Northern Tanzania working at a camp site. These personal experiences gave me a more nuanced understanding of Tanzanian culture before I embarked on any research in the country.

Born and educated across Western Europe—in England, Denmark, and the Netherlands—my perspectives been shaped by predominantly Eurocentric ideas. My supervisory team, all European, has further reinforced the lens through which I have been academically trained. These factors inevitably affect how I interpret the world and more specifically, how I engaged with the communities in Tanzania where my research is based. Being a foreign researcher also came with opportunities that influenced the research. For instance, I have had access to resources and education that are not equally accessible to those involved in the study.

During my MSc thesis, I researched an agroforestry restoration intervention in Dodoma, Tanzania. I collected field data alongside a monitoring and evaluation project by MetaMeta research. Observing how fieldwork formalities worked in Tanzania was useful for my PhD field work. After this, I then did a remote internship, due to COVID-19 restrictions, with the International Union for Conservation of Nature (IUCN) on their Restoration in Supply Chains (RESUPPLY) project in the Kilombero Valley. RESUPPLY was partnering with Kilombero Sugar Company to propose restoration interventions that could increase their supply chain resilience. As a part of this, one of my key tasks was a stakeholder network analysis which I did mainly through video/phone interviews with different organisational stakeholders. This experience gave me an excellent basis of understanding of the dynamics within the Kilombero Valley before starting my PhD and cemented my desire to focus on smallholder farmers as the ones implementing agroforestry who seemed most affected by top-down interventions. However, due to COVID-19 restrictions, I was unable to visit the Kilombero Valley until I started my fieldwork 2 years later, which was a limitation.

As a white researcher in a previously colonised country, power dynamics were at the forefront of my mind, particularly during my fieldwork. Tanzania's colonial past continues to influence contemporary policy and practice, especially within agricultural industries that are increasingly shaped by international forces. For example, in my study area, the sugarcane plantation is owned by Illovo, a subsidiary of Associated British Foods, underscoring the enduring impact of British interests in the region. Within the Kilombero Valley, many conservation NGOs pushing for expansion of protected areas and exclusion of local people are run by white European academics (Reforest Africa, Association Mazingira, Southern Tanzania Elephant Program) and I have found this very difficult to reconcile. My own values support inclusive decision-making models such as community-led projects where local people have sovereignty over their resources.

In undertaking this research, I remained conscious of the ethical complexities involved in being a foreign researcher working in Tanzania. I have struggled throughout my PhD with the implications of conducting research as a European in a former colonial context. Particularly because most scientific research in the area, including my own, is led by Europeans. I am conscious that knowledge and data are forms of power that are centred at universities in the Global North. To decolonise some of this knowledge and data, I returned to Tanzania to feedback my results to local communities through presentations and leaflets. I also did presentations to organisations and government officials working in the area. Moreover, I was able to employ Peter, the lead field assistant in some of the data analysis and manuscript writing process to help him broaden his skill set.

Throughout my PhD and particularly when I was doing my fieldwork, I constantly reflected on how my position and Eurocentric academic background shape the questions I ask, the methods I employ, and the interpretations I make. I strived to mitigate the potential biases and limitations of this by engaging in reflexive practices and being open to local perspectives, even when they challenged my own preconceptions. I often turned to Dr Deo Shirima for research advice as the co-lead on the Agrisys project and to the research assistants who had worked in the Kilombero Valley for a longtime. Despite some familiarity with Tanzanian culture, I remain an outsider, especially given my limited proficiency in Swahili. This language barrier, combined with cultural differences, presents challenges to fully understanding the lived experiences of the smallholder farmers with whom I worked.

When conducting my data collection, I worked with Tanzanian field assistants. The lead field assistant, Peter, conducted the interviews with farmers. He is fluent in English; university educated and grew up in Northern Tanzania. He now lives in the Kilombero Valley and works full time for Reforest Africa, a local restoration non-governmental organisation (NGO), in a community engagement position. I also hired a local assistant who did not speak much English and is from one of the study villages. I always listened to, debated with and took the perspectives of the research assistants into account. I now consider them friends; I have helped them with job applications, and we have worked together since on different projects.

My PhD research commenced in September 2020, during the ongoing COVID-19 pandemic. Thankfully, I maintained good physical and mental health during this period, but the global situation and associated travel restrictions significantly influenced the development and execution of my research. When I started my PhD, we were in the middle of the COVID-19 pandemic, and we could not travel for over a year. Therefore, I had to plan my research without ever having been to the field site. My MSc experiences, alongside my previous travel in Tanzania was extremely helpful in this situation because I already had a good understanding of Tanzanian culture and the landscape of which my PhD was based.

Due to the uncertainty surrounding travel and the inability to conduct fieldwork as initially planned, I adapted my research approach to ensure I could deliver a doctoral thesis within the permitted timeframe. As a result, the structure of my thesis evolved in the following ways:

- *Systematic Literature Review (Chapters 2 and 3):* Starting the thesis during the COVID-19 pandemic meant I began my PhD planning for an inability to travel and conduct fieldwork. These restrictions prompted me to focus on conducting a comprehensive systematic review of the literature for my first chapters. This allowed me to lay a robust theoretical foundation for my research and informed the subsequent chapters of my thesis whilst I waited to see if travel was possible.
- *Virtual implementation of scenario workshops (Chapter 4):* I began this PhD as a part of the Agrisys project led by Professor Marion Pfeifer. The scenario workshops which form *Chapter 4* were conducted as part of this project. However, due to travel restrictions we were unable to travel to Tanzania to carry out this data collection ourselves. Therefore, I was involved in designing and implementing these workshops remotely. While this approach enabled the continuation of the

project, it also introduced certain limitations. My inability to be physically present during the workshops meant that I experienced the activities and interactions second-hand. Consequently, my understanding of the context and nuances of the data collected is slightly less comprehensive than if I had been able to engage directly with participants. This limitation influenced the depth of analysis in Chapter 4. To mitigate this, we had in-depth debriefings with the field team after every workshop and recorded all speech which was then transcribed for analysis. It was also a reason for including Peter, who was in the field team, in conducting the sentiment analysis of *Chapter 4*.

- *Adaptation of Field Research (Chapter 5):* My original research plan involved conducting participatory on-farm agroforestry trials with farmers. However, the inability to travel made this approach unfeasible. Consequently, I redirected my focus to examining existing agroforestry systems, specifically homegardens, which formed the basis of the research presented in *Chapter 5*.

The pandemic in particular, necessitated flexibility and creativity in my research design and execution. Despite these challenges, I was able to adapt my methods to produce a comprehensive and meaningful body of work. Throughout this thesis, I highlight the trade-offs involved with restoration actions such as agroforestry. Additionally, I have used novel methods in this field such as sentiment analysis (*Chapter 4)* and learnt how to conduct research in innovate ways with international teams. For the entire doctoral research, I have built partnerships with academics and research groups internationally. This is evidenced by the variety of co-authors in my research chapters and by my presenting my work at multiple conferences. Despite the limitations, I have done my best to develop this research using both desk-based and field approaches to understand the trade-offs involved for stakeholders in tree-cover restoration.

I hope for this research to have implications that extends beyond the boundaries of academic research. By examining the trade-offs of tree-cover restoration to smallholder farmers in the Kilombero Valley, this thesis aims to bridge a critical gap between ecological objectives and the socio-economic realities of those most affected by these initiatives. This work is grounded in the understanding that successful restoration efforts should be underpinned by social inclusivity—ensuring that the voices of those impacted by land-use policies are both heard and valued.

Influence on Policy and Practice: The insights gathered on smallholder perspectives and experiences with agroforestry contribute valuable knowledge that can help inform policymakers, NGOs, and development organisations working on land management in Tanzania. This research highlights the need for policies that reflect the complex needs and aspirations of local communities, aligning conservation goals with food security and livelihood improvements. To aid this, I did presentations to organisations working in the area such as Reforest Africa and IUCN and produced a report focussed on the key results of *Chapter 4* relating to trees and tree planting. This report was also disseminated to decision-makers from government and other non-governmental organisations who attended regional level workshops, at which we also presented the work.

Inclusivity in restoration efforts and decision-making: Although logistical and cultural barriers sometimes limited full realisation, the emphasis on amplifying smallholder voices underscores the importance of incorporating local knowledge and preferences into restoration planning. As such, this thesis aims to inspire similar efforts for those planning tree-cover restoration interventions in the area, where engaging local stakeholders early and often could lead to more equitable and sustainable outcomes.

Contribution to Interdisciplinary Academic Research: By integrating methods from different disciplines, this work provides a template for approaching environmental research from a more holistic perspective. Traditionally, restoration work has been heavily grounded in ecological disciplines and quantitative data; however, by giving equal weight to social dimensions and qualitative work, I am to demonstrate the value of interdisciplinary approaches in addressing complex environmental challenges. It is my hope that this research encourages further cross-disciplinary collaboration, providing a richer understanding of the interactions between human and ecological systems.

Global Relevance for Restoration Initiatives: Although this research is situated in Tanzania, the challenges it addresses—balancing restoration with local livelihood needs—are globally relevant. Many regions around the world face similar challenges between environmental goals and community wellbeing. It is my hope that these findings will contribute to global discussions on sustainable land-use practices and help guide equitable restoration efforts for both people and the environment.

Through this research, I aim not only to inform local and global science and policy but also to advocate for a more participatory, inclusive approach to ecological restoration. As the impacts of climate change and the biodiversity crisis intensify, there is an urgent need for restoration models that respect and enhance the interconnectedness of social and ecological systems. This work is a step toward such an approach, and I hope it serves as a foundation for continued research and action in Tanzania and beyond.

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First and foremost, I would like to express my deepest gratitude to my supervisors, Dr Marion Pfeifer and Dr Pete Howson. Marion, as the lead supervisor, provided invaluable guidance, support, opportunities for growth and encouragement throughout this journey. Pete, your feedback and discussion was instrumental in shaping this research. I am immensely grateful to my colleagues on the Agrisys project, particularly Dr Margherita Lala and Dr Susannah Sallu. To those that aided data collection in the field, particularly Peter Nnyiti and Evodius Ishengoma, your support in the field and the friendships we formed made the challenging aspects of this research more manageable and enjoyable. Special thanks go to Ben and Will for their companionship and support during fieldwork and for making every day more enjoyable. I would also like to extend my gratitude to the Modelling Evidence and Policy group and, Tropical Landscapes (TROPs) group for their camaraderie and the stimulating discussions that enriched my research experience. I am deeply thankful to my case partners, Reforest Africa and the International Union for Conservation of Nature (IUCN). Your support, both in the field and through my placements, significantly contributed to my personal and professional growth. Lastly, I would like to thank everyone who has contributed to this journey, directly or indirectly. Your support and encouragement have been invaluable, and I am deeply appreciative of your contributions.

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Abbreviations

AEO - agricultural extension officers

AGG - Agricultural Green Growth

AMCOS - Agricultural Marketing Cooperative Societies

CBD - Convention on Biological Diversity

COP15- Conference of the Parties

GBF - Global Biodiversity Framework

HLRA - Household Livelihood Resilience Approach

IPCC- Intergovernmental Panel on Climate Change

IUCN - International Union for Conservation of Nature

KSC – Kilombero Sugar Company

MOA – Ministry of Agriculture

NGO - Non-governmental organisation

NNP - Nyerere National Parks

RESUPPLY - Restoration in Supply Chains

SAGCOT - Southern Agricultural Growth Corridor of Tanzania

SER - Society of Ecological Restoration

SDG – Sustainable Development Goals

SLA - Sustainable Livelihoods Approach

STEP – Southern Tanzania Elephant Program

TANAPA - Tanzania National Parks Authority

TFS – Tanzania Forest Service

UMNP - Udzungwa Mountains National Park

UN - United Nations

URT – United Republic of Tanzania

WEF - World Economic Forum

1-Introduction

This chapter introduces the central issue of the thesis: reconciling the trade-offs and benefits of agroforestry for smallholder farmers in the Southern Agricultural Growth Corridor of Tanzania. I begin by discussing the need for inclusive and equitable tree-cover restoration in tropical landscapes that addresses the trade-offs involved, with a specific emphasis on agroforestry practices in Africa and their impact on livelihoods. Following this, I provide a detailed examination of the Tanzanian regional context, including the national policy framework in which this research is situated. I also present an in-depth description of the Kilombero Valley, the study area, and some of the key stakeholders that influence or are influenced by tree-cover restoration. This chapter concludes by highlighting the knowledge gaps that this thesis addresses through its research questions and offers a brief overview of the thesis structure.

1.1 Ecosystem restoration

Tropical landscapes are among some of the most biodiverse (Hawkins, 2001), however, they are also undergoing major changes in agricultural and human development, raising concerns over tropical deforestation and biodiversity loss (Pendrill et al., 2022). Ecosystem restoration and reforestation is seen as a nature positive approach to slowing or reversing these declines in degraded areas whilst also benefiting local livelihoods (Chazdon, 2008; Ota et al., 2020; Rey Benayas and Bullock, 2012). In this thesis, ecosystem restoration is understood as proposed by Löfqvist et al., (2023), who put forward an equity-centred definition as 'restoration that places the most vulnerable and affected actors (current and future) of a restoration project at the centre of decision making, whilst simultaneously promoting ecological recovery' (Löfqvist et al., 2023). This is particularly relevant to this thesis, given that smallholders in the Kilombero Valley, Tanzania, have historically been excluded from environmental management decision-making processes whilst bearing costs such as increased crop damage from wildlife (Lala et al., 2023).

This definition differs of ecological restoration from the Society of Ecological Restoration's (SER), which understands restoration as the 'process of assisting the recovery of ecosystems that have been degraded, damaged, or destroyed' (Society for Ecological Restoration International Science and Policy Working Group, 2004). However, this definition has been critiqued in the environmental social sciences for implying a return to a past pristine state without people and overlooking the socio-political dimensions of landscapes which can in turn, hinder successful outcomes (Aronson & Alexander, 2013; Fleischman et al., 2020). In line with more recent scientific scholarship, this thesis adopts a more nuanced view, framing restoration as a negotiated and socially embedded process that must consider historical land use, local knowledge and equity outcomes (Löfqvist et al., 2023; Fleischman et al., 2022; Elias et al., 2022).

Tree-cover restoration refers to the process of increasing tree presence in landscapes, whether through natural regeneration, assisted regeneration, or active planting on areas that were originally forested but currently lack tree-cover (Shyamsundar et al., 2022). Strategies may include a portfolio of activities such as forest restoration, woodlots, agroforestry, industrial plantations (Shyamsundar et al., 2022). There are ambitious restoration commitments at global, national and local scales for tree-cover restoration. For instance, the United Nations (UN) has declared 2021-2020 the Decade on Ecosystem Restoration. Meanwhile, the Bonn Challenge aims to bring 350 million hectares of degraded and deforested landscapes into forest landscape restoration by 2030 (Bonn Challenge, 2024a). The challenge is composed of regional pledges, typically made by individual countries. However, it is not clear how this is implemented on the ground and no progress or outcomes are reported (Bonn Challenge, 2024a). Tropical landscapes, particularly in Africa and Latin America are the key focus of many of these global restoration pledges. There is one pledge in Europe, two in North America for the Bonn Challenge but 31 in Africa alone (Bonn Challenge, 2024a).

Alongside restoration efforts, Target 3 of the 2022 Convention on Biological Diversity's Kunming-Montreal Global Biodiversity Framework aims to increase the global coverage of protected areas and other area-based conservation measures by at least 30 percent by 2030 (also referred to as 30x30) (Convention on Biological Diversity, 2024). However, there are significant competing demands on land for food production, energy production, and infrastructure development that creates a complex challenge for policymakers and stakeholders, as they must balance the urgency of biodiversity conservation with competing interests and needs (Mehrabi et al., 2018). These competing demands are evident in spatial development initiatives such as Growth Corridors. Growth Corridors are geographical areas, usually along a major transport route such as highways or railways that is targeted for economic investment, urban expansion and infrastructure development. They promote spatially targeted and coordinated public and private investment with focussed policy reforms to increase economic development and often have a sectoral focus to emphasise sectors such as agriculture, manufacturing or logistics. Agricultural growth corridors aim to leverage transport infrastructure to support farming and attract investment for agribusiness within the corridor. There are four agricultural growth corridors in Africa: Southern Agricultural Growth Corridor of Tanzania (SAGCOT) in Tanzania, Beira and Nacala in Mozambique, and Lagos-Kano-Jibiya in Nigeria. These are designed to attract concentrated economic development and investment while promoting infrastructure expansion yet, they frequently overlap with regions of high ecological value in the tropics (Smalley, 2017).

Similarly, top-down global priority maps using area-based conservation targets such as 30x30 that seek to optimise relationships between biodiversity, carbon sequestration and cost-effectiveness, also tend to focus on the tropics (Strassburg et al., 2020). However, biodiversity, carbon, and cost-effectiveness assessments often overlook the fact that tropical landscapes are often managed by smallholder farmers (Salami et al., 2010) and increasingly by agricultural industries, both of whom have objectives such as food production, improved livelihoods, and business profits. These goals are often not aligned with biodiversity conservation or restoration efforts (Sulle, 2020).

Trade-offs will apply and decisions need to be made for prioritisation of land use and management. However, often the current targets and priority maps do not take social considerations into account, such as who decides on these priorities, who lives in these areas, how they are using the land and, their rights to these areas (Fleischman et al., 2022; Sandbrook et al., 2023). The objectives of government and organisations promoting tree restoration and agroforestry often relate to commitments to reduce poverty, mitigate and adapt to climate change and improve biodiversity. However, these cannot be considered a motivating argument for smallholders, whose objectives tend to relate to their cultural and livelihood needs (Mbow et al., 2014). Scientists have called for greater integration of social considerations into ecosystem restoration (Elias et al., 2022). Integrating social considerations into restoration decision-making can improve the equity and effectiveness of ecosystem restoration and help plan for and mitigate trade-offs (Löfqvist et al., 2023).

We need to develop equitable pathways for tree-cover restoration to deliver on biodiversity and climate outcomes whilst benefiting those living in and managing these landscapes. In East Africa, where smallholders account for 75% of agricultural production (Salami et al., 2010), future scenarios of climate change predict decreased yields, reduced land suitability for crops and altered disease trends for humans, livestock and crops, resulting in narrowed livelihood options and food insecurity (Kogo et al., 2021; Thornton et al., 2011). Most acutely impacted are those for whom agriculture is the primary source of sustenance and income (Barbier and Hochard, 2018; Schlenker and Lobell, 2010a; Thornton et al., 2011). These groups find themselves with limited adaptive capacity and scarce resources to mitigate the threats posed by climate change, including the increased risks of drought and floods (Kogo et al., 2021; Pörtner et al., 2022).

Reconciling objectives and embracing nuanced local conditions is essential to scale tree-cover restoration and promote resilient livelihoods (Tschora and Cherubini, 2020). Tree-cover restoration can play an important role in strengthening the resilience of smallholder farming systems. By improving soil health, regulating water availability, and providing diversified livelihood options such as timber, fruit, or shade for crops and livestock, restoration initiatives can help buffer communities against shocks (Tschora and Cherubini, 2020; Quandt et al., 2019; Jose 2009). In this thesis, I focus on livelihood resilience, which is the 'capacity of all people across generations to sustain and improve their livelihood opportunities and well-being despite environmental, economic, social, and political disturbances' (Tanner et al., 2015, p.23).

While this thesis focuses on household-level resilience, restoration also contributes to broader landscape resilience through enhanced ecosystem functioning and connectivity

(Rey Benayas and Bullock, 2012; Besseau et al., 2018). The extent to which restoration enhances resilience depends not only on ecological processes but also on institutional arrangements, governance structures, and the distribution of benefits and decision-making power (Fleischman et al., 2020, Fleischman et al., 2022; Löfqvist et al., 2023).

Restoration efforts also do not exist in a vacuum. In areas such as Tanzania's Southern Agricultural Growth Corridor (SAGCOT), tree-cover restoration is often promoted alongside potentially conflicting policies such as contract farming. Contract farming, or out-grower schemes, are when agricultural products are produced according to a prior agreement where farmers produce a crop under contract to a commercial buyer (Actionaid, 2015). While such schemes can offer market access, they may also promote land use changes such as the expansion of monocultures that undermine agrobiodiversity and the multifunctional benefits of diverse agroecological systems (Mwavu et al., 2016; Sulle 2020). Limited empirical research has examined the direct interactions between contract farming and ecosystem restoration. This thesis contributes to this gap by investigating how smallholders in the Kilombero Valley navigate overlapping pressures from restoration initiatives and agricultural commercialisation.

Trade-offs will be determined by socio-economic and biophysical factors and need to be understood from the farmers' perspective (Dumont et al., 2017). For instance, a study in Tanzania found that there was a trade-off in species selection between positive environmental impacts and positive economic value (German et al., 2006). Understanding trade-offs allows us to anticipate better how risks and opportunities to people may emerge from interventions in different contexts and plan for more equitable outcomes (Löfqvist et al., 2023). In turn, leading to a more nuanced and locally relevant approach on how to mitigate climate change and improve livelihoods concurrently (Reppin et al., 2020).

1.1.2 Agroforestry

Agroforestry, the deliberate integration of trees into agricultural systems, is an indigenous land practice in Africa (Nair et al., 1993). It has gained international prominence as a tree-cover restoration practice that can deliver on multiple social and environmental objectives such as improving biodiversity, livelihoods and food security across the continent (Jose, 2009; Muthuri et al., 2023; Ntawuruhunga et al., 2023). In Africa alone, croplands comprise 39% of the area with the greatest potential for low-cost tree-cover restoration, and approximately 75 million people live in or near these areas (Cohn et al., 2017; Shyamsundar et al., 2022). Here, agroforestry, the deliberate integration of trees into agricultural systems, presents an opportunity for tree-cover restoration that can be managed by households and communities and provide well-being benefits (Shyamsundar et al., 2022).

This raises broader questions about the goals of restoration, whether it is primarily for ecological recovery, climate mitigation, or socio-economic development (Strassburg et al., 2020). Agroforestry straddles these objectives, offering an approach that recognises and values human-environment interactions rather than seeking to exclude them (Shyamsundar et al., 2022). As such, it challenges traditional restoration paradigms focused solely on ecological benchmarks (Society for Ecological Restoration International Science and Policy Working Group, 2004; Wortley et al., 2013) and aligns more closely with integrated, people-centred approaches advocated in the literature ((Shyamsundar et al., 2022; Löfqvist et al., 2023).

Roughly a third of agricultural land in sub-Saharan Africa is estimated to have had at least 10% tree cover during 2008-2010, although densities can vary considerably (Zomer et al., 2009). Almost one third of smallholders grow trees on their farms in Ethiopia, Malawi, Nigeria, Tanzania and Uganda (Miller et al., 2017). Moreover, households with more trees on their farms tend to be located within 10 km of a forest, suggesting that agroforestry is an important component within forest-agricultural landscapes (Miller et al., 2017). Figure 1.1 presents the major types of agroforestry practiced in East Africa. These are homegardens, hedgerow intercropping or hedgerows, perennial tree-crop systems, woodlots, scattered trees on farm, silvopastoral systems, parkland systems, boundary planting, fruit tree-based agroforestry and trees on soil conservation structures as documented in (Muthuri et al., 2023).

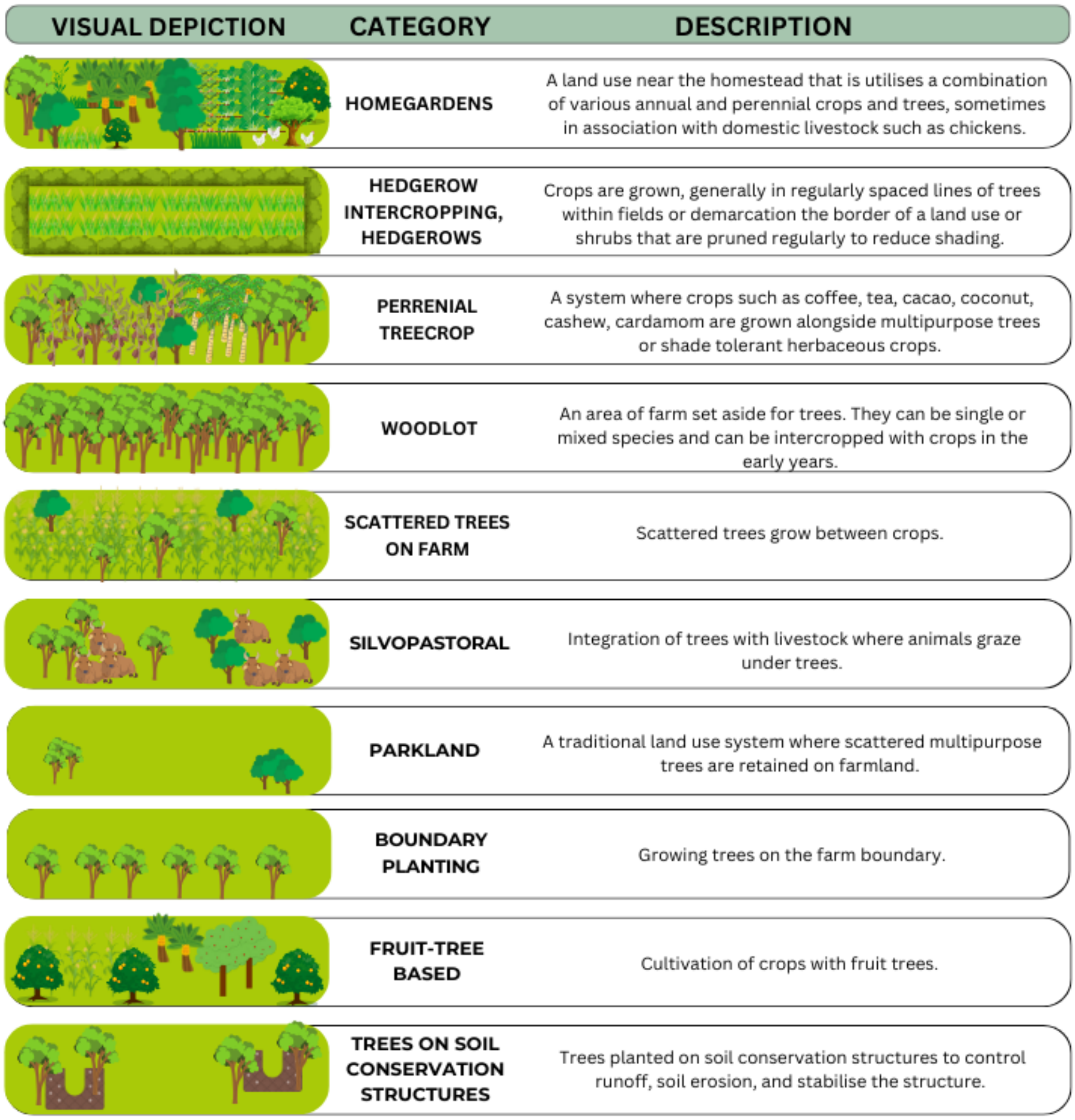

Figure 1.1The major types of agroforestry documented in East Africa. Source: author but the categories and descriptions taken from a systematic review by (Muthuri et al., 2023).

The Intergovernmental Panel on Climate Change (IPCC) highlights that ecosystem restoration plays a vital role in both climate adaptation and mitigation. By improving ecosystem health and functioning, such as enhancing soil fertility, regulating water flows, and increasing carbon sequestration, restoration can reduce vulnerability to climate impacts like crop failure and heat stress, while also contributing to long-term carbon storage (IPCC, 2023). These dual benefits create synergies between adaptation (adjusting to the effects of climate change) and mitigation (reducing or preventing greenhouse gas emissions) (IPCC, 2023).

Agroforestry is explicitly recognised by the IPCC as a strategy to address climate change through adaptation and mitigation (Lee et al., 2023). Moreover, Waldron et al., (2017) argues that agroforestry has the potential to advance multiple Sustainable Development Goals (SDGs), particularly for smallholders in the tropics, including food security (SDG2), energy security (SDG7), climate change mitigation (SDG13), biodiversity and ecosystem services (SDG15). Whilst (Jose, 2009) maintains agroforestry can agroforestry can **improve** soil fertility, **reduce** soil erosion, **improve** water quality, **enhance** biodiversity and **sequester** carbon (Jose, 2009) (Figure 1.2).

However, the evidence to support these claims is both mixed and limited, many studies are observational and the high variation in context limits wider interpretability of results. While one meta-analysis in sub-Saharan Africa reports improved crop yields from agroforestry (Kuyah et al., 2019), another found no significant impact (Castle et al., 2021). Moreover, whilst Kuyah et al., (2019) also reported improved soil fertility, run-off control, soil loss and water infiltration, Castle et al., (2021) could not collect enough data to perform a meta-analysis on other environmental indicators. Although some of the differences in these results are due to geographical scope and inclusion criteria, they highlight how we need to start to move beyond field observations to more long-term and experimental research in agroforestry systems.

The potential of agroforestry for climate mitigation is based on the large areas suitable for agroforestry, rather than a high carbon density (Mbow et al., 2014). Agroforestry systems (50-75 Mg C ha^{-1}) contain over four times less carbon per hectare than primary forest (>300 Mg C ha^{-1}) in tropical humid zones, but over five times more carbon per hectare than row crop systems alone (<10 Mg C ha^{-1}) (Verchot et al., 2007). The overall average carbon stocks of agroforestry in East Africa are estimated to be 24.2 ± 2.8 Mg C ha^{-1} in biomass and 98.8 ± 12.2 Mg C ha^{-1} in the soil but this varies according to practice type, ranging from 153±23 Mg C ha^{-1} in homegardens to 26.7 ± 7.0 Mg C ha^{-1} in improved fallows (Muthuri et al., 2023).

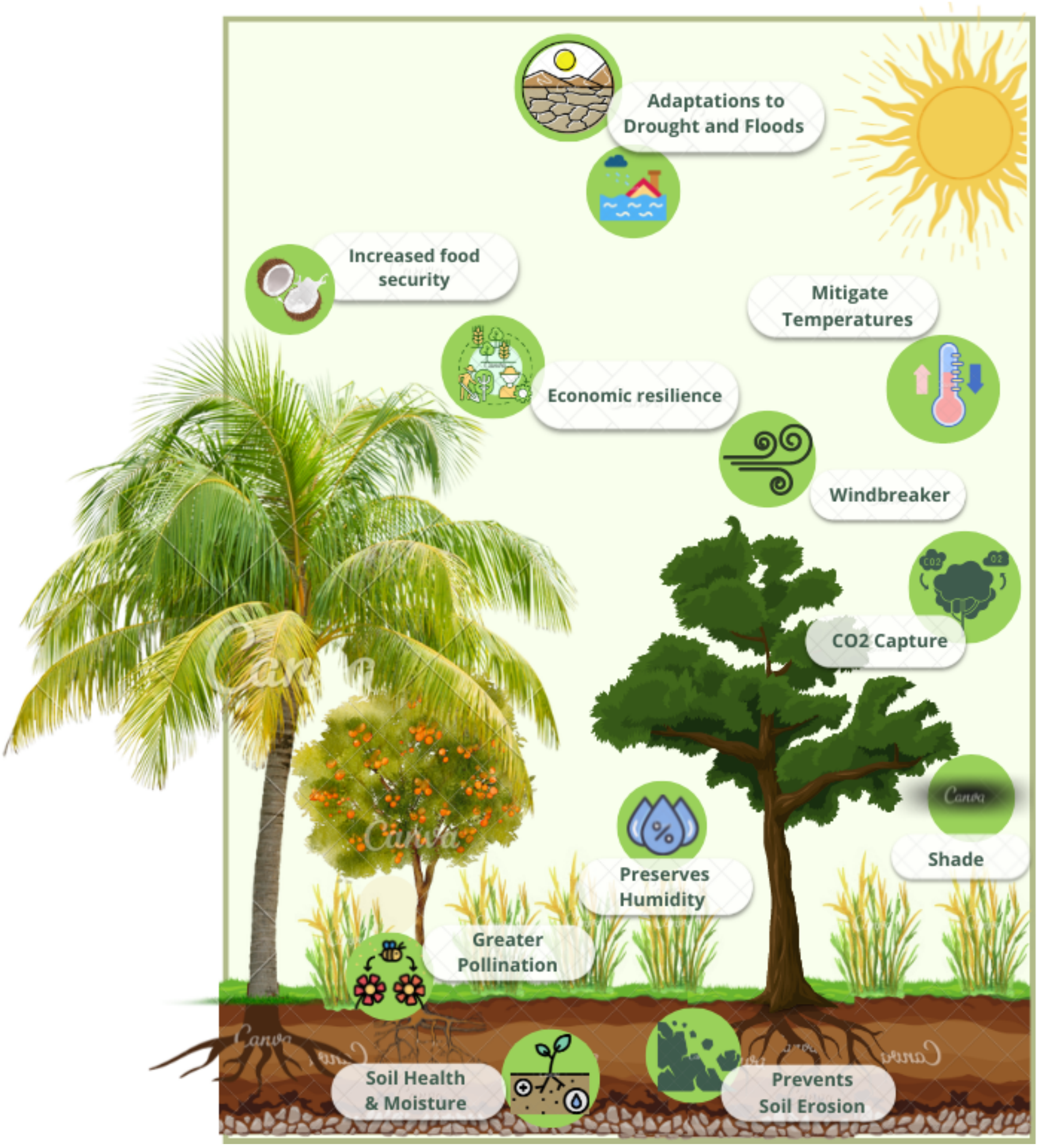

Figure 1.2 An infographic showing the potential benefits of agroforestry, the integration of trees into farming systems. Agroforestry can provide multiple benefits thus mitigate climate risks, i.e. reducing exposure and hazards or vulnerability of communities. These may include reducing the impacts of drought and flooding, microclimate regulation, windbreaking and humidity preservation. Trees can improve economic resilience by providing an extra income stream and diversifying livelihoods, also increasing food security and providing shade on the farm. Soil benefits may include improved soil health and moisture and prevention of soil erosion, whilst they may also improve biodiversity and improve pollination (Jose, 2009; Muthuri et al., 2023). Source: author

1.3 Regional context

Following the introduction to tree-cover restoration and agroforestry, I now offer a detailed overview of the study country, the United Republic of Tanzania, and the specific study area, the Kilombero Valley. This section provides essential context for this thesis on tree-cover restoration and agroforestry at both the national and local levels.

1.3.1 Country overview

The United Republic of Tanzania is in East Africa and includes the islands of Zanzibar, Pemba and Mafia. It was formed as a sovereign state in 1964, following independence from Britian and the union of Tanganyika and Zanzibar under President Julius Nyerere. Dodoma is the official capital of Tanzania whilst Dar es Salaam is the largest city and port. Most Tanzanians are of Bantu descent and there are over 120 indigenous African peoples. Swahili and English are both official languages, although the majority of Tanzanian's speak Swahili and the language of their ethnic group (Mascarenhas and Fahy Bryceson, 2024).

The population was 67,438,106 in 2023 with an annual growth rate of 2.9% (World Bank, 2024a). In 2018, 44.9% of the population was estimated to live on less than $2.15 per day and life expectancy is 67 (World Bank, 2024a). It has a mixed economy with agriculture being a major sector, employing 75% of the population and contributing to 25% of Gross Domestic Product (GDP) (USAID, 2023). 44.6% of land area is classed as agricultural land while 51.1% of land area is classed as forest (World Bank, 2024b).

Most of Tanzania has a tropical savannah climate with clearly defined wet and dry seasons. Annual rainfall varies across the country, from under 600 mm in some areas to over 1500 mm in others (World Bank Group, 2024). Climate models predict an increase of approximately 1.6 degrees Celsius across the country by 2050. Whilst total precipitation amounts are not predicted to change significantly, variability in rainfall is expected to grow. Many crops, including sugarcane are predicted to decrease in yields if the weather becomes hotter and drier (World Bank Group, 2024).

The World Bank predicts that if no action is taken, climate change could push up to 2.6 million Tanzanians into poverty and internally displace over 13 million people by 2050. These projections underscore the urgency of climate adaptation and mitigation through sustainable land-use practices. The CCDR specifically highlights optimising land and water management and investing in climate-smart agriculture, such as agroforestry, as pivotal interventions for bolstering resilience, enhancing productivity, and reducing greenhouse gas emissions (World Bank Group, 2024).

Tanzania's dependence on rainfed agriculture and vulnerability to floods means that tree-cover restoration and agroforestry can not only sequester carbon but also improve water regulation, reduce erosion, and diversify livelihoods. By contributing to both adaptation (e.g. soil protection, flood resilience) and mitigation (reducing carbon emissions), agroforestry presents a dual-benefit strategy that the World Bank recommends as part of its low-carbon, resilient growth pathway ((World Bank Group, 2024).

The initial demarcation of protected areas within Tanzania was derived from a colonial vision for African landscapes, where national parks were for wildlife and elsewhere was for agricultural development (Brockington et al., 2008). Gazettement of forested areas began under German colonial rule in the interest of conservation and future economic exploitation, introducing discursive and physical boundaries under a European-centric scientific vision of forestry that expanded state control and exploitation (Mgaya, 2016). There are now 872 areas that are under some form of legal protection which are mostly governed by federal or national ministries or agencies. This includes 23 National Parks constituting 39.94% of terrestrial land and inland waters (UNEP-WCMC, 2024). Growth in protected areas from 9% of land area in 1959 to nearly 40% today is argued to be reflective of vigorous state support boosted by tourism revenues alongside powerful international conservation lobbying (Brockington et al., 2008). Indeed, tourism revenue represents 17.2% of GDP (Tanzania Investment Centre, 2024) and there is a dominance of northern-based organisations in the Tanzanian conservation sector (Brockington and Scholfield, 2010). However, since demarcation of protected areas, there has been repeated eviction and continual exclusion of communities across the country (Brockington et al., 2008).

The mean annual deforestation rate in mainland Tanzania was 1.47% between 2002 and 2013 and 1.42% between 2010 – 2017 (Doggart et al., 2020; URT, 2017). Whilst multiple drivers typically were acting to cause widespread forest loss, crop farming was the most frequently recorded driver of deforestation during this period, whilst other common drivers included livestock (69%), domestic fuelwood collection (41%), charcoal production (35%) and harvesting building poles (30%) (Doggart et al., 2020). Tanzania has committed to restoring 5.2 million hectares of land by 2030 under the Bonn Challenge (Bonn Challenge, 2024b). To implement this, government targets state that 1.5 million trees must be planted in each district each year until 2026.

Tanzania has a long history of agroforestry systems, such as the spice agroforestry systems in the Eastern Arc Mountains (Kitalyi et al., 2013) or Kihamba system (Chagga homegardens) which has been identified as a globally important agricultural heritage system by the FAO (Kitalyi et al., 2013). 54% of households have reported to having at least one tree on their land, with emphasis on fruit and timber trees (Miller et al., 2017).

1.3.2 Tanzanian policy context and review

Since the 1980s, alongside the expansion of protected areas, Tanzania has gradually transitioned towards a market-orientated economy, encouraging private investment for agricultural commercialisation and farming expansion (Bergius et al., 2020). This shift has not only significantly influenced land-use practices and environmental management, but also agricultural livelihoods. Understanding the current biodiversity and agricultural policy landscape, including that of the Southern Agricultural Growth Corridor of Tanzania, is essential for providing the context to which this PhD is situated and provides understanding of the broader land-use decision-making processes in Tanzania. The national policies related to biodiversity conservation and agriculture discussed below influence the balance between environmental goals and livelihoods. They can drive certain livelihood strategies and act as a barrier to others, influencing livelihoods at the household level (Stringer et al., 2016).

1.3.2.1 Environmental policy

The Tanzanian government has ratified the Convention on Biological Diversity and is a signatory of the 2010 Aichi Biodiversity Targets which then guided the national biodiversity strategies and action plans such as the National Biodiversity Strategy and Action Plan 2015-2020. The Aichi targets failed to be met, and the Global Biodiversity Framework (GBF) targets were adopted at the 15th Conference of the Parties (COP15) to the Convention on Biological Diversity (CBD) in 2022, however, there are not yet any updated national policies based on the GBF targets.

The National Biodiversity Strategy and Action Plan 2015-2020 generally focuses on sustainable use of ecosystems and how functioning ecosystems are crucial for human wellbeing and socio-economic development (Vice President's Office, Division of Environment, URT, 2015). This is demonstrated in the vision statement that declares "By 2025, biodiversity and ecosystems are well protected, restored and used sustainably, ecosystem functioning maintained, so that they perpetually deliver sustainable intrinsic benefits for socio-economic development." Strategic goal D target 14 of the plan is focussed on "ecosystem resilience and the contribution of biodiversity to carbon stocks enhanced, through conservation and restoration, thereby contributing to climate change mitigation and adaptation and to combating desertification." Whilst Strategic goal D target 15 states that "by 2020, ecosystems that provide essential services, related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, local and vulnerable communities" (Vice President's Office, Division of Environment, URT, 2015). Moreover, the policy identifies agroecological approaches as among the biodiversity conservation approaches in agriculture.

The National Climate Change Response Strategy (2021-2026) (United Republic of Tanzania (URT), 2021a) devises and implements strategic adaptation and mitigation measures. These are in line with the national circumstances, requirements of climate change related multilateral environmental agreements, the SDGs, Sendai Framework for Disaster Risk Reduction and related bilateral and regional agreements. It aims to align climate change interventions with the national development agenda of an industrialised economy. It also aims to promote and facilitate the transfer of climate-smart technologies to support climate change adaptation and mitigation. Its objectives are to ensure sustainable management and resilience of water resources, forests, key ecosystems and the agricultural sector for sustainable livelihoods through promoting climate-smart practices. Agriculture is a priority area for adaption and mitigation strategies in this policy (United Republic of Tanzania (URT), 2021a), as Tanzania has committed to reduce greenhouse gas emissions economy-wide between 30-35% relative to the Business-As-Usual scenario by 2030 (United Republic of Tanzania (URT), 2021b).

Tanzania has recently passed Wildlife Conservation Regulations (2018), aka the 'Corridor Regulations" to maintain and restore critical wildlife corridors to sustain biodiversity. The plan identifies and assesses 61 corridors across Tanzania, signalling further expansion of protected areas (Ministry of Natural Resources and Tourism (MNRT), 2022). The objectives include to (1) reduce human-wildlife conflict, (2) maintain sustainable flow of ecosystem services for wildlife and people, (3) provide tangible benefits and livelihoods for local stakeholders.

1.3.2.2 Agricultural policy and the Southern Agricultural Growth Corridor of Tanzania

Tanzania places significant emphasis on the importance of the agricultural sector for the national economy and individual livelihoods. However, wildlife conservation and tourism are more frequently addressed in agricultural policies rather than biodiversity and human wellbeing (Pfeifer 2024). Like in the environmental policies, agricultural policy documents tend to be based on an extractive view of nature and the environment, focusing on how economic development and poverty alleviation is not possible without sustainable use of environmental resources.

The vision of the National Agriculture Policy 2013 is "An agricultural sector that is modernized, commercial, highly productive and profitable; that utilizes natural resources in an overall sustainable manner in Eastern and Central Africa that acts as an effective basis for inter-sectoral linkages by the year 2025." (Ministry of Agriculture (MOA) URT, 2013). This policy discusses using the agricultural sector to ensure food security and poverty alleviation, and states that agricultural development is dependent on environmental resources. Issues of land degradation and soil erosion are mentioned as among the issues that have affected agrobiodiversity and led to declined land productivity. However, it does not address the interconnectedness of social and ecological systems in producing outcomes for people and nature like the National Biodiversity Strategy and Action Plan 2015-2020.

Alongside the National Agriculture Policy there are several efforts in place to stimulate technology adoption, promote market growth and strengthen collaboration within the agricultural sector. One of which is the SAGCOT. SAGCOT is a Public-Private Partnership running until 2030 that was initiated at the World Economic Forum (WEF) Africa Summit in Dar es Salaam in 2010 and is funded by the Government of Tanzania, international aid agencies and the private sector. It is one of many growth or development corridors across the continent (Smalley, 2017). Its ultimate objective is the commercialisation of smallholder agriculture to boost agricultural productivity, improve food security, reduce poverty and ensure environmental sustainability (SAGCOT, 2024a). To do this, SAGCOT has designated agricultural clusters divided into development stages (Figure 1.3) where investment is channelled into large farms and plantations, outgrower schemes, irrigation works, post-harvest storage and processing and improvement of road, rail and port infrastructure (Smalley, 2017). It covers one-third of mainland Tanzania, stretching from the port in Dar es Salaam across to the border with northern Zambia. SAGCOT was funded and developed largely by private sector companies such as Yara International as a strategy to increase demand for fertiliser and agricultural products among Tanzanian farmers by supporting the growth of high-value agricultural markets (Smalley, 2017).

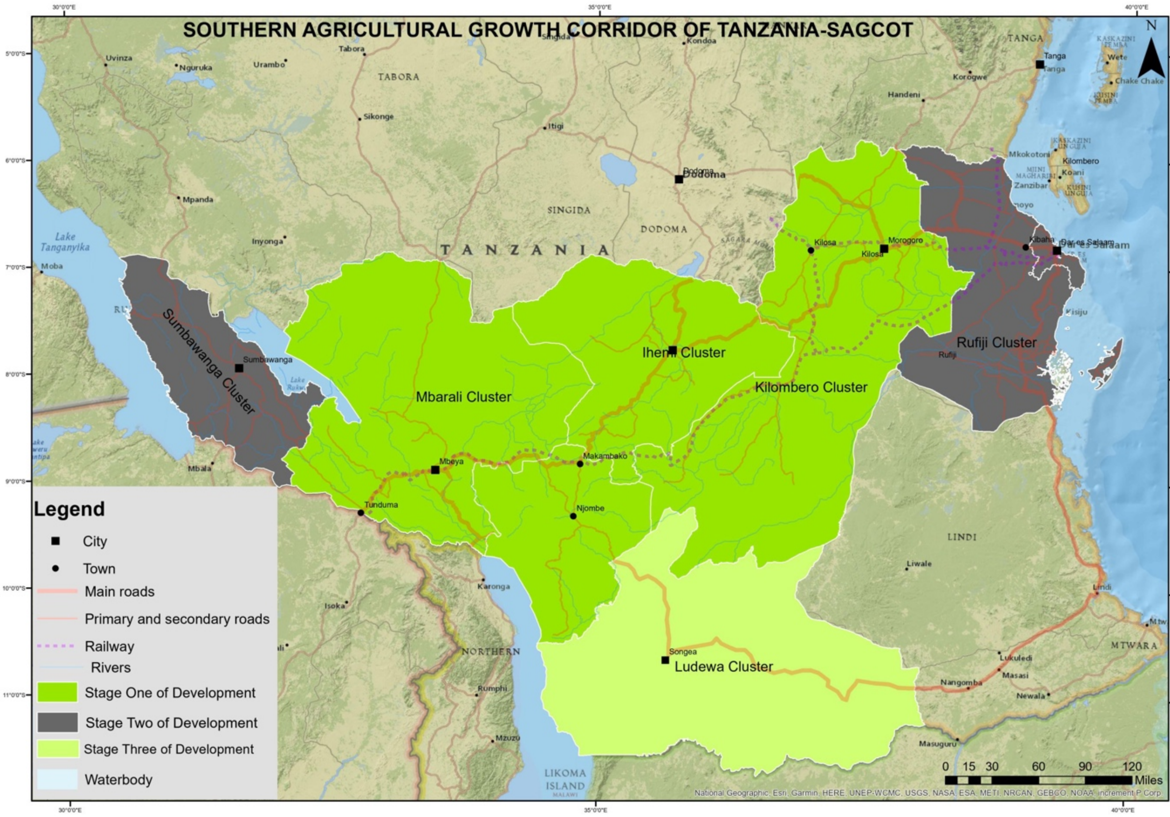

Figure 1.3 Map of the area covered under the Southern Agricultural Growth Corridor of Tanzania. The study area of this thesis lies in the Kilombero cluster (source: https://sagcot.co.tz/about-clusters/)

From the beginning SAGCOT has had a clear top-down agri-business profile dominated by foreign multi-national organisations and corporations. However, it developed under a narrative of agricultural green growth that emphasises the need to create economic growth while enhancing possibilities to utilise the natural environment (Buseth, 2017). Buseth (2017) argues SAGCOT is a vehicle for various actors to enhance their potential for capital accumulation under the guise of being green, using slogans such as 'green growth' without corresponding changes to content and practice of the initiative. As part of their framework for green growth, SAGCOT has released the SAGCOT Green Print, a green growth investment framework that has some key goals relating to agriculture, restoration and climate mitigation (SAGCOT, 2012a):

- Generate an additional 2.2 million tons of rice and field crops per year, worth approximately US $600 million (936 billion TZS) at recent market prices by 2030 through Agricultural Green Growth

- More than 300,000 hectares will be avoid deforestation by 2030
- The carbon contained in these forests, combined with emissions reductions associated with AGG, will generate net emissions reductions of about three million tons of CO_2-equivalent per year by 2030, worth about US $30 million at current carbon prices
- Save nearly one billion cubic meters of water per year due to increased irrigation water use efficiency, while also increasing water use efficiency for rainfed agriculture.

However, it is unclear what 'Agricultural Green Growth' really means.

Sugarcane is key value chain within SAGCOT due to its potential to generate both industrial output and rural employment (SAGCOT, 2024a). It was identified as a target sector for attracting public-private investments and developing sugarcane estates and mills, including through small- and medium-scale outgrower schemes (SAGCOT, 2024a). The Tanzanian sugar sector has experienced significant growth and transformation since independence, shaped by state-led development, liberalisation and, increasing domestic demand. In the post-independence period, the government established several parastatal sugar estates, including Kilombero and Mtibwa, aiming to foster rural development and self-sufficiency in sugar production (Sulle and Dancer 2020). Similarly to other southern African countries, Tanzanian agricultural policy promotes a large-scale sugarcane production model that combines large estates that have processing mills with independent outgrowers that supply the mills under a pre-negotiated agreement (Sulle and Dancer 2020). Historically, sugar production, largely concentrated in regions like Morogoro, Kagera, and Kilimanjaro, saw shifts in output, notably experiencing a decline in the late 1980s before a rebound in the 1990s following trade liberalisation policies (Tarimo & Takamura, 1998). However, despite efforts to enhance productivity, the domestic sugar production volume, at approximately 370,000 tons, is significantly below the target of 700,000 tonnes by June 2026 (Sugar Board of Tanzania, 2023).

1.3.3 The Kilombero Valley

The Kilombero Valley, Morogoro region, is part of the SAGCOT Kilombero cluster, which is a designated geographic area aimed at concentrating investment and promoting agricultural commercialisation within the broader corridor (Figure 1.4). SAGCOT has planned to the development 51,800 ha for agricultural production within the Kilombero Valley, with particular focus on the expansion of rice and sugarcane value chains to increase revenue and employment in the region (Bassi et al., 2018). It does this through helping attract pubic and private-sector investment in the area, which has led to the building of new roads and, the building of a new factory to increase sugarcane processing (SAGCOT, 2011).

In the following description of the Kilombero Valley, I will also touch on how the policies described in the previous section 1.3.2, particularly those associated with SAGCOT, are shaping land use and smallholder livelihoods on the ground.

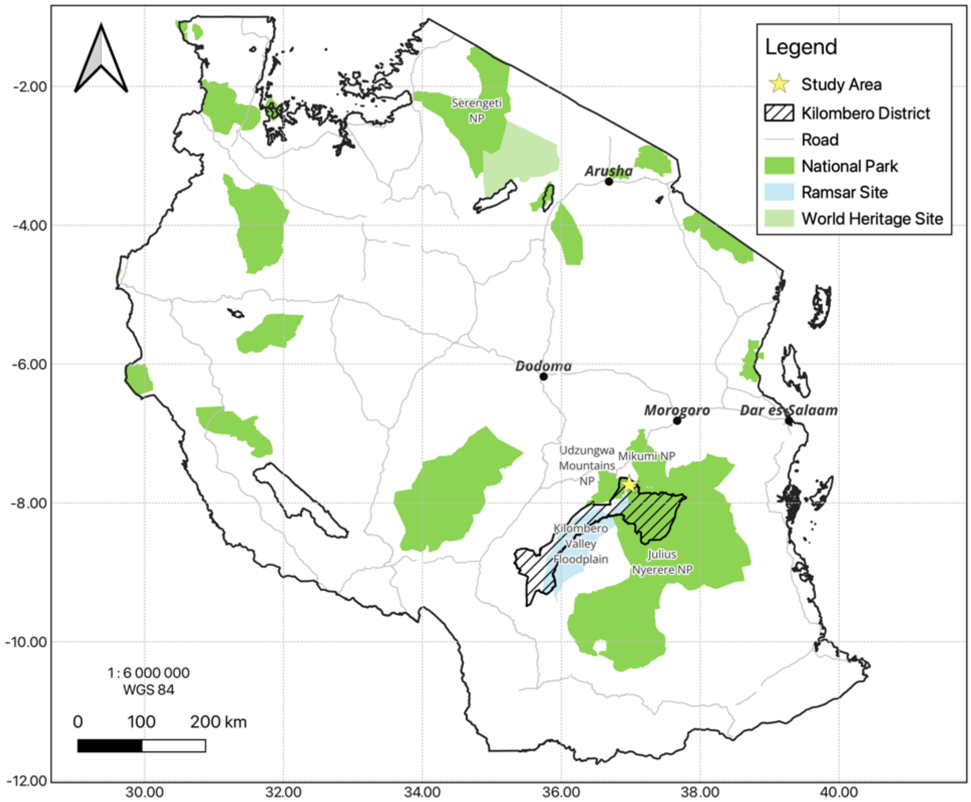

Figure 1.4 A map of Tanzania with the study area for this thesis within Kilombero District highlighted with a star. Source: William Ovenden

The Kilombero Valley has a sub-humid tropical climate across two rainy seasons: a long rainy season in March-May and a short rainy season in October-December. Annual rainfall varies between 1000 m to 1500 mm. Between 1990 and 2017, annual temperatures increased whilst rainfall decreased (Msofe et al., 2019). Rainfall is predicted to decrease and become more unpredictable leading to increased risk of flooding and more frequent and prolonged droughts as the climate changes (United Republic of Tanzania (URT), 2007). Impacts from rainfall changes are already being noticed by farmers who are mostly reliant on rainfed agriculture (Balama et al., 2016). Farming households are already implementing strategies focussed on earlier planting, livelihood diversification and agricultural diversification in response to perceptions of their local climate changing (Balama et al., 2016).

The Kilombero Valley floodplain, encompassing Kilombero, Ulanga, and Malinyi districts, increased from 174,222 people in 1967 to 672,383 people in 2012 (Msofe et al., 2019). It experienced an annual growth rate of 2.4% between 1967 and 2012, and 3.7% between 2012 and 2022 (URT 2022). This is higher than the national average growth rate of 2.7% for Tanzania (URT 2022).

Historically, the valley was a forested area that allowed wildlife to cross across the lowlands unhindered. Now, it has now mostly been converted to agriculture. Msofe et al., (2019) estimate that 3,129 km^2 of forest was converted to bushland, grassland and agriculture between 1990 and 2016 across the Kilombero Valley. In response to forest loss and in the wake of the Wildlife Conservation Regulations of 2018, there are multiple planned wildlife corridors in the area, further increasing the planned area of land under protected status.

Deforestation and land use change within the Kilombero Valley has been driven by a complex interplay of social and ecological drivers. It has been attributed to market growth and demand for timber products and cash crops such as rice and sugarcane driving conversion of forest to agricultural land (Msofe, 2019; Msofe et al., 2019). This has been influenced by government agricultural policies promoting private investment such as the opening of large-scale commercial ventures for rice and sugarcane that have intensified large areas of land and promoted outgrower contract farming. The fertile soils and commercial opportunities have also driven increased migration to the area and the population is increasing, putting further demands on natural resources such as wood for fuel (Msofe, 2019; Msofe et al., 2019).

Improvements in agricultural and wood harvesting technologies have further aided land clearing and deforestation, while climate variability is causing farmers to expand their farms to mitigate rainfall unpredictability. Insecure land tenure is also listed as a driving force of deforestation, as most land is acquired through inheritance and clearing, and most people do not have land titles. Regarding forest, the implementation of private investment in the forestry sector encouraged by the Tanzania Forest Policy of 1998 and driven by national and international demands for teak timber has influenced the conversion of over 20,000 ha of native forest into teak plantations by Kilombero Valley Teak Company (KVTC) (Msofe, 2019; Msofe et al., 2019).

1.3.3.1 The Northern Kilombero Valley

This thesis focuses on the northern part of the Kilombero Valley (Figure 1.5). The area was chosen based on previous research co-led by Newcastle University and Sokoine University of Agriculture as it is an area undergoing rapid changes in land use and management, partially driven by SAGCOT investment.

Current land use in the area comprises settlements, an industrial sugarcane plantation owned by Kilombero Sugar Company (KSC) and smallholder farms (Figure 1.5). Forest and savannah ecosystems, such as the Udzungwa Mountains National Park, Julius Nyerere National Park or Magombera Nature Reserve border the farmed landscapes on almost all sides. They are generally under some form of conservation protection and cannot be entered or used without permission. The Kilombero Elephant Corridor which will be under protected status, is currently being planted. This corridor will link Udzungwa Mountains National Park with Julius Nyerere National Park and runs alongside the study villages Katurukila and Man'gula B (Figure 1.5).

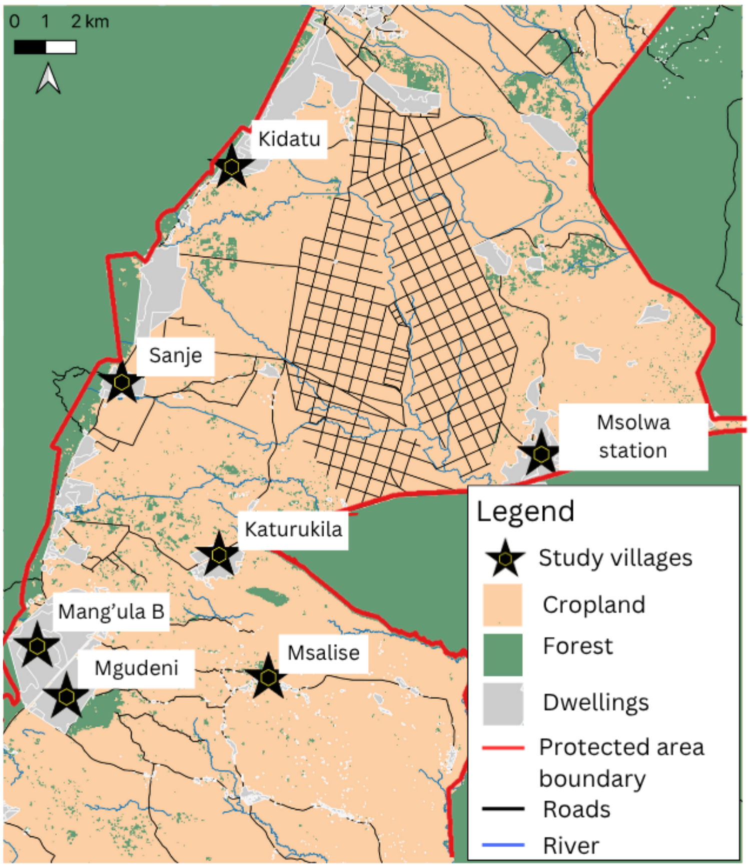

Figure 1.5 Map of Northern Kilombero Valley and the seven villages that were focussed on in this thesis. The area was chosen based on previous research co-led by Newcastle University and Sokoine University of Agriculture. The grided road area is part of Kilombero Sugar Company's sugar estate.

The predominant agricultural system is smallholder farming. Smallholders use a diversity of farming practices, including agro-chemicals and acro-ecological methods such as mulching, intercropping and post-harvest use of residues (Milheiras et al., 2022) to grow subsistence crops (e.g. pumpkin, okra, cassava) and cash crops (e.g. rice, sugarcane) (Durrant and Pfeifer, 2024). Farmers utilise multiple strategies to maintain their livelihoods alongside growing subsistence and commercial crops including agroforestry and off-farm activities (Nnko et al., 2022; Sulle and Dancer, 2020). Trees are often interspersed within homegardens and the farmed land at varying densities.

SAGCOT has supported commercial contract farming outgrower schemes to boost agricultural productivity within the study area, such as that by KSC (SAGCOT, 2024b). KSC is a large-scale sugarcane plantation and processing business that has their own plantation (seen by grid style roads in figure 1.5) and a grower network of over 6000 farmers. The estate: outgrower model employed by KSC dates back to its establishment in 1962 with foreign donor backing before being nationalised in 1967 following Tanzanian independence (Sulle and Dancer 2020). The company was privatised again in 1998, with Illovo Sugar Africa acquiring a majority stake of 55% (Sulle and Dancer 2020). They have access to aerial application of inputs and a well-established irrigation network on their own plantation. The company is increasing processing capacity by building another factory and will source all the extra sugarcane needed by expanding their grower network to over 12,000 farmers and further conversion of agricultural land to sugarcane across the valley. *Their expansion and associated infrastructure development has been financed by the government of Tanzania, the EU, donor agencies, local and international financial institutions and NGOs (Sulle and Dancer 2020).*

1.3.3.2 – Stakeholders within the Northern Kilombero Valley

The fertile land, agricultural potential and conservation value of the Kilombero valley has led to a diverse range of stakeholders with competing interests from government, private sector, conservation and development NGOs (Figure 1.6). Below, I describe some of the key stakeholders that both affect and are affected by tree-cover restoration initiatives in the study area, split across the site, landscape and national level. This section is written from personal knowledge and stakeholder communications throughout my PhD and work with the project partners, Reforest Africa and IUCN.

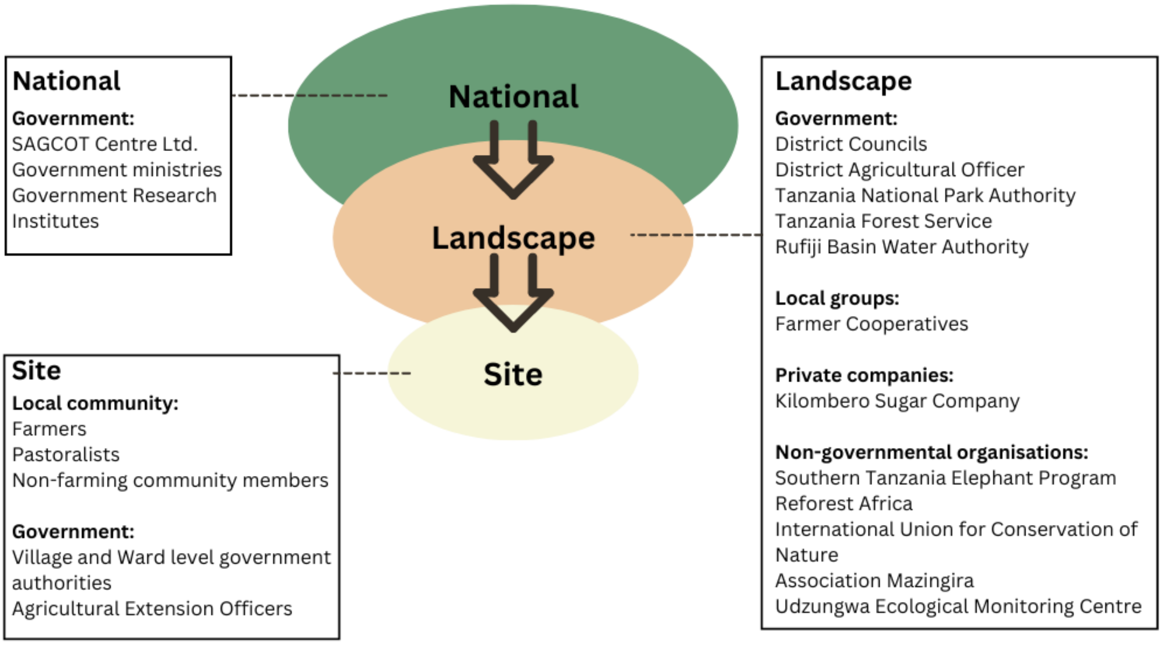

Figure 1.6 Stakeholders across different scales working within the Northern Kilombero Valley from the local community, government, local groups, private sector and non-governmental organisations

1.3.3.3.1 Site level

At the site level, those managing the land are the most influential stakeholders, the majority of which are smallholder farmers (Figure 1.6). There are also medium and large-scale farmers and agribusiness such as KSC, whose influence spans the site, landscape and national level. The scale of smallholder farming in the clusters means that agroforestry and tree-cover restoration could have a large effect at the landscape level.

Other stakeholders that are locally important and can affect how farmers manage the land include agricultural extension officers (AEO, Figure 1.6). AEO services have been reported as the most important connection and first source of advice for smallholders and so are very influential as to how farming is practised (IPSOS, 2023). They specifically advise on farming practices, usually input and pest advice, but not on how to improve marketing or sales. Despite high demand for extension services, there are not enough officers available, they often fail to reach remote villages and lack up to date training (IPSOS, 2023). KSC also employ sugarcane extension officers to advise sugarcane growers on sugarcane agricultural practices and so have great potential for influence here.

Pastoralists are present and are particularly more widespread in the more southern parts of the Kilombero Valley where the influx of livestock has degraded grasslands and caused soil erosion. They are often heavily involved in conflicts with farmers over grazing areas and farmland (IPSOS, 2023), although this is of limited relevance in my specific study landscape as it tends to occur further south in the valley.

Local governments are involved in the implementation of policies, regulations and development programs. They provide advisory services such as agricultural extension officers, promote farmer access to inputs/technologies and access to other actors in need, facilitate training and market linkages. Moreover, they are involved in village land use planning and development of village level committees to oversee resource use. They also have the mandate to create by-laws for resource management such as governing the use of village forest. Through governance of natural resources, local government authorities bridge the gap between site and landscape management.

1.3.3.3.2 Landscape level

Landscape level stakeholders can influence tree-cover restoration over larger areas or multiple sites. These stakeholders generally influence tree-cover restoration by (1) influencing or enforcing regulation for stakeholders at the site level or (2) management of larger landscape level areas such as Tanzania National Parks Authority (TANAPA). They are influenced by national level policy and priority but also influence policy making.

Regarding government entities, the district council manage and oversee natural resources for the district. They enforce and monitor the compliance of laws set by the central government for resource use. District Agricultural officers provide education of proper waste disposal and education of the use of agro-chemicals and general agriculture education to farmers. They work alongside other landscape actors such as NGOs on alternative charcoal and charcoal burners. Tanzania National Parks Authority (TANAPA) is responsible for the management of national parks, specifically Udzungwa Mountains National Park and Julius Nyerere National Park.

KSC runs a 10,000-ha plantation to supply its sugar mill alongside sugarcane grown by over 8,000 growers in the region and is the largest commercial agricultural business in the Kilombero Valley. It was established as a private company in 1960 but has since been state-run and privatised again. It became a public-private company in 1998, and the majority shareholder is Illovo Sugar Ltd that holds 55%. ED&F own 20% and the Government of the United Republic of Tanzania hold 25%. Growers currently supply approximately 45% of cane production while the estate produces 55% (Sulle and Dancer, 2020). The company is currently expanding its production capacity by constructing a new mill that will allow it to double its sugar production, the supply for this mill will come from the expansion of its grower scheme further across the valley (Illovo Sugar Africa, 2024). To meet their sustainability commitments, KSC is planning to restore the riparian zones on its estate along the Ruaha river which will alter soil erosion, water quality and availability and above-ground biodiversity. They are also working in conjunction with the NGO Landesa to update land use plans for cane supply villages, one reason for this is to ensure that none of their cane is supplied from protected areas to uphold their commitment to zero deforestation.

There is a Grower Department within KSC that looks after growers, undertaking activities like extension work, training, connection to financial institutions and finding input suppliers. KSC runs a monopsony market so growers can only sell their cane to KSC; cane growers are contracted through the Cane Supply Agreement which details the price of the cane based on sucrose content measured upon arrival at the mill. Sugarcane growers must be members of the Sugarcane Agricultural Marketing Cooperative Societies (AMCOS) to sell their cane to KSC. The Sugarcane AMCOS help with agro-chemical input distribution and is the communication channel between farmers and the company, such as when negotiating terms of the Cane Supply Agreement.

Multiple NGOs operate in the area, they often employ local Tanzanians but have European directors who are/were academics that make strategic decisions e.g. Reforest Africa, Southern Tanzania Elephant Program (STEP) and Mazingira Association (Figure 1.5). A key theme across NGOs is nature restoration coupled with enhanced livelihoods

(Table 1.1). As part of their activities, many NGOs promote agroforestry and provide trees to smallholders to restore tree cover on smallholder farms and improve livelihoods. SAGCOT has also supported agroforestry interventions to benefit ecosystems, biodiversity and climate through its partners across the corridor (Nnko et al., 2022; SAGCOT, 2012b).

Several restoration and sustainability interventions are being planned and implemented to strengthen protected areas, restore and expand tree cover that are being driven by NGOS. For instance, STEP has worked with the Ministry of Natural Resources and Tourism to release the Tanzania Wildlife Corridors Assessment, Prioritization and Action Plan and has been very important in the implementation of the Kilombero Elephant Corridor (Ministry of Natural Resources and Tourism (MNRT), 2022). They also monitor and have data on human-elephant interactions within farms and villages, alongside their tests for mitigation strategies such as chilli or beehive fences with farmers. However, NGOs in the area do not openly share data and there has been no public monitoring and evaluation of any of these restoration actions and so no comment can be made on their effectiveness.

Table 1.1 An overview of some of the environmental organisations that are active in the study area and their goals

Organisation / Project	Goal – taken from organisation webpages
Non-governmental organisations	
International Union for Conservation of Nature: SUSTAIN Pro and Eco and African Wildlife Foundation	Addressing livelihood inequality, ecosystem degradation and agricultural challenges (“Launch of SUSTAIN Pro | IUCN,” 2022)
Reforest Africa	Native forest restoration, train and inspire local people to care for trees and find ways to use them sustainably to boost their income and livelihoods (“Reforest Africa,” n.d.)
Mazingira Association	Integrate environmental sustainability into international solidarity interventions, increase environmental awareness, conserve the natural environment, and promote an improvement in the living conditions of local populations. (“Who we are – Mazingira Association,” n.d.)
Southern Tanzania Elephant Program (STEP)	Focuses on the importance of strong protected areas and the welfare of people living around their boundaries, Enhancing human-elephant coexistence through farmer-led beehive fence

	and livelihoods projects ("Southern Tanzania Elephant Program," n.d.)

Reforest Africa is focussed on forest restoration activities including the protection and management of Magombera Nature Reserve, management of a tree nursery, environmental programs in schools and fuel-efficient stoves. Their senior management team are European academics who do not live within the Kilombero Valley. Dr Andrew Marshall is the founder of Reforest Africa, previously the Chief Executive Officer, he recently moved to Chief Scientist and was succeeded by Dr Robin Loveridge. The day-to-day implementation is carried out by a local Tanzania team who lives nearby to Magombera Nature Reserve. They were successful in their campaign to upgrade the protected status of Magombera Nature Reserve which led to the exclusion of local villagers from using the forest. They are also currently building a botanical garden in M'angula village and are looking to expand into the management of other forest reserves through introducing Carbon offset credit schemes through their soon-to-be registered company Tanzania Carbon Solutions. They use their tree nursery to provide trees to farmers and actively plant and restore within Magombera Nature Reserve and other protected areas. They are also leading the tree planting of the Kilombero elephant corridor connecting Udzungwa Mountains and Magombera Nature Reserve. Reforest Africa has the potential to have a large impact on tree cover but communities in the localised areas where they work. For instance, their work planting the elephant corridor will influence human-wildlife interactions including elephant x crop conflicts, landscape connectivity, total carbon stocks and threatened species (Pfeifer et al., 2022).

IUCN has two programs in the area, SUSTAIN-Eco and SUSTAIN-Pro. SUSTAIN-Pro focuses on how to improve the sustainability of food systems and healthy productive landscapes in SAGCOT while SUSTAIN-Eco focuses on healthy ecosystems and prosperous communities in Tanzania, championing improved governance and rights, sustainable management and catalysing investment for the conservation and restoration of ecosystems and biodiversity. African Wildlife Foundation are the implementing partner for IUCN SUSTAIN. They have both worked for years within the Kilombero area where their work contributes to the SAGCOT 2030 objectives such as increasing farm productivity and lifting people out of poverty. Projects they have implemented include the creation of water user associations, laptops to AMCOS leaders, supply of solar dryers for coca drying and provision of technology for sugarcane seed production.

Mazingira Association carries out environment and development projects, particularly in relation to mitigating negative impacts of Udzungwa Mountains National Park for neighbouring villages. Projects that have been implemented include agroforestry and tree-planting for farmers, schools and churches and environmental education.

Collaboration between NGOs and government bodies is common in the biodiversity conservation space. The Udzungwa Landscape Strategy Partnership is a recent collaboration between Udzungwa Ecological Monitoring Centre, STEP, Association Mazingira and Tanzania Forest Services Agency (TFS) and Tanzania National Parks (TANAPA). This strategy plans to work on projects that address challenges in communities from Protected Areas such as human-wildlife interactions and restrictions on access to forest resources in villages surrounding Udzungwa Mountains National Park, Kilombero Nature Forest Reserve, and Udzungwa Scarp Nature Forest Reserve. A key goal of this is to foster cooperation across the landscape, which it claims to have achieved in its development as TANAPA and TFS co-developed and agreed to work together under joint budgets and strategies. Reforest Africa also runs the Greater Udzungwa-Kilombero Landscape Restoration Forum, holding multiple meetings that focus specifically on how to reach restoration objectives. However, there is a prevalence of top-down decision making and a lack of involvement from smallholder farmers and other key local stakeholders such as village leaders in these collaborations. For instance, the Greater Udzungwa-Kilombero Landscape Restoration Forum has no village or farmer representatives.

1.3.3.3.3 National level

National level stakeholders include SAGCOT centre limited, government ministries such as Ministry of Agriculture, Livestock and Fisheries, Ministry of Natural Resources and Tourism and the Department of Land Use and Planning. These Ministries create policies and acts such as the ones described in section 1.3.2 that lead to the creation of other institutions such as the Rufiji Basin Water Authority, Government research Institutes and National Carbon Monitoring Centre. These National stakeholders have a top-down influence on tree-cover restoration as those at the landscape level work to implement policy or use policy as guide for their work.

1.3.3.3 Agrisys Tanzania project

This PhD research formed as an extension of the Agrisys Tanzania project that aimed to quantify how and to what extent integrated landscape management can enhance benefits to and from agriculture (Pfeifer et al., 2022). The project conducted extensive surveys on ecological health through biodiversity and soil samples, and social variation through quantifying human wellbeing. The respondents that participated in this PhD research were randomly selected from a subset of 512 who partook in the Agrisys Tanzania household survey. Participants for the survey had been randomly chosen from the village register (Milheiras et al., 2022). This thesis uses a subset of the household survey data collected as part of this project in *Chapter 4* and *Chapter 5* (Milheiras et al., 2022).

1.4 Knowledge gaps

Below I describe the scientific knowledge gaps in which this thesis is situated. Despite the many strategies and international calls for tree-cover restoration, there are still many unknowns of how the co-benefits and trade-offs from tree growing are experienced by those managing the system including smallholder farmers. There is increasing recognition by the scientific community of the importance of placing equity at the centre of tree-planting efforts, needing to understand co-benefits and trade-offs for communities involved in restoration projects (Elias et al., 2022; Fleischman et al., 2020; Löfqvist et al., 2023). This involves placing social considerations at the heart of restoration planning to lead to improved social, ecological, and environmental outcomes (Löfqvist et al., 2023). Therefore, we need more holistic methods for restoration planning that enable stakeholders to influence research and decision-making processes.

Moreover, approaches should offer insights into the perceptions, attitudes, and trade-offs that stakeholders experience, ultimately leading to restoration outcomes that benefit both people and the environment.

This thesis focusses on three specific scientific advancements in this rapidly developing space. First, I explore the concrete, robust evidence that may exist, globally, on the use of participatory scenarios in ecological restoration and associated objectives with regards to restoration outcomes. I then investigate in the context of a case study in the Kilombero Valley, Tanzania (2) whether understanding how farmers perceive and envision trees in their future farming systems may open avenues for scaling restoration of trees in rural landscapes, and (3) whether agroforestry alongside contract farming can contribute to household livelihood resilience to climate change and climate mitigation efforts (Table 1.2).

Table 1.2 A summary of the scientific advancements addressed in this thesis, including details of the knowledge gap and key references

Science advancements	Knowledge gap	Brief details of impact of the knowledge gap	Key references to understand knowledge gaps
What evidence exists on the use of participatory scenarios in ecological restoration?	No systematic understanding of how participatory scenarios are being used in restoration planning.	Participatory scenarios are posited as a tool to analyse potential restoration trade-offs and co-benefits across environmental, social, and economic dimensions with stakeholders. However, there is little synthesised evidence to support these claims that limits their usefulness for decision-makers.	Acosta et al., (2018); McDonald et al., (2016); Metzger et al., (2017); Oteros-Rozas et al., (2015); Reed, (2008)
How do farmers perceive and envision trees in their farming systems?	Heterogeneity in stakeholders' desired futures, perceptions and attitudes towards tree-cover will influence decision-making, but this has been inadequately addressed in restoration planning and interventions.	Failure to understand and include stakeholder perceptions and desires in decision-making is a threat to scaling equitable restoration interventions.	Amare and Darr, (2024); Buyinza et al., (2020); Löfqvist et al., (2023); Loyau and Schmeller, (2017); Massingham et al., (2023); Meijer et al., (2015a)
	Limited application of sentiment analysis as a tool to inform conservation and restoration planning.	Sentiment analysis can be used to quantitatively measure attitudes towards tree-cover restoration, allowing practitioners to measure responses to and help improve restoration interventions.	Drijfhout et al., (2016); Novák et al., (2021); Tebboth et al., (2020)
How can agroforestry and contract farming contribute to household livelihood resilience to climate change and climate mitigation efforts?	Limited knowledge on how agroforestry and contract farming are used together to build livelihood resilience to climate change.	Agroforestry and contract farming are two possible pathways for allowing agricultural communities to adapt and build livelihood resilience to shocks that are both being encouraged for smallholders in rapidly transforming African landscapes. We need to understand how these strategies drive livelihood resilience to identify vulnerable groups and build on specific pathways for scaling adaptation efforts.	Dapilah (2023); Ota et al., (2020); Quandt et al., (2019); Tanner et al., (2015)

1.4.1 Scientific advancement 1: Systematically mapping the evidence on the use of participatory scenarios in ecological restoration

Achieving ambitious restoration targets will necessitate complex trade-offs against limited time, competing knowledge, costs, resources and varying societal preferences among stakeholders. Scientists have called for greater integration of social considerations for 'people-centered' ecosystem restoration that looks to be both ecologically effective and socially just (Elias et al., 2022; Fleischman et al., 2020; Löfqvist et al., 2023). Meanwhile, there is evidence for the benefits of incorporating traditional or local ecological knowledge into restoration projects (Eisenberg et al., 2019; Martinez, 2003). The Society of Ecological Restoration now lists collaboration and participation with partners and stakeholders as an underpinning principle of its International Standards (McDonald et al., 2016). However, despite calls for the need to include a broad range of objectives, outcomes and indicators, particularly social dimensions, there is insufficient evidence this is the case (Sigman and Elias, 2021).

In this light, participatory scenarios have been proposed as a tool that can be used to take a holistic approach to restoration planning by incorporating social, ecological and economic complexities whilst including and respecting different forms of knowledge (Aronson et al., 2020; Metzger et al., 2017; Oteros-Rozas et al., 2015; Reed et al., 2013). Participatory scenarios are representations or storylines of possible futures in which stakeholders take a role in the decision-making (Ferrier et al., 2016; Metzger et al., 2017; Reed, 2008). They can be used for a variety of objectives such as to explore uncertainty and trade-offs (Bremer et al., 2018), understand the effects of different management interventions (Sisk et al., 2006), identify collaborative solutions (Palacios-Agundez et al., 2013) and prioritise resources (Swart et al., 2018).

The participation of stakeholders in this process can help to identify costs and benefits associated with different outcomes for each stakeholder group and potential solutions for them to ensure that outcomes are compatible with restoration objectives and stakeholder expectations (Metzger et al., 2017). For instance, Bremer et al., (2018) quantified ecological and economic outcomes of scenarios alongside qualitative evaluation of cultural outcomes to understand trade-offs between them. The restoration objectives and scenarios were also developed through discussions with the local community and the landowner, who wanted to incorporate multiple values in their decision-making (Bremer et al., 2018). This highlights the propensity of participatory scenarios for integrating diverse data collection and analysis (Bremer et al., 2018; Huxham et al., 2015), alongside facilitating participatory discussion that allows for more social and economic dimensions to be captured in a discipline that has traditionally focussed on evaluating environmental components alone (Martin and Lyons, 2018; Prach et al., 2019; Wortley et al., 2013).

Moreover, Metzger et al., (2017) put forward that stakeholders should participate throughout the entire process, from developing the scenario objectives to disseminating the results (Metzger et al., 2017). This approach aligns with Reed et al., (2013) who also argues that participation is a process, and that stakeholder participation needs to considered as early as possible and throughout the process from concept development to evaluation of outcomes. Moreover, participation should integrate local and scientific knowledge, have clear objectives and emphasise empowerment, equity, trust and learning (Reed, 2008). It is also recommended that methods such as stakeholder analysis are used to ensure systematic representation of stakeholder groups (Reed, 2008; Reed et al., 2013).

In practice, the evidence of whether studies adhere to these principles of participation is limited. Oteros-Rozas et al (2015) found that participation in scenario planning can not only engage with a wide variety of stakeholders to develop a shared understanding but also contribute towards improving equity, legitimacy and quality of environmental decision-making by providing voice to multiple perspectives. However, participation can be constrained by lack of stakeholder diversity and continuity in the decision-making process (Oteros-Rozas et al., 2015).

Knowledge gap: Despite calls and guidance for participatory scenarios in restoration planning (Metzger et al., 2017; Oteros-Rozas et al., 2013), most studies have not used participatory approaches (Acosta et al., 2018). Acosta et al., (2018) conducted a systematic map on the use of scenarios in restoration planning and included a total of 419 studies published between 1990 and 2016, only 11% of these were classified as participatory. The authors categorised a participatory approach as binary (yes/no) but did not delve further into how participation occurred. Moreover, this evidence synthesis mainly focussed on the ecological aspects of restoration planning. Their data extraction categories for the main objective of the restoration goals only gave ecological categories such as restoring habitat or species and other economic or social goals were classified under ecosystem service objectives. They also did not delve into how scenarios are being used to explore trade-offs in different outcomes of restoration (Acosta et al., 2018).

The application of participatory methods in restoration scenarios may be limited by a lack of systematic understanding on the evidence that exists on their use in restoration planning. This knowledge gap was addressed through conducting a systematic map to collate existing evidence on the use of participatory scenarios in restoration planning from both the scientific and grey literature as documented in *Chapters 2 and 3*. This systematic map goes beyond what was previously done by authors such as Metzger et al., (2017) Oteros-Rozas et al., (2015) and Acosta et al., (2018) to systematically examine participatory scenarios only, exploring the restoration contexts, involved stakeholder groups, methods used for scenario development and application of participatory scenarios in exploring diverse sets of objectives, outcomes, and trade-offs.

1.4.2 Scientific advancement 2: How do farmers perceive and envision trees in their farming systems?

Building on Scientific advancement 1 of understanding the evidence that exists on the use of participatory scenarios in restoration planning, Scientific advancement 2 uses participatory scenario workshops to explore smallholder farmers' visions, perceptions and attitudes towards tree-cover restoration in their farming system.

Scaling tree-cover restoration efforts in farmed landscapes often looks to transform social-ecological landscapes and food systems (Tedesco et al., 2023). Whilst scenario planning allows for participants to visualise and plan for transformative pathways

(Metzger et al., 2017), Tedesco et al., (2023) also argue that social-ecological dimensions such as diverse perceptions and attitudes should be considered in decision-making processes (Löfqvist et al., 2023; Tedesco et al., 2023). Diverse representation of communities and underrepresented groups helps to ensure negative impacts are minimised and there is equitable distribution of both impacts and benefits within communities (Löfqvist et al., 2023; a et al., 2023). Practitioners should assess potential drivers of negative impacts and explore how communities have experienced changes associated with restoration (Tedesco et al., 2023).

There is little research that has examined the role of intrinsic factors such as attitudes towards agroforestry, and most of this has focussed on agroforestry adoption (Amare and Darr, 2024; Meijer et al., 2015a, 2015b). However, stakeholders' perceptions and attitudes influence their preferences and willingness to participate in conservation and restoration interventions (Kideghesho et al., 2007; Loyau and Schmeller, 2017; Meijer et al., 2015a). For instance, Loyau and Schmeller (2017) found that visitors to a French National Park who have positive attitudes towards amphibians were more likely to accept measures to prevent spread of amphibian disease such as restricted access to national parks and disinfection points. Moreover, positive attitudes towards agroforestry have been shown to reinforce intentions to integrate and adopt trees into farming systems (Amare and Darr, 2024; Buyinza et al., 2020) and have been associated with positive benefits to livelihoods (Shennan-Farpón et al., 2022).

Indeed, failure to understand and include stakeholder attitudes, perceptions and desires in decision-making is a threat to scaling equitable restoration interventions as practitioners risk increasing or triggering negative attitudes and perceptions (Ihemezie et al., 2021; Kideghesho et al., 2007). Kideghesho et al., (2007) found that prohibition from access to resources and participation in community-based projects were important factors in shaping attitudes towards conservation in the Serengeti buffer zone, Tanzania. Sentiment analysis is emerging as a valuable tool to characterise people's attitudes towards a particular object or entity, such as agroforestry and forests, as reflected in written text (Liu, 2020). It has previously been employed in the conservation sector to analyse the sentiment of large online datasets such as scientific abstracts (Lennox et al.,

2020) or social media data (Acerbi et al., 2023). It offers a mechanistic way of understanding the way people think about restoration issues that can influence policy and allows consideration of intersecting social differences such as gender and wellbeing (Tebboth et al., 2020).

Evidence on the influence of wellbeing on attitudes towards restoration or agroforestry as a land management intervention in agriculture is limited (Massingham et al., 2023; Verma and Sinha, 2018; Ward et al., 2016). Most research has explored how ecosystems influence human wellbeing, focusing on the role of agroforestry and restoration in shaping wellbeing outcomes (Castle et al., 2022; Shennan-Farpón et al., 2022). However, such an exploration is crucial for understanding perspectives and to enable efforts focussed on improving livelihoods and reducing inequalities, particularly in the context of restoring trees and forests. By using individual variables that are components of wellbeing, Massingham et al., (2023) identified that having basic needs met, feeling safe, absence of worry, participation, feeling a sense of agency and happiness all influence attitudes towards conservation actions (Massingham et al., 2023).

Knowledge gap: Despite the potential of participatory scenarios to help stakeholders envision agroforestry and tree-cover restoration futures, their application in conjunction with the analysis of stakeholder attitudes remain underexplored (Andreotti et al., 2020; Durrant et al., 2023; Novák et al., 2021). Moreover, there has been limited application of sentiment analysis as a tool to inform restoration planning even though it can be used to quantitatively measure attitudes towards tree-cover restoration, allowing practitioners to measure responses to and help improve restoration interventions (Drijfhout et al., 2016; Novák et al., 2021). Lastly, evidence of the effect of wellbeing on attitudes towards restoration or agroforestry as a land management intervention in agriculture is limited (Verma and Sinha, 2018; Ward et al., 2016; Massingham et al., 2023).

To address these knowledge gaps, I use participatory scenarios and sentiment analysis to understand smallholders' ideal visions of on-farm tree-cover restoration alongside their attitudes and perceptions towards tree-cover restoration in *Chapter 4*. I employ sentiment analysis to quantify attitudes and demonstrate its utility for restoration planning and in complementing participatory research efforts.

1.4.3 Scientific advancement 3: How can agroforestry and contract farming contribute to household livelihood resilience to climate change and climate mitigation efforts?

Large-scale efforts are needed to mitigate the effects of climate change and allow agricultural communities to adapt and build resilience. Agricultural livelihoods and food security are especially vulnerable to climate change and require urgent adaptation efforts (Anderson et al., 2020). Some of the most acutely impacted are smallholder farmers in rural tropical landscapes for whom agriculture is the primary source of sustenance and income (Schlenker and Lobell, 2010b; Thornton et al., 2011). In East Africa climate change scenarios predict decreased yields and reduced land suitability, resulting in narrowed agricultural livelihood options (Kogo et al., 2021; Thornton et al., 2011).

Livelihood resilience is the 'capacity of all people across generations to sustain and improve their livelihood opportunities and well-being despite environmental, economic, social, and political disturbances' (Tanner et al., 2015, p. 23). Adopting a livelihood resilience lens in the context of climate change adaptation, focuses less on people's recovery from shocks and more on how coping and adaption lead to broader social transformations (Tanner et al., 2015). It is suitable to study livelihood resilience at the household level because households are central in managing responses to external shocks, and many assets, capacities, and functions required to respond to shocks have historically been dictated by household-level dynamics (Frankenberger and McCaston, 1998). Table 1.3 provides an overview of three different ways that household livelihood resilience has been conceptualised and measured in the scientific literature in agricultural contexts.

Table 1.3 An overview of three different ways household livelihood resilience has been conceptualised in the scientific literature, including the advantages and drawbacks of each method

Method and reference	Short description	Context and scale	Advantages	Drawbacks
Household Livelihood Resilience Approach (HLRA) (Quandt, 2018)	Composite indicator method based on the Sustainable Livelihood Assets framework. Households build livelihood resilience based on accumulating financial, natural, social, physical, and human capital. These five dimensions are then combined to create a composite indicator.	Scale: Household Context: Empirically tested in agroforestry systems in Eastern Africa Takes and objective approach, focussing on observable socio-economic variables and measurable resources and assets	Has been empirically tested in agroforestry systems. Combines quantitative and qualitative data. Includes subjective and objective measures. Household level analysis can identify vulnerable groups to target for interventions. Incorporates access to capital assets with human agency to actively build capacity through accumulating capital.	Provides only a snapshot in time of resilience. Does not prioritise indicators, but some may be more important than others. Difficult to include large scale factors that can influence resilience such as national politics, international markets. Provides a contextual insight due to specific indicators so difficult to generalize. It excludes people's own knowledge of their resilience, arguing a move to include 'resilience as defined and measured by whom' (Quandt and Paderes, 2023)

(Speranza et al., 2014)	Resilience is based on three major attributes: buffer capacity, self-organization, capacity for learning. Buffer capacity building on the Sustainable Livelihoods Assets framework of the give types of capital. Self-organisation aims to capture how human agency, power and social interactions shape resilience such as through institutions, participation in groups, trust within the community. Capacity for learning incorporates previous experience and the acquisition of knowledge or skills such as knowledge of threats, planning and openness.	Scale: Can be applied at the individual, household, group, village, or district level depending on the indicators chosen for each component.	Can be applied at multiple scales.	Not empirically tested as an approach but put forward as a theoretical framework only when proposed. However, it has since been used as a livelihood resilience measurement tool e.g. (Jacobi et al., 2018). Provides a contextual insight due to specific indicators so difficult to generalize. Provides only a snapshot in time of resilience.
Subjective measure of household resilience (Jones et al., 2018; Jones and Tanner, 2017)	Subjective resilience framework builds on the premise that people understand the factors that contribute to their ability to anticipate, buffer, and adapt to disturbance and change. Corresponds to how people rate their own resilience and is associated with perceptions of risk, sense of place, beliefs, culture, social norms and cohesion, power, marginalization, and cultural identity.	Scale: household	Can be used alongside objective measures. Recognizes that people have a good understanding of their own capabilities and capacities to deal with shocks. Challenges the notion that experts are best based placed to evaluate other people's lives.	Yet to be fully explored conceptually and practically. Subjective measurements are more difficult to compare between contexts.

Studies such as Quandt (2018) and Speranza et al., (2014) (Table 1.3) have examined livelihood resilience by drawing on the Sustainable Livelihoods Approach (SLA), which suggests there are five key types of assets that households and individuals draw upon to build their livelihood: human, social, natural, physical, and financial assets. See Table 1.4 for a tabular overview of the sustainable livelihoods approach including a brief background, definitions and examples of capital assets. These capital assets overlap and can be exchanged or allocated to generate income and sustain well-being and/or stored and accumulated so reserves and buffers are available in times of stress or shocks (Serrat, 2017). Depletion of capital assets through use or consumption can lead to or hold a household in poverty and further limit their adaptation options and livelihood resilience (Stringer et al., 2016).

Household livelihood resilience is an understudied aspect of agroecosystems (Lin, 2011), and sustainable livelihood perspectives grapple with debates around longer-term shifts in rural economies and agrarian change (Scoones, 2009). Many African landscapes have become the focus of a myriad of agricultural interventions from public, private, and non-government entities promoting different agricultural and rural development models. Pathways promoted for building livelihood resilience include contract farming and agroforestry and smallholders are undertaking both, whilst adapting to the effects of climate change (Balama et al., 2016).

Table 1.4 A summary of the Sustainable Livelihoods approach, including the background, definitions, examples, advantages and drawbacks

Sustainable Livelihoods Approach (SLA)		
Background	The concept of sustainable livelihood originates from the Brundtland Commission on Environment and Development in the 1990s as an approach to improve understanding of the livelihoods of the poor in a more holistic and sustainable manner. The SLA recognizes that livelihoods are influenced by a complex interplay of social, economic, environmental, and institutional factors (Krantz, 2001). It is an approach that is methodologically based in earlier development paradigms such as Participatory Rural Appraisal (Chambers, 1994; Krantz, 2001). The approach states that there are five key types of assets that households and individuals draw upon to build their livelihood: human, social, natural, physical, and financial assets (see definitions and examples below). These capital assets constitute a stock of capital that can be stored, accumulated, exchanged or allocated to generate income and sustain their wellbeing (Serrat, 2017). These capitals may be accumulated so reserves and buffers are available in times of stress or shocks (Scoones, 1998). A household is assumed to need a balance of these five capitals to maintain adaptive capacity and wellbeing (Jacobs et al., 2015). The capitals can and do overlap such as natural capital can create financial capital and vice versa, but there are also trade-offs such as diminishing financial capital to increase human capital by paying for school fees.	
Capital assets	Definition (Serrat, 2017)	Examples
Human	The skills, knowledge, ability to labour and good health that allows people to pursue and achieve livelihood strategies.	Amount and quality of labour Health Education level

Social	Social resources which people draw upon in pursuit of their livelihood strategy	Membership of groups Relationships of trust, reciprocity, and exchange Networks and connectedness
Natural	Natural resource stocks from which resource flows and services useful for livelihoods come from.	Trees, land, soil, nutrients
Physical	Basic infrastructure and producer goods	Transport, Shelter, Water supply and sanitation, Energy
Financial	Financial resources - note here that it can relatively easily be converted into other types of capital	Savings Remittances
Advantages and drawbacks of the SLA		
Advantages	Proponents of the SLA argue that it seeks to understand changing combinations of what constitutes a sustainable livelihood, acknowledges the need to move beyond sectoral perspectives and emphasizes seeing links between sectors, moves beyond a homogenous view of communities and draws attention to relationships between different activities that constitute livelihoods such as social relations (Serrat, 2017).	
Drawbacks	Critics of the approach argue that it is a static framework, there is an overemphasis on assets at the expense of power dynamics and social inequalities, it is based on normative assumptions of what constitutes a 'sustainable' livelihood which may not align with local values, aspirations, or cultural contexts, it can underplay macro issues with as macroeconomic trends and conflict (Serrat, 2017).	

There is evidence within rural Africa of the role forests play in helping households cope with shocks and stresses that have negatively affected their income (Kalaba et al., 2013). Waldron et al., (2017) argue that this is also the case for agroforestry systems. Agroforestry has been found to be beneficial for household livelihood resilience in Kenya and Cameroon (Awazi and Quandt, 2021; Quandt et al., 2019). It can influence all five livelihood assets and therefore, livelihood resilience, both positively and negatively, although negative outcomes for livelihoods are less frequently discussed (Ota et al., 2020). Table 1.5 gives an overview of how a lack of capital assets may limit agroforestry uptake and how uptake of agroforestry may benefit capital asset accumulation. Agroforestry and tree-cover restoration can also have a negative impact on social capital if it excludes marginalised groups and reduces their access to tree-related resources (Ota et al., 2020).

Table 1.5 Link of agroforestry to livelihood resilience using the Sustainable Livelihoods approach

Capital assets	**How capital assets may limit agroforestry uptake**	**How agroforestry may benefit capital asset accumulation**
Human	Lack of labour resources, limited knowledge and technical capability (Ota et al., 2020).	Improve diet diversity, improving knowledge and capabilities and generating employment opportunities (Ota et al., 2020).
Social	May exclude marginalised groups and reduce their access to reforestation resources (Ota et al., 2020).	Enhanced collective action, social networks and trust (Ota et al., 2020).
Natural	Lack of land (Ota et al., 2020).	Improvements to agrobiodiversity, soil fertility and decreased erosion and carbon sequestration (Ota et al., 2020; Quandt et al., 2019).
Physical	Lack of technology and infrastructure	Higher physical protection of homes and farms against extreme weather (Ota et al., 2020).

Financial	Lack of financial resources (Ota et al., 2020).	Providing products for household consumption and sale such as fruit (Ota et al., 2020; Quandt et al., 2019).

Meanwhile, contract farming, or out-grower schemes, refers to agricultural production according to a prior agreement in which the farmer agrees to grow a product and the buyer commits to purchasing (Actionaid, 2015). Contract farming agreements may enhance livelihood resilience by lowering farmers' costs and risks through increasing access to credit information, training, markets, inputs, improved seeds services, support groups, and yearly income (Dapilah, 2023; West and Haug, 2017).

However, the benefits are not homogenous across communities and can exacerbate structural inequalities. raising equity concerns (Mwavu et al., 2018; Sulle and Dancer, 2020). Participation in contract farming tends to involve wealthier farmers with more land and smaller farms have substantially lower income effects (Ton et al., 2018). It is questioned whether agricultural development schemes centred around contract farming, such as agricultural growth corridors, can meet their commercial and development objectives, particularly for smallholders (Dapilah, 2023; Sulle and Dancer, 2020; West and Haug, 2017). Moreover, contract farming can also increase vulnerability through market specialisation and the producer bearing all production risk, for which farmers may become more vulnerable as the climate becomes increasingly unpredictable (Dapilah, 2023).

Knowledge gap: Agroforestry and contract farming are two possible pathways for allowing agricultural communities to adapt and build livelihood resilience to climate change that are both being encouraged for smallholders in rapidly transforming African landscapes. Mbow et al., (2014) pose the question of whether adaptation benefits from agroforestry are greater than those of alternative land uses, but often farmers are employing multiple land use and livelihood strategies.

The scientific literature to date, has mostly focussed on examining these two pathways separately (Dapilah, 2023; Quandt et al., 2019). For instance, when examining agroforestry and household livelihood resilience, Quandt et al., (2019) reported the most common livelihood activities and used the number of livelihood activities practiced as a variable, but did not explore how these activities interact with agroforestry in building household livelihood resilience. However, smallholders are utilising multiple pathways when building their livelihoods and therefore, we need to examine them together for to understand how they interact for climate adaptation and mitigation outcomes. To my knowledge, only one study by Mwavu et al., (2016) has examined the agroforestry in the context of contract farming in Uganda. However, this study explored the agrobiodiversity of homegardens and contribution to household livelihood strategies more broadly, instead of assessing agroforestry and contract farming as strategies for livelihood resilience to climate change. This knowledge gap is addressed in *Chapter 5* where I examine the livelihood resilience to climate change and climate mitigation trade-offs and co-benefits for smallholder farmers practising sugarcane contract farming and agroforestry.

1.5 Research questions and objectives

The overarching objectives of this thesis are to better understand the trade-offs involved for smallholders in tree-cover restoration for more informed policy and decision-making. Specifically, I address the scientific advances as elaborated in section 1.4.1, 1.4.2 and 1.4.3 within (1) the published literature base (*Chapters 2 and 3*) and (2) within the Kilombero Valley, Tanzania (*Chapters 4 and 5*). Figure 1.7 gives an overview of the conceptual framing of how the research questions link together.

- *What evidence exists on the use of participatory scenarios in ecological restoration?* (*Chapters 2 and 3)*
- *How do farmers perceive and envision trees in their farming systems? (Chapter 4)*
- *How can agricultural strategies contribute to household livelihood resilience to climate change and climate change mitigation efforts? (Chapter 5)*

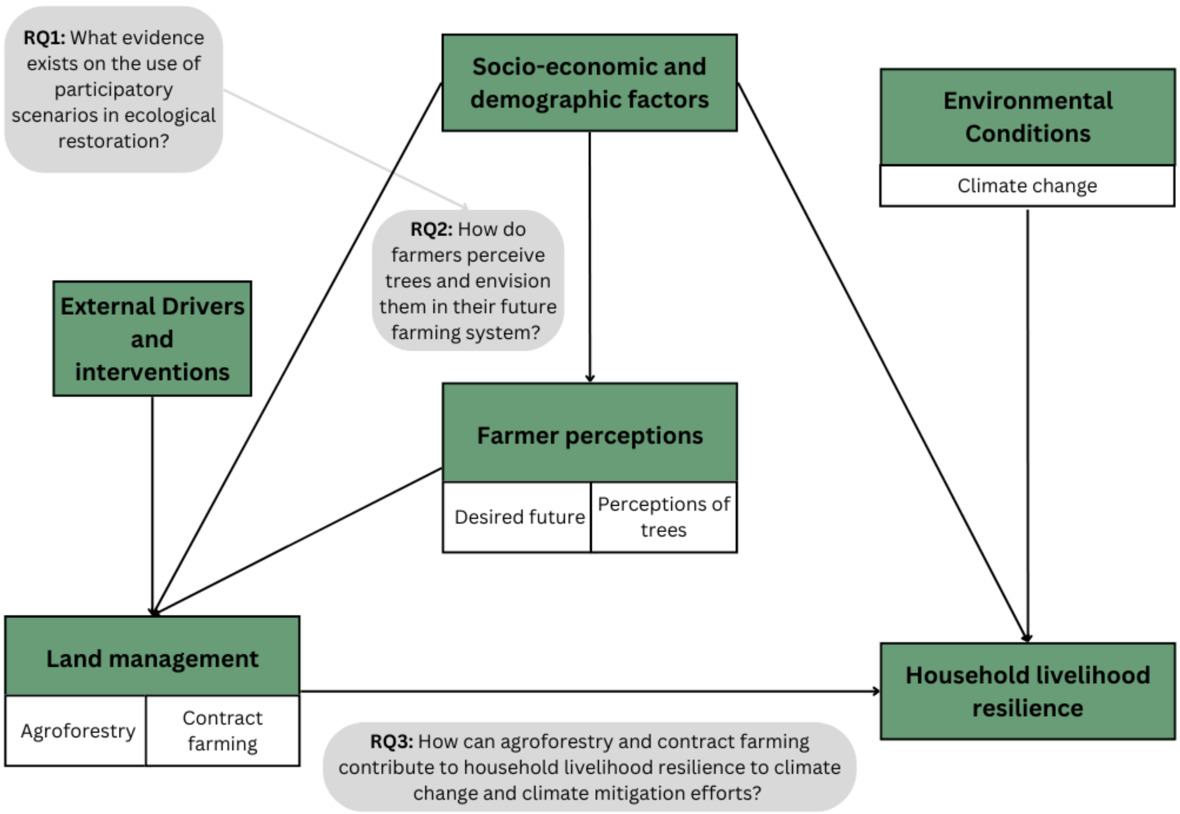

Figure 1.7 Conceptual framing for the PhD research

1.6 Thesis structure

This thesis is presented according to the requirements of the Newcastle University degree of Doctor of Philosophy in Biology and follows the research article format. Chapters 2,3,4 and 5 have been published in or are currently in review at peer-reviewed journals and are formatted accordingly to the journal they were submitted to.

Chapter 1 Introduction explored background information and the current state of knowledge on tree-cover restoration and agroforestry within Africa. It then focussed specifically on research within Tanzania, providing a summary of the national and policy context and providing detailed context the study area, the Kilombero Valley. This chapter set out the knowledge gaps and research questions that this thesis addresses. The knowledge gaps are structured by the research questions addressed in the subsequent chapters, *Chapter 2, 3, 4 and 5*.

Chapter 2 The role of participatory scenarios in ecological restoration: A systematic map protocol sets out the protocol that was then followed to complete the systematic map presented in *Chapter 3*. This paper adheres to the Environmental Evidence guidelines for authors, it sets out the review questions that explore the existing evidence on the use of participatory scenarios for ecological restoration planning, It describes the comprehensive and reproducible methodology that was planned, including bibliographic database and web-based searches, a two-step screening process against pre-determined inclusion criteria and the data that was extracted to answer the research questions. This research paper was published in *Environmental Evidence*.

Chapter 3 Existing evidence on the use of participatory scenarios in ecological restoration: a systematic map details the systematic map results that were planned in *Chapter 2*. It describes and justifies any changes that were made to the protocol in *Chapter 2*, presents an updated methodology and the results of the review research questions. The chapter maps the evidence on (1) the characteristics of the evidence base, (2) the types of study designs being used, (3) the types of outcomes being explored using participatory scenarios, (4) how trade-offs are explored and (5) the role of participants in the scenario process and outcome determination. I discuss how it is difficult to understand how useful scenarios are for the restoration planning process, but the evidence suggests that they allow for the integration of different knowledge types and methodological approaches. This research paper was published in *Environmental Evidence*.

Chapter 4 Understanding farmers' attitudes and scenarios towards tree-cover restoration in the Kilombero Valley, Tanzania investigates the perceptions and attitudes of smallholder farmers towards tree-cover restoration in their farming landscape. I use sentiment analysis to quantify the positive and negative attitudes farmers expressed in participatory workshops towards agroforestry and forests from transcript data. The chapter explores (1) what influences smallholders' ideal on-farm tree configurations, (2) what perceptions are associated with farmer attitudes towards agroforestry and surrounding forest, (3) how gender and wellbeing influence farmer attitudes. I discuss how agroforestry scaling campaigns can develop proactive strategies to address farmers' concerns and desires using participatory methods for more equitable restoration outcomes. This research paper is in review at Forest *Policy and Economics*.

Chapter 5 Contract farming for sugar and agroforestry can have positive and negative impacts on livelihood resilience in Tanzania aims to understand how agroforestry and contract farming, two agricultural strategies prominent in rural African landscapes, influence livelihood resilience to climate change and climate mitigation efforts. I explore how contract farming and agroforestry are used together to build household livelihood resilience to climate change and, how agroforestry can contribute to climate change mitigation. The chapter adopts a multi-disciplinary approach, using systems modelling and a qualitative framework analysis to answer the research questions. I discuss the co-benefits and trade-offs involved for farmers pursuing these livelihood strategies and how we can contribute to a more equitable transformation of smallholder systems. This research paper is in review at *Regional Environmental Change*.

Chapter 6 Synthesis and Conclusion integrates the conclusions significance and novelty of thesis across the four data chapters. Lastly, I provide an outlook for future research directions according to each scientific advancement and end with concluding remarks.

The next section, *Chapter 2* is the first data chapter of this thesis and lays out the protocol that was followed when doing the systematic map of the evidence that exists on using participatory scenarios for restoration planning.

1.7 References

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2-The role of participatory scenarios in ecological restoration: A systematic map protocol

Linking statement: I first wanted to systematically explore the evidence base for using participatory scenarios in restoration planning. Hence, in this chapter I followed the Guidelines of the Collaboration for Environmental Evidence to produce a systematic map protocol. This protocol lays the foundation for conducting the systematic map in *Chapter 3* and lays out the research questions, key themes and methods that underlie the evidence synthesis.

This chapter titled "The role of participatory scenarios in ecological restoration: A systematic map protocol" was published in the peer reviewed journal Environmental Evidence on 22nd June 2022. The final submitted manuscript has been included in here. Most supplementary materials have been uploaded to Figshare and the DOIs have been included at the appropriate places in the text. Please note, I changed my surname mid-way through this PhD to Durrant from Moore. This manuscript was published under Eleanor Moore.

Contribution statement: I conceptualised the idea, developed the methodology based on the Environmental Evidence guidelines for authors, wrote the manuscript and subsequent drafts and prepared the additional materials, including design of the search strategy and data extraction file. Dr Matt Grainger provided valuable advice and feedback on the protocol design for appropriate evidence synthesis methods. Dr Pete Howson contributed to the conceptualisation and writing around participatory research. Dr Marion Pfeifer provided supervision and was involved in all stages from conceptualisation. During the peer review process, I responded to all reviewer comments and reviews during the peer review process. All co-authors provided feedback on manuscript drafts.

2.1 Abstract

The scale of land degradation worldwide has led the UN to declare the Decade of Ecosystem Restoration and movements such as the Bonn Challenge, have placed ecological restoration on the global policy agenda. Achieving such ambitious policy targets and restoration goals will necessitate complex trade-offs against limited time, competing knowledge, costs, resources, and varying societal preferences among different stakeholders.

Participatory scenarios are a tool to navigate uncertainties surrounding future trajectories and simultaneously incorporate different stakeholder perspectives. They can provide a path to identify collaborative solutions best suited for the local cultures and societies they are tied to. However, there is no systematic understanding of how participatory scenarios are being used in ecological restoration planning to navigate trade-offs in restoration outcomes. We will fill this research gap by mapping the existing evidence from participatory restoration scenarios to answer the primary research question 'How are outcomes explored in participatory ecological restoration scenarios?'. This will be done through five sub-questions focussing on characteristics of the evidence base, types of study design, how outcomes and trade-offs in those are explored, and an examination of the role of participants in the scenario process and outcome determination.

This protocol outlines the methods for a systematic map to identify studies that have used participatory scenarios in restoration planning. A comprehensive and reproducible search strategy will be undertaken across bibliographic databases, web-based engines, and targeted searches in organisational online libraries. Searches will be done online in English, but results in all languages will be screened. Search results will go through a two-step screening process against pre-determined criteria of inclusion and exclusion, for title and abstract and then full text. Data will be extracted from eligible studies using a standardised data extraction spreadsheet where details on study characteristics, design and outcomes will be recorded. A searchable database of studies and mapping outcomes will be available upon completion of the work. The aim is to inform how

scenarios can be better used as a decision-making tool to increase stakeholder participation and account for trade-offs in restoration outcomes across social, ecological, and economic dimensions.

Keywords: *Evidence synthesis, alternative futures, place-based research, socioecological systems, trade-offs, co-production, stakeholder engagement*

2.2 Background

The scale of land degradation worldwide has led the UN to declare 2021-2030 the Decade of Ecosystem Restoration and targets such as the Bonn Challenge that aims to restore 350 million hectares by 2030 have placed ecological restoration on the global policy agenda (United Nations, 2021; IUCN, 2021). Ecological restoration is an important tool for managing and improving highly degraded or altered environments (McBride et al., 2010). We define ecological restoration as “the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value” (Martin, 2017). This definition incorporates the social aspect that drives restoration planning and implementation by including the motivating rationale (Martin, 2017).

Currently, under the Bonn Challenge, 210 million hectares have been pledged across 71 countries, although the extent of success is unclear and will not be evident for some time (IUCN, 2021, 2020). Achieving such ambitious policy targets and restoration goals will necessitate complex trade-offs against limited time, competing knowledge, costs, resources, and varying societal preferences among different stakeholders. There is also surmounting evidence of the value of incorporating traditional or local ecological knowledge in restoration projects (Martinez, 2003; Eisenberg et al., 2019). In this light, we need strategic planning that takes a holistic approach to the social, ecological, and economic complexities while also including and respecting different forms of knowledge (Aronson et al., 2020).

2.1.1 Participatory scenarios

Scenarios are representations or storylines of possible futures (Ferrier et al., 2016). They are useful in restoration planning, often a short-term process that aims to achieve long-term outcomes. Scenarios can be applied to restoration planning for a variety of objectives, including to explore uncertainties or understand the effect of a specific management intervention on restoration objectives, or to understand the effect of different management interventions on specific desired outcomes (Metzger et al., 2017). As a decision-making tool, the outcomes can be used to prioritise (in space and time) decisions and resources and to reduce costs (Swart et al., 2018). The integration of participatory methods in scenario planning provides a path to identify collaborative solutions best suited for the local cultures and societies they are tied to (McDonald et al., 2016). It is now widely considered in the literature and international standards that active engagement with stakeholders will underpin long-term restoration success (Swart et al., 2018; McDonald et al., 2016). Stakeholder participation is “a process where individuals, groups and organisations choose to take a role in making decisions that affect them” (Reed, 2008). There is an emerging consensus that the probability of multiple positive outcomes for biodiversity and livelihoods in forest systems increases with participation in decision-making (Persha et al., 2011).

Participatory scenarios are a tool to navigate uncertainties surrounding future trajectories and simultaneously incorporate different stakeholders (Bremer et al., 2018; Palomo et al., 2011). For instance, Palacios-Agundez et al. (2013) downscaled the Millennium Ecosystem Assessment global scenarios with stakeholders in Basque Country, Spain. Participants were able to relate the global scenarios to local drivers of change and suggest management actions towards achieving their desirable scenario framed by the local culture and context (Palacios-Agundez et al., 2013). The authors reported participants learned to see and understand different perspectives and collaborated on proposing feasible management responses. This holistic approach to the future that seeks to manage uncertainties with stakeholders and compare different possible outcomes of decisions is what separates the method from others such as

Theories of Change (Derbyshire, 2019) and Participatory Rural Appraisal (Chambers, 1994).

Despite extensive reports of success in participatory methods for environmental management, there is also evidence of them failing to meet their objectives (Lane & Corbett, 2005; Gerrits & Edelenbos, 2004). Assessment suggests that for example, a lack of participant diversity and representativeness may lead to outcomes not reflecting the multitude of viewpoints within a community, undermining a key motivation for using participatory methods (Gerrits & Edelenbos, 2004). Guidance to implement participatory scenarios in restoration planning has been developed (Ferrier et al., 2016; Metzger et al., 2017). Recent advice, drawing from the six best practice principles for scenarios in restoration planning, Metzger et al., (2017) concludes that stakeholders should participate through the whole process; from method planning to creation and review of scenarios.

2.1.2 Trade-offs in achieving desired outcomes

Ecological restoration projects are often no longer about solely achieving ecological success. Instead, they are positioned alongside narratives of 'win-win' and win-lose, aiming to investigate restoration legacies for improved social outcomes such as enhanced livelihoods and climate change mitigation (United Nations, 2021; UN-REDD Programme, 2020; Gourevitch et al., 2016). Previous research has noted that ecological indicators have often focussed on structure or composition as surrogates for ecosystem functioning (Prach et al., 2019) but called for greater focus on social in addition to ecological outcomes (Wortley et al., 2013). Yet traditionally ecological restoration has predominantly focused ecological outcomes and this is insufficient to understand the array of impacts on the socio-ecological system targeted by restoration interventions (Prach et al., 2019; Wortley et al., 2013; Martin & Lyons, 2018).

Stakeholder engagement and scenarios have been suggested as a key tool to analyse trade-offs in outcomes across time, space, and stakeholders (Metzger et al., 2017; Daw et al., 2015; Brown, 2004). Participatory scenario methods facilitate discussions around outcomes and how stakeholders may respond to interventions allowing for social and economic dimensions to also be captured (Oteros-Rozas et al., 2015). They also allow for the integration of multiple disciplines and methods, for instance, Bremer at al., (2018) quantified ecological and economic outcomes in scenarios of grassland restoration alongside qualitative evaluation of cultural ones.

Determining and balancing outcomes of restoration objectives can be challenging because values differ between stakeholders, who often have diverse knowledge systems and expectations (Etienne et al., 2003; Hagger et al., 2017). Using scenarios allows us to investigate alternative futures and evaluate the inherent trade-offs that may need to be made, looking to reduce uncertainty (Peterson et al., 2003). Besides, trade-offs tend to feature heavily in participants discussions, even when they are not explicitly addressed (Oteros-Rozas et al., 2015). For example, when planning restoration of native grassland in central France, sheep farmers' primary objective was maintaining sheep production while conservationists were concerned with the preservation of local biodiversity (Oteros-Rozas et al., 2015). Furthermore, even if restoration objectives are agreed upon, the interventions suggested to achieve them can be vastly different between stakeholders. In the restoration of ponderosa pine forests to reduce fire risk, some participants recommended no treatment while others recommended extreme thinning at the same location in the landscape (Sisk et al., 2006). Despite a push towards participatory methods, a review by Acosta et al. (2018) into scenarios for restoration planning found only 11% of publications adopted a participatory approach. There is currently little known on the extent of participation by stakeholders in participatory scenarios (Acosta et al., 2018), and this will vary depending on study context, time, and resources available. Here we aim to take a broad definition of participation that stakeholders must play a role in decision-making at any stage in the scenario process, and this may not necessarily be throughout the whole process. This role in decision making can take many different forms from one-way engagement such as consultation, to co-production in which there is two-way knowledge exchange and production (Agarwal, 2001; Arnstein, 1969).

There is currently no systematic understanding of how participatory scenarios are being used in ecological restoration, including the geographic and spatial scope through which they are applied, the types of restoration projects they are being used for and the restoration outcomes they are addressing. Moreover, despite calls for the need to include a broad range of outcomes and indicators there is insufficient evidence this is the case (Sigman & Elias, 2021). We will fill this research gap by mapping the existing evidence from participatory restoration scenarios to examine how restoration outcomes are explored using participatory scenarios and how participants are involved in the scenario process. We will determine what outcomes and trade-offs are being examined using participatory scenarios, and where there are knowledge gaps to improve further research.

2.1.3 Stakeholder involvement

This systematic map is being led by a team at Newcastle University and Northumbria University. The authors all specialise within the fields of ecological restoration across both ecological and social sciences. The main aims were formulated between the review team and then it was sent to five external experts in environmental restoration to review. These experts were purposefully selected from the networks of the review team because they have experience in different regions and topic areas within restoration. They provided a broader understanding of the topic, knowledge gaps and contributed to the list of synonyms for the search string. Through publishing the protocol with Environmental Evidence, we have adhered to their review standards and taken advantage of being able to undergo a peer review process for the protocol and gain valuable feedback to improve the final systematic map. When undertaking the review, we will do a call for submissions through organisational networks, an open call through social media and review team networks. Once the map is finished, we plan to do a one-page summary with infographics for academics and practitioners to disseminate results.

2.1.4 Research objectives

The aim of this systematic map is to inform how scenarios can be better used as a decision-making tool to increase stakeholder participation and account for trade-offs in restoration outcomes across social, ecological, and economic dimensions. The research question was designed using the SPIDER framework because of the qualitative and mixed method nature of the literature base (Cooke et al., 2012) (Table 2.2). This led to the following overarching research question:

How are outcomes explored in participatory ecological restoration scenarios?

The main research question will be answered through the following sub-questions:

- What are the characteristics of the current evidence base – location, scale, design, restoration intervention type?
- What types of study designs are used for participatory scenarios in restoration planning?
- What types of outcomes are explored using participatory scenarios?
- How are trade-offs in outcomes explored in participatory scenarios?
- What is the role of participants in the scenario process and outcome determination?

2.2 Methods

2.2.1 Search strategy

2.2.1.1 Search string

A benchmark list of eight articles was created that captured a range of relevant studies for the review through scoping searches and bibliographies of relevant papers (supplementary materials 2.5.1.1, Table S2.1 and Table S2.2). Search terms were collated through keywords extracted from the benchmark papers, consultation with academic experts, a librarian, and a thesaurus (supplementary materials 2.5.1.3, Table S2.5 and Table S2.6). Search terms were based on the key components of the question (Table S2.5, Table S2.6). The search string was developed using the Web of Science Core

Collection and Boolean operators. Themes were combined using “AND”, while synonyms within themes were combined using “OR”. Combinations of different synonyms were then applied to searches and tested against a list of benchmark articles (see https://doi.org/10.6084/m9.figshare.26253101 for the search string building). The final search string was the minimum number of terms to gain high sensitivity but low specificity. The search string and all searches will be conducted in English but results in all languages will be screened.

Final search string based on the research question:

Scenario: Scenario* OR forecast* OR backcast* OR futur* OR trajector*

AND

Participatory: participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*

AND

Ecological: ecolog* OR environment* or ecosystem*

AND

Restoration: restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*"

Is a wild card and includes any characters on the end of the word. For example, participat may include participation, participatory, participative.

2.2.1.2 Bibliographic database searches

Bibliographic database searches will follow the logic of the search string described above (see supplementary materials 2.5.1.4 for search string details for each database). The following bibliographic databases will be searched:

1. Web of Science by Thomson-Reuters (All collections): A multi-disciplinary database of peer-reviewed scientific literature, books, book chapters and conference proceedings (Thomson Reuters, 2021).

2. Scopus by Elsevier: A multi-disciplinary database of peer-reviewed scientific literature, books, book chapters and conference proceedings (Elsevier Science Publishers, 2004).

3. Cab abstracts by CAB international: covers research in the fields of agriculture and land use (C.A.B. International, 1990).

4. ProQuest (Natural Science Collection and Social Science Collection): A full range of natural science and social science databases (ProQuest, 2010, 2006).

5. Lens.org ('The Lens - Free & Open Patent and Scholarly Search', 2021)

2.2.1.3 Web-based search

An internet search will be performed using Google Scholar. Due to search capability limitations, a simplified modified search string will be used: "scenario" AND "participatory" OR "collaborative" AND "restoration" OR "regeneration" OR "reforestation" AND "ecological" OR "ecosystem". The first 500 articles will be screened.

2.2.1.4 Specialist search for grey literature

Grey literature targeted searches were determined through two avenues. Firstly, through discussion with six academic experts in restoration or participatory research identified through the reviewers' academic network. Secondly, through scoping searches for organisations linked to the Bonn Challenge or UN Decade of Restoration. Due to limitations in search capabilities and to ensure a broad search in these databases, only the term ‘scenario’ will be searched for and then all results screened. A full list of the organisations is found in Table 2.1.

Table 2.1 A list of the organisations and accompanying URLs that will be searched.

Organisation	Link as of *(19/11/2021)*
International Union for Conservation of Nature (IUCN)	https://portals.iucn.org/library/
Food and Agriculture Organisation of the United Nations (FAO)	http://www.fao.org/scripts/catweb/frees.htm
Society for Ecological Restoration (SER)	https://www.ser-rrc.org/resource-database/
Global Landscapes Forum (GLF)	https://www.globallandscapesforum.org/#
Landscapes for People, Food and Nature	http://peoplefoodandnature.org/
World Resources Institute	https://www.wri.org/
Stockholm Resilience Centre	https://www.stockholmresilience.org/
UN-REDD	https://www.un-redd.org/
WWF	https://wwf.panda.org/
Tropenbos International	https://tropenbos.org
Ecoagriculture Partners	https://ecoagriculture.org/
International Tropical Timber Organisation	https://www.itto.int/
World Agroforestry (ICRAF)	https://www.worldagroforestry.org/
Center for International Forestry Research (CIFOR)	https://www.cifor.org/
Consultative Group on International Agricultural Research (CGIAR)	https://www.cgiar.org/
European Forest Institute	https://efi.int/
Rainforest Alliance	https://www.rainforest-alliance.org/

2.2.1.5 Targeted searching

The bibliographies and citing articles of other relevant evidence syntheses or publications on the use of participatory scenarios in natural resource management will be screened for relevant literature. This will include already discovered literature (Metzger et al., 2017; Acosta et al., 2018; Oteros-Rozas et al., 2015), and any found during the screening process. Acosta et al., (2018) will also be contacted for the list of included studies of their evidence synthesis to be screened.

2.2.1.6 Other literature searches

We will make use of social media channels and email list servers to inform the ecological restoration community of this review and request submissions of relevant literature (both scientific and grey). A targeted call for evidence will be placed within the International Union for Conservation of Nature, Science for Nature and People network and the Global Landscapes Forum. All submitted publications will be screened for eligibility according to the methods described below.

We will also perform forward and backward citation chasing using the *citationchaser* package (Haddaway, Grainger, et al., 2021) on all publications that pass full-text screening. Duplicates will be removed, and the remaining publications will be screened for eligibility.

2.2.2 Article screening and study eligibility

2.2.2.1 Pilot testing

The eligibility criteria were pilot tested by three reviewers (see supplementary materials 2.5.1.2 and Table S2.3 and Table S2.4). Firstly, reviewers screened the titles and abstracts of the test papers. Screening decisions were compared, and any inconsistencies were discussed, and the criteria subsequently adjusted. Then, the process was repeated for full-text versions of the test list. Once the eligibility criteria were set, the data extraction codebook was also pilot tested by three reviewers on the test list. Any inconstancies were discussed, and the codebook was adjusted accordingly.

2.2.2.2 Study eligibility

Each publication will be screened according to the eligibility criteria in Table 2.2, all publications must also be available in an online format. A list of excluded articles with the reason for exclusion will be included in full text.

2.2.2.3 Screening process

A two-stage screening will take place: title and abstract screening and then full-text. Title and abstract screening will be conducted using the web programme Rayyan (Ouzzani et al., 2016). At each stage, inclusion will be determined through the eligibility criteria (Table 3). Suppose the reviewer is unsure or there is not enough information to determine eligibility at the title and abstract stage. In that case, the study will be included in the full-text stage. Doubts of inclusion at the full-text stage will be discussed and determined by the review team, the majority decision will be taken forward. A complete list of excluded studies alongside the reasoning will be included upon publishing the review as required by the RepOrting standards for systematic Evidence Syntheses standards (ROSES) (Haddaway et al., 2018) (see https://doi.org/10.6084/m9.figshare.26253143 for the ROSES checklist).

The screening process will be conducted and be predominantly performed by the primary reviewer. At each stage, a random 30% subset of articles will be screened by a minimum of two other reviewers. Randolph's free-marginal Kappa coefficient will be calculated to test for consistency (Randolph, 2008). This measures the agreement between reviewers corrected for how often this may be due to chance. Any disagreements between reviewers will be discussed, and the decision to include or exclude the article made together.

The reviewers do not expect to be authors on any of the publications included in the final review. If this does occur, then it will be declared, and detailed reasoning for each decision will be reported.

Table 2.2 Description of each question components using the SPIDER framework and the accompanying inclusion and exclusion criteria for publication screening.

SPIDER framework	Question component	Criteria
Sample	Participants	*Inclusion*: The research has some form of participation with stakeholders as defined "A process where individuals, groups and organisations choose to take an active role in making decisions that affect them" (Reed, 2008). Participation can be at any stage in the scenario construction process, for example, input into scenarios that are then used in modelling, data collection with participants or feedback from participants on scenario outputs. Stakeholders include everyone directly or indirectly affected by the restoration planning or future scenarios discussed, but they must be outside the investigation team.
Phenomenon	Ecological restoration	*Inclusion*: The publication must address any form of ecological restoration as per the definition "Ecological restoration is the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value" (Martin, 2017). Types of restoration may include, but are not limited to landscape, species, ecosystem, ecosystem service, native species, invasive species removal, habitat, water catchment, coastal, marine. Ecological restoration may be addressed through either of the following criteria: 1. The main goal of scenario building is explicitly for ecological restoration. 2. The main goal of the scenario building is not explicitly stated as restoration within the publication however it must be identifiable to coders. For instance, if the study area or associated ecological functions are described as degraded and the scenarios are addressing the future of these components.

		3. Ecological restoration is not the main aim of building scenarios but features as a possibility from at least one scenario. For example, one scenario may be ecological restoration while another may be conversion to an alternative land use.
Design	Future scenarios	*Inclusion*: Publication must build or evaluate as least one 'scenario' per the definition "Plausible representations of possible futures for one or more components of a system, or as alternative policy or management options intended to alter the future state of these components" (Ferrier et al., 2016).
Evaluation	Outcomes	*Inclusion*: The systematic map will display what and how outcomes are explored within eligible study types. All types of outcomes are eligible, but they must be explored in a future scenario.
Research type	Qualitative, quantitative, mixed method	*Inclusion*: Methods used may be qualitative, quantitative or a mixed methods approach.

2.2.3 Data coding and extraction strategy

Studies that have met the eligibility criteria at full-text screening will undergo data coding and extraction. Each publication will be assessed using a codebook to capture the relevant data. The data extraction template consists of pre-defined fixed answers and open questions (https://doi.org/10.6084/m9.figshare.26253266.v1). A minimum of one other reviewer will code a random 20% of articles. Any differences will be discussed and adjusted according to what is agreed between the reviewers. If critical information is missing or unclear, the lead author of the study will be contacted and asked to provide the information. The extracted data records will be made available as additional files upon publishing.

The data to be extracted will be grouped into the following categories and subcategories based on the themes of the research questions:

1. Data coding of study characteristics
    a. Bibliographic information
    b. Study context
    c. Restoration context
2. Scenarios
    a. Methods
    b. Outcomes
    c. Trade-offs in outcomes
    d. Analysis and dissemination
3. Participation information
    a. Participant selection
    b. Participant engagement in the process

For each outcome explicitly addressed, we will classify the outcomes explored in each study into whether they are social, ecological, or economic. The indicators used for each outcome will be listed and ecological outcomes and indicators will be further categorised into compositional, structural, or functional restoration attributes (Gatica-Saavedra et al., 2017; Wortley et al., 2013). Compositional indicators refer to the identity and variety of elements of the system such a species richness and diversity (Noss, 1990), while structural indicators measure the physical organisation of the systems like tree height and diameter (Franklin, 1981). Functional indicators identify ecological processes, these often relate to soils such as chemical composition or bioindicator assemblages (Gatica-Saavedra et al., 2017; Franklin, 1981). We will extract the reasoning given for choosing each outcome, and how it was analysed (qualitatively or quantitatively and methods).

Each study will be documented as to whether analysis of trade-offs in outcomes is explicit or implicit and whether they are explored across space, time, and stakeholders. Each outcome will also be classified as to whether it is analysed as a trade-off and if it is, whether the individual outcome was always positive, always negative, or dependent on the scenario. We will also extract the method stage that trade-offs are analysed and how this occurs in the publication.

To understand participation, we will first look at how participants were chosen, how many were included, and which stakeholders were involved. Stakeholders will be categorised, e.g. Academics, NGO, government, and we will record if participants are involved in development of scenario objectives, design of methods, scenario creation, analysis of outcomes and trade-offs and dissemination of results. For each participatory stage, we will record the method of participation used.

2.2.4 Study mapping and presentation

To identify characteristics of the evidence base and explore patterns in the data, the publication years, temporal and spatial scale of the scenarios, and restoration type will be visualised alongside a narrative synthesis. A geographic map will display the location of studies. A narrative synthesis will be used to summarise the methods being used and describe trends between methodologies and study characteristics. This will be accompanied by a visual representation in the form of a decision tree to display the different passages from method planning to outputs.

Patterns will be reported in which categories of outcomes are analysed and trends within each group to identify underrepresented outcomes. The reasons for choosing outcomes will be narratively synthesised alongside how they were analysed within the scenarios. We will also report on trends of which outcomes were usually reported to have a positive trade-off and which a negative, and if trade-offs are explored across different scales. A spider diagram based on frequency of studies will show the different types of trade-offs being analysed and identify knowledge gaps and clusters.

We will use narrative synthesis to describe how participants are chosen and how many are included. Stakeholder categories will be visualised using a graph. A visualisation using a heat map to display a gradient of higher to lower participation in the different stages of the scenario process will be created based on frequency of studies to highlight underrepresented stages.

Results will be presented as a publication and in machine-readable and human-readable format to ensure a searchable list of both included studies and the extracted meta-data. Machine-readable formatting will follow the guidelines of (Haddaway, Gray, et al., 2021) to ensure design allows for translation, has appropriate naming conversions and is clear to use. This way, searches can be done against criteria such as geographic location or restoration type.

2.3 Declarations

2.3.1 Ethics approval

Due to the inclusion of manuscripts reporting studies involving human participants, ethics approval was obtained through Newcastle University for this research.

2.3.2 Consent for publication

Not applicable

2.3.3 Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

2.3.4 Competing interests

The authors declare no competing interests.

2.3.5 Funding

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2.3.6 Authors' contributions

EM, YAT and MP conceptualised the idea. EM wrote the manuscript and prepared the additional materials, including design of the search strategy and data extraction file. EM, YAT and MP reviewed and piloted eligibility criteria and the data extraction file. MG provided valuable advice and feedback on the protocol design for appropriate evidence synthesis methods. PH contributed to the conceptualisation and writing around participatory research.

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2.5 Supplementary materials

2.5.1 Search strategy development

2.5.1.1 Test list of benchmark articles

Bibliographic information of benchmark articles:

1. Bizikova, L. and Krcmar, E., 2015. Integrated scenario planning and multi-criteria decision analysis framework with application to forest planning. *Open Journal of Forestry*, *5*(02), p.139.
2. Bremer, L., Mandle, L., Trauernicht, C., Pascua, P., McMillen, H., Burnett, K., Wada, C., Kurashima, N., Quazi, S., Giambelluca, T. and Chock, P., 2018. Bringing multiple values to the table: assessing future land-use and climate change in North Kona, Hawaiʻi. *Ecology and Society*, *23*(1).

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7. Sisk, T.D., Prather, J.W., Hampton, H.M., Aumack, E.N., Xu, Y. and Dickson, B.G., 2006. Participatory landscape analysis to guide restoration of ponderosa pine ecosystems in the American Southwest. *Landscape and Urban Planning*, *78*(4), pp.300-310.
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Table S2.1 Scope of the test set extracted from the title, abstract and key words against the SPIDER research question design framework. NA refers to components that were not indicated.

Article	Sample - Participants	Phenomenon – Ecological Restoration	Design – Scenarios	Evaluation - outcomes	Research type- qualitative, quantitative, mixed methods
1	Industry, business associations, local and regional governments, and non-governmental organizations.	Forest Restoration	(1) Current conditions (2) Diversification of the forest sector	Economic benefits Total harvest volume Harvest flows over time	Mixed methods.
2	NA	Tropical dry ecosystem.	(1) Agroforestry (2) Pasture (3) Coffee (4) Native forest restoration	Cultural services. Regulating services. Biodiversity. Revenue.	Mixed methods.
3	Conservation managers.	Forest and native species restoration.	(1) Current conditions (2) Historical	Ecological	Quantitative

			(3) Hybrid	Hydraulic Cultural	
4	Local residents and resource users.	Coastal restoration	Assessed restoration solutions.	Ecological Hydraulic	Quantitative
5	Stakeholder and expert input	Native grassland restoration	NA	Biodiversity	NA
6	Stakeholders and experts	Native reforestation	NA	Ecosystem health Smallholder income	Quantitative
7	NA	Forest restoration	Effects of management decisions.	Fire threat Wildlife habitat	Quantitative
8	Stakeholders and experts	National level restoration feasibility.	11 scenarios	NA	Quantitative

Table S2.2 Overall scope of the test list articles.

Participants:	**Experts**	**General stakeholders**	**Private sector**	**Government**	**Non-governmental organisations**	**Local residents**	**NA**
	4	3	1	1	1	1	2
Ecological Restoration:	Forest restoration	Grassland restoration	Dryland ecosystem	Coastal	Mixed restoration type		
Number of papers from test list:	4	1	1	1	1		
Number of scenarios created:	1	2	3	4	11	NA	
Number of papers from test list:	2	1	1	1	1	2	
Number of outcomes examined:	1	2	3	NA			
Number of papers from test list:	1	3	3	1			
Research type:	Qualitative	Quantitative	Mixed methods	NA			
Number of papers from test list:	0	5	2	1			

2.5.1.2 Pilot screening of the test list against inclusion and exclusion criteria

Table S2.3 *Reasoning for inclusion of the test list in title and abstract screening pilot.*

Title and abstract screening				
Reference	**Sample: Participants**	**Phenomenon: Ecological Restoration**	**Design: Future Scenarios**	**Evaluation: outcomes**
Bizikova et al., 2015	Yes: *"structured stakeholder groups' interactions"*	Yes: *"case study of forest restoration"*	Yes: *"modelled scenarios"*	Yes: *"economic benefits, harvest volumes and flows"*
Bremer et al., 2018	Yes: *"native forest restoration"*	Yes: *"participatory deliberative methods"*	Yes: *"land-use scenarios"*	Yes: *"cultural, biodiversity, and ecosystem service value"*
Burnett et al., 2019	Yes: *"hybrid restoration"*	Yes: *"scenarios designed by conservation managers"*	Yes:	Yes: *"ecological, hydraulic and cultural"*
Hemmerling et al., 2019	Yes: *"restoration planning"*	Yes: *"participatory modelling"*	Yes: *"modelling scenarios"*	Yes: *"applicability of solutions"*
Mitchell et al., 2016	Unsure: → move to full text screening	Yes: *"stakeholder and expert input"*	Yes: *"scenario narratives"*	Yes: *"biodiversity"*
Rodorff et al., 2018	Yes: *"native forest restoration"*	Yes: *"collaboration with stakeholders and experts"*	Yes: *"modelled scenarios"*	Yes: *"conservation of resources and income"*
Sisk et al., 2006	Yes: *"restoration of ponderosa pine"*	Yes: *"participatory landscape analysis"*	Yes: *"management scenarios"*	Yes: *"fire threat and wildlife habitat"*
Tobón et al., 2017	Yes: *"restoration planning"*	Yes: *"engaged stakeholders and experts"*	Yes: *"11 scenarios"*	Yes: *"priority sites"*

Table S2.4 Reasoning for inclusion of the test list in full text screening pilot.

Full text screening				
Reference	**Sample: Participants**	**Phenomenon: Ecological Restoration**	**Design: Future Scenarios**	**Evaluation: outcomes**
Bizikova et al., 2015	30 stakeholders included in the process from community, business and government agencies.	Restoration of forests infested with mountain pine beetle.	Uses qualitative scenario planning and then quantified them using multi-criteria decision analysis.	Outcomes focus on socioeconomic and environmental goals e.g. Employment, sales, annual harvest of timber.
Bremer et al., 2018	Scenarios defined through discussions with owners of the land and local community.	Native forest restoration and agroforestry are regarded as restoration scenarios in the paper.	4 scenarios: current use, native forest restoration, agroforestry, coffee	Net revenue streams for land manager, indigenous cultural and community values, groundwater recharge, fire risk reduction and native biodiversity,
Burnett et al., 2019	Designed research questions with conservation managers, and they described restoration scenarios.	Restoration of an area of a nature preserve comprising of non-native species.	3 scenarios designed.	Ecological, hydraulic and cultural.
Hemmerling et al., 2019	Technical and local knowledge experts	Costal restoration	2 participatory scenario models of restoration management.	Land loss, storm surges, salinity intrusion, freshwater intrusion.

Mitchell et al., 2016	Expert input from 27 experts from government, science and rural organisations and land holders.	*Note: although not explicitly clear in the paper*. The goal is to conserve and restore endangered native grassland.	4 scenarios	Biodiversity outcomes.
Rodorff et al., 2018	Experts provided input into modelling. Model used for quantitative scenarios were built from stakeholders input in a workshop.	Describes the areas as degraded: "free grazing is accountable for the absence of *S. tuberosa* seedlings on degraded Caatinga sites"	Scenarios used for the modelling adoption potential to restore *S tuberosa* in the stud area.	Ecosystem health, agricultural income
Sisk et al., 2006	Targeted experts and stakeholders to guide development and gain data. Did workshops to prioritise restoration areas, management options to then use in scenarios.	Ponderosa pine restoration, particularly due to increasing wildfire risk.	4 management scenarios created.	Tree stem density, fire hazard, biodiversity density and habitat.
Tobón et al., 2017	Workshop with 19 experts to design indicators and criteria for scenarios and modelling. Second discussion was used to evaluate scenarios and choose a priority one.	Describes almost half of Mexico as in a degraded state and objective is for priority restoration areas.	11 scenarios.	Biological importance and restoration feasibility.

2.5.1.3 Keyword development for the search string

Table S2.5 Keywords present in the title, abstract and keywords of the test set that were relevant to the four main components of the research question.

Article	Scenario	Ecological	Restoration	Participatory
1	Scenario Scenario planning Futures	Species Forest	Forest Restoration	Stakeholders Experts
2	Scenarios	Forest Ecosystem Ecological	Forest Restoration	Participatory
3	Future Scenarios	Environmental Ecosystem	Restoring Restoration Reforestation	Collaborative
4	Scenarios	Ecological Nature-based	Restoration planning Restoration	Participatory modelling Engagement Stakeholders
5	Scenario Scenario planning Biodiversity futures	Ecology	Restoration	Collaborative Stakeholders
6	Future Scenarios	Ecosystem Environmental	Reforestation	Collaboration
7	Scenarios	Ecosystem	Restoration Restore	Participatory Collaboration Stakeholder Collaborative
8	Scenarios	Ecological Ecosystem Biological Environmental	Restoration Restoration	Participatory process Engaged

Table S2.6 Key question components and accompanying synonyms taken from the test list, consultation with restoration experts, a librarian, and a thesaurus.

Scenario	**Ecological**	**Restoration**	**Participatory**
Forecasting	Environment	Reforestation	Collaborative
Backcasting	Ecosystem	Afforestation	Co-production
Future		Revegetation	Collective
Trajectory		Regeneration	Engagement
		Afforestation	Stakeholder
		Remediation	
		Rehabilitation	
		Rewilding	
		Conservation translocation	

2.5.1.4 Final search string by database

Web of science: All databases

Command line:

(((TS=(restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND TS=(participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND TS=(ecolog* OR environment* OR ecosystem*) AND TS=(Scenario* OR forecast* OR backcast* OR futur* OR trajector*))))

1864-present.

Databases include

- Web of Science Core Collection (1970 – present)
- KCI - Korean Journal Database (1980 – present)
- MEDLINE (1950 – present)
- Russian Science citation index (2005 – present)
- SciELO Citation Index (2002 – present)
- Zoological record (1964 – 2007)

SCOPUS

Command line:

TITLE-ABS-KEY((restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND (participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND (ecolog* OR environment* OR ecosystem*) AND (Scenario* OR forecast* OR backcast* OR futur* OR trajector*))

CAB abstracts

Command line:

ti(((restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND (participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND (ecolog* OR environment* OR ecosystem*) AND (Scenario* OR forecast* OR backcast* OR futur* OR trajector*)))

OR

ab(((restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND (participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND (ecolog* OR environment* OR ecosystem*) AND (Scenario* OR forecast* OR backcast* OR futur* OR trajector*)))

Note: keyword search is not available on CAB abstracts

ProQuest: Natural and social science collections

Natural Science collection 1946 – present

Social science premium collection 1914 – present

Command line:

ti(((restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND (participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND (ecolog* OR environment* OR ecosystem*) AND (Scenario* OR forecast* OR backcast* OR futur* OR trajector*)))

OR

ab(((restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND (participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND (ecolog* OR environment* OR ecosystem*) AND (Scenario* OR forecast* OR backcast* OR futur* OR trajector*)))

OR

if(((restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*") AND (participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*) AND (ecolog* OR environment* OR ecosystem*) AND (Scenario* OR forecast* OR backcast* OR futur* OR trajector*)))

Page options (peer reviewed)

- Peer-reviewed option selected
- All languages selected

Page options (grey literature)

- Peer-reviewed option not selected
- All languages selected
- Document types:
    - Book chapter
    - Case study
    - Working Papers
    - Dissertations and Theses
    - Reports
    - Government and Official publications

Lens.org

Scholarly works search.

Command line:

Title: (restor* OR (reveg* OR (regener* OR (reforest* OR (afforest* OR (remediat* OR (rewild* OR (re-wild* OR ("conservation translocat*" OR rehabilitat*)))))))) AND ((participat* OR (collabor* OR (co-product* OR (collectiv* OR (stakehold* OR engag*))

))) AND ((ecolog* OR (environment* OR ecosystem*)) AND (Scenario* OR (forecast* OR (backcast* OR (futur* OR trajector*))))))

OR

Abstract: (restor* OR (reveg* OR (regener* OR (reforest* OR (afforest* OR (remediat* OR (rewild* OR (re-wild* OR ("conservation translocat*" OR rehabilitat*))))))) AND ((participat* OR (collabor* OR (co-product* OR (collectiv* OR (stakehold* OR engag*))))) AND ((ecolog* OR (environment* OR ecosystem*)) AND (Scenario* OR (forecast* OR (backcast* OR (futur* OR trajector*))))))

Google scholar

Command line:

(scenario) AND (participatory OR collaborative) AND (restoration OR regeneration OR reforestation) AND (ecological OR ecosystem)

Sort by relevance (first 500 results will be collected and screened)

3-Existing evidence on the use of participatory scenarios in ecological restoration: a systematic map

Linking statement: Having created the systematic map protocol in *Chapter 2*, this chapter provides the results of the systematic map. It describes and justifies any deviation from the protocol in *Chapter 2*, presenting an updated methodology and the results.

This chapter titled "Existing evidence on the use of participatory scenarios in ecological restoration: a systematic map" was published in the peer reviewed journal Environmental Evidence on 30th November 2023. The final submitted manuscript has been incldued in here. If any supplementary material has been uploaded to Figshare, the DOIs has been included at the appropriate place in the text.

Contribution statement: I led conducting the systematic map after the protocol (*Chapter 2*) was published. This included bringing on team members for article screening. I wrote the manuscript and subsequent drafts and prepared the additional materials, including design of the search strategy and data extraction file. Dr Matt Grainger provided valuable advice and feedback on evidence synthesis methods. Dr Marion Pfeifer provided supervision and was involved in all stages from conceptualisation. During the peer review process, I responded to all reviewer comments and reviews. All co-authors provided feedback on manuscript drafts.

3.1 Abstract

The scale of land degradation worldwide has led to nearly one billion hectares committed to restoration globally. However, achieving such restoration targets will necessitate complex trade-offs against limited time, competing knowledge, costs, resources and varying stakeholder and societal preferences. Participatory scenarios allow a way to identify collaborative solutions for restoration planning and implementation best suited for the local cultures and societies they are tied to. They can be used to navigate uncertainties surrounding future trajectories of restored areas by evaluating trade-offs in outcomes. This research aims to systematically map the evidence on the use of participatory scenarios in restoration planning. We use the following research question: What evidence exists on the use of participatory scenarios in ecological restoration? This is answered by examining the characteristics of the evidence base, types of study design, types of outcomes, trade-offs in outcomes, and the role of participants.

A comprehensive and reproducible search strategy was followed using bibliographic databases, web-based searches, and targeted searching. Search results underwent a two-step screening process according to eligibility criteria. Metadata on key areas of interest were extracted from included texts and were narratively synthesised alongside data visualisations to answer the research questions.

18,612 records were initially identified, and 106 articles were included in the final map. Most studies were conducted in Europe and North America, focusing on restoring agricultural land or forests. Most texts used mixed methods and explored multiple outcome types, but environmental outcomes were the most assessed. Within environmental outcomes, indicators for ecological function were assessed more frequently than structural or compositional indicators. The most common reason for choosing outcomes and indicators was stakeholder interest. Trade-offs in social, ecological, and economic outcomes were mainly examined across space using mapping techniques, while far fewer studies looked at trade-offs across stakeholders and time. Participants were mostly included in the scenario creation step and were usually chosen purposefully by the research team.

It is difficult to understand how useful scenarios are for restoration planning because few texts reported how scenarios fed into the process. Despite this, the range of outcomes used, and different method types adopted suggests participatory scenarios allow for integration of different knowledge and approaches, alongside facilitating the use of qualitative or semi-quantitative data when this is more appropriate or quantitative data is not widely available.

To better use participatory scenarios as a tool for ecological restoration planning, decision-makers can push for greater levels and definitions of participation from the offset of restoration projects with specified, regular, and structured communication and participation channels. We also recommend more systematic methods of participant selection, such as stakeholder analysis. Further research is needed to understand the effectiveness of participatory scenarios in restoration planning and whether the participation of stakeholders was successful in meeting objectives. To improve the evidence base, future studies should clearly evaluate their effectiveness in the restoration planning process and their success in meeting their participatory objectives.

Keywords: Evidence synthesis, stakeholder engagement, collaboration, alternative futures, socioecological systems, co-production

3.2 Background

20-40% of global land area is estimated to be degraded (FAO, 2021), adversely affecting 3.2 billion people, approximately 40% of the world's population (United Nations Environment Programme, 2021). The scale and urgency of this issue has led the United Nations to declare 2021-2030 the Decade on Ecosystem Restoration, and nearly one billion hectares are committed to restoring degraded ecosystems globally (Sewell et al., 2020). Ecological restoration, "the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value" (Martin, 2017), aims to reverse the negative impacts of degradation. However, achieving ambitious restoration targets will necessitate complex trade-offs between costs, benefits, and resources, and seeking consensus between varying stakeholder and societal preferences can be difficult, all against the pressures of limited time. Against this background, there is growing evidence of the value of incorporating traditional or local ecological knowledge in restoration projects through participatory means (Aronson et al., 2020; Martinez, 2003). This is built on the understanding that a holistic and equitable approach to strategic restoration planning that embraces inherent complexities and includes and respects different forms of knowledge and value frameworks to achieve multiple outcomes is needed (Aronson et al., 2020; Löfqvist et al., 2023).

3.2.1 Participatory scenarios

It is now considered that active stakeholder engagement should underpin long-term restoration success (Swart et al., 2018; McDonald et al., 2016), and there is evidence that the probability of positive outcomes for biodiversity and livelihoods increases with the extent to which participants can shape decisions (Persha et al., 2011; Newig et al., 2023). Stakeholder participation is "a process where individuals, groups and organisations choose to take a role in making decisions that affect them" (Reed, 2008). In this light, scenarios, defined as "representations or storylines of possible futures" (Ferrier et al., 2016), provide a pathway for stakeholder participation in restoration planning. Participatory scenarios are a tool to identify collaborative solutions best suited for the local cultures and societies they are tied to (McDonald et al., 2016; Palacios-Agundez et al., 2015) while integrating different epistemologies (Bremer et al., 2018), accommodating diversity in stakeholders (Do et al., 2021) and giving them a sense of ownership (Kok & van Delden, 2009). Decision-makers can use them as a holistic approach to explore future uncertainties in restoration outcomes (Hemmerling et al., 2020), the impact of interventions on restoration outcomes (Slaughter et al., 2004), prioritise resources, and reduce costs (Bremer et al., 2018; Metzger et al., 2017). For instance, Palacios-Agundez et al. (2015) worked with stakeholders to downscale global scenarios to local ones. Participants suggested management actions towards achieving their desired scenario framed within their local culture and context. They reported learning to see and understand different perspectives and collaborated on proposing feasible management responses (Palacios-Agundez et al., 2015). Despite reports of success in participatory methods, there is also evidence of them failing to meet their objectives (Lane & Corbett, 2005; Gerrits & Edelenbos, 2004), potentially undermining motivations for using participatory methods. Guidance for implementing participatory scenarios in restoration planning has been developed to help avoid failings (Metzger et al., 2017; Oteros-Rozas et al., 2015). Metzger et al. (2017) consulted an international group of scientists and practitioners to conclude that stakeholders should participate in the whole process, from method planning to creating and reviewing scenarios. This way, stakeholders can decide upon and evaluate restoration scenario objectives, outcomes and possible trade-offs (Sisk et al., 2006).

3.2.2 Outcomes and trade-offs in restoration planning

Restoration objectives are often posited to achieve ecological success alongside improved social and economic outcomes, such as enhanced livelihoods and climate change mitigation (UN-REDD Programme, 2020; Gourevitch et al., 2016). Scenarios and stakeholder engagement are suggested as key tools to analyse potential trade-offs and co-benefits in these various restoration objectives and outcomes across space, time and stakeholders (Metzger et al., 2017; Daw et al., 2015; Brown, 2004). Their propensity for integrating diverse data collection and analysis (Bremer et al., 2018; Huxham et al., 2015) alongside facilitating participatory discussion allows for more social and economic dimensions to be captured in a discipline that has traditionally focussed on evaluating environmental components alone (Wortley et al., 2013; Prach et al., 2019; Martin & Lyons, 2018). In contrast, Bremer et al., (2018) quantified ecological and economic outcomes of scenarios alongside qualitative evaluation of cultural outcomes to understand trade-offs between them. The restoration objectives and scenarios were also developed through discussions with the local community and the landowner, who wanted to incorporate multiple values in their decision-making (Bremer et al., 2018). Moreover, previous research has noted that ecological indicators appeared to focus on attributes that are more easily measured, i.e., the structure or composition of ecological communities or ecosystems, at the expense of evaluating ecosystem function (Prach et al., 2019).

In creating and analysing scenarios, team's and participating stakeholders can evaluate the inherent trade-offs that will exist and reduce uncertainty around future outcomes of interventions (Peterson et al., 2003), which can be particularly useful for creating a shared understanding across groups that often have diverse knowledge systems and expectations (Etienne et al., 2003; Hagger et al., 2017). Regardless of the approach, trade-offs tend to feature heavily in participant discussions, even when not explicitly addressed (Oteros-Rozas et al., 2015). One example of such trade-offs has been described by Etienne et al. (2003), who documented that when restoring native grassland, sheep farmers' primary objective was to maintain sheep production while conservationists were concerned with the preservation of native biodiversity, objectives that do not always align (Etienne et al., 2003). Even if objectives are agreed upon, the interventions suggested to achieve them can vastly differ between stakeholders (as in Sisk et al. (2006)). Scenarios help navigate these complexities by assessing outcomes and trade-offs in different restoration objectives or management interventions.

Despite calls and guidance for participatory scenarios in restoration planning (Ferrier et al., 2016; Metzger et al., 2017), Acosta et al. (2018) found that only 11% of texts were participatory. Further, there is no systematic understanding of the restoration contexts, involved stakeholder groups, methods used for developing participatory scenarios and application of participatory scenarios in exploring diverse sets of objectives, outcomes, and trade-offs. To address this, we map the evidence on the use of participatory scenarios in restoration planning. We examine how research outcomes are explored, how participants are involved, and the trade-offs considered. We inform how participatory scenarios are currently used within ecological restoration planning by systematically collating and mapping the distribution and abundance of evidence on this topic.

3.2.3 Role of stakeholders

This systematic map is led by a team at Newcastle University. The authors specialise in ecological restoration, using tools from ecological and social sciences across different geographies. The aims were formulated by the initial review team and then sent to five external experts who gave feedback on the topic, knowledge gaps and synonyms for the search string. The experts were purposefully chosen from the review team networks for their diverse geographic focuses and topic areas. Six additional members were added to the review team for the randomised screening and data coding; they also could contribute to the final map and manuscript if they wished. Through publishing with Environmental Evidence, we have adhered to the Collaboration for Environmental Evidence (CEE) review standards and taken advantage of the peer review process for both the protocol and final systematic map to gain valuable feedback. We did an open call for submissions through social media and networks when undertaking the review. We also produced a lay summary of results to distribute through networks for results dissemination.

3.2.4 Objective of the review

This review aims to systematically map and present the evidence on the use of participatory scenarios in restoration planning. Due to the mixed methods nature of the literature base, we used the SPIDER framework for question formulation (Cooke et al., 2012) (Table 3.3).

Sample: People participating in scenarios for ecological restoration planning
Phenomenon of interest: Ecological restoration across any ecosystem type
Design: Published literature using future scenarios
Evaluation: Articles that evaluate those scenarios and their outcomes
Research type: qualitative, quantitative, and mixed methods published literature, including peer-reviewed studies, book chapters, reports, grey literature publications and student theses.

The primary research question was: *What evidence exists on the use of participatory scenarios in ecological restoration?*

The secondary research questions are:

1. *What are the characteristics of the current evidence base – location, scale, design, restoration intervention type?*

2. *What types of study designs are used for participatory scenarios in restoration planning?*
3. *What types of outcomes are explored using participatory scenarios?*
4. *How are trade-offs in outcomes explored in participatory scenarios?*
5. *What is the role of participants in the scenario process and outcome determination?*

3.3 Methods

This systematic map followed the CEE guidelines and standards for evidence synthesis in environmental management (Collaboration for Environmental Evidence, 2018) and the Reporting Standards for Systematic Evidence Synthesis (Haddaway et al., 2018) (https://doi.org/10.6084/m9.figshare.26250275), based on published methods (Moore et al., 2022).

3.3.1 Deviations from the protocol

Firstly, we altered this review's primary question and title to "What evidence exists on the use of participatory scenarios in ecological restoration?". This was done to depict the aims and systematic mapping method more accurately and has had no implications for sub-research questions and the mapping methodology as outlined in the protocol (Moore et al., 2022).

Additional inclusion and exclusion criteria were added based on the study format (Table 3.3). Results were excluded if the format did not provide sufficient information for screening, e.g. presentations or conference proceedings, journalism pieces or proposals of work. Books were also excluded because relevant book chapters were found using the search strategy.

There were some deviations during the targeted organisational searches for grey literature due to difficulties with each website's search capabilities and the limited resources of the review team to mitigate them. The search string was edited on the Food and Agriculture Organisation (FAO) library because the initial search of 'scenario' listed 4989 hits. The results could not be exported for screening in Rayyan, and it was beyond the capacity of the review team to review all 4989 within the FAO website. Therefore, we modified the search string to 'scenario participatory restoration' for which all results (896) were screened. On the International Tropical Timber Organisation search, search capabilities were low, showing only the first 100 results of 435; therefore, only the first 100 were screened. The World Agroforestry website yielded 1078 results, but we only screened the first 590 after 250 articles were rejected in a row. Since only five grey literature texts were included in the review of 2040 screened, we are confident these modified searches still allowed us to identify a comprehensive set of texts. We also did not perform the forward and backward citation chasing on all publications that passed full-text screening because this was beyond the capacity of the review team.

There were some minor modifications to the data coding sheet to extract additional details from publications, including columns for the lead author name, institutional address and country, publication type, further detail on scales of scenarios, and describing what was done with scenarios after creation, for instance, whether scenarios were made spatially explicit or if qualitative scenarios were then quantified. A column was added on how the study meets the restoration inclusion criteria. Extra categorisations were added to the data coding sheet to ensure consistency between the open coding of texts and to enable improved identification of trends and knowledge gaps. Economic benefits, aesthetic value and recreational value, were added as categories into 'other aspects of the restoration objective'. River and inland waters, and coastal/mangrove/estuary were added as categories into 'land types being restored'. When categorising how stakeholders were selected, 'chosen purposefully by researchers' was added. We added extra categorisations in the outcomes data coding sheet for the outcomes and indicators, methods of outcome and indicators analysis, and further details. 'Land use land cover' was added as a category when categorising outcomes and indicators; this was also further categorised according to the land types listed in the data coding sheet regarding the focal environment, with the addition of 'species habitat'. The 'level of analysis' for outcomes was removed because most studies had insufficient data to record this consistently.

3.3.2 Search for articles

3.3.2.1 Search terms and strings

Searches were conducted in the bibliographic databases listed in Table 3.1, accessed through a Newcastle University institutional subscription. Search results were first imported into EndNote and then into Rayyan for de-duplication and screening by reviewers. The following Boolean search string forms the basis of searches (for specific search details of each database see Chapter 2 supplementary materials 2.5.1.4):

Scenario: Scenario* OR forecast* OR backcast* OR futur* OR trajector*

AND

Participatory: participat* OR collabor* OR co-product* OR collectiv* OR stakehold* OR engag*

AND

Ecological: ecolog* OR environment* OR ecosystem*

AND

Restoration: restor* OR reveg* OR regener* OR reforest* OR afforest* OR remediat* OR rehabilitat* OR rewild* OR re-wild* OR "conservation translocat*"

The * character is a wild card and will include words containing any characters on the end of the word, so long as the beginning of the word returns a match. For example, participat* may include participation, participatory, participative.

Table 3.1 Bibliographic platforms searched including details of each database, date range and results as of 3rd August 2022, all accessed through Newcastle University institutional subscription.

Bibliographic platform	Database option selected	Date range selected	Results
Web of science (Thomson Reuters, 2021)	All databases: Web of Science Core Collection KCI - Korean Journal Database MEDLINE Russian Science citation index SciELO Citation Index Zoological record	Maximum date range: 1970 – present 1980 – present 1950 – present 2005 – present 2002 – present 1962 - 2007	4060
SCOPUS (Elsevier Science Publishers, 2004)	NA	NA	3691
CAB abstracts (C.A.B. International, 1990)	NA	NA	907
ProQuest (ProQuest, 2010, 2006)	Natural sciences collection Social sciences collection	1946 – present 1914 – present	3656
Lens.org ('The Lens - Free & Open Patent and Scholarly Search', 2021)	Scholarly works		3427

The search string was developed using Web of Science to test combinations of search terms against a benchmark list of eight articles to ensure comprehensiveness (Supplementary materials Chapter 2, section 2.5.1.1). All benchmark articles except one which is not present in the Web of Science bibliographic database were found using the final search strategy. The final search string chosen had a high sensitivity but low specificity (https://doi.org/10.6084/m9.figshare.26253101 for search string building). All date ranges imposed on searches were the maximum allowable per database (Table 3.1). All searches were done in English with no language limitations, so results with bibliographic data translated into English before indexing would be found. However, searching in English only is a limitation of the searches, alongside targeted searching in the grey literature being biased towards international English-speaking organisations due to the knowledge base of the review team. All bibliographic and the web-based search strings have been uploaded to searchRxiv ('searchRxiv', 2023).

3.3.2.2 Web-based search

The web-based search was through Google Scholar, where the first 500 results were screened for a modified search string: "scenario" AND "participatory" OR "collaborative" AND "restoration" OR "regeneration" OR "reforestation" AND "ecological" OR "ecosystem". This is due to the limited search capabilities of the internet search engine.

3.3.2.3 Specialist search for grey literature

Searches for grey literature were done across 17 organisational websites within the ecological restoration field (Table 3.2). Due to limited searching capabilities, only the term' scenario' was searched for, and all results were screened. The exception was the FAO website where the search string was modified to 'scenario participatory restoration' and all results screened. For the International Tropical Timber Organisation, only the first 100 results were screened due to poor search capabilities, and only the first 590 results on World Agroforestry due to 250 publications being rejected in a row.

3.3.2.4 Targeted literature searching and other searches

The bibliographies of four relevant evidence syntheses or publications were screened for relevant literature (Acosta et al., 2018; Oteros-Rozas et al., 2015; Metzger et al., 2017; Quintero-Uribe et al., 2022) (n=255). For the systematic review of Quintero-Uribe (2022), the included articles and citing articles were also screened (n=71). We contacted the lead author of the Acosta et al., (2018) review for their list of included articles in their systematic map but received no response.

Table 3.2 Organisational websites used for specialist search of grey literature including the link, search details and results as of 3rd August 2022.

Organisation	Link as of 03/08/2022	Search details	Results
International Union for Conservation of Nature (IUCN)	https://portals.iucn.org/library/	Publications	14
Food and Agriculture Organisation (FAO)	https://www.fao.org/publications/search/en/		896
Society for Ecological Restoration (SER)	https://www.ser-rrc.org/resource-database/	Keyword search	64
Global landscapes Forum (GLF)	https://www.globallandscapesforum.org/#		16
Landscapes for People, Food and Nature	http://peoplefoodandnature.org/	Publications only.	5
World Resources Institute	https://www.wri.org/resources	Research	95
Stockholm Resilience Centre	https://www.stockholmresilience.org/	Publications	137
UN-REDD	https://www.un-redd.org/document-library		0
WWF	https://wwf.panda.org/discover/knowledge_hub/		13
Tropenbos International	https://www.tropenbos.org/resources/publications		21
Ecoagriculture Partners	https://ecoagriculture.org/resources/publications/		7
International Tropical Timber Organisation	https://www.itto.int/		100 screened of 435
World Agroforestry (ICRAF)	https://www.worldagroforestry.org/publications-all	Documents and publications	590 screened of 1078
Center for International Forestry Research (CIFOR)	https://www.cifor.org/knowledge/publications/		6
Consultative Group on International Agricultural Research (CGIAR)	https://www.cgiar.org/research/publications/		60
European Forest Institute	https://efi.int/		10
Rainforest Alliance	https://www.rainforest-alliance.org/resource/latest/		6

Social media channels and email lists were used to request submissions of relevant literature (scientific and grey). Targeted calls were placed within the International Union for Conservation of Nature, Science for Nature and People network and the Global Landscapes Forum. All submitted publications (n=5) were screened for eligibility.

3.3.3 Article screening and study eligibility criteria

3.3.3.1 Screening

Articles had a two-stage screening process: title and abstract and then full text. Title and abstract screening were conducted using Rayyan (Ouzzani et al., 2016) according to the eligibility criteria in Table 3. Some grey literature had no abstract and so underwent title screening only. Any articles a reviewer was unsure of were put through to full-text screening.

At both screening stages, the primary reviewer screened all articles, while three other reviewers each screened a random 30% subset. The Kappa coefficient was calculated to test for reviewer consistency at both stages (Dotmatics, 2024; Landis & Koch, 1977). Generally, agreement tended to be considered fair (kappa >0.21) at title and abstract screening and substantial (kappa >0.61) at full text (Landis & Koch, 1977) (See supplementary material 3.9, table 3.1 for full results). Any reviewer disagreements were discussed, and the decision to include or exclude the article was made together. Generally, disagreements tended to be due to a lack of clarity in the text, particularly at the title and abstract stage. The reviewers were not authors of any of the articles retrieved. The core review team screened articles in a non-English language using translated bibliographic information at title and abstract stage. At full-text stage they were screened by a reviewer fluent in that language. This required three extra reviewers to join the team to review French, Spanish, Korean and German texts.

3.3.3.2 Eligibility criteria

Each publication was screened according to the eligibility criteria presented in Table 3.3 to determine inclusion or exclusion. The eligibility criteria are expressly related to each component of the research question based on the SPIDER framework (Cooke et al., 2012). All publications must also be available in an online format.

3.3.4 Data coding strategy

All studies that met the eligibility criteria at full-text screening underwent data coding and extraction according to the codebook (see https://doi.org/10.6084/m9.figshare.26250368 for codebook). The codebook contains a mix of pre-defined multiple-choice answers alongside open questions and was pilot tested by three reviewers on the benchmark list of articles. One other reviewer coded a random 20% of articles. Due to the largely qualitative and open questions in the data codebook, we did not quantitatively test for consistency between reviewers, but instead, we held regular meetings and any differences were discussed, agreed upon by the reviewers and then adjusted. If critical information was missing or unclear, we were to contact the study's lead author (Moore et al., 2022); however, this was not deemed necessary for any texts.

The data extraction was based on the themes of the research questions and has the following groupings:

1. Data coding of study characteristics: bibliographic information, study context, restoration context.
2. Scenarios: objectives and methods, outcomes, trade-offs.
3. Participation: participant selection, participatory process.

Table 3.3 Description of each question component using the SPIDER framework (Cooke et al., 2012) and the accompanying inclusion and exclusion criteria for publication screening.

SPIDER framework	**Question component**	**Criteria**
Sample	Participants	*Inclusion*: The research has some form of participation with stakeholders as defined "A process where individuals, groups and organisations choose to take an active role in making decisions that affect them" (12). Participation can be at any stage in the scenario construction process, for example, input into scenarios that are then used in modelling, data collection with participants or feedback from participants on scenario outputs. Stakeholders include everyone directly or indirectly affected by the restoration planning or future scenarios discussed, but they must be outside the investigation team.
Phenomenon of interest	Ecological restoration	*Inclusion*: The publication must address any form of ecological restoration as per the definition "Ecological restoration is the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value" (4). Types of restoration may include, but are not limited to landscape, species, ecosystem, ecosystem service, native species, invasive species removal, habitat, water catchment, coastal, marine. Ecological restoration may be addressed through either of the following criteria: 4. The main goal of scenario building is explicitly for ecological restoration. 5. The main goal of the scenario building is not explicitly stated as restoration within the publication however it must be identifiable to coders. For instance, if the study area or associated ecological functions are described as degraded and the scenarios are addressing the future of these components.

		6. Ecological restoration is not the main aim of building scenarios but features as a possibility from at least one scenario. For example, one scenario may be ecological restoration while another may be conversion to an alternative land use.
Design	Future scenarios	*Inclusion*: Publication must build or evaluate as least one 'scenario' per the definition "Plausible representations of possible futures for one or more components of a system, or as alternative policy or management options intended to alter the future state of these components" (9).
Evaluation	Outcomes	*Inclusion*: The systematic map will be displaying what and how outcomes are explored within eligible study types. All types of outcomes are eligible, but they must be explored in a future scenario.
Research type/Study design	Qualitative, quantitative, mixed method	*Inclusion*: Methods used may be qualitative, quantitative or a mixed methods approach.
Additional criteria	Format of the result	*Exclusion*: Results will be excluded if the format 1. does not provide sufficient information, i.e. there are no associated publication with result, faulty links, presentations, conference proceedings 2. is journalism, i.e. news and magazine articles, 3. is a proposal, i.e. manuals and grant proposals. 4. is that of a book because book chapters will be found in the search strategy Inclusion: Book chapters, reports, grey literature publications, scientific publications, student theses (BSc, MSc, PhD)

3.3.5 Data mapping method

The systematic map database with all included articles, bibliographic information and extracted data is presented in a Microsoft Excel Workbook and csv files (see https://doi.org/10.6084/m9.figshare.26250368 for the Excel Workbook). This can be used to find any studies with respect to the evidence of interest e.g. studies conducted in a particular country or focussing on a particular environment type. This database is readily updatable with new studies and includes explanations on how the literature is organised and coded (https://doi.org/10.6084/m9.figshare.26250368).

Narrative synthesis alongside bar charts, histograms, a choropleth map, and heat map were used to map the data according to the five secondary research questions and identify knowledge gaps and clusters. All visualisations were made in R v4.2.1 (R Core Team, 2022), using the tidyverse package collection and ggplot, ggVenndiagram, and maps packages (Wickham et al., 2019; Wickham, 2016; Gao et al., 2021; Deckmyn, 2022). Based on these results, recommendations are made for future research and for restoration practitioners.

3.4 Review findings

Searches were conducted in August 2022. 18,612 records were identified through bibliographic databases (n = 15,741) and other sources (n = 2,871) (Figure 3.1). After de-duplication, 11,703 unique publications underwent title and abstract screening. 270 articles passed to the full-text screening stage; however, eight records were unretrievable, so 262 were screened: 253 English, two French, three German, one Mandarin, one Korean and two Spanish. 153 texts were excluded at full-stage screening due to not creating future scenarios (n = 62), not being participatory (n=54), not studying ecological restoration (n = 16) or not examining outcomes of scenarios (n=6). 106 publications passed full-text screening to be included in the systematic map. Four of these used multiple case studies in which we extracted data for each case study (n=111). A full list of texts at the full-text screening stage, the reason for exclusion, and in which database they were found are available at https://doi.org/10.6084/m9.figshare.26250506, including articles that were not found or not accessible.

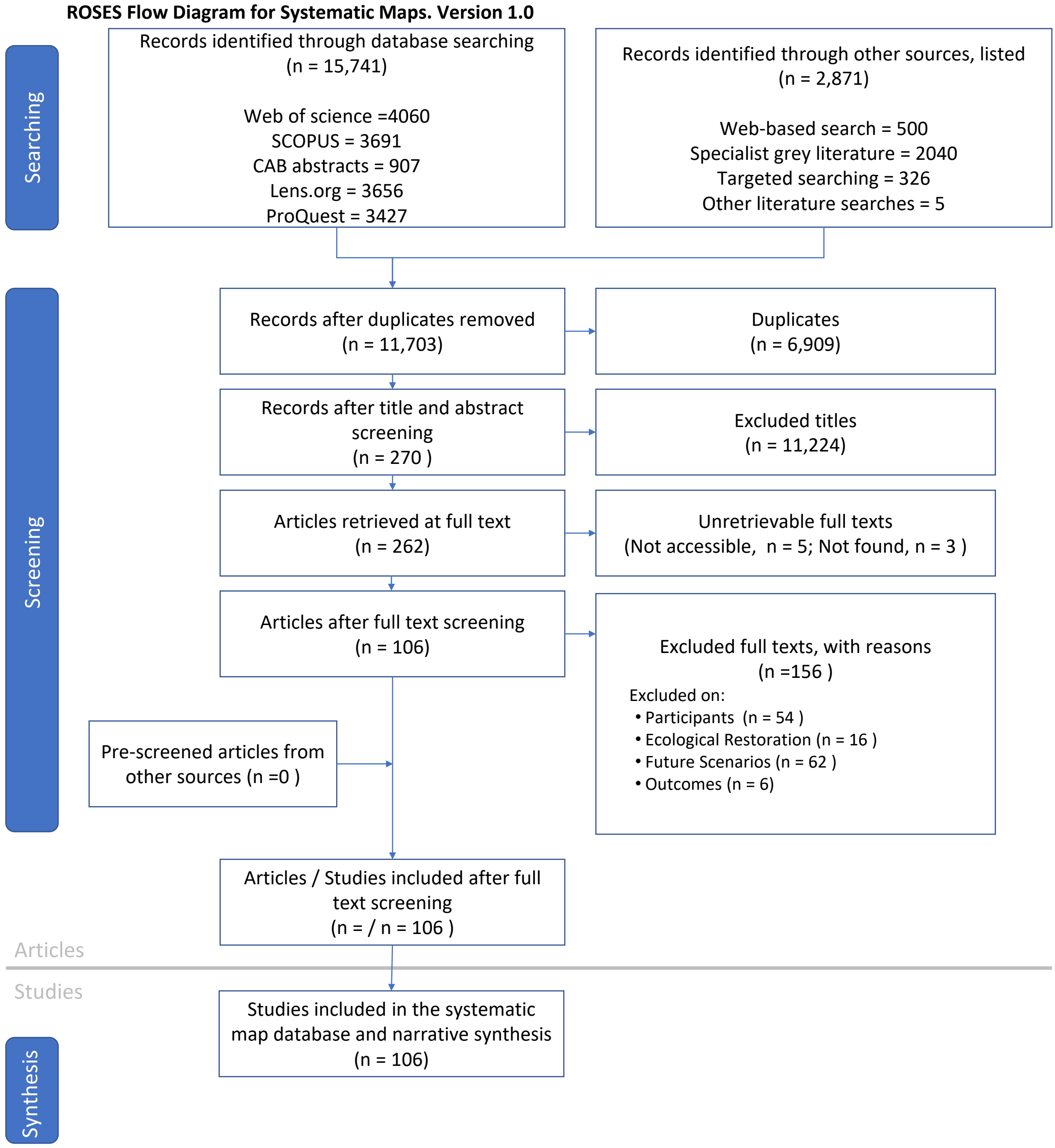

Figure 3.1 Roses flow chart showing the number of texts at each stage of the review process (Haddaway et al., 2017).

3.4.1 Characteristics of the evidence base

3.4.1.1 Publication type and year

86% of texts were scientific journal articles (n=91), and 6% were reports. There were three PhD theses, one MSc thesis, three book chapters, and a conference paper. 96 studies had an academic author listed (91%), and 40 studies (38%) listed authors from multiple professions. The earliest text included was published in 2003, with the most studies published in 2018 and 2020 (n=14) (Figure 3.2). 2022 may have a smaller number of studies because the search took place in August of that year and therefore excludes articles published after this time.

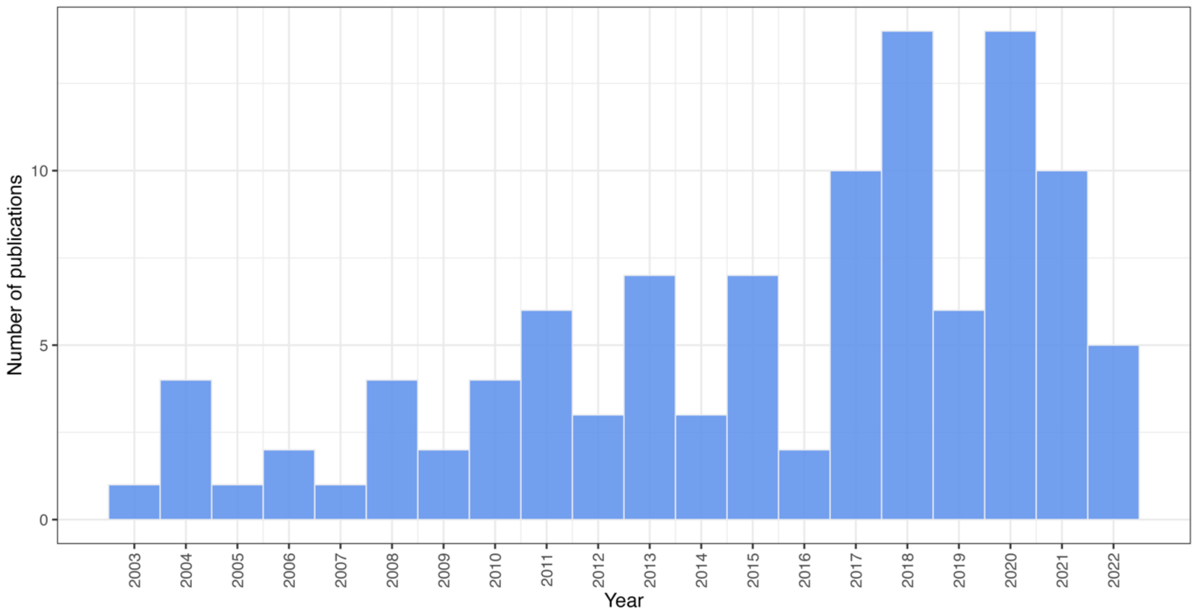

Figure 3.2 Number of included studies in the systematic map by year of publication.

3.4.1.2 Study geography and environment

Most studies were conducted in Europe (n=37, 32%), followed by North America (n=27, 23%), Africa (n=20, 17%) and Asia (n=19, 16%). Publications spanned 43 countries, with the most studies conducted in the United States of America (21/116, 20%), followed by France (n=9/116, 8%) and Spain (n=8/116, 7%) (Figure 3.3). The primary focal environment in most studies were mixed farms and natural vegetation (n=37, 33%), followed by forest (n=28, 25%), and coastal and estuarine-related systems e.g. mangroves and sandbanks (n=15, 14%).

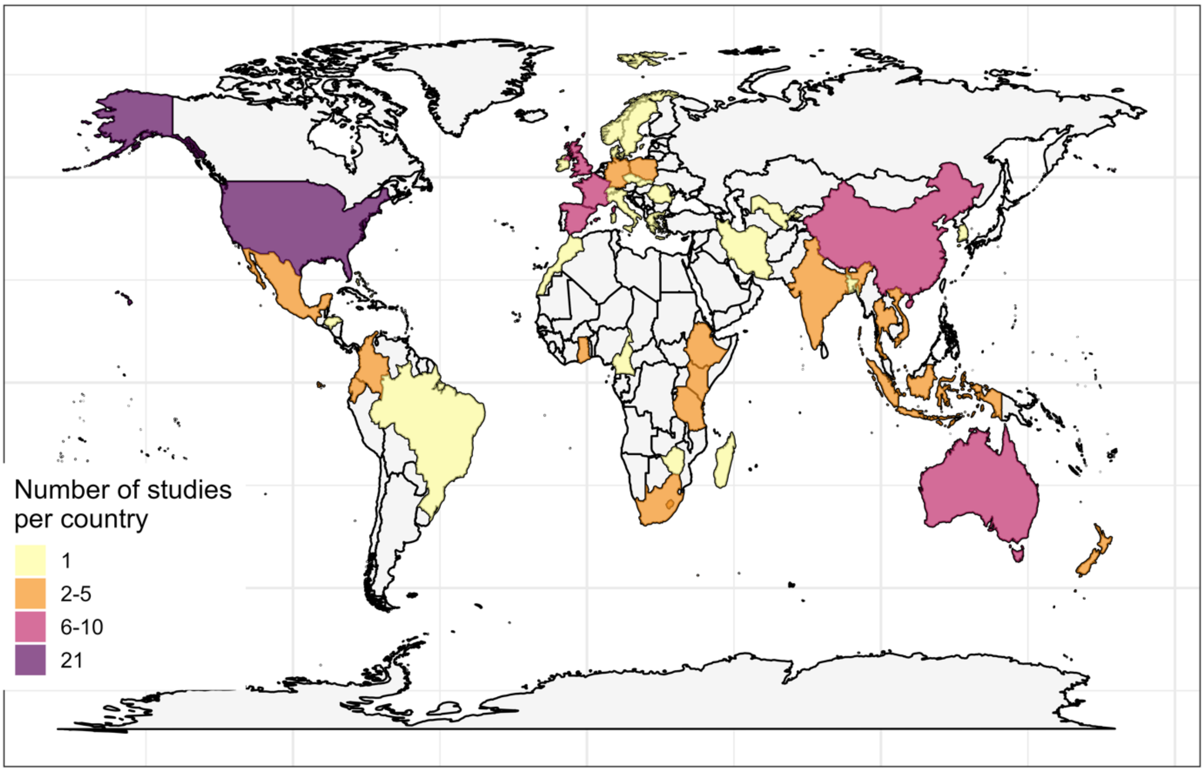

Figure 3.3 A choropleth map showing the global distribution of studies. Studies spanned 43 countries.

3.4.1.3 Restoration context and scale of scenarios

For 48% (n=51) of studies, ecological restoration was the primary goal of developing participatory scenarios, whereas in 31% (n=33), restoration featured but was not the overarching objective of developing scenarios. The remaining studies (21%, n=18) met the inclusion criteria based on a clear description that the study area was 'degraded', and as such, future scenarios were developed to address the possible alternative states of these degraded components. The dominant driver of degradation was land conversion (n=55, 23%), followed by urbanisation (n=33, 14%) and demographics (n=26, 11%). In the 'other' category, the focus was mainly on the overexploitation of resources and chemical pollution of land and waterways. This relates to land types of focus; most restoration was focused on agricultural land (n=48) and forests (n=48) (Figure 3.4).

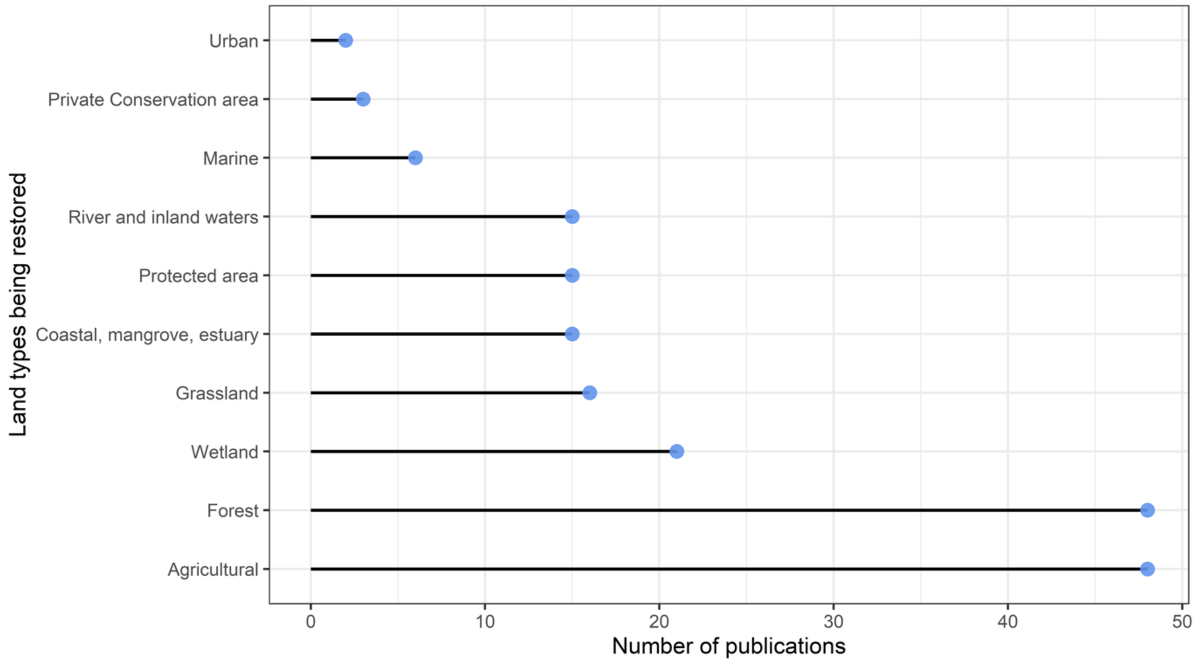

Figure 3.4 The frequency of land types being restored, some publications examined more than one land type.

The mean number of restoration objectives listed per text was 3.6, and there is a disparity between the number of ecological objectives (n=182, 59%) and the number of non-ecological objectives (n = 129, 41%). Habitat restoration was the most popular ecological restoration objective (n=70, 39%), followed by ecosystem services (n=61, 34%). Only five studies stated invasive species removal as an objective and only one study on limiting disease spread. For non-ecological restoration objectives, economic benefits (n=19, 15%), livelihood resilience (n=17, 16%), climate change adaptation and mitigation were the most popular (n=16, 12%).

Most scenarios were exploratory (exploration of possible futures based on driver trajectories) (n=52) or policy-screening (forecasting the effects of policy or management interventions) (n=49) and used a forecasting approach (n=104) (Ferrier et al., 2016). The spatial scale used for scenarios was usually administrative boundaries (n=38, 34%), such as regions or districts, or natural features, such as watersheds or floodplains (n=39, 35%). Only 58% (n=61) of texts specified a scenario timeframe, of which 20 years was the most popular (n=11, 18%). Future timeframes ranged from 5 to 96 years, and 4 texts created scenarios over multiple timeframes. The most reported reason for choosing a timeframe was to align with the industry of interest, e.g. Johansson et al., (2022) chose a 10-year timeframe that aligned scenarios to agricultural planning and action on the farm level.

53 texts were identified as part of a wider restoration project, but only 28% (n=30) of texts described how the created scenarios fed back into the project. Usually, scenarios and results contributed to developing a restoration management plan (n=19, 63%), they were disseminated to decision-makers (n=4, 13%), or the feasibility of proposed interventions from scenarios was discussed by decision-makers (n=3, 10%).

3.4.2 Study designs used in participatory scenarios for restoration planning

Generally, publications were varied in their methods and took a mixed-methods approach (n=65, 61%). Many built on or combined scenarios with established scientific methods or frameworks such as multi-criteria analysis (n=10), InVEST ecosystem services valuation models (n=11), framework for participatory assessment (n=4), agent-based modelling (n=3), Bayesian belief networks (n=4) and fuzzy cognitive mapping (n=3). This demonstrates the flexibility through which scenarios can be used alongside other methodologies to suit team skills and study contexts.

When creating scenarios, 43 studies did this qualitatively, and 35 did this quantitatively, with the remainder using semi-quantitative methods (e.g. multi-criteria analysis, n=16), or a mix (n=3). Most qualitative studies employed workshops to create scenarios with participants (n=36, 84%) and 17 studies (40%) used maps as a methodological aid. 14 qualitative scenarios were made spatially explicit during creation, while 26 were made spatially explicit post-creation (Figure 3.5). 33 (78%) publications quantified the qualitative scenarios or specific outcomes after creation. Of the quantitative scenarios, 27 were also spatially explicit during creation (77%). Besides modelling techniques, a few also used workshops (n=11) and group discussions (n=8) to engage participants when creating scenarios.

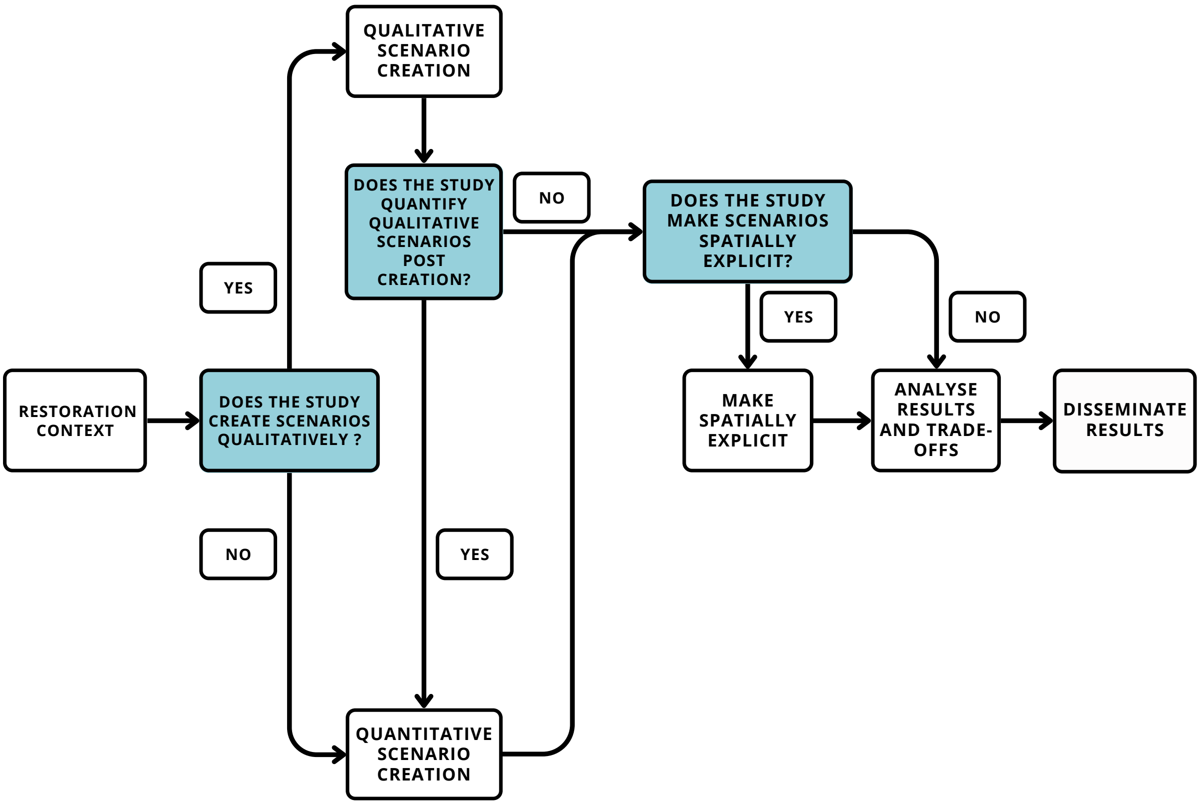

Figure 3.5 A flow chart depicting popular methodology routes used for scenario creation in restoration planning.

3.4.3 Outcomes and trade-offs explored using participatory scenarios

The mean number of outcomes explored was 7, and the median was 5, the lowest number of outcomes studied was 1, while the highest was 59, and many texts had multiple indicators for a single outcome. 88% (n=98) of texts studied environmental outcomes, followed by economic outcomes (61%, n=68), land use land cover (53%, n=59) and social outcomes (37%, n=41) (Figure 3.6A). 78% of studies (n=86) examined more than one outcome category, demonstrating that scenario planning is useful for integrating outcomes across different dimensions. The most popular described reason for choosing social, ecological, and environmental outcomes and indicators was that they were chosen by or resulted from stakeholder interactions. Whereas for land use land cover, this was to understand better future land use land cover patterns.

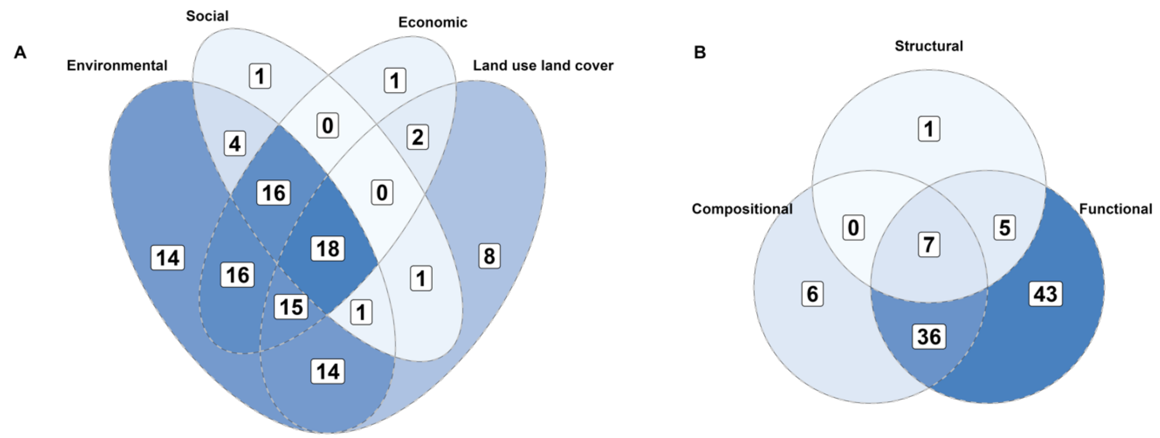

Figure 3.6 A) The outcome categories and the combinations of categories explored across publications B) The categorisations for environmental outcomes and indicators and the combinations explored across publications.

Social outcomes tended to be semi-quantitatively or qualitatively examined, and only 11% of social outcomes were quantified compared to 47% of environmental and economic outcomes. Of the 555 environmental indicators, functional indicators were the most studied (n=385, 69%), followed by compositional (n=141, 26%) and structural (n=28, 5%) (Figure 3.6B). Under half of the functional (n=166, 43%) and compositional (n=58, 41%) indicators examined were quantified. Conversely, structural indicators tended to be quantified (n=19, 67%).

Within environmental indicator sub-categories, biodiversity was the most evaluated (n=127, 23%), followed by indicators for ecosystem health (n=60, 11%), and water quality (n=57, 10%) (Figure 3.7). Economic indicators were usually linked to the production of goods such as food and timber (n=84, 45%), and the costs of scenario interventions (n=36, 19%). The land use and land cover indicators predominantly focussed on mixed environments of farms and natural vegetation (n=73, 23%) and forests (n=71, 22%), reflecting the land use types most commonly being restored. Social indicators primarily related to recreation (n=35, 20%), culture (n=29, 16%), and governance (n=24, 14%).

52 studies explicitly addressed trade-offs between outcomes in the text; however, coders identified a further 47 that addressed them implicitly. Only 9 texts did not address trade-

offs in any way. Trade-offs were mainly addressed after scenario construction (n=79, 75%) and usually within the text (n=86), using a visual depiction (n=34), workshops (n=23) or mathematical modelling (n=13). 51 publications addressed spatial variation in trade-offs, generally through spatially explicit mapping. 23 texts addressed trade-offs between stakeholders, generally through qualitative discussion, while only 9 publications addressed trade-offs across time by comparing different time steps. 31 adopted a participatory approach when analysing trade-offs, usually through workshop discussion.

Figure 3.7 The frequency of indicator sub-categories that were explored across included texts.

3.4.4 Role of participants in the scenario process and outcome determination

The median number of participants was 27, while the minimum was 4 and the maximum was 570. Of those who gave details, most participants were chosen purposefully by the publication team (n=20). Other common methods of selection include stakeholder analysis, snowball sampling and through a local partner. Members of the local community and conservation groups/non-governmental organisations, co-management groups were the most included stakeholder groups (n=53) (Figure 3.8). Natural Resource Management Agencies, local government and academics were also highly represented. Of the 15 categories for stakeholder groups in the data coding, the mean number of groups was 3.4, and the median was 3. Power was not considered in relation to stakeholder group representation.

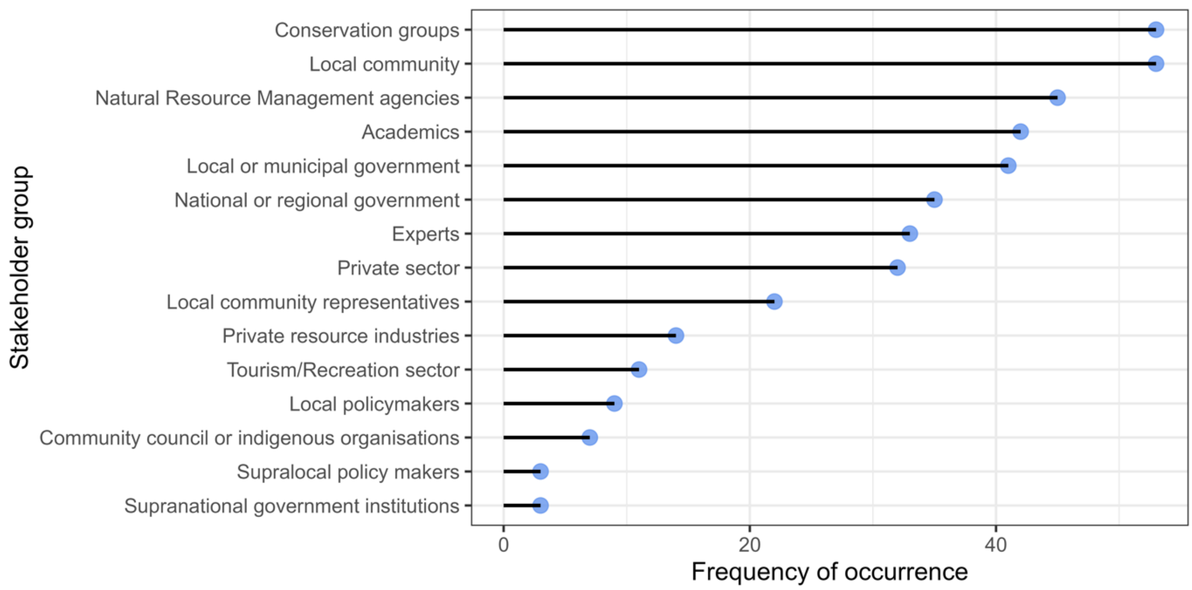

Figure 3.8 The frequency of different categorised stakeholder groups represented in participatory scenarios across the included texts.

We categorised six stages of the scenario process through which stakeholders participated: develop scenario objectives, design methodology, create scenarios, analyse scenarios, analyse trade-offs, and disseminate results. Creating scenarios was the most common stage of participation (n=83), followed by contributing to the analysis of results (n=57) and developing objectives (n=48) (Figure 3.9). Very few studies took a participatory approach to results dissemination (n=8). Only 17 studies specified the duration of stakeholder collaboration and participation, of which 13 explicitly stated collaboration was over years. The only 2 studies that used participatory methods for all stages of the scenario process had multi-year collaborations. The length of collaboration is not indicative of participation, some multi-year studies only had one participatory stage. The average number of stages stakeholders participated in was 2. 18 studies had 4 or more stages of participation in the scenario process; these studies tended to have specified, regular, and structured communication and participation channels such as through workshops, meetings, steering groups or working sessions.

Participants were often included in developing scenario objectives and scenario creation through meetings and workshops. Participation in methodological design usually took the form of co-constructing a conceptual or mathematical model and deciding on model formation, inputs, and indicators. For the quantitative scenarios, sometimes participants assisted in parameterising the model (n=10) or ran the model themselves (n=4). Participatory scenario analysis and review of trade-offs were often through workshops or follow-up meetings where the study team presented created scenarios to be evaluated and analysed by participants before being revised. The few studies that used participatory methods to disseminate results used workshops to disseminate to other community members, partook in producing media outputs, or influenced dissemination methods.

There was a plethora of reasons for publications using a participatory approach in scenario design, such as to integrate different knowledge types, facilitate a common understanding, accommodate diversity in stakeholders and perceptions, enhance collaboration and a sense of ownership, ensure local relevancy, and increase the likelihood of study acceptance and success.

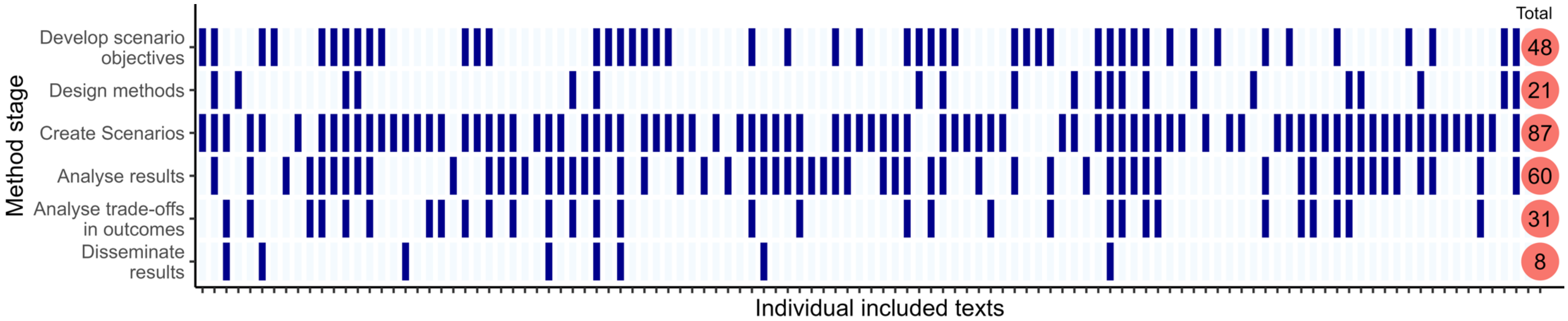

Figure 3.9 The stages of which stakeholders participated in the scenario process. Blue tiles indicate stakeholder participation, the total number of texts that used participatory methods for each stage is shown in the red circle.

3.4.5 Limitations of the map

A limitation of the map was that searches were conducted in English, and only translated bibliographic information would appear in the results. This will have biased article distribution towards English-speaking countries or organisations that publish in English. The high number of articles from French and Spanish-speaking countries indicates that including these languages may have increased the range of the map, but this would still lead to the same bias against countries speaking other languages and was beyond the capacity of the review team. To try and counter these biases, we chose the search strings or terms with high sensitivity but low specificity to capture a broader range of articles. Additionally, eight articles were not accessible, or we could not find the full text, and due to the limited capacity of the review team, we had to review and consequently forgo our original strategy of performing forward and backward citation chasing.

Despite pilot testing the coding strategy beforehand, we had to modify the coding sheet to include further details or categorisations. Adding further categorisations allowed consistency between open answers for grouping and comparisons of studies. During data coding, the categorisation of outcomes and indicators into social, ecological, and environmental indicators was sometimes difficult due to the simplicity of the categorisation. For example, the indicator' tuna occurrence' used by Langhans & Schallenberg (2021) was categorised as an economic indicator because it was under the outcome 'Satisfactory harvest of mahinga kai' (Māori, resources that are customarily used/harvested), and therefore linked more to the productive harvestable economic value of tuna (Langhans & Schallenberg, 2021). However, this indicator overlapped with the environmental category because it relates to a species population and the social category, recognising the cultural significance of mahinga kai for Māori people. For these, the reviewers discussed and decided on the best fit, but we recognise that there is a level of value judgment in this. We strived to have a balance between categorising variables to identify trends and knowledge gaps while maintaining the integrity of the data.

3.5 Conclusions

This systematic map explored the use of participatory scenarios in restoration planning, focussing on how outcomes are evaluated and the role of participants. The section below relays the implication of our results for policy/management and research.

3.5.1 Implications for policy/management

It is difficult to understand how useful scenarios are for restoration planning because few texts reported how scenarios fed into the process. Of those that did, it was common that they supported management plans or were being used by decision-makers. Despite this, our systematic map has shown the flexibility of using participatory scenarios for restoration planning; evidence was distributed across 43 countries and many different types of environments. Study authors were often from different disciplinary and professional backgrounds, which was evident in the wide range of approaches taken, with most studies using mixed methodologies. Regardless of greater attention to environmental outcomes, they were usually explored across multiple categories (social, environmental, economic, and land use land cover). These were typically included due to the interest of the multiple stakeholder groups involved. This highlights that participants value various restoration outcomes such as water quality, sustainable production, recreation, and cultural values. We found a wide range of outcomes used and method types adopted in the different studies. We suggest that this evidences that participatory scenarios allow for integrating different knowledge and method types, alongside facilitating qualitative or semi-quantitative data when this is more appropriate or quantitative data is not widely available. For instance, Arias-Hidalgo et al. (Arias-Hidalgo et al., 2013) quantified water quality and quantity indicators alongside conducting a semi-quantitative multi-criteria analysis with experts for outcome indicators where quantitative information was unavailable, such as touristic potential and biodiversity. This flexibility is advantageous to ensure scenarios are adaptable to stakeholder needs, resources available and the objectives and outcomes being explored.

92% of texts addressed trade-offs in outcomes, supporting that scenarios are suitable for evaluating trade-offs across different methods such as workshops, mapping, or mathematical modelling. Spatial variation in trade-offs was addressed by 52% of texts that examined trade-offs; this was fewer than the review team expected given the spatial nature of ecological restoration interventions but may be reflective of the high number of exploratory scenarios created.

Regardless of guidance to include participants in all stages of the scenario process for restoration planning (Metzger et al., 2017), only 2 texts did this, and very few studies took a participatory approach to method design and results dissemination. Moreover, only 31% of the texts analysed trade-offs in a participatory manner. To better use participatory scenarios as a tool for ecological restoration planning, decision-makers should push for greater participation from the outset of restoration projects, particularly in the stages before and after scenario creation, as recommended elsewhere (Metzger et al., 2017). Despite a wide range of methods, texts that included participants in more stages of the scenario process tended to have specified, regular and structured communication and participation channels. There was a high representation of stakeholder groups interested in ecological restoration, such as conservation groups and natural resource management agencies. Communication intensity and participants' environmental stance have recently been shown to improve environmental governance outcomes (Newig et al., 2023). Participants were most often chosen purposefully by the study team and despite advantages such as the ability to select the most beneficial participants, this method can also be vulnerable to researcher bias and an inability to generalise (Berndt, 2020). Systematic methods such as stakeholder analysis are recommended in the literature to ensure the whole range of perspectives and interests are represented (Metzger et al., 2017; Reed et al., 2013).

3.5.2 Implications for research

Now that there is a systematic map of how participatory scenarios are being used, further research is needed to understand the effectiveness of participatory scenarios in restoration planning. Due to the wide range of the publication base and lack of this information within publications, this would need to be done by conducting primary research into the included studies in this review with study teams and the restoration decision-makers.

This is also the case in understanding whether stakeholders' participation succeeded in meeting the objectives for undertaking a participatory approach. Newig et al. (2023) found that the extent to which participants can shape decisions was the strongest predictor of positive outcomes for environmental governance. Stakeholders on average, only participated in 2 stages of the participatory scenario process across studies. Further analysis of included texts using their framework may better indicate how participatory studies are, and how likely they are, to achieve positive outcomes for restoration planning. To improve the evidence base, future participatory scenarios research should evaluate their effectiveness in the uptake of scenarios in the restoration planning process and their success in meeting their participatory objectives.

3.6 Declarations

3.6.1 Ethics approval

Due to the inclusion of manuscripts reporting studies involving human participants, ethics approval was obtained through Newcastle University Research Policy Intelligence and Ethics Team for this research.

3.6.2 Consent for publication

Not applicable

3.6.3 Availability of data and materials

All data generated or analysed during this study are included in this published article [and its supplementary information files].

3.6.4 Competing interests

The authors declare no competing interests.

3.6.5 Funding

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3.6.6 Authors' contributions

EM conducted the searches, screened all articles and both stages, extracted the data and wrote the manuscript. RP, SP, YSF screened 30% of articles at both stages. YSF, MP, NA, YJ, screened and extracted data from non-English articles. NS extracted a random 20% of the data. MG contributed to methods and data formatting. All authors read and approved the final manuscript.

3.6.7 Acknowledgements

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3.8 Supplementary material

3.8.1 Kappa coefficient for consistency between reviewers

Table S3.1 The kappa coefficient calculated between reviewers at each stage of the screening process ('Quantify interrater agreement with kappa', n.d.)

	Reviewer 1 initial	**Reviewer 2 initial**	**Kappa**
Title and abstract screening	EM	BP	0.50
	EM	SP	0.36
	EM	YSF	0.29
Full text screening	EM	BP	0.64
	EM	SP	0.64
	EM	YSF	0.83

4-Understanding farmers' attitudes and scenarios towards tree-cover restoration in the Kilombero Valley, Tanzania

Linking statement: Chapter 3's systematic map highlighted that participatory scenarios are effective for integrating diverse knowledge and approaches, as well as for facilitating qualitative and semi-quantitative methods in data analysis. This review also recommended that future studies should document how scenarios are utilized in restoration planning and evaluate the effectiveness of the participatory process in achieving its objectives. Building on these insights, this chapter presents participatory scenario workshops conducted in the Kilombero Valley, Tanzania, applying the recommended practices where feasible. To address the research objectives, a blend of methods was used, including participatory art within workshops and both qualitative and quantitative analyses of participants' ideal scenarios, trade-offs, and perceptions of tree-cover restoration. Additionally, participant feedback on the participatory approach is discussed in this chapter and the supplementary materials. Below, I report how the scenarios informed restoration planning.

How these scenarios informed restoration planning: I wrote a report for the NGO Reforest Africa who focus on forest restoration in the Kilombero Valley. Therefore, the report focussed on the key results of the workshops relating to trees and tree planting. This report was also disseminated to decision-makers from government and other NGOs who attended regional level workshops, at which we also presented the work. I am not aware whether the report or presentation influenced or was used to aid any decision-making regarding restoration interventions, or whether there have been changes to more inclusive and participatory decision-making processes.

This chapter is currently in review at the peer-reviewed journal Forest Policy and Economics. The submitted manuscript has been included in here.

Contribution statement: I conceptualised this research alongside Dr Pete Howson, Dr Susannah M Sallu, Dr Margherita Lala and Dr Marion Pfeifer. The methodology was designed with Dr Susannah M Sallu, Dr Margherita Lala, Dr Marion Pfeifer, Dr Francis Lyimo and I. I performed the analysis, visualised the results and wrote the original draft manuscript. The workshops were facilitated in Tanzania by Dr Francis Lyimo, Petro P Nyiti and Lilian Mwanga. All co-authors, including Dr Deo D Shirima, Dr Sergio G. Milheiras and Dr Esther Kioki provided feedback on the manuscript. Dr Marion Pfeifer and Dr Pete Howson provided supervision throughout.

4.1 Abstract

Restoring tree cover to meet international commitments requires approaches such as agroforestry, particularly on agricultural lands. Understanding local attitudes towards forests and restoration methods is crucial for developing effective, context-specific strategies that address stakeholder concerns and motivations. This paper investigates farmers' desires and attitudes towards tree-cover restoration using participatory future farm scenarios and sentiment analysis in the Kilombero Valley, Tanzania. We explore the variables influencing smallholders' ideal farm scenarios with a focus on agroforestry configurations, the perceptions associated with farmer attitudes towards agroforestry and adjacent forests, and the effects of gender and wellbeing on attitudes. Our findings reveal positive attitudes towards agroforestry associated with provision of direct benefits. There was a dominance of negative attitudes towards forests, primarily due to concerns about resource access and human-wildlife interactions. Gender was an important factor in shaping scenarios and attitudes towards tree-cover restoration, but we found no effect of wellbeing. Men had more favourable attitudes towards tree planting, seeing agroforestry as a potential income source, while women preferred scattered trees for subsistence use. We highlight the need for a shift to inclusive decision-making in restoration practice that is aligned with local preferences and needs. While the diversity of attitudes highlights the necessity to adopt inclusive and gender-sensitive approaches in tree-cover restoration planning. Our results emphasise the importance of developing tailored strategies with restoration stakeholders that address their specific concerns and motivations, thereby improving the effectiveness and acceptance of restoration interventions.

Keywords: agroforestry, forest restoration, forest landscape restoration, participatory scenarios, sentiment analysis, attitudes

4.2 Introduction

Scaling up tree-cover restoration worldwide has become the focus of international commitments such as the Bonn Challenge, which aims to bring 350 million hectares of degraded and deforested landscapes into ecosystem restoration by 2030 (IUCN, 2021). The United Nations has declared 2021-2030 the Decade for Ecosystem Restoration highlighting the global urgency of this endeavour. A critical component to scaling-up tree restoration efforts to meet these ambitious commitments is tackling deforestation caused by land use change for agriculture (Pendrill et al., 2022), which constitutes 45% of habitable land worldwide (Ritchie and Roser, 2024). In the tropics alone, croplands comprise about half of the area with the greatest potential for low-cost tree-cover restoration, and 210 million people live in or near these areas (Shyamsundar et al., 2022). Here, agroforestry, the deliberate integration of trees into farming systems, offers a viable solution for tree-cover restoration that can connect forest stands in the landscape in a way that can be managed by households and communities (Shyamsundar et al., 2022). This indigenous land practice (Nair et al., 1993) has gained prominence in scientific research, conservation and development domains to improve biodiversity, livelihoods and food security across the continent (Ngango et al., 2024; J. Reed et al., 2017).

Scaling tree planting on farmland often looks to transform global landscapes and food systems (Tedesco et al., 2023). However, for large-scale tree-cover restoration efforts to be effective, restoration goals must align with the interests and preferences of the people responsible for managing these ecosystems (Fleischman et al., 2020), such as landowners who retain their land rights but are expected to plant and nurture the trees. Participatory scenarios have been used to identify collaborative solutions for restoration planning, showcasing stakeholders' preferences for tree restoration in their landscapes (Durrant et al., 2023). They can be used as a basis for stakeholder engagement and participatory decision-making and processes by bringing stakeholders into decision-making when developing restoration plans or evaluating an interventions feasibility (Durrant et al., 2023; Metzger et al., 2017; Reed et al., 2013). By advancing the understanding of various on-the-ground realities, they help develop a more nuanced and context-specific representation of possible landscape futures, informed by local knowledge and prioritising the perspectives of the most vulnerable (Löfqvist et al., 2023).

Research highlights the need to place equity at the centre of tree-planting efforts (Elias et al., 2022; Fleischman et al., 2020; Löfqvist et al., 2023). This involves placing social considerations at the heart of restoration planning to lead to improved social, ecological, and environmental outcomes (Löfqvist et al., 2023). Identifying stakeholders' perceptions and attitudes is crucial, as these factors influence their preferences and willingness to participate in restoration interventions such as agroforestry (Meijer et al., 2015a; Sirivongs and Tsuchiya, 2012). In the context of tree-cover restoration in rural tropical landscapes, smallholder farmers and their attitudes towards trees on farms are particularly relevant. In East Africa, smallholders alone account for 75% of agricultural production (Salami et al., 2010). Their interest in agroforestry may vary with distance to forests and dependency on them (Miller et al., 2017; Muhamad et al., 2014).

Positive attitudes towards agroforestry have been shown to reinforce intentions to integrate and adopt trees into farming systems (Amare and Darr, 2024; Buyinza et al., 2020), and have been associated with positive benefits to livelihoods (Shennan-Farpón et al., 2022). However, there are also negative aspects that stakeholders may associate with trees or forests (Razafindratsima et al., 2021) that may be driven by top-down exclusionary interventions (Howson, 2018). Both negative and positive experiences can coexist within and between stakeholder groups, influencing their attitudes, perceptions, and future desires (Shackleton et al., 2016). Exploring the benefits and trade-offs between these experiences in tree-cover restoration scenarios across actors allows for better anticipation of risks and opportunities from interventions among different contexts, before a single tree is planted (Durrant et al., 2023; Löfqvist et al., 2023). While research has explored how to optimise agroforestry management scenarios to minimise trade-offs in economic outcomes, climate change mitigation and adaptation (Rahman et al., 2016; Tschora and Cherubini, 2020), there is a lack of evidence on how smallholders themselves perceive and desire to manage these trade-offs (German et al., 2006).

Understanding attitudes and perceptions may prevent further marginalisation of vulnerable groups and acknowledge intersectional differences by informing more nuanced and effective restoration strategies (Löfqvist et al., 2023; Tebboth et al., 2020). Recognising how characteristics such as gender influence perceptions and attitudes can ensure inequalities are not exacerbated and enable efforts focussed on improving gender equity and women's participation in agroforestry decision-making across Africa (Kiptot and Franzel, 2011; Razafindratsima et al., 2021). Most research has explored how ecosystems influence human wellbeing, focusing on the role of agroforestry and restoration in shaping wellbeing outcomes (Castle et al., 2022; Shennan-Farpón et al., 2022). However, evidence on the influence of wellbeing on attitudes towards restoration or agroforestry as a land management intervention in agriculture is limited (Verma and Sinha, 2018; Ward et al., 2016). We assert the importance of examining the interplay between gender and human well-being in attitudes towards tree-cover restoration. Such an exploration is crucial for understanding perspectives on farm and landscape futures, particularly in the context of restoring trees and forests. This approach can provide valuable insights for enhancing stakeholder engagement processes, addressing prevalent attitudes, and mitigating the risk of exacerbating existing inequalities in forest-adjacent communities (Löfqvist et al., 2023).

Despite the potential of participatory scenarios to help stakeholders envision agroforestry and tree-cover restoration futures, their application in conjunction with the analysis of stakeholder attitudes remain underexplored (Andreotti et al., 2020; Durrant et al., 2023; Novák et al., 2021). Sentiment analysis is emerging as a valuable tool to characterise people's attitudes towards a particular object or entity, such as agroforestry and forests, as reflected in written text (Liu, 2020). In this study, we employ sentiment analysis to understand attitudes in contexts where large online datasets are not available and demonstrate its utility in complementing participatory engagement efforts.

Using the Kilombero Valley, Morogoro, Tanzania as a case study, we integrate ideal farm scenarios with sentiment analysis to investigate farmers' perceptions, attitudes and aspirations towards tree-cover restoration. Tanzania has pledged to restore 5.2 million ha, 5.87% of its land area to restoration through the Bonn Challenge. The Kilombero Valley is a human-dominated agricultural landscape experiencing rapid changes in tree cover, land use and management (Msofe et al., 2019). The region has experienced deforestation for conversion to agriculture (Msofe et al., 2019), prompting government and conservation organisations to implement tree-cover restoration efforts (Matejcek and Verne, 2021). Specifically, we explore (1) the variables that may influence smallholders' ideal farm scenarios, focussing on agroforestry tree configurations, (2) the perceptions associated with farmer attitudes towards agroforestry and the forests adjacent to farms, (3) the effects of gender and wellbeing on farmer attitudes. Our aim is to demonstrate how conservation organisations can use participatory tools to explore future scenarios whilst also gaining a quantitative understanding of smallholder attitudes. Scaling restoration of trees and tree cover at landscape scale within the Kilombero Valley will require the support of smallholder farmers which will be influenced by their perceptions, desires and attitudes towards trees and forests. Our conceptual framework exploring perceptions, desires and attitudes towards tree-cover restoration, can help build engagement processes to design tree-cover restoration strategies with smallholders that align with their desired outcomes and reduce negative perceptions and attitudes.

4.3 Conceptual framework

The conceptual framework for this study (Figure 4.1) draws upon the literature exploring attitudes towards nature and agroforestry, including that which has used attitudes as a variable in constraining or promoting agroforestry adoption (Amare and Darr, 2024; Ihemezie et al., 2021; Kideghesho et al., 2007; Meijer et al., 2015a, 2015b; Sirivongs and Tsuchiya, 2012). Figure 1 shows a visual representation of our hypothesised relationships between farmer perceptions, attitudes and scenarios of tree-cover restoration. We assert that farmer perceptions of tree-cover restoration will influence their attitudes towards it, which will then also influence their desired tree-cover restoration scenarios. Within this framework, farmer characteristics such as gender and wellbeing have been hypothesised as influential on perceptions, attitudes and desires. Perceptions and attitudes are important intrinsic factors that affect decision-making by smallholders on planting of trees on farms and in the wider landscape (Amare and Darr, 2020; Meijer et al., 2015a). In this context, perceptions are the views farmers hold about tree cover restoration based on their experiences and needs whilst their attitudes are the negative or positive responses towards tree-cover restoration (Kideghesho et al., 2007; Lucungu et al., 2022; Meijer et al., 2015a).

Meijer et al., (2015a) argue that farmers' attitudes about agroforestry are shaped by their knowledge and perceptions. These attitudes are further affected by characteristics and external factors such as gender, wellbeing, geographical setting, political conditions, and the characteristics of the restoration innovation (Meijer et al., 2015a). Here, we draw on these framings to explore farmers' desired agroforestry systems in relation to their perceptions and attitudes. These intrinsic factors have been far less explored than extrinsic ones, particularly socio-economic variables within the agroforestry literature in Sub-Saharan Africa (Meijer et al., 2015a). However, more recent research has begun to address this gap (Amare & Darr, 2020; Lucungu et al., 2022).

To apply this framework, we used participatory workshops, artistic drawings, and a sentiment analysis of the transcript data in a field where most of the work analysing attitudes has been done using household surveys as the main data collection tool (Amare and Darr, 2024; Kideghesho et al., 2007; Lucungu et al., 2022; Meijer et al., 2015b). This approach offered an in-depth approach with a smaller number of participants in which they could guide the discussions and design their ideal scenario whilst allowing analysis of attitudes and perceptions.

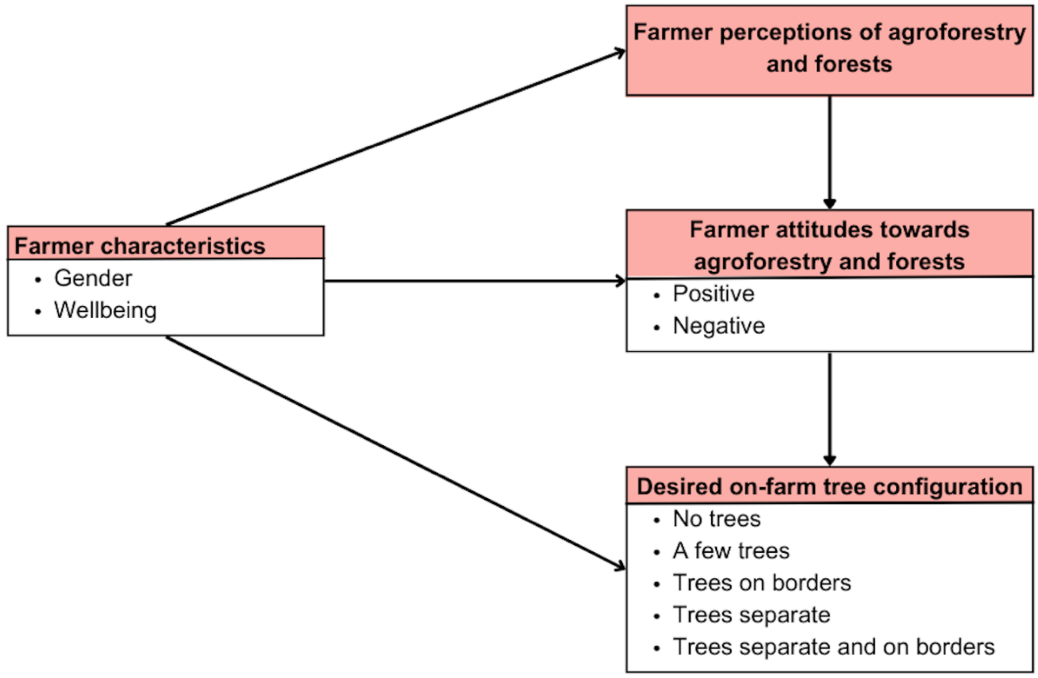

Figure 4.1 Conceptual framework linking farmer perceptions, attitudes and desires for trees on farms and in the wider landscape.

4.5 Methods

4.5.1 Study area

The northern part of the Kilombero Valley, Morogoro region, Tanzania, comprises heavily protected forest and savanna ecosystems, settlements, an industrial sugarcane plantation and smallholder farms (farmer managing less than 10 hectares (FAO, 2024)). Smallholders in the area use a diversity of farming practices including agroecological methods such as mulching, intercropping and post-harvest use of residues (Milheiras et al., 2022) to grow subsistence crops (e.g. maize, pumpkin, okra, cassava) and cash crops (e.g. rice, sugarcane) (Durrant and Pfeifer, 2024). Trees are often interspersed within the smallholder farmed land, at varying densities. Forested areas are generally under some form of conservation protection and cannot be entered or used without permission, such as the Udzungwa Mountains National Park, Julius Nyerere National Park or Magombera Nature Reserve. They border the farmed landscapes on almost all sides (Figure 4.2). The area has a sub-humid tropical climate across two rainy seasons: a long rainy season in March-May and a short rainy season in October-December.

The study area is also part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), a partnership between the government and the private sector for promoting market-driven transformation and modernisation. Many international and local non-governmental organisations (NGOs) are active in the landscape, some of which promote agroforestry and provide trees to smallholders to restore tree cover on smallholder farms and improve livelihoods. Much of the restoration work in the area is planned, led and implemented by NGOs partnering with other NGOs and government bodies to strengthen protected areas, restore and expand forest cover (Matejcek and Verne, 2021). Ongoing and planned interventions include the Kilombero Elephant Corridor (Southern Tanzania Elephant Program, 2024) and riparian forest restoration along rivers (Pfeifer et al., 2022). A key theme is the prevalence of top-down interventions and a lack of participation in decision-making from smallholder farmers and other key local stakeholders such as village leaders (Lala et al., 2023; Matejcek and Verne, 2021).

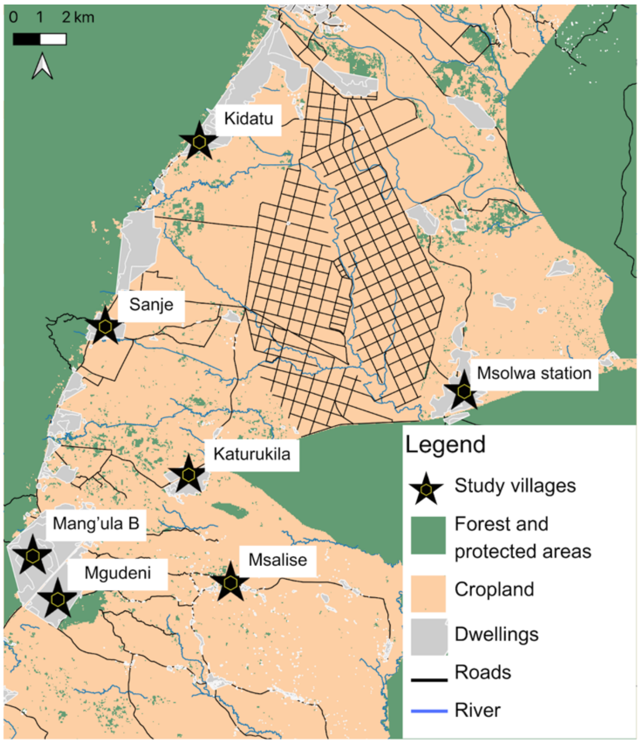

Figure 4.2 Map of the northern Kilombero Valley, Morogoro region, Tanzania including the location of the villages in this study (Source: Author)

4.5.2 Data collection

This work is based on nine participatory scenario workshops with smallholder farmers that were conducted to explore smallholders' aspirations for the future. Their aim was to involve smallholders in the research process, focussing on co-generation of knowledge and understanding of the local farming context, needs and perspectives. A detailed methodology is published in (Lala et al., 2023) and can also be found in the Supplementary materials 4.10.1. The workshops involved 80 smallholder farmers from seven villages: Kidatu, Sanje, Msolwa Station, M'angula B, Mgudeni, Msalise and Katurukila (Figure 4.2) and were conducted between July and August 2022. Workshop participants were randomly selected among 440 people who had previously participated in a household survey (Milheiras et al., 2022) and comprised 38 women and 42 men. Restricting participation to individuals who had previously completed the household survey introduces potential sources of bias, including the influence of prior participation on workshop responses, research fatigue, and the risk of under-representing perspectives from those not included in the original sample. Nevertheless, this approach provided a practical advantage: it enabled the direct linkage of participants' quantitative wellbeing data from the survey with the qualitative insights generated during the workshop, without requiring the recruitment of a new sample or the administration of an additional survey.

The workshops were differentiated by age and wellbeing (mixed=3, high=3 and low=3) which was quantitatively measured in the survey (Loveridge et al., 2020; Milheiras et al., 2022). We adopt the definition developed by the Wellbeing in Developing Countries research group, human wellbeing is 'a state of being with others, which arises where human needs are met, where one can act meaningfully to pursue one's goals and where one can enjoy a satisfactory quality of life.' (Gough and McGregor, 2007). There were two workshops for youth (18-35) (n=20) and seven workshops for adults (35+) (n=60) (Supplementary materials Table S4.1). Each workshop was a full day and took place in Swahili, hosted by a Tanzanian facilitator, two research assistants and two artists. Participants described their current farming system and then they created a scenario of their ideal farming system, looking 5-10 years into the future. They were free to describe as they wished, but they usually included details such as the size, configuration, and the main characteristics such as crops, trees, rivers, and wells. They also described their surrounding landscape, this was defined by the participants themselves and usually referred to the nearby surroundings of the farm. The artists depicted the ideal farm for each participant so that they could visualise, explain and compare their scenario with the broader group. They then explored the barriers and opportunities they face in achieving their ideal farming scenario. At the end of the workshop, participants were guided through booklets to disseminate previous research in the landscape on topics such as birds and trees. They were asked to give feedback on the information they were given and the wider workshop to reflect on the participatory research process (Durrant et al., 2023; Oteros-Rozas et al., 2015). Each workshop was audio recorded and then transcribed into English for analysis.

4.5.3 Data Analysis

Based on the transcript text and the artist's depiction of the ideal farm, we categorised the ideal tree agroforestry configurations by participants (Figure 4.3), defining agroforestry as any form of integration of trees into the smallholder’s farming system. The categories used in this analysis are those described by more than five participants; no trees on the farm, a few scattered trees within fields or on the border, trees lining the borders of crop fields, trees in a separate plot to any crops such as woodlots or a plantation, and trees on a separate plot and on the borders of crop fields (Figure 4.3). We have classified these categories using similar language used by participants in the workshops.

ARTIST DEPICTION	CATEGORY	DESCRIPTION
	**NO TREES**	No trees on the farm
	**A FEW TREES**	A few scattered trees within fields or on the border
	**TREES ON BORDERS**	Trees lining the borders of crop fields
	**TREES SEPARATE**	Trees in a separate plot to any crops such as a small woodlot or plantation
	**TREES SEPARATE AND ON BORDERS**	Trees in a separate plot to crops e.g. a small woodlot or plantation and on the borders of crop fields

Figure 4.3 Ideal agroforestry configuration categories that were described by more than five participants.

To analyse the explicit or implicit expression of attitudes towards agroforestry and forests based on the transcripts, we used four points of classification for our sentiment analysis: the attitude holder, the target object, the claim, and the attitude (Jost et al., 2019; Kim and Hovy, 2004). The attitude holder is the individual workshop participant that can be linked to attributes for analysis such as gender and wellbeing and the target object is "trees" or associated words. We applied sentiment analysis to passages of text that included the target objects of "tree" or "forest" to quantify individual attitudes to tree-cover restoration on and surrounding farms. The key words were chosen based on synonyms of trees and forests alongside contextual knowledge of the study area. For instance, the 45 key words or phrases for forests included phrases such as 'forest reserve', 'Magombera forest', 'Selous game reserve' and 'TANAPA forest'. There were 124 keywords for trees which included both English and Swahili words for trees such as 'coconut tree', 'lemon tree', 'mfuru', 'mkundekunde'. Often Swahili words for trees were left untranslated in the transcripts, particularly if the transcriber was unsure of the English translation. See https://doi.org/10.6084/m9.figshare.26135752 for the full list of keywords used for analysis.

Table 4.1 Description of each classification used for the manual sentiment analysis with example claims from the workshop transcripts from when farmers describe their current and ideal farming scenario.

Classification	**Description**	**Example from the current farm**	**Example from current farm**	**Example from the ideal farm scenario**
Attitude holder	Individual participant	Workshop 1, woman 3	Workshop 1, woman 3	Workshop 1, woman 3
Target object	Trees	Tree	Tree	Tree
Claim	Different topic or context surrounding the target object	'*Benefits are like if the tree is not at the middle of the farm, if it is peripheral, I can benefit from tree fruits, when I work there I can take fruits for eating,*'	'*When the tree is in the middle of the farm, when you plant crops, may not grow, and even if they grow they don't produce, if you expected to harvest 1 back, you just end up to get 2 buckets, that is the effect of tree.*'	'*I don't want more trees, if possible I should decrease the number of trees or I should cut them all down.*'
Attitude	Sentiment or orientation of the claim, i.e. positive (1), negative (-1) or neutral (0)	1	-1	-1

The claim is the different topics or context surrounding the target object, while the attitude is the orientation of this claim, i.e. positive (1), negative (-1), or neutral (0) (Table 4.1). A score was given for each mention of the word tree or associated keywords. Scores for each participant were then added to give a total score for when describing their current farm, when describing their ideal farm and across the entire workshop. This method allowed the integration of quantitative sentiment scoring with qualitative analysis of the perceptions driving expressed sentiment using the claim classification. Qualitative coding was conducted using QSR NVivo 14. The coding identified dominant themes associated with the passages of text discussing trees and associated key words or phrases that were classified in the sentiment analysis such as the example in Table 4.1.

Natural language processing (NLP) or computational linguistics have been employed in the environmental sector to analyse sentiment in large online datasets such as scientific abstracts (Lennox et al., 2020) or social media data (Acerbi et al., 2023). However, sentiment is difficult to assess automatically because of the semantic complexity of language (Murphy, 2014). Training sets in NLP need to be sufficiently large to achieve accurate results (Mozetič et al., 2016) and despite interobserver disagreement in human classification being as high as 20%, this is similar to results achieved through NLP processes (Ogneva, 2010). It was not possible to do the sentiment analysis in Swahili because the data was directly transcribed from recordings into English. To achieve the highest accuracy given a relatively small corpus and the nature of the translated data, we used human classification. Two analysts (ED and PN) did the human classification, and the scores were subsequently compared. PN is Tanzanian, fluent in Swahili and English, was present at the workshops, translated and transcribed the data. The Intraclass correlation coefficient (ICC) (A,1) was calculated to evaluate the agreement between the two independent raters for the total score per participant. The obtained ICC value was 0.99 (CI [0.98, 0.99]), indicating excellent agreement between raters.

All analyses were done using R version 4.2.1 (R Core Team, 2022) and visualisations were created using *ggplot2* (Wickham, 2016). To understand the variables that may influence smallholders' ideal farm scenarios we first evaluated if the current farm sentiment score was statistically different from the ideal farm sentiment score (see Table 4.1 for example) using Wilcoxon signed rank test to compare mean sentiment scores. We then used linear mixed effects models to assess if there was an influence of current farm sentiment score and gender on ideal farm sentiment score to account for the nested structure of observations within workshops (n=80) and used a likelihood ratio test to compare the model to a null model. We used a regression model to explore the influence of wellbeing on ideal farm sentiment score. To assess whether the agroforestry configurations in the ideal farm were influenced by gender, wellbeing and sentiment when discussing the current farm we used Fisher tests. If the Fisher test was significant, we followed this with a multinomial regression to examine the association further. We removed all configuration categories with less than 5 data points (n=73) for this.

To understand the effects of gender and wellbeing on farmer attitudes, we first examined the effects of gender on the participants' total sentiment score through linear mixed-effects models using the *lme4* package (Bates et al., 2015), allowing us to account for the nested structure of observations within workshops (n=80). We then used a likelihood ratio test to compare the model to a null model. To analyse differences in sentiment between those with high and low wellbeing (n=52), we performed a non-parametric Mann-Whitney U test. To assess the interaction between gender and wellbeing in affecting total sentiment score (n=52), we used linear regression, acknowledging that a random effect did not apply because workshops were already split by wellbeing category.

4.6 Results

4.6.1 Ideal farm agroforestry configurations

Participants had more positive attitudes towards trees when discussing their ideal farm scenario than when discussing their current farm (Figure 4.5, Wilcoxon signed-rank test $V=348.5$, $p<0.005$). Through configuration of the farm, they discussed how to maximise benefits such as food production and income diversification and minimise the trade-offs with crops. Most farmers desired trees in their ideal farming system but they have very few in their current farm and reported removing trees more commonly than planting where they owned the land. 16 farmers (20% of all participants) desired no trees in their ideal scenario. Most participants also preferred a larger farm than they currently have, where they could grow crops with just a few trees or have the space to grow trees separately on borders or in small plantations (note: this was usually for timber trees, see 'trees separate' in Figure 3); only two participants wanted to intercrop trees and crops. A few scattered trees or trees on the borders were usually desired for boundary marking or to provide subsistence fruit, firewood and timber, and were associated more with women (Figure 4.4). It was often mentioned that these trees needed to have small canopies to mitigate perceived negative effects on crops. In the ideal farm scenario, only a couple of participants wanted to be close to the forest. Most participants wanted to be surrounded by neighbouring farms for safety from wild animals and pests. Some even specified that they should not be near forested areas, driven by the perceived increase in incidents and severity of crop losses due to wild animals. Only one participant specified they wanted to be neighbouring the forest.

Variation in ideal farm sentiment score was not explained by current farm sentiment score (likelihood ratio test of linear mixed model chi sq.=0.47, $p>0.05$), gender (likelihood ratio test of linear mixed model chi sq.=3.77, $p>0.05$) or wellbeing (linear regression $R^2=0.04$, $F=2.1$, $p>0.05$). Moreover, the current farm sentiment score did not explain the likelihood of ideal tree configuration categories (likelihood ratio test of multinomial model chi sq. = 3.7, $p=0.45$).

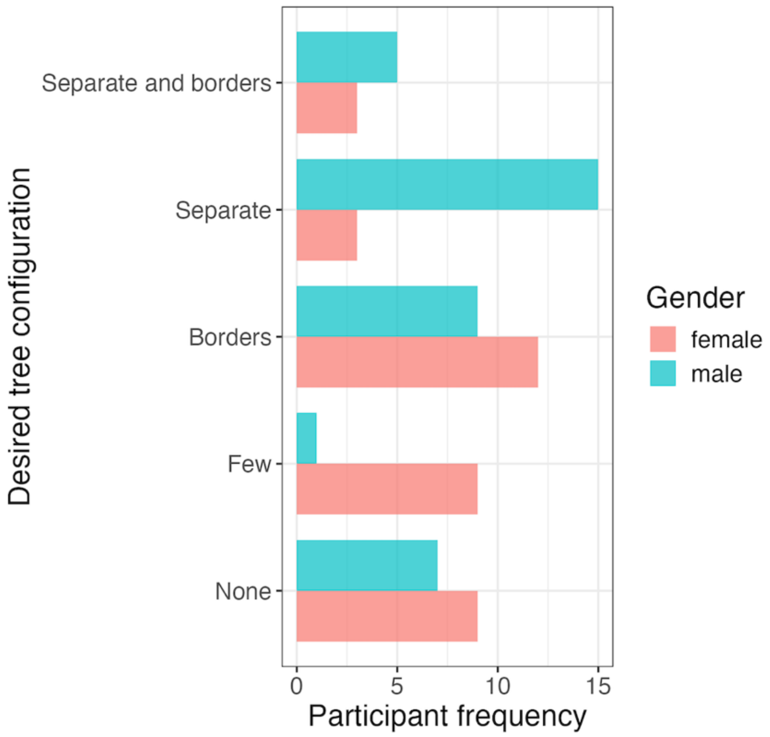

Figure 4.4 The frequency of desired tree configurations by gender.

The qualitative analysis indicated that male participants tended to want more trees in their farming systems than women. More men desired small plantation plots whereas more women preferred a few trees scattered on their farms (Figure 4.4). Women often wanted to expand their food crops and minimise the perceived negative effects of trees on yields, relying on a smaller number of trees for shade and household use. Men were more inclined to desire plantations for timber or sometimes fruits, perceiving the income from timber and hanging beehives for honey production as additional livelihood opportunities. Fisher's exact test indicated an association between gender and ideal farm configuration ($p=0.002$), but not between wellbeing and ideal farm configuration ($p=0.85$). Our multinomial regression also showed that gender influences the likelihood of choosing different ideal farm configurations (likelihood ratio test of multinomial model chi sq. = 17.3, $p=0.0017$). Keeping all other variables constant, the relative log odds of desiring trees separately to crops in a plantation plot compared to desiring no trees on the farm increased if the participant was male ($b= 1.86$, Wald $\chi2(1) = 2.3$, $p =0.02$) (Table 4.2).

Table 4.2 Results of the multinomial regression of gender and ideal farm configuration.

	Dependent variable:			
	Borders	Few	Separate	Separate and borders
	(1)	(2)	(3)	(4)
Male	0.96	0.14	6.43*	2.14
	(0.67)	(1.17)	(0.81)	(0.89)
Constant	1.33	1.00	0.33	0.33
	(0.44)	(0.47)	(0.67)	(0.67)
n	73	73	73	73
Akaike Inf. Crit.	225.17	225.17	225.17	225.17
Note:	*p<0.05			

4.6.2 Perceptions associated with farmer attitudes

Farmers were more positive about agroforestry but more negative about forests when discussing their current and ideal farming systems (Figure 4.5). Most of the perceptions associated with a positive attitude towards agroforestry came from the provision of multiple benefits such as fruit, shade, wind control, firewood, medicine, farm boundary control and timber. Often, products such as fruit, palm oil and timber were first described for household use or consumption, with excess being sold to diversify incomes. Another strong theme was that trees attract rainfall to the farm and surrounding area and a few participants with farms besides a river mentioned planting to reduce soil erosion.

Negative attitudes towards agroforestry were most strongly associated with the perception that crops, particularly rice and sugarcane are negatively impacted by trees due to light and root competition. This perception was the leading driver for farmers who owned their land to remove trees from their farm and stop planting trees, and there was a strong narrative that farm plots are for food only and trees should be grown separately. There was also a strong perception that some trees, such as fruit trees, attract wild animals such as elephants to the farm, leading to increased crop losses, farm damage and causing conflict with neighbours. For those that lived further from their farm, theft of trees, fruit and firewood was also described as an issue.

Attitudes towards surrounding forests focussed on how they influenced the farm and farmer. There were strong negative attitudes towards forest in the landscape, particularly when describing the current farming system (Figure 4.5). This was driven by the perception that farmers no longer have access to direct benefits such as firewood as most forests are under some form of protection regime which is exclusionary to enter without a permit. Meanwhile, they mainly face challenges such as fuel wood shortages and crop losses caused by wild animals from the surrounding forest areas, particularly elephants and monkeys. Crop losses from wild animals have a large spatial component, with farmers describing that those closer to forests being more affected than farms located further away from forests. They also perceived wildlife-crop interactions to have worsened in the past few years due to increased protection of both protected areas and animals themselves. Additionally, farmers perceived that land is being taken from agriculture and integrated into reserves which is decreasing land availability for farming (Figure 4.6). The few positive sentiments regarding forests were associated with them being a source of rainfall and rivers.

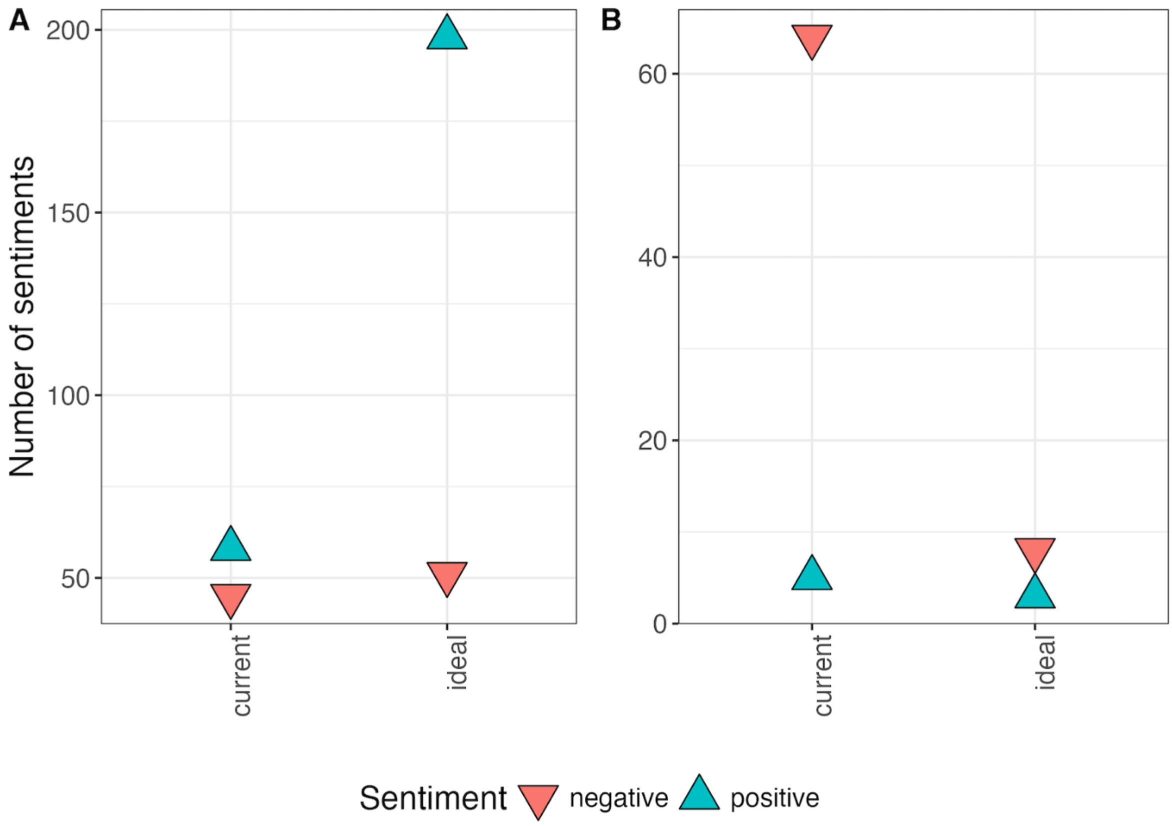

Figure 4.5 The number of positive and negative sentiments towards (A) agroforestry, now and in the ideal future scenario and (B) forest adjacent to farms, now and in the ideal future scenario.

Figure 4.6 A diagram of perceptions associated with positive (blue circles) and negative (red circles) attitudes of agroforestry and forests from the qualitative analysis.

4.6.3 Influence of gender and wellbeing on farmer attitudes

Our mixed effect model shows that gender affects attitudes towards trees (likelihood ratio test of linear mixed model chi sq.=6.4, p=0.01), as men tended to have a higher total sentiment score than women (β= 3.16 +/- 1.24 std errors, t = 2.541, 95% CI [0.72, 5.60]) (Figure 4.7A). The model explained approximately 15.8% of the total variance, 7% was explained by gender whilst random effects (encoded as workshop type) accounted for 9.5%. There were no statistical differences of total sentiment score between those with higher or lower wellbeing (Mann-Whitney U W=398.5, p=0.266) (Figure 4.7B) or of the interaction of gender and wellbeing (linear regression R^2=0.13, F=3.78, p>0.05).

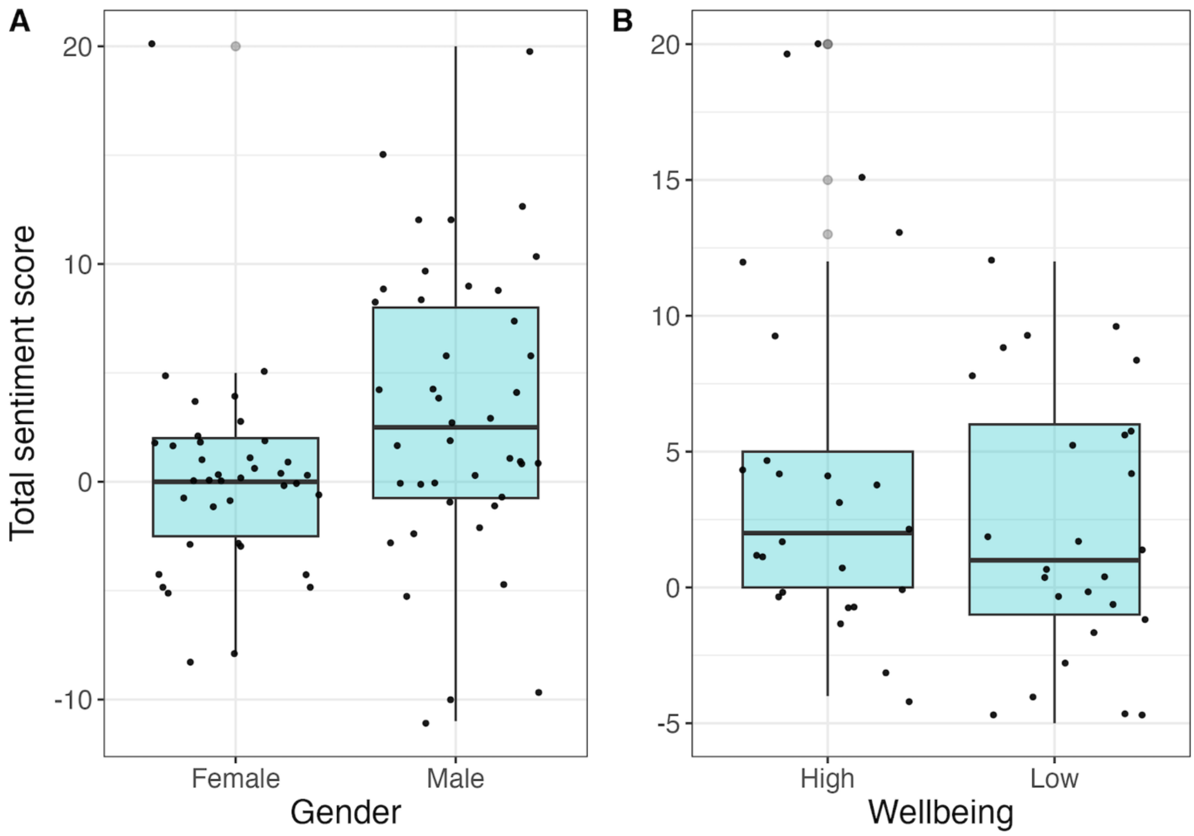

Figure 4.7 Total sentiment score towards trees and forest by (A) men and women (n=80), (B) high and low wellbeing (n=52).

4.7 Discussion

Placing equity at the core of forest landscape restoration for biodiversity, climate and human livelihoods is a complex challenge. Our findings highlight significant differences between current tree-cover restoration efforts and the ideal scenario preferences of smallholder farmers in the Kilombero Valley. While farmers generally showed positive attitudes towards agroforestry, they expressed negative sentiments towards forests, primarily due to concerns about crop losses from wildlife and restrictions on forest use. Additionally, gender differences were evident, with men showing more positive attitudes towards agroforestry than women. Despite gender explaining only a small proportion of the variance in our model, these insights underscore the necessity of adopting an inclusive, participatory approach to restoration that addresses the diverse needs and preferences of different community members. This approach can help align restoration goals with local interests, potentially leading to more sustainable and accepted tree-cover restoration outcomes at landscape scales.

4.7.1 Ideal tree-cover restoration scenarios and attitudes towards forests

Participants' scenarios do not align with the ongoing and planned restoration interventions by NGOs and government bodies in the study area, which are looking to expand and strengthen protected forest areas. Instead, participants expressed a desire to be surrounded by neighbouring farms for safety from wild animals and pests, some specifying they did not want to be near the forest. Expanding forest cover in linear formations, such as wildlife corridors and riparian forests, will increase the number of farms adjacent to forests. The anticipated impacts of such current and planned restoration projects on communities are unclear; however, research has indicated that an increase in forest cover will raise the overall probability of crop raiding risk and alter its spatial distribution, likely increasing human wildlife interactions (Pfeifer et al., 2022). Elsewhere, (Vedeld et al., 2012) documented tensions in villages surrounding the nearby Mikumi National Park due to wildlife crop raiding, estimating living close to the park incurs a cost of 2-20% of household income mainly through wildlife raiding crops and livestock. Wildlife crop losses have been shown to have adverse effects on attitudes to wildlife (Baker et al., 2014; Malley and Gorenflo, 2023). Malley & Gorenflo (2023) documented that attitudes towards elephants in the Kilombero Valley have shifted from positive to negative in the past decade due to factors such as the amount of crop lost to elephants, perceived benefits from elephants, and perceived trends of increased human-elephant conflict in both space and time. Misalignment between community impacts and institutional restoration programs reflects the current approach to restoration planning, driven by organisations with priorities different from those of local farmers, who control decision-making (Pfeifer et al., 2022; Southern Tanzania Elephant Program, 2024). Matejcek and Verne (2021) argue that top-down interventions often attempt to gain community approval through capacity enhancement activities, seeking to influence local aspirations to align with their own plans and objectives. Through these interventions, organisations look to maintain their access to natural resources through legal, economic and political mechanisms (Ribot and Peluso, 2003). Despite there being evidence that participation in conservation projects is associated with more positive attitudes towards conservation actions in the Serengeti buffer zone, Tanzania (Kideghesho et al., 2007), these efforts fall short of engaging in inclusive governance models that prioritise the needs and aspirations of local stakeholders (Löfqvist et al., 2023).

Low benefits from conservation have been shown to trigger negative attitudes towards forest conservation in Sub-Saharan Africa (Ihemezie et al., 2021). Kideghesho et al., (2007) also found that prohibition from access to resources was an important factor in shaping attitudes towards conservation. This is perhaps reflected in our results, where farmers expressed negative attitudes towards lack of access to forest resources from the forest alongside experiencing increasing disadvantages, particularly from crop losses due to wildlife. Attitudes have previously been linked to the conservation actions people will accept (Loyau and Schmeller, 2017) and willingness to participate (Sirivongs and Tsuchiya, 2012).

In the context of forest conservation in Tanzania, our findings should cause pause for thought on how to reconcile ambitious forest conservation interventions with the diversity of community needs and attitudes, in particular in rural landscapes with high dependencies between people's livelihoods and natural resources. Expanding and strengthening protected areas within the study region while simultaneously restricting local use will likely exacerbate distributional inequalities in the costs and benefits associated with forests and incurred to local communities (Ihemezie et al., 2021; Löfqvist et al., 2023; Vedeld et al., 2012). This has been documented elsewhere in Tanzania, where restricting forest use removed charcoal production as a coping strategy for income in extreme droughts (Robledo et al., 2012). Neglecting these aspects can jeopardise long-term restoration success for forests in the wider landscape and exacerbate injustice for those already marginalised from decision-making (Löfqvist et al., 2023). Moreover, (Kijazi and Kant, 2011) showed that local communities had more positive attitudes towards participatory management regimes that would increase their power to manage forest resources over bureaucratically centralised regimes in the Mount Kilimanjaro region of Tanzania.

4.7.2 Ideal tree-cover restoration scenarios and attitudes towards agroforestry

Farmers often preferred tree configurations that diversified their production system while maximising their desired benefits and minimising the interaction between trees and crops. Scenarios characterised by increasing on-farm tree cover for the purpose of diversification aligns with findings in a previous study (Andreotti et al., 2020). Diversification is a widely recognized strategy for reducing risks within agriculture such as crop failure (Ellis, 2000) and tree products can act as a safety net in times of shock or food insecurity (Kilonzo, 2022; Quandt et al., 2019). Participants also tended to desire more trees than they currently have, perhaps emphasising the gap that often exists between the decisions farmers would like to make and those they are able to undertake, given their households' circumstances and available resources (Emerton and Snyder, 2018). This is reiterated by farmers wanting to own larger farms and have irrigation systems but being constrained by factors such as financial capital (Lala et al., 2023). The desire for land ownership and to grow trees on their own land, may also be reflective of farmers' desire to control access to tree resources (Ribot and Peluso, 2003).

Our results show that positive attitudes are associated with agroforestry's beneficial and instrumental contributions to their livelihoods such as through firewood and shade (Pascual et al., 2017; Shennan-Farpón et al., 2022). Promoting agroforestry alongside protection and sustainable management of existing forests may therefore offer a more equitable pathway for reconciling tree planting targets with local community livelihood needs, as long as people are empowered to select the trees they need and maintain their local food production systems (Fleischman et al., 2020). Yet, this will rely on stronger evidence from the field with regards to tree: crop combinations that can deliver on these objectives as the perceived negative impact of trees on crop yields, particularly due to canopy shading, was the biggest driver of negative attitudes. The scientific evidence for the presence of trees on food production in the tropics is limited, a review by Reed et al., (2017) found 54% of studies reported a positive effect on food yields. This is evidently an area in which further research is needed with farmers to overcome barriers of perceived negative tree-crop interactions when scaling agroforestry.

4.7.3 The influence of gender on ideal scenarios and attitudes

Both men and women expressed a desire for agroforestry systems in their ideal farms, consistent with other research in Morogoro and Dodoma, Tanzania, where gender did not influence agroforestry adoption (Jha et al., 2021). However, our findings reveal a gendered divide in the desired intensity and configurations of trees. Women preferred fewer scattered trees, prioritising the expansion of food crops and relying on a smaller number of trees for shade and household use. In contrast, men were more inclined to favour the presence of more trees, viewing agroforestry as an additional livelihood opportunity. These findings are consistent with other studies conducted in Africa, as highlighted by Kiptot (2015), who emphasises that women predominantly bear the responsibility for meeting household needs related to food and fuel. Conversely, men tend to control the more commercially valuable agroforestry products such as timber (Kiptot and Franzel, 2011). Furthermore, a study across five African countries, including Tanzania, also notes that land allocation to tree cash crops is lower among female-headed households (Miller et al., 2017). Our results indicate that agroforestry interventions need to address the specific needs and constraints of both men and women, promoting equitable access to resources and opportunities for participation (Kiptot and Franzel, 2011).

Although men spoke more than women (Wilcoxon test $W=444$, $p<0.005$), there was no correlation between word count and total sentiment score (spearman's $rho=0.19$, $p>0.05$), indicating that this was not the driver of differences. It is also important to note that gender accounted for only 7% of the variation in our model, underscoring the substantial heterogeneity of attitudes influenced by a multitude of intersecting factors (Meijer et al., 2015a).

4.7.4 Intersecting wellbeing and attitudes to trees and forests

Conservation and restoration research has focussed on operationalising the measuring and monitoring of human wellbeing to capture effectiveness of interventions (Loveridge et al., 2022, 2020; Milheiras et al., 2022). It set the pathway for using defined and measurable indicators of wellbeing to track intervention outcomes, policy progress and highlight social issues requiring attention (Loveridge et al., 2020). Using an aggregated metric has simplified the complexity of wellbeing across the five main dimensions of material, health, social, security and freedom. However, our study highlights the constraints and limitations associated with the use of a composite wellbeing metric when trying to understand intersections between people, their attitudes and perceptions of forests or trees on their land. Aggregating variables, like when creating a single index to capture wellbeing, can obscure patterns and differences across the five dimensions of wellbeing and individual indicators. This then hinders the design of effective management interventions.

Specific to our study, using the wellbeing index as an aggregate index for workshop participants may be misleading. The same wellbeing score can apply to two individuals (see Supplementary materials 4.10.2, Figure S4.1) but may translate to different scores along each of the five dimensions of wellbeing thus masking mechanisms underlying attitudes and perceptions to trees on farms and in the landscape. Consequently, making specific recommendations to address prevalent attitudes without exacerbating existing inequalities in wellbeing is challenging due to the unclear localisation of these inequalities. Recognising that restoration interventions affect people differently and may enhance specific aspects of wellbeing while worsening others (Woodhouse et al., 2015), the composite indicator lacks the information to provide such insights. Therefore, we recommend that future studies in this field examine individual dimensions of wellbeing rather than relying solely on an aggregate metric to obtain more nuanced and insightful results.

Conclusion

Our findings reveal several insights with policy and practice implications for those aiming to scale-up planting for tree-cover restoration efforts to meet ambitious commitments and tackle deforestation caused by conversion to agriculture.

Firstly, farmers' ideal future landscapes do not align with current tree-cover restoration efforts driven by external actors within the landscape. To foster sustained and meaningful landscape restoration with smallholders, which could address urgent land degradation concerns and climate risks (Shyamsundar et al., 2022), we reiterate previous calls for restoration interventions to be implemented through inclusive governance processes that incorporate social and equity considerations to achieve improved social, ecological, and environmental outcomes (Löfqvist et al., 2023). There has been considerable research guidance published on processes that foster inclusive governance models such as legitimate representation of stakeholders, structured engagement processes and methods, balancing power dynamics and provision of information and decision-making power to all participants (de Vente et al., 2016; M. S. Reed et al., 2017; Wood et al., 2016). Africa specific, structured and transparent approaches to co-design and co-production of policies and management plans that align objectives of all social groups has been shown to support more resilient and equitable landscapes (Favretto et al., 2021). Additionally, we suggest using sentiment analysis to measure responses to and help improve restoration interventions, using this data as a baseline assessment (Drijfhout et al., 2016). It could be useful in this instance to measure whether shifts towards inclusive governance structures and interventions aimed at reducing risks to human life and crop losses from wildlife succeed in improving attitudes towards forests. Furthermore, quantitative insights are crucial for reporting and monitoring changes over time, providing valuable feedback for adapting and improving restoration strategies.

Secondly, positive attitudes towards agroforestry may indicate that farmers are interested and willing to integrate and adopt trees into their farming systems (Amare and

Darr, 2024; Buyinza et al., 2020). This lends strong support for agroforestry scaling opportunities in rural landscapes as a climate change mitigation and adaptation strategy. These results can be used by organisations to anticipate risks, trade-offs and opportunities that may emerge through agroforestry interventions. Gender emerged as a significant factor influencing ideal scenarios and attitudes towards agroforestry and forests. This finding emphasises the importance of adopting a gender-sensitive approach that addresses the unique needs and aspirations of both genders when engaging smallholders in agroforestry interventions. It is crucial to implement inclusive, participatory decision-making processes that enhance gender equity and actively involve women. Our results also indicate the necessity of considering a wide array of intersectional factors in future research to fully understand attitudes towards agroforestry and forest restoration.

Third, we demonstrate that participatory scenarios can be a useful tool to give space for local communities' voices that have been historically marginalised from conservation governance (Lala et al., 2023). Participants cited the benefits of the workshops such as the two-way transfer of knowledge and having their own experiences heard, and they valued the dissemination of research results at the end (see Supplementary materials 4.10.3 for a longer summary and quotes). The diversity in scenarios and attitudes highlights the unique experiences of each participant, providing a nuanced and context-specific representation of possible landscape futures informed by local knowledge that prioritises the perspectives of smallholders (Löfqvist et al., 2023). Overall, they reiterate the importance of incorporating diverse local attitudes and preferences in tree-cover restoration efforts and highlight the need for inclusive and participatory decision-making processes that genuinely include the voices and needs of smallholder farmers.

4.8 Declarations

4.8.1 Acknowledgements

We would like to acknowledge and thank everyone who participated in this research and contributed to its success.

4.8.2 Ethics

Ethical review and approval were granted by the University of Leeds Ethics Committee (ref: AREA 19-017) and Research Permission was granted by COSTECH (ref: 2019-118-NA-2016-101) in accordance with the local legislation and institutional requirements.

4.8.3 Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

4.8.4 Author contributions: CRediT

Eleanor Durrant: Conceptualization; Methodology; Formal analysis; Investigation; Data Curation; Writing - Original Draft; Writing - Review & Editing; Visualization. **Pete Howson:** Conceptualization; Writing - Review & Editing; Supervision. **Susannah M Sallu:** Funding acquisition; Conceptualization; Methodology; Investigation; Writing - Review & Editing. **Deo D Shirima**: Funding acquisition; Writing - Review & Editing. **Margherita Lala:** Conceptualization; Methodology; Investigation; Writing - Review & Editing. **Sergio G. Milheiras:** Methodology; Investigation; Writing - Review & Editing. **Francis Lyimo:** Investigation; Methodology; Writing - Review & Editing. **Petro P Nyiti:** Investigation; Writing - Review & Editing. **Lilian Mwanga:** Investigation; Writing - Review & Editing. **Esther Kioko:** Funding acquisition; Writing - Review & Editing. **Marion Pfeifer:** Funding acquisition; Conceptualization; Methodology; Writing - Review & Editing; Supervision

4.8.5 Data availability

All data and code used in this publication and analysis is available in Figshare:
https://doi.org/10.6084/m9.figshare.26946505.v1,
https://doi.org/10.6084/m9.figshare.26946493.v1,
https://doi.org/10.6084/m9.figshare.26136196.v1,
https://doi.org/10.6084/m9.figshare.26135752.v1,
https://doi.org/10.6084/m9.figshare.26135746.v1,
https://doi.org/10.6084/m9.figshare.26135692.v1

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4.10 Supplementary materials

4.10.1 Detailed description of the workshop methodology

This research formed part of the Agrisys Tanzania project that aimed to quantify how and to what extent integrated landscape management can enhance benefits to and from agriculture (Pfeifer et al., 2022). The project conducted extensive surveys on ecological health through biodiversity and soil samples, and social variation through quantifying human wellbeing. Human wellbeing was measured across five dimensions put forward in the Millennium Ecosystems Assessment (MEA, 2003), namely ‘basic material for a good life’, ‘health’, ‘social relations’, ‘security’, and ‘freedom of choice and action’, following the approach of (Loveridge et al., 2020)). 467 surveys were conducted with households randomly chosen from the village register across seven villages: Kidatu, Sanje, Msolwa Station, M’angula B, Mgudeni, Msalise and Katurukila (Milheiras et al., 2022). In the same villages participatory workshops with smallholder farmers were also conducted to explore smallholders’ aspirations for the future and to elicit narratives of change on farms which are described in greater detail below (Lala et al., 2023). Nine participatory workshops involving 80 smallholder farmers were conducted between July and August 2022. Workshops comprised 38 women and 42 men. Workshops were differentiated by age and wellbeing (Table S4.1). There were two workshops for youth (18-35) (n=20) and seven workshops for adults (35+) (n=60). Wellbeing was measured with a composite indicator score calculated using household survey questions (Milheiras et al., 2022). Two respondent wellbeing groups were determined by hierarchical cluster analysis of the five dimensions constituting the composite indicator. After a posteriori confirmation that the two resulting clusters had significantly different (p-value<0.001) mean wellbeing scores, respondents were classified as having ‘high’ or ‘low’ wellbeing. Workshop participants were randomly selected among 440 people who had participated in the household survey (Milheiras et al., 2022). It was possible to have separate adult workshops (n=6) based on participant wellbeing cluster in three village groups. In one village group and the youth group it was only possible to have one mixed wellbeing workshop due to a smaller pool of potential participants.

Each workshop was run for approximately six hours and consisted of two main activities. In activity 1 participants described their current farming system and then they created a scenario of their ideal farming system, looking 5-10 years into the future. Participants were free to describe as they wished, but they usually included details such as the size, configuration, and the main characteristics such as crops, trees, rivers, and wells. They also described their surrounding landscape; this was defined by the participants themselves but usually referred to the nearby surroundings of the farm. Activity 2 then explored the barriers and opportunities they face in achieving their ideal farming scenario. Workshops were of mixed gender, but groups were divided into male and female for each activity and then came together for plenaries, allowing an exchange of ideas and discussion between genders.

The workshops took place in Swahili and were hosted by a Tanzanian facilitator, two research assistants and two artists. The artists depicted the ideal farm for each participant so that they could visualise, explain and compare their scenario with the broader group. Each workshop was audio recorded and then transcribed into English for analysis. Based on the transcript text and the artist's depiction of the ideal farm, we categorised the ideal agroforestry configurations by participants, defining agroforestry as any form of integration of trees into the smallholder’s farming system. The categories are no trees, a few scattered trees, trees on the borders of fields, trees in a separate plot, and on the borders of fields.

Table S4.1 Each workshop differentiated by age and wellbeing.

Workshop number	Age	Wellbeing
1	Youth	Mixed
2	Youth	Mixed
3	Adult	High
4	Adult	Low
5	Adult	High
6	Adult	Low
7	Adult	High
8	Adult	Low
9	Adult	Mixed

4.10.2 Principal component analysis of wellbeing dimensions

Figure S4.1Principal Components Analysis along the five dimensions of wellbeing for each participant, colour coded into high and low categories.

4.10.3 Impact of the scenario planning objectives

4.10.3.1 Participant feedback

Participants appreciated the booklets for previous research dissemination, reporting that they have often participated in research and do not hear the results. They were also positive about the participatory aspects and having researchers listen to their perspectives. Areas for improvement were increasing the notice period for joining the workshop and that it was a long day for older participants.

Regarding the research dissemination, there was a lot of interest in the information about how trees can be used to reduce pests such as neem oil as a natural pesticide and how birds can eat pests on the farm. Questions also often focussed on pest control, highlighting how this is a key area of concern for farmers. They also expressed that they wanted their perspectives to be fed back to influence government decision-making.

Quotes about workshop feedback

'I was interested with participation method, you have interacted with us, you have asked us, and then you shared with us.'

'I liked the way you gave chance to everyone to explain individually according to their working places and experience'

'I have enjoyed the way each participant shared the ideas, this is the meaning of workshop, not one way transfer of knowledge.'

'You make us feel free to speak out without any worries'

'We didn't expect this kind of calling to express the challenges present in our community.'

4.10.3.2 Dissemination of results

The results of this work were presented to tree-cover restoration decision-makers from government and non-governmental organisations through presentations and a report summarising the key results. It is not known to the authors whether they were used in any decision-making or whether they have resulted in changes to more inclusive and participatory decision-making processes.

4.10.4 References

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5-*Contract farming for sugar and agroforestry can have positive and negative impacts on livelihood resilience in Tanzania*

Linking statement: The findings from Chapter 4 illustrate the diverse strategies that smallholders in the Kilombero Valley currently use to sustain their livelihoods, as well as their aspirations for future agricultural livelihood development. Notably, that they both use and aspire to use agroforestry and contract farming to do this. Moreover, my anecdotal knowledge from working within the Kilombero Valley alongside reading the scientific literature, was that farmers are already feeling the effects of climate change. Therefore, in this chapter, I wanted to understand how agroforestry and contract farming interact to build household livelihood resilience to climate change and what the trade-offs may be for smallholders.

This chapter is currently in review at the peer-reviewed journal *Regional Environmental Change*. The latest submitted manuscript has been included in here.

Contribution statement: I conceptualised this chapter, designed the research methodology, conducted the data analysis, visualised the results and wrote the original draft of the manuscript**.** I collected the interview and tree inventory data alongside the research assistant, Petro P Nyiti. Dr Steve Rushton helped me with the quantitative data analysis. Dr Marion Pfeifer and Dr Pete Howson provided supervision throughout, and all co-authors provided feedback on the manuscript.

Data statement: This chapter uses the following data: a quantitative household survey, qualitative interviews and a homegarden tree inventory. The quantitative household survey was collected in 2019 by the Agrisys Tanzania project, I was not involved in this data collection, but I have included a detailed description of how it was collected in the Supplementary Materials 5.8.1.1. Petro P Nnyiti was involved in this data collection. The qualitative interviews and a homegarden tree inventory data were collected by me, Petro P Nnyiti and other research assistants.

5.1 Abstract

Tropical smallholder agriculture is one of the most vulnerable sectors to climate change and a priority area for adaptation. Strategies such as contract farming and agroforestry are encouraged to allow agricultural households to adapt and build livelihood resilience. We examine the livelihood resilience co-benefits and trade-offs of smallholder sugarcane contract farming and agroforestry, also exploring the climate mitigation potential of agroforestry by combining structural equation modelling and qualitative analysis on data collected in the Kilombero Valley, Tanzania. Our research found that the number of farming plots owned quantitatively drove livelihood resilience. Both agroforestry and contract farming aid households in diversifying their livelihoods to build resilience but have trade-offs. Contract farming has altered spatial land and cropping patterns, impacting how farmers build livelihood resilience. Farmers have cleared trees from their farm plots for sugarcane, leading to a concentration of farmers' trees within homegardens. This suggests that homegardens may be important for ensuring the direct benefits of trees and conserving aboveground carbon stocks, which were similar to other studies in East Africa. Further research is needed into the future impact of contract sugarcane farming on food security as farmers bear all production risks and the weather becomes increasingly unpredictable.

Keywords: Climate change; climate adaptation; climate change mitigation; social-ecological systems; homegardens

5.2 Introduction

The multifaceted consequences of the climate crisis are being felt disproportionately worldwide (IPCC, 2023). Agricultural livelihoods and food security are especially vulnerable and require urgent adaptation efforts (Anderson et al., 2020). Some of the most acutely impacted are smallholder farmers in rural tropical landscapes for whom agriculture is the primary source of sustenance and income (Schlenker & Lobell, 2010; Thornton et al., 2011). Smallholders occupy 30% of agricultural land in tropical regions and produce 70% of regional food calories (Samberg et al., 2016). These groups find themselves with limited adaptive capacity and scarce resources to mitigate the threats perpetuated by climate change, including food insecurity, land degradation, and declining soil fertility and crop yields (IPCC, 2023; Smith et al., 2020). In East Africa, where smallholders account for 75% of agricultural production (Salami et al., 2010), future scenarios of climate change predict decreased yields, reduced land suitability for crops and altered disease trends for humans, livestock and crops, resulting in narrowed livelihood options and food insecurity (Thornton et al., 2011; Kogo et al., 2021).

Large-scale efforts are needed to mitigate the effects of climate change and allow agricultural communities to adapt and build resilience. Two possible pathways include contract farming (Dapilah, 2023; Smalley, 2017) and agroforestry (Smith et al., 2020; Verchot et al., 2007; Mbow et al., 2014). Contract farming, or out-grower schemes, refers to agricultural production according to a prior agreement in which the farmer agrees to grow a product and the buyer commits to purchasing (Actionaid, 2015). Contract farming agreements may enhance livelihood resilience by lowering farmers' costs and risks through increasing access to information, training, markets, inputs, services, support groups, and yearly income (West & Haug, 2017). However, there is limited evidence for these benefits (Ton et al., 2018; Machimu & Kayunze, 2019), and it is questioned whether agricultural development schemes centered around contract farming, such as agricultural growth corridors, can meet their commercial and development objectives (West & Haug, 2017; Dapilah, 2023; Sulle & Dancer, 2020). Out-grower schemes are complex; they may improve livelihoods but can increase vulnerability through market specialization (Dapilah, 2023), and benefits are not homogenous across communities, which can exacerbate structural inequalities (Sulle & Dancer, 2020; Mwavu et al., 2018). Moreover, they undermine agrobiodiversity and the multifunctional benefits of diverse agroecological systems (Mwavu et al., 2016; Sulle 2020) and drive food insecurity (Mwavu et al., 2018).

Meanwhile, agroforestry, the integration of trees into crop production and livestock systems for achieving multiple benefits from the same land parcel (Nair et al., 2021), is also advocated for building livelihood resilience to climate change while also mitigating the effects (Smith et al., 2020; Verchot et al., 2007; Mbow et al., 2014; Quandt et al., 2019). Approximately 1500 million hectares are estimated to be suitable for agroforestry in Africa alone (Unruh et al., 1993). Agroforestry has been shown to provide products such as firewood, construction materials, and fruit (Quandt et al., 2019), which can then be directly used to build livelihoods such as by providing construction materials, paying school fees, or providing healthy food options (Quandt et al., 2019; Ota et al., 2020). For climate mitigation, agroforestry systems have been estimated to contain over five times more carbon per hectare than row crop systems alone (Verchot et al., 2007). In western Kenya, field studies found homegardens to have the highest aboveground carbon stocks per hectare compared to other agroforestry compositions such as boundary and cropland planting (Reppin et al., 2020). Homegardens, a form of agroforestry, are 'intimate, multistorey combinations of various crops and trees, sometimes in association with domestic animals, around the homestead' (Nair et al., 2021). Homegarden agroforestry occupies a unique position in the human-nature nexus, where people actively live, manage, and rely on natural resources for their livelihoods and are practiced extensively in tropical regions (Nair et al., 2021).

Livelihood resilience is the 'capacity of all people across generations to sustain and improve their livelihood opportunities and well-being despite environmental, economic, social, and political disturbances' (Tanner et al., 2015, p.23). Adopting a livelihood resilience lens in the context of climate change adaptation, focuses less on people's recovery from shocks and more on how coping and adaption to shocks lead to broader social transformations (Tanner et al., 2015). Households are central in managing responses to external shocks, and many assets, capacities, and functions required to respond to shocks have historically been dictated by household-level dynamics (Frankenberger & McCaston, 1998). Analyzing livelihood resilience at the household level allows identification of vulnerable groups and specific pathways for building livelihood resilience and adapting to changing climatic conditions (Quandt, 2018; Speranza et al., 2014).

A significant challenge for an improved understanding of livelihood resilience and underlying drivers is the choice of appropriate metrics and methods of analysis (Bahadur & Pichon, 2017). Many have built upon the Sustainable Livelihoods Approach (SLA) (Bahadur & Pichon, 2017; Quandt, 2018; Speranza et al., 2014), which suggests there are five key types of assets that households and individuals draw upon to build their livelihood: human, social, natural, physical, and financial assets. Human capital includes skills, knowledge, and labour needed to achieve livelihoods. Social refers to the social resources people draw upon, such as group membership and access to information. Natural assets are the natural stocks from which resources and services flow, such as farmed areas, livestock, crops, and fertile land. Physical assets refer to infrastructure such as access to roads, irrigation, and drinking water. Lastly, financial assets include savings and ownership of belongings and services that enable livelihoods (Serrat, 2017). These capital assets overlap and can be exchanged or allocated to generate income and sustain well-being and/or stored and accumulated so reserves and buffers are available in times of stress or shocks (Serrat, 2017). Livelihood resilience can be measured with an indicator based on the SLA because it has been empirically tested in agroforestry systems in East Africa and offers a way to measure observable resources and assets (Quandt et al., 2019; Bahadur & Pichon, 2017).

Discussions around livelihood resilience have often taken place at the community level (Cabell & Oelofse, 2012; Lindstädter et al., 2016; Berkes & Ross, 2013), where many strategies are applied in practice in Africa (Otsuki et al., 2018). Critics of resilience approaches argue that there is an overemphasis on assets at the expense of agency, power dynamics, and social inequalities that exist within communities (Tanner et al., 2015). Moreover, the SLA is criticized for being based on normative assumptions of what should constitute a 'sustainable' livelihood, which may not align with local values, aspirations, or cultural contexts (Serrat, 2017). Yet, there is unequal access to resources between community members and human agency plays a role in the capacity to prepare for and cope with shocks (Tanner et al., 2015; Quandt, 2018). A multidisciplinary approach can be used to address these drawbacks at least partially, combining quantitative indicators with qualitative interview data such as by Quandt, (2018).

Livelihood resilience is an understudied aspect of agroecosystems (Lin, 2011), and sustainable livelihood perspectives can fail to grapple with debates around longer-term shifts in rural economies and agrarian change (Scoones, 2009). Many African landscapes have become the focus of a myriad of agricultural interventions from public, private, and non-government entities promoting different agricultural and rural development models. Agroforestry is a traditional practice across Africa that can benefit livelihood resilience through diversification and act as a safety net in times of shock or food insecurity (Quandt et al., 2019). Meanwhile, agricultural growth corridors are a recent prominent policy, coordinating public and private investment to catalyze agricultural development through infrastructure and market linkages. Growth corridors aim to intensify agriculture and commercialize smallholders through contract farming schemes of cash crops, increased adoption of technology and agricultural inputs, and the creation of a business-friendly environment (Smalley, 2017). Growth corridor and contract farming policies particularly rapidly alter farming landscapes and how people build their livelihoods, affecting climate mitigation and livelihood resilience. However, little is known about how strategies such as contract farming (Dapilah, 2023) and agroforestry (Quandt et al., 2019; Ota et al., 2020) are used together to build livelihood resilience to climate change in rapidly transforming landscapes.

5.2.1 Research Objectives

This research aims to understand how agroforestry and contract farming, two prominent agricultural strategies in rural African landscapes, influence livelihood resilience in the face of climate change and contribute to climate mitigation efforts. Focusing on the Kilombero Valley in Tanzania, a region undergoing rapid agricultural transformation (Lala et al., 2023), the study investigates: (1) how agroforestry contributes to building livelihood resilience, including how households use their capital assets to respond to environmental shocks such as erratic rainfall, crop raiding, and drought; (2) how contract farming of sugarcane influences farmers' capacity to adapt and sustain their livelihoods under changing climatic conditions; and (3) the role of agroforestry in supporting climate mitigation.

5.3 Methods

5.3.1 Study area

This study was conducted in the northern part of the Kilombero Valley, Morogoro region, Tanzania, chosen because it is an area that is experiencing rapid changes in land-use and management (Msofe et al., 2019; Lala et al., 2023). The area has a sub-humid tropical climate across two rainy seasons: a long rainy season in March-May and a short rainy season in October-December. The landscape consists of heavily protected forest and savannah ecosystems, settlements, an industrial sugarcane plantation and smallholder farms. It is part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), an agricultural growth corridor promoting market-driven transformation and modernization with a win-win narrative of 'green growth' (SAGCOT, 2024). Plans for the corridor include a 320 km road upgrade ad 60 km power transmission lines, and SAGCOT has supported commercial contract farming out-grower schemes to boost agricultural productivity (SAGCOT, 2024). One such scheme is the Kilombero Sugar Company Limited (KSC). KSC runs a 10,000-ha sugarcane plantation to supply 45% of cane to its sugar mill, while the remaining 55% is supplied by over 8,000 growers in the region (Sulle & Dancer, 2020). Alongside this, several conservation and sustainability interventions are being planned and implemented in the area to strengthen protected areas, such as a wildlife corridor to facilitate elephant movement. Many international and local non-governmental organizations are active in the landscape, some of which promote agroforestry and provide trees to smallholders with the goal of increasing tree cover and improving livelihoods. SAGCOT has also supported agroforestry interventions to benefit ecosystems, biodiversity and climate through its partners across the corridor (Nnko et al., 2022; SAGCOT, 2012).

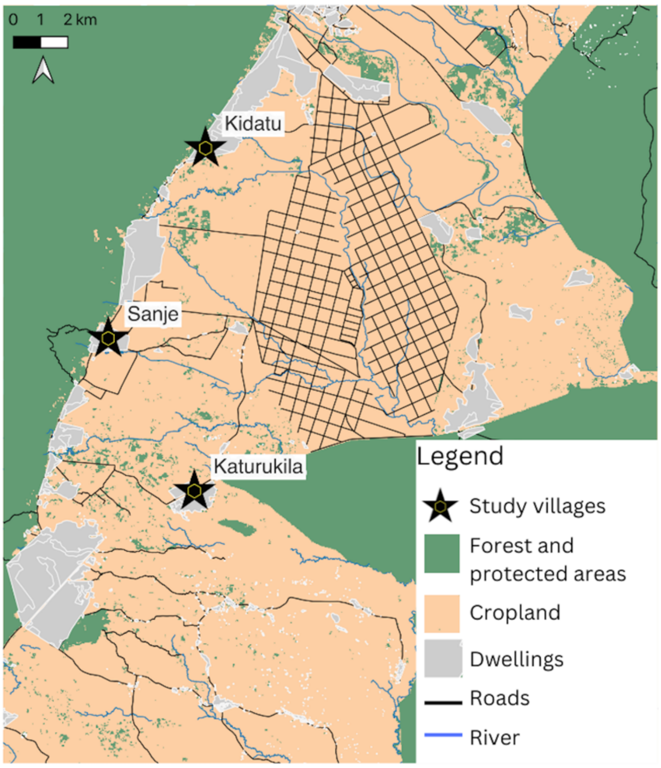

Figure 5.1 Map of the study area, the Kilombero Valley, Tanzania, showing the three study villages and surrounding landscape

5.3.2 Data collection

Data were collected from 65 farmers across three villages: Kidatu (n=24), Sanje (n=22) and Katurukila (n=23) (Figure 5.1), from February-April 2022 at the onset of the rainy season. These three villages are representative of the rapidly expanding pressure on natural resources due to transnational and national interest in converting farmland for sugarcane production or expanding protected areas. The predominant agricultural system is rainfed smallholder farming. Sugarcane is grown as a cash crop for KSC, while rice and other crops are grown for sale or subsistence use. A tarmac main road running alongside the Udzungwa Mountains National Park, Sanje, and Kidatu villages has recently been completed.

We used data collected from a household survey conducted between November to December 2019 (Milheiras et al., 2022) (Supplementary materials 5.8.1.1) to (1) randomly select a sub-set of participants for a qualitative interview and homegarden tree inventory and (2) construct a quantitative indicator for livelihood resilience. Participants were stratified using data from the household survey by gender (men =32, women =33) and sugarcane farming (yes/no) to ensure balanced sampling. The farmer was interviewed at each household, and a homegarden tree inventory was taken. We used semi-structured qualitative interviews to understand perceptions of livelihoods, shocks, and adaptation strategies (Supplementary materials 5.8.1.2). This approach allowed farmers to express the shocks and strategies they deemed important to explore household livelihood resilience from contract farming and agroforestry. Interviews were performed in Swahili by a locally trained enumerator after gaining free prior and informed consent.

For the homegarden inventory, we measured the size of their home plot and inventoried all the crops and trees within the home area to collect data on species richness and abundance of homegarden agroforestry. We include banana and papaya as crops because they are domesticated herbs for home and commercial consumption. We took a GPS reading at each corner of the home plot, as shown by the participant, to calculate the home plot size (ha) and distance to the tarmac road (m). All adult trees ≥ 5 cm diameter stem at ankle height (30 cm aboveground) were sampled, including palms (Cazzolla Gatti et al., 2022). For each tree, the diameter at breast height (DBH) (cm), diameter at ankle height (cm), and height (m) were recorded. We measured all stems that were forked below 1.3 m, and a botanist was consulted for any unidentifiable species.

To estimate aboveground biomass (AGB), we followed the allometric equation from (Chave et al., 2014) per tree (Mg), where $AGB_{\text{est}} = 0.0673 \times (\rho D^2 H)^{0.976}$ (trunk diameter D (cm, 130cm above ground/breast height), total tree height H (m), wood density ρ (g cm−3)). Wood density (g cm^{-3}) was derived from the global wood density database (Zanne A. E., 2009) (Supplementary materials 5.8.1.3, Table S5.1). This was calculated for all trees except *E. guineensis* and *C. nucifera,* where species-specific equations were used to estimate AGB stocks per tree. *For E. guineensis* we followed (Khasanah et al., 2015): $AGB_{\text{est}} = 0.1839 \times (H)^{0.766}$ and for *C. nucifera* we followed (Zahabu et al., 2018): $AGB_{\text{est}} = 3.7964 \times (H)^{0.8130}$. AGB was not calculated for individuals under 130 cm in height or those inaccessible in the field (~2%) meaning there may be a slight underestimation in AGB and carbon estimates. Estimates were scaled to the homegarden level by summing AGB for all trees and dividing this by the homegarden area (ha). AGB was then converted to aboveground carbon (t C ha^{-1}) by multiplying it by a conversion factor of 0.55 (Ponce-Hernandez & Land and Water Division, 2004).

5.3.3 Qualitative analysis

We adopted a framework analysis approach (Ritchie et al., 2013) using QSR NVivo 1.6.1 to analyze the qualitative interview data. Data were sorted into framework matrices arranged by themes/concepts, wherein transcripts were coded, summarized, and categorized to identify patterns and associative links in the data. Three interviews were not analyzed due to faulty recording. Where useful, quotes are used, but all names or identifiable features have been removed to protect participant confidentiality.

5.3.4 Statistical analysis

To complement the qualitative analysis, we adopted a structural equation modelling (SEM) approach to analyze social-ecological systems, which allows the assessment of direct and indirect relationships between variables and the construction of latent variables (Grace, 2006). Our main aim was to quantify the direct and indirect pathways with which contract farming and agroforestry affect livelihood resilience. Two types of models are included in SEM: (1) the measurement model, a linear model that generates a latent construct *livelihood resilience* as a function of observed variables and (2) a structural model that quantifies relationships between the latent construct and observed variables. A latent construct represents an unobservable variable, *livelihood resilience*, inferred from observed indicators, capturing underlying dimensions or traits that cannot be directly measured. SEMs evaluate hypothesis-driven causal relationships (outlined in Supplementary materials 5.8.1.4, table S5.2), visualized in directed acyclic graphs (Figure 5.2), assuming no feedback or bidirectional relationships. We hypothesized that homegarden tree abundance and diversity would directly increase household livelihood resilience by increasing the availability of multiple products and benefits for household use or sale (Quandt et al., 2019; Ota et al., 2020). Indirectly, agroforestry can increase farm productivity and wealth through enhanced environmental conditions, e.g. soil fertility and microclimate regulation reducing heat stress (Thorlakson & Neufeldt, 2012; Ota et al., 2020). We also hypothesized that those who had been contract farming for longer would have a higher livelihood resilience, although the literature has limited evidence. In support, a systematic review found that contract farmers tend to be significantly wealthier than the average farmer (Ton et al., 2018). Financial capital can be built and exchanged, increasing other capital assets. However, Machimu & Kayunze (2019) found that sugarcane farmers had been unable to improve their livelihoods through sugarcane farming, while Sulle & Dancer (2020) argues that sugarcane has led to increased social differentiation where those with more land can accumulate assets, but those with less land cannot, because of on structural inequalities. Moreover, a long delay in deriving financial benefits from sugarcane farming arises due to high start-up costs and a delay in returns across growing seasons. Other variables also hypothesized to impact livelihood resilience directly were included to be accounted for. These are age, distance to tarmac road, tree diversity, home plot size, number of livelihood activities and number of plots owned (Supplementary materials 5.8.1.4, table S5.2). We did not include home plot tenure as a driving variable because most participants owned their homes (n=58). We hypothesized that aboveground carbon stocks would be directly driven by homegarden tree abundance (Verchot et al., 2007; Mbow et al., 2014; Reppin et al., 2020) and diversity (Reppin et al., 2020; Birhane et al., 2020; Ma et al., 2020). Homegarden tree abundance is hypothesized to be driven by age, plot size and number of livelihood activities (Quandt et al., 2019; Kuyah et al., 2020). We fitted the SEM using the *Lavaan* package (Rosseel, 2012) in R version 4.2.1 (R Core Team, 2022).

Each path in the conceptual model (Figure 5.2) reflects a causal relationship hypothesized from previous studies and our existing knowledge of the study system as the basis of the SEM (Supplementary materials 5.8.1.4, table S5.2). Before fitting the SEM, we omitted samples containing NAs (n=61 remaining). Despite households being nested within villages, we did not include village as a random factor in the model because there were only three levels, so the model would struggle to partition the variance. Due to the small sample size (n = 61), we applied non-parametric bootstrapping with 1,000 resamples to estimate the SEM. Bootstrapping generates empirical standard errors and confidence intervals that are more robust to violations of normality and better suited to small samples. This approach enhances the reliability of parameter estimates by resampling the data with replacement and producing more accurate inference than standard maximum likelihood estimation alone. This was implemented was implemented using the sem() function in the lavaan package in R, with the se = "bootstrap" option specified (Rosseel, 2012).

We first obtained the measurement model for the latent variable *livelihood resilience*. We took an initial 3-5 variables for each SLA asset category chosen following the method of (Quandt, 2018) (Supplementary materials 5.8.2.1, table S5.3) and reduced this to one variable per asset category by conducting spearman's rank correlations. We chose the variable with the highest correlations with other variables within that category (e.g. social: group membership) (Supplementary materials 5.8.2.2, Figure S5.1) and constructed the measurement model. This led to the following variables being used to create the latent variable *livelihood resilience*: household belongings or services, household labour availability, participation in groups, access to inputs, size of farm. Construct validity and reliability were checked by assessing standard factor loadings, composite reliability and average variance extracted (AVE). We then developed the structural model based on the conceptual model (Figure 5.2). The qualitative and quantitative results are presented together and compared to triangulate results.

5.4 Results

5.4.1 Household characteristics

The median age of participants was 53, ranging from 22 to 82. 41 households owned at least one farming plot and the total farm area ranged from 0.25 ha to 60 ha (mean = 6.11, median = 4) (Supplementary materials 5.8.3.1, table S5.4). Most farmers (62/65) in this study are classified as smallholders as their land holdings are below 24 acres (FAO, 2024). The mean number of people contributing to household income was 1.75, with values ranging from 0-4. The number of groups a participant was involved in ranged from 0 -7 with a mean of 1.46. Inputs had been applied a mean of 3 times in the past year, but the maximum was 17. The mean number of belongings or services was 4.5, and the maximum was 9. The most common were a mobile phone (n=61), a bicycle (n=46) and a radio (n=38). No participants owned a car and only one owned a tractor. The highest education level recorded was college, but primary standard 3-7 was the most frequent response. The livelihood activities ranged from 1 to 10 (median = 4). Growing and selling rice was the most common livelihood activity (n=59), followed by sugarcane (n=41) and planting and selling trees for timber (n=18).

5.4.2 Homegarden characteristics and carbon stocks

We measured 1183 trees from 61 species across the 65 homegarden plots; the mean was 18.2, and the median was 11 trees per plot (Supplementary materials 5.8.3.2, table S5.5). *Mangifera indica* (muembe, mango), was the most common tree species within homegardens (Supplementary materials 5.8.3.2, table S5.5). A multi-purpose tree valued for its fruit, timber, and branches for firewood, it was found in 50/65 plots, representing 23.2% of total tree abundance (n=274). This was followed by *C. nucifera* (mnazi, coconut) (9.2%, n=109, 34/65 plots), which was used primarily for its fruit but also timber and dried leaves as a firewood substitute during periods of scarcity and to make brooms for home use and sale. *E. guineensis* (mchikichi, oil palm) (9.2%, n=109, 35/65 plots), which is used for oil production, ranked third, followed by *Senna siamea* (mjohoro) (6.7%, n=79, 27 plots), an important source of firewood. Regarding climate mitigation, the mean aboveground carbon stocks per hectare was 53.1 t C ha-1, and the median was 29.4 t C ha-1. Our hypotheses regarding drivers of carbon stocks per hectare were rejected in the structural model.

5.4.3 Drivers of livelihood resilience

5.4.3.1 Shocks to livelihoods

Farmers perceive their climate as changing, with a growing unpredictability of the rains. Narratives of pest damage, extreme weather events (drought and flooding), and crop raiding emerged, all of which are perceived to have increased in severity in recent years, resulting in reduced crop yields and increased food insecurity. Illustrated by a female farmer in her 50s who stated, '*We used to harvest a lot of rice but … every harvesting season we get less yield and this affects our livelihood…It is climate change… the rice gets affected by the prolonged sunshine to the extent of harvesting just a bag of rice.*' Livelihood shocks tend to revolve around farming, and feelings of a lack of control over shocks and an inability to adapt were prominent, particularly for extreme weather events and crop raiding. Some participants perceived shocks to be interlinked; for instance, drought was reported to increase certain pests, diseases, and weeds. Shocks experienced in recent years also manifested in worries about their future occurrence.

5.4.3.2 Livelihood resilience

In our final measurement model to construct the latent variable *livelihood resilience*, all standardized factor loadings were above 0.4 for the final indicators (Supplementary materials 5.8.3.3, table S5.6), indicating that the observed indicators are related to their associated constructs, particularly for those above 0.5 (Buyinza et al., 2020). The Goodness of Fit indices for the measurement model indicated satisfactory fit (Chi-square= 1.157, df = 5, p-value = 0.949, CFI = 1, TLI = 1.25, RMSEA = 0.00, SRMR = 0.029). The composite reliability of the model is 0.52, but 3/5 standardized factor loadings were below 0.5 (Supplementary materials 5.8.3.3, table S5.6), and the AVE was 23%. This indicates that the observed indicators are moderately related to their associated constructs.

After obtaining a satisfactory measurement model, the structural model was estimated to test the hypotheses. The model had a good fit to the data, indicated by the non-significant Chi-square values (Chi-square= 65.024, df = 59, p-value = 0.275) and the Goodness of Fit indices (CFI = 0.991, TLI = 0.987, RMSEA = 0.04, SRMR = 0.09). Figure 5.2 shows the results of the structural model (see also Supplementary materials 5.8.3.4, table S5.7). As hypothesized, livelihood resilience of households increased with the number of plots owned, and this aligns with our qualitative results. Farmers described having multiple plots across the landscape because it is difficult to get land in their village, so they had to go elsewhere in the landscape. However, this also increased resilience to spatial shocks. Some described renting farms in the valley as an adaptation if their main farm plot had flooded and their crops had failed. There was a strong narrative that only those with more land could significantly improve their livelihoods and resilience because of the higher income they receive. Renting out land was a strategy to maintain livelihood resilience, trading off natural capital to pay for healthcare or school fees in times of need. Moreover, those who own land do not have to find the financial capital to rent, which is much higher for sugarcane farms than rice. However, the model rejects our other hypotheses linking potential drivers to livelihood resilience (Figure 5.2).

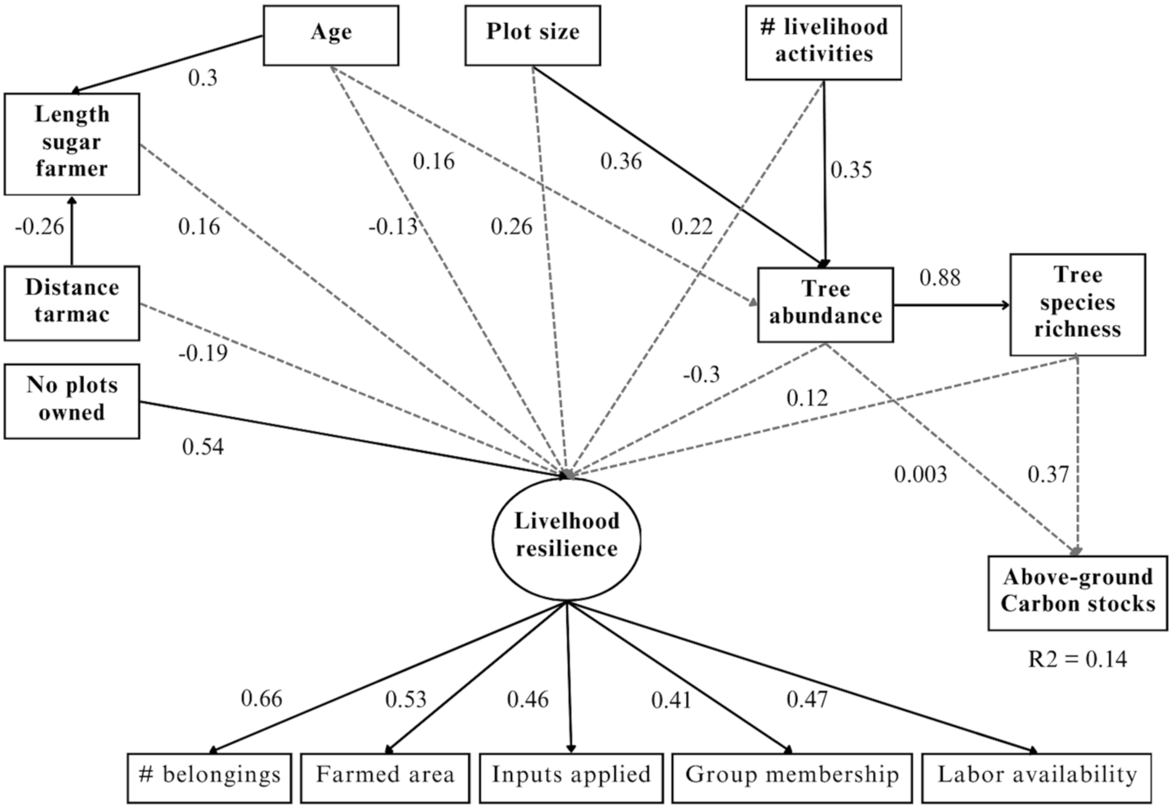

Figure 5.2 Directed acyclic graph of the structural equation model with the standardized factor loadings for each pathway. Pathways with p<0.05 are shown with a black line, while ones with p>0.05 are shown with a dashed line. Group membership refers to how many groups the participant is a part of such as an Agricultural Marketing Cooperative Society, whilst labour availability is the number of people contributing to household income.

5.4.3.3 Contract farming and livelihood resilience

Motivations to undertake contract farming were varied. Many farmers were motivated by the potential of contract farming for sugarcane to improve their livelihoods through higher income. Although usually, farmers preferred to add sugarcane to their livelihood and farming portfolio, instead of completely replacing other crops grown on their land. This is particularly true for rice, which constitutes an important food crop in the valley. Additionally, farmers perceived sugarcane as being more drought-resistant than rice and less susceptible to crop damage by birds and elephants; they highlighted sugarcane farming as a means for enhancing their livelihoods by providing them with yearly financial capital that enables them to invest more in children's schooling, housing improvements or other livelihood activities, particularly rice farming.

Sugarcane growers have greater access to capital assets as they are members of growers' associations, which increases their access to loans and inputs (Figure 5.3). Growers and non-growers report that the opportunity for factory employment or paid labour on smallholder sugarcane farms was a critical short-term adaptation strategy that has emerged since the presence of the factory. Despite these benefits, farmers are also experiencing difficulties and reported failure in harvesting due to accidental fire outbreak, wildlife damage or harvest issues with the growers association. In these instances, the farmer bears all the costs of production and mitigating the impacts on livelihoods. For instance, when the sugarcane crop is lost due to accidental fire, the farmer has the costs of no harvest and must pay for someone to come and clear the burnt cane. Moreover, many reported declining tonnage and sucrose content in recent years, reducing the positive benefits initially seen to their livelihoods. There was also the perception that only those with larger sugarcane areas could get high enough yields to build financial capital to improve livelihoods.

As hypothesized, the number of years since farmers adopted sugarcane farming increased with age ($p < 0.001$) and decreased with distance to the tarmac road ($p < 0.001$). This later result partially reflects the recent conversion to sugarcane for those participants living and/or farming in Katurukila or surrounding villages. Within Katurukila, most participants had converted to sugarcane in the past 1-5 years (n=21). This is a long-term adaptation strategy to elephant crop raiding, as sugarcane is seen as less susceptible to damage than rice, maize, and vegetables. Conversion to sugarcane decreases the diversity of crops grown in the landscape, as demonstrated by a female participant in her 40s: *"Years ago all farms in the village were used to grow paddy, sweet potatoes, cassava, pumpkins and maize but after sugarcane farming was established everyone had converted to sugarcane."* Additionally, some tree species, such as *Mangifera indica* (muembe, mango), *Cordyla africana* (mlenda, wild mango) and *Albizia lebbeck* (mtanga) were described as worsening the effects of elephant crop raiding by attracting elephants to farms and homes and endangering safety. This was also listed as a motivation for farmers to remove trees from their farmed land.

5.4.3.4 Agroforestry and livelihood resilience

Despite a lack of a quantitative relationship in our SEM, the interview analysis indicated that trees positively and negatively influenced capital assets and livelihood resilience (Figure 5.3). For example, trees delivered benefits as human and physical capital by acting as a windbreak. However, there was significant concern about personal and housing safety if trees were blown over during a storm, particularly for coconut (mnazi) trees. As hypothesized, tree abundance increased with home plot size ($p < 0.05$) and number of livelihood activities ($p < 0.001$), while tree abundance drove species diversity ($p < 0.001$). The mean number of livelihood activities was 3.14; only 3/65 participants made their livelihoods with one activity, farming only rice or sugarcane. Diversifying livelihood activities was the primary adaptation strategy to shocks as farmers struggled to meet their needs from farming alone. Trees aid diversification, building financial and human capital through (1) the provision of fruits for food, reducing reliance on buying, (2) the sale of fruit and timber, and (3) facilitating livelihood activities that require firewood (Figure 5.3). It was reported that timber has recently become more valuable, and infrastructure for felling within the villages has improved, increasing their value for financial and physical capital and motivating the planting of timber trees.

Many homegarden trees were described as planted within the past 5-10 years, and farmers are only now starting to receive direct benefits from these trees. The scarcity of trees in recent years was apparent through the interviews, and some participants described using dried coconut leaves as a replacement for firewood. This scarcity has come about through restrictions on collecting firewood from protected areas combined with the clearing of farms due to conversion to and farming of sugarcane and rice, driven by the perceived adverse effects on yields through shading and reducing farm area. These factors, combined with the delay from planting to harvest of trees, have led to a shortage, as demonstrated by this female in her 80s, *"Tree shade is not good for crops so we cleared our farms and we expected to collect firewood from the forest but now we have nowhere to get firewood."* This scarcity narrative is supported by the fact that the average size of homegarden trees was small, the average DBH was 18.75 cm, and the average height was 8.62 cm, indicating many have been planted more recently. There was a strong theme that trees attract rainfall, mitigating the effects of drought. Many participants believe drought has increased in severity in recent years due to ongoing deforestation for conversion to sugarcane farms.

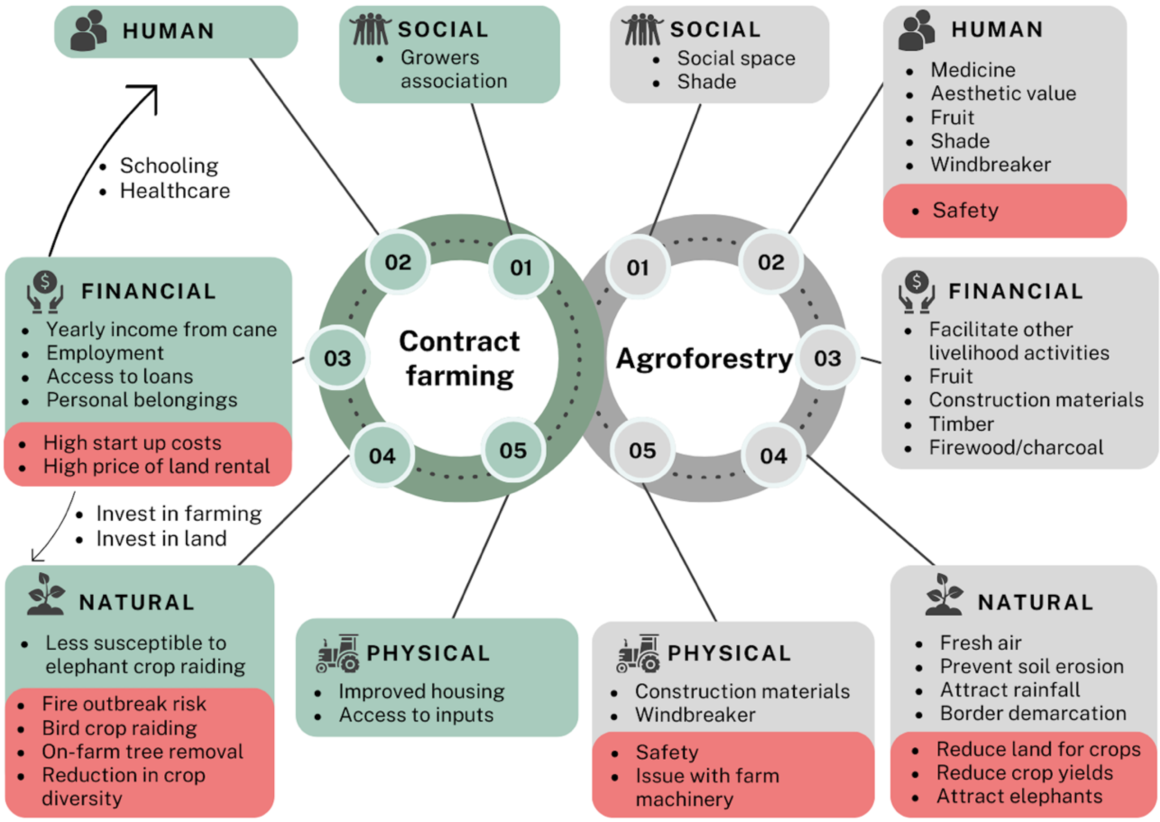

Figure 5.3 A conceptual diagram that emerged from the qualitative analysis of interviews. Green and grey indicates the ways agroforestry builds capital assets for resilience livelihoods whilst red indicates ways agroforestry can reduce capital assets.

5.5 Discussion

Understanding how different agricultural strategies influence household livelihood resilience to climate change and climate change mitigation is important in the context of decision-making for agricultural transformation in rural East Africa. We demonstrate the complexities of building livelihood resilience and mitigating climate change for smallholder farmers in the Kilombero Valley, Tanzania. Focusing on homegardens, an agroforestry farming approach, and contract sugarcane farming, we find that both strategies positively and negatively influence livelihood resilience and interact with each other, as well as livelihood shocks from unpredictable weather and crop raiding. Homegardens and contract farming contribute to a livelihood diversification strategy. However, while contract farming has aided access to and transfer of capital assets, cane growers bear all production risks that may be exacerbated by climate change. Clearing trees on farms for sugarcane has led to a concentration of trees within homegardens, suggesting they may be essential for ensuring direct benefits of trees for smallholders and be important aboveground carbon reserves within the landscape for climate mitigation. However, reducing crop diversity and trees to convert to sugarcane and mitigate wildlife crop damage is concerning for future food security. This may suggest that interventions promoting livelihood resilience for climate adaption and mitigation need to take a holistic approach and consider how different agricultural interventions, within the study context contribute to both positive and negative outcomes.

5.5.1 Livelihood resilience

5.5.1.1 Livelihood diversification

Agricultural growth corridors such as SAGCOT operate under 'win-win' narratives of green growth for poverty reduction and food security enhancement, where contract farming is promoted as a sustainable intensification strategy that will reduce pressure on natural resources through technologies such as agrochemicals or genetically modified seeds (SAGCOT, 2012). Livelihood diversification is a widely recognized strategy for reducing risk (Ellis, 2000) and is reported as a core idea underpinning and enabling sustainable intensification to mitigate risks and improve livelihoods (SAGCOT, 2012). This strategy is desired by smallholders but is constrained by access to land and resources (Lala et al., 2023). Our results show that agroforestry is part of a livelihood diversification strategy for farmers through direct benefits and facilitation of other livelihood activities, such as making palm oil or local brew for sale.

Moreover, farmers can utilize tree-related products to improve their financial capital by selling timber, physical capital by providing construction materials or human capital by providing fruit for healthy diets (Figure 5.3), as also demonstrated in (Quandt et al., 2019). This may help to increase households' overall resilience by balancing the five livelihood capitals, which are crucial for coping with shocks and disturbances, as they often complement each other in generating livelihoods (Jacobs et al., 2015). Homegardens are documented to address challenges in multiple poverty dimensions, particularly through providing food and nutritional security (Sharma et al., 2022). The dominance of fruit trees in homegardens is well documented in the tropics (Nnko et al., 2022; Sharma et al., 2022) and can supplement diets and sometimes provide income through sale, particularly during food shortages (Muthuri et al., 2023; Sharma et al., 2022). This may decrease dependency on using financial capital to buy food during times of shock, which is usually related to crop failures. The lack of a quantitative relationship of tree abundance driving livelihood resilience may be due to the scarcity of trees and recent planting in the area, meaning that many farmers have yet to realize the benefits of mature trees. The livelihood benefits of homegardens vary over time because of the different plant species and stages of establishment. In earlier stages, when trees are young, homegardens provide more vegetables, spices, and traditional medicine. At an older establishment stage where trees are old enough to produce fruit (up to 8 years for Mango) or large enough to be used for timber, fruits, tree products, and income are more prevalent (Muthuri et al., 2023).

Diversification is widely recognised as a key strategy for building resilience and adapting to environmental and economic shocks (Ellis, 2000). However, in the study area, land scarcity and persistent crop raiding by elephants constrain farmers' ability to maintain diverse farming systems. Farmers reported reducing their crop portfolios, particularly of subsistence food crops, when converting land to sugarcane, a trend driven both by market incentives and the need to avoid crops most vulnerable to elephant damage. This shift toward monocultures undermines agrobiodiversity and contradicts the diversification goals promoted under initiatives such as SAGCOT. Similar patterns have been documented elsewhere in East Africa, where commercial sugarcane cultivation has displaced traditional food production and eroded household resilience (Mwavu et al., 2016; Netondo et al., 2010). Our findings show that livelihood shocks, including those caused by wildlife damage, are associated with increased household food insecurity. This may be further exacerbated when households become reliant on sugarcane income to purchase food, particularly if that income is unstable or insufficient. Evidence from Uganda similarly indicates that land conversion from food crops to contract-farmed sugarcane can result in heightened food insecurity due to reduced self-sufficiency and limited financial capacity to purchase adequate nutrition (Mwavu et al., 2018).

Diversified farming systems have been shown to absorb shocks more effectively and maintain livelihood resilience by allowing households to stagger production across the year, buffer against market fluctuations, and ensure a steady supply of both food and income (Verchot et al., 2007; Thorlakson & Neufeldt, 2012; McCord et al., 2015). Yet in this context, elephant crop raiding is compounding the erosion of diversification: participants described the loss of fruit and vegetables from their homegardens, which has negative implications for health and household nutrition (Raphela & Pillay, 2021). In response, some farmers reported removing trees thought to attract elephants which may further reduce the diversity and ecological value of agroforestry systems. These responses may inadvertently reduce the long-term adaptive potential of their farming systems and limit the mitigation and adaptation potential of agroforestry in homegardens and farms as they attempt to ensure their safety and food security.

5.5.1.2 Spatial patterns

Our findings underline the complexity of the relationship between contract farming and livelihood resilience. Ownership of multiple farmed plots seems to benefit livelihood resilience, presumably because it allows farmers to build redundancy into the system against spatial shocks such as flooding and pest infestations (McCord et al., 2015). This ownership of multiple plots in the landscape has come about because KSC has a distance limit for cane supply. Consequently, sugarcane production is concentrated in the cane supply areas such as our study villages, while farmers then must go further afield to grow other crops such as rice (Sulle & Dancer, 2020; Isager et al., 2022).

Spatial patterns of agricultural production have dramatically changed since sugarcane was privatized in the 1990s, driving mass land purchasing (Isager et al., 2022). For those who own land, renting it to others when in acute financial need from crop failures or health problems, has also been documented elsewhere as land and rental prices have increased (Isager et al., 2022). However, for those who don't own land, spatial availability and prices may limit access to this natural asset.

Our results demonstrate how trees and contract farming interact to produce outcomes for livelihood resilience. The concentration of trees within home gardens appears to be partially driven by the expansion of sugarcane contract farming in the landscape, a trend that is likely to increase with the industry's plans to double production capacity. Once complete, an additional 1 million tons of sugarcane per year will be sourced from growers by 2026/2027 (KSCL, 2024) which is assumed to be met by farmers converting to sugarcane farming in areas outside the current cane supply area. Deforestation during land preparation for sugarcane is already observed in the landscape (Msomba et al., 2021). Households experience trade-offs in accumulating capital assets by reducing their on-farm tree abundance to grow sugarcane. This removes the potential benefits of trees to the soil as increased soil porosity, reduced runoff, and increased soil cover can help to maintain soil water infiltration and decrease soil moisture stress in years of low rainfall (Verchot et al., 2007). Many farmers did describe the loss of on-farm trees increasing the severity of drought on their crops. However, the loss of direct benefits such as firewood, timber, and fruit may be somewhat mitigated by homegarden trees and the protection of homegarden crops during drought.

5.5.1.3 Risks from climate change

Motivations for contract farming were usually based on the perceived ability to improve livelihoods and overcome livelihood shocks such as drought and wildlife crop damage. This aligns with research in Ghana, where farmers reported joining contract farming as a strategy to overcome the increasing impacts of climate change (Dapilah, 2023). Indeed, while sugarcane is resilient to temperature rise, variations in precipitation and water availability are expected to be the limiting factor to sugarcane yields in future climate scenarios within East Africa (Adhikari et al., 2015). In Tanzania, rainfall is predicted to decrease and become more unpredictable (United Republic of Tanzania (URT), 2007), effects which already appear to be experienced by farmers in the landscape (Balama et al., 2016). The SAGCOT Green-print claims that it has considered the climate and environmental risks of its policies for the livelihoods of local people and communities, acknowledging that rainfall is becoming less predictable, which is an increasing risk for farmers (SAGCOT, 2012). However, changing rainfall may negatively impact sugarcane yields for rain-fed agricultural systems such as in the Kilombero Valley (Adhikari et al., 2015). Farmers are already reporting declining income, and they expressed experiencing multiple livelihood shocks impacting their sugarcane yields, such as accidental fire outbreaks, extreme weather events, pests, disease, and cane not being harvested.

Sugarcane growers bear all production risks and associated costs, potentially leaving them indebted going into the next growing season and resulting in higher food insecurity. These production risks may undermine any improvements to smallholder resilience from contract farming (Dapilah, 2023), particularly for those farmers who have invested significant proportions of their available resources into sugarcane farming. Within the valley, smallholders desire access to water for irrigation to overcome the effects of increased drought (Lala et al., 2023). Suggestions from SAGCOT to buffer risk are access to irrigation, inputs, and markets, although it states that by 2030, less than 10% of the corridor will be irrigated (SAGCOT, 2012). Moreover, despite claiming significant investments are needed now to build adaptive capacity against climate risks in a multi-level approach, microinsurance is the only clear strategy for reducing the risk profile for smallholders (SAGCOT, 2012). In our study, many farmers had only recently converted to growing sugarcane. This complexity in outcomes, combined with high start-up costs of sugarcane and a delay in benefits due to growing seasons, alongside already depleted capital assets from livelihood shocks, may be a reason for the of quantitative relationships in the data.

5.5.2 Climate change mitigation

The homegarden carbon stocks in our study area is higher than the average for general agroforestry (24.4 t C ha^{-1}) and homegardens (28.2 t C ha^{-1}) found across East Africa in a recent systematic review (Muthuri et al., 2023) but aligns with individual field studies in Kenya and Ethiopia (Reppin et al., 2020; Birhane et al., 2020). As farms have been cleared, homegardens play a vital role in tree-cover restoration by maintaining tree diversity and may become an important contributor to climate mitigation efforts in the landscape. Indeed, Reppin et al., (2020) found homegardens to have the highest aboveground carbon stocks when comparing different land use types within households, and they are also important systems for below-ground carbon sequestration, particularly in the tropics (Feliciano et al., 2018). However, since we only measured aboveground carbon stocks in homegardens, we cannot quantitatively understand the influence converting to sugarcane has had on above and below-ground carbon at the farm and landscape level. However, there is evidence that converting to sugarcane results in initial carbon loses above and below ground (Beza & Assen, 2016) and soil carbon content declines with long-term sugarcane cultivation (Hess et al., 2016).

When considering mitigation potential, it is essential to consider the management of the trees for long-term carbon storage. Home-garden trees are usually retained for fruit, shade, aesthetics, weather protection and boundary demarcation and so, despite being pruned for firewood and other uses, are rarely cut down when compared to other land use types such as woodlots (Reppin et al., 2020). However, trade-offs between building livelihood resilience and mitigating climate change are expected to occur depending on how and when trees are used, clear felling of trees may threaten livelihood resilience by negatively impacting long term capital assets. If the population continues to increase (Msofe et al., 2019), leading to more densely populated villages and smaller or more closely spaced home plots, there may be safety issues from large trees around homes. Particularly if large storms become more prevalent in the future as predicted (United Republic of Tanzania (URT), 2007). Tree abundance was partially driven by plot size, a relationship found elsewhere in the literature in a study of over 20,000 households across five African counties (Miller et al., 2017). Contrary to our hypothesis, we found no relationship between tree abundance and aboveground carbon stocks, perhaps due to the predominately smaller size of home-garden trees in the study sites. Increasing land scarcity may reduce the benefits of agroforestry and climate mitigation potential by limiting the size and number of large trees. Moreover, the largest trees within homegardens were fruit trees similar to systems in Kenya (Reppin et al., 2020), particularly *M. indica* (muembe, mango), *E. guineensis* (mchikichi, oil palm) and *C. nucifera* (mnazi, coconut). This indicates a synergy between food security and climate mitigation potential, but a trade-off with biodiversity that is documented elsewhere in East Africa (Reppin et al., 2020). The restoration literature increasingly recognises that successful outcomes must balance ecological goals such as native species promotion, with local livelihood priorities that often depend on non-native but highly valued species (Birhane et al., 2020; Reppin et al., 2020).

5.6 Conclusion

Contract farming and homegarden agroforestry can contribute to a household's livelihood diversification strategy, allowing communities to respond to livelihood shocks. While the primary benefits of contract farming to livelihood resilience are a yearly income that can be transferred or used to build other capital assets, agroforestry paints a more holistic picture, providing direct and indirect benefits such as food, firewood, construction materials and a windbreak from storms. However, our results indicate that both farming strategies can positively and negatively affect livelihood resilience as smallholders grapple with trade-offs from limited land, costs of planting and maintaining, and risks to livelihood outcomes. Careful consideration of both positive and negative outcomes for livelihood resilience may contribute to decreasing the unintended negative impacts of top-down policies present in Agricultural Growth Corridors. Decision-makers need to support bottom-up climate adaptation strategies within farming systems, as farmers are already experiencing changing weather patterns. We stress that homegardens may provide important climate mitigation services in the landscape as trees on farms have been cleared to grow sugarcane and rice. We also highlight some areas that need further research, such as the intersection of wildlife-induced crop loss, contract farming and food insecurity. Our study is only a snapshot in time of a rapidly changing landscape, particularly as farmers bear all production risks for growing sugarcane and are starting to experience climate change. Our results reflect a limitation of only measuring a single timepoint shared by many livelihood resilience studies (Bahadur & Pichon, 2017; Quandt et al., 2019), which may be addressed by future resampling and a more extensive sample size. Understanding the nature of resilient livelihoods within the landscape will contribute to a more equitable transformation of smallholder systems.

5.7 Declarations

5.7.1 Acknowledgements

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5.7.2 Compliance with ethical standards

Ethical approval for this research study was granted by Newcastle University, project number 21-041-MOO under TAWIRI project number 2021-721-NA-2021-215. Free, prior, and informed consent was collected from participants before any data was collected. The authors declare no conflicts of interest.

5.7.3 Data availability

The quantitative data and code that support the findings of this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.25226258, https://doi.org/10.6084/m9.figshare.25226216 and, https://doi.org/10.6084/m9.figshare.25226207. The interview transcripts are not publicly available because of they contain information that could compromise the privacy of research participants, but the framework matrices for data analysis are openly available in Figshare at https://doi.org/10.6084/m9.figshare.25226288.

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5.7.5 Author contributions

E.D., M.P. and P.H. conceptualized and designed the research. E.D. and P.P.N. collected data in the field. E.D. wrote the manuscript. E.D. and S.R. did the data analysis. All authors reviewed, gave feedback, and approved the manuscript for publication.

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5.8 Supplementary Materials

5.8.1 Data collection

5.8.1.1 Household Survey

This study uses data collected from a household survey conducted between November to December 2019 (Milheiras et al., 2022) part of the Agrisys Tanzania project to construct an indicator for livelihood resilience. For this project, seven villages were randomly chosen from the northern Kilombero Valley area and within each village, households were randomly selected after consulting the village registry to ensure the sample reflected local socio-economic variation. Sampling effort was proportional to village size and one individual was surveyed per household, alternating between men and women where possible to avoid gender bias. Surveys were conducted by three locally trained enumerators (one of which also performed the semi-structured interview below). The final survey underwent pilot testing and a focus group discussion to ensure wording was suitable for the local context. The questionnaire was developed in English and translated to Swahili and data was collected using Open Data Kit Collect and Aggregate, taking approximately 60 minutes to complete. The questionnaire had nine different sections: basic information, household characteristics, health and education, livelihood and labour, assets, perspectives on ecosystem services and disservices, perspectives on nature, quality of life and farming practices.

5.8.1.2 Interview checklist

Please tell us about your farming history and livelihood. (crops grown, family involvement, contribution to livelihood activities, how make livelihood, livelihood opportunities, livelihood changes over past five years)

Please tell us about the role and value of trees and forest in relation to your farm and the surroundings. (Trees on the farm, forests, protected areas, villages reserves, agroforestry. Previous and present projects related to tree planting – institutions involved.)

Please tell us if trees contribute to your livelihood, this may be in any way that they help/hinder the household from achieving their livelihood (How, what species, and why those species, where are they growing, changes of this over past 5 years and how exactly)

Please tell us about the shocks you have experienced farming in the past 3 years e.g. drought, fire, flooding (only give example if the participant is struggling to understand) (what shocks, when were they, describe effects)

Please tell us about strategies you used to deal with these shocks (what strategies to deal, role of trees in dealing with these– how helped/hindered, what species)

Please tell us about the biggest shocks you are worried about farming in the next 3 years e.g. drought, fire, flooding (only give example if the participant is struggling to understand) (what challenges, when will these happen, describe potential effects)

Please tell us about strategies you are employing to deal with these future shocks (what strategies to deal, role of trees in dealing with these– how helped/hindered, what species)
Please tell us about the sugarcane industry in your area (Changes in the landscape, changes to people's livelihoods, planned expansion).

Sugarcane farmers only

Please tell us about growing sugarcane (How long, why did you start, what was on the land before sugarcane)

Please tell us how sugarcane changed your livelihood (opportunities to livelihoods, challenges to livelihood, use of trees)

Please tell us about any future concerns you have for your livelihood

Non sugar farmers

Please tell us why you choose to grow the crops you do (why start, how long)

Please tell us about any future opportunities to improve your livelihood

Please tell us about any future concerns you have for your livelihood

5.8.1.3 Wood Density

Table S5.1 Table of wood density values per species. Wood density (g cm^{-3}) was derived from the global wood density database (Zanne A. E., 2009). The database was filtered to only include individuals measured in the Africa tropical and extratropical region, and the average of values for each species was taken. If the wood density of a species was not measured in the Africa tropical and extratropical region, then we used the overall species average. If a species was not present on the database, we used the average of the genus across all regions.

Table S5.1 Wood density values for each species derived from Zanne A. E., (2009)

Species	Mean	Min	Max	SD	n	Level	Geography
Acacia mangium	0.507	0.474	0.594	0.051	7	species	Australia/PNG (tropical)
Acacia melanoxylon	0.531	0.389	0.637	0.084	8	species	Australia/PNG (tropical), South America (extra tropical), Oceania, Australia
Albizia lebbeck	0.613	0.453	0.8	0.119	7	species	South-East Asia, China, India
Allophylus rhus	0.513	0.26	0.77	0.139	13	genus	Africa (tropical), South America (tropical), Mexico, Africa (extratropical)
Anacardium occidentale	0.431				1	species	Africa (tropical)
Annona muricata	0.36	0.32	0.4	0.057	2	species	Central America (tropical), South America (tropical)
Anthocleista grandiflora	0.578	0.523	0.633	0.078	2	species	Africa (tropical), Africa (extratropical)
Antiaris toxicaria	0.383	0.31	0.568	0.058	17	species	Africa (tropical)
Artocarpus altilis	0.495				1	species	Africa (tropical)
Artocarpus heterophyllus	0.492	0.44	0.551	0.043	6	species	South America (tropical), China, South-East Asia (tropical)
Averrhoa bilimbi	0.5	0.42	0.56	0.072	3	species	India, South-East Asia (tropical)
Azadirachta indica	0.64	0.66	0.62	0.028	2	species	South-East Asia, South-East Asia (tropical)

Bauhinia thonningii	0.808	0.58	1.197	0.242	12	genus	Australia/PNG (tropical), South America (extra tropical), South-East Asia (tropical), Afria (extratropical), India
Blighia unijugata	0.508	0.5	0.516	0.011	2	species	Africa (tropical)
Borassus aethiopum	0.87				1	genus	South-East Asia
Breonadia unijugata	0.818				1	genus	Africa (tropical)
Bridelia micrantha	0.51	0.435	0.577	0.055	7	species	Africa (tropical), South-East Asia (tropical)
Cedrela odorata	0.447	0.34	0.66	0.094	14	species	South America (tropical), central America (tropical), Mexico
Citrus aurantiifolia	0.74	0.7	0.78	0.057	2	genus	India, South-East Asia
Citrus aurantium	0.74	0.7	0.78	0.057	2	genus	India, South-East Asia
Citrus clementina	0.74	0.7	0.78	0.057	2	genus	India, South-East Asia
Citrus limona	0.74	0.7	0.78	0.057	2	genus	India, South-East Asia
Citrus sinensis	0.78				1	species	India
Cocos nucifera	0						
Codiaeum variegatum							
Deinbollia borbonica							
Delonix regia	0.534	0.379	0.689	0.219	2	species	Africa (tropical)
Diospyros spp	0.705	0.46	1.076	0.129	32	genus	Africa (tropical), Australia/PNG (tropical), South America (tropical), Australia

Diospyros zombensis	0.705	0.46	1.076	0.129	32	genus	Africa (tropical), Australia/PNG (tropical), South America (tropical), Australia
Elaeis guineensis	0						
Eucalyptus spp	0.803	0.3	1.087	0.144	461	genus	South-East Asia (tropical), Australia, Australia/PNG (tropical), China
Ficus spp	0.412	0.14	0.68	0.093	153	genus	Central America (tropical), Australia/PNG (tropical), South-East Asia (tropical), Africa (extratropical), Mexico, China, India, South America (extratropical), Africa (extratropical), Africa (tropical)
Ficus sycamorus	0.422	0.413	0.439	0.015	3	species	Africa (extratropical), Africa (tropical)
Gmelina arborea	0.423	0.391	0.479	0.03	6	species	Africa (tropical)
Grevillea robusta	0.513	0.51	0.517	0.005	2	species	Africa (tropical)
Grisicidia sepium	0.56				1	species	Africa (tropical)
Khaya anthotheca	0.491	0.43	0.552	0.043	11	species	Africa (tropical)
Kigelia africana	0.564				1	species	Africa (extratropical)
Leucaena glauca	0.68	0.45	0.94	0.176	7	genus	South America (tropical), Central America (tropical), Mexico, South-East Asia (tropical)

Leucaena leucocephala	0.683	0.45	0.84	0.206	3	species	South America (tropical), Mexico, Central America (tropical)
Mangifera indica	0.536	0.52	0.552	0.023	2	species	Africa (tropical)
Mdamba							
Milicia excelsa	0.575	0.44	0.671	0.061	24	species	Africa (tropical)
Moringa oleifera	0.262				1	species	South-East Asia (tropical)
Mpemba duma							
Mpilipili dume							
Muntingia calabura	0.3				1	species	South America (tropical)
Palm spp	0						
Persea americana	0.523	0.516	0.53	0.013	2	species	Africa (tropical)
Polyalthia longifolia	0.564	0.537	0.59	0.037	2	species	India, South-East Asia (tropical)
Psidium guajava	0.652	0.579	0.8	0.101	4	species	South America (extratropical), South America (tropical), South-East Asia (tropical)
Senna siamea	0.66	0.44	0.87	0.176	4	species	South America (tropical), South-East Asia (tropical)
Sorindeia madagascariensis	0.56				2	species	Africa (extratropical)
Spondias dulcis	0.37				1	species	Australia/PNG (tropical)
Syzygium cumini	0.673	0.604	0.76	0.08	3	species	China, India
Syzygium guineense	0.61	0.57	0.649	0.035	3	species	Africa (extratropical), Africa (tropical)
Tamarindus indica	0.903	0.732	1.05	0.131	4	species	Africa (extratropical), Africa (tropical)

Tectona grandis	0.601	0.493	0.717	0.058	33	species	Africa (tropical)
Theobroma cacao	0.42	0.41	0.43	0.014	2	species	South America (tropical)
Thespesia garckeana	0.732				1	species	Africa (extratropical)
Trichilia dregeana	0.482				1	species	Africa (extratropical)
Vangueria infuasta	0.689				1	species	Africa (extratropical)
Vitex doniana	0.4				1	species	Africa (extratropical)
Voacanga africana							

5.8.1.4 Hypothesis-driven causal relationships

Table S 5.2 Hypothesis-driven causal relationships examined using the structural equation model.

Response	Predictor	Hypothesis	Rationale
Livelihood resilience	Length sugarcane farmer	Contract farming for longer will lead to higher livelihood resilience	A systematic review of the scientific literature found that contract farmers tend to be significantly richer than the average farmer (Ton et al., 2018). Financial capital can be built and exchanged, theoretically then increasing other capital assets. In contrast, Machimu & Kayunze (2019) found that sugarcane farmers had been unable to improve their livelihoods through sugarcane farming, while Sulle & Dancer (2020) argue that sugarcane has led to increased social differentiation where those with more land are able to accumulate assets but those with less land are not drawing on structural inequalities. Moreover, a two – three-year delay for deriving financial benefits from sugarcane farming arises due to start-up costs and a delay in returns across the growing season and renting a sugarcane farm is much more expensive than rice farms in other locations which may limit returns (ED personal obs).
	Home plot size	A larger plot will increase livelihood resilience	A larger plot has more space for livelihood activities and accumulating capital assets such as livestock, trees, and crops (Quandt et al., 2019).
	Homegarden tree abundance	More trees will increase livelihood resilience	Agroforestry trees can increase income by providing products for sale (Quandt et al., 2019; Ota et al., 2020). Indirectly, agroforestry can increase farm productivity and wealth through enhanced environmental conditions, e.g. soil fertility, and microclimate regulation reducing heat stress (Thorlakson & Neufeldt, 2012; Ota et al., 2020).

	Tree species diversity	Higher trees species richness will increase livelihood resilience	Higher tree diversity is associated with a higher livelihood resilience as there is higher availability of multiple products and benefits (Quandt et al., 2019).
	Distance to tarmac road	Those closer to a tarmac road will have higher livelihood resilience	Living nearby the tarmac main road will provide greater access to markets and services and is shown to confer financial benefits (Jacoby, 2000).
	Number of livelihood activities	Livelihood diversification will increase livelihood resilience	Livelihood diversification builds redundancy into the system (Quandt et al., 2019; Ellis, 2000; Balama et al., 2016).
	Respondent age	Older participants will have higher livelihood resilience	Older farmers have more time and ability to accumulate capital assets.
	Number of plots owned	Farmers with more farming plots will have a higher livelihood resilience	Multiple plots in different areas may build redundancy into the system: allowing farmers to grow more crops and insuring them against livelihood shocks e.g. flooding (ED personal observation).
Carbon stocks per hectare	Homegarden tree abundance	Higher tree abundance will increase carbon stocks	Trees store carbon in aboveground biomass (Verchot et al., 2007; Mbow et al., 2014; Reppin et al., 2020).
	Tree species diversity	Higher tree diversity will increase carbon stocks	Evidence is varied. (Reppin et al., 2020; Birhane et al., 2020) found no association of species richness and carbon stocks, while a global meta-analysis by (Ma et al., 2020) found a positive effect.

Homegarden tree abundance	Number of livelihood activities	Households with more livelihood activities are more likely to have more trees	Growing and selling timber can be part of a diversification strategy for farmers (Quandt et al., 2019; Kuyah et al., 2020).
	Home plot size	Larger plot size will increase tree abundance	Those practicing agroforestry had bigger farms (Quandt et al., 2019).
	Age of respondent	Older farmers are more likely to have more trees	Older farmers are more likely to own their home and have the time to accumulate trees (Quandt et al., 2019).
Tree species diversity	Homegarden tree abundance	More trees will increase the probability of a higher species richness	Farmers with more trees will grow more species for higher availability of multiple products (Quandt et al., 2019).
Length sugarcane farmer	Age of respondent	Older farmers will have farmed sugarcane for longer	Older farmers will have been farming for longer and so have a higher chance of converting to sugarcane.
	Distance to tarmac road	Those closer to the tarmac road will have been growing sugarcane for longer	Villages closer to the tarmac road are also closer to the sugarcane plantation so will have likely been some of the first villages where farms were converted (ED personal observation).

5.8.2 Data Analysis

5.8.2.1 Livelihood resilience indicators

Table S5.3 A description of the collated variables from the household survey and interview to measure household livelihood resilience themed under the five capital asset categories. Rows highlighted in bold are those used in the structural equation modelling to create the latent variable livelihood resilience

Category	Description of indicator | Variable type | Categories	Data source	Reason for inclusion
Financial			
Formal banking	Has a bank account or phone banking | binary | 1 = yes, 0 = no	HHS	Literature
Household belongings or services	**Total household assets from electricity, solar panels, television, radio, mobile phone, animal drawn plough, tractor, fridge, improved cooking stove, bicycle, motorbike, car, household-owned water tap | Integer | 0 = none, 13 = all**	**HHS**	**Literature**
Savings	Amount of savings| ordinal | 0 = 0, 1 = ≤ 100,000, 2= 100,000-500,000, 3=500,000-1,000,000, 4 = >1,00,000	HHS	Literature
Perception of income generating opportunities	Satisfaction with the opportunities available to the participant to generate income | ordinal | 0 = don't know 5 = completely agree	HHS	Literature
Human			
Labour availability	**Number of people who contribute to household income | integer**	**HHS**	**Literature**
Education	Highest education level of respondent | ordinal | 0 = no formal education, 1 = No formal education but can read and write, 2 = Primary (Standard 1-4), 3 = Primary	HHS	Literature

	(Standard 5-7), 4 = secondary (Form 1-4), 5=secondary (Form 5-6), 6 = college, 7 = university		
Health problems impact on ability to practice livelihood	Any days too unwell to work in the last 12 months | binary | 1 = yes, 0 = no	HHS	Literature
Social			
Role or responsibility	Publicly known in the village for a role or responsibility | binary | 1 = yes, 0 = no	HHS	Literature
Participation in groups	**Number of groups a member of | integer**	**HHS**	**Literature**
Access to information	Received farming advice in the past 3 years | binary | 1 = yes, 0 = no	HHS	Local context
Physical			
Access to drinking water	Minutes walking to reach drinking water | ordinal | 0 = 0-1, 1 = 2-10, 2 = 11-120	HHS	Literature
Access to irrigation	Access to irrigation for farming activities | binary | 1 = yes, 0 = no	HHS	Local context
Distance to road	Distance of house to road | meters	GPS of house to road	Literature
Access to inputs	**Number of times synthetic inputs were applied in the past year | integer**	**HHS**	**Local context**
Natural			

Size of farm	**Total currently farmed area owned and rented | acres | continuous**	**Interview/ HHS**	**Literature**
Ownership of farmland	The respondent's household owns farming plots | binary | 1 = yes, 0 = no	Interview/HHS	Literature
Diversity of farm crops planted throughout the year	Number of different crops planted in the previous year | integer	Interview/HHS	Literature
Livestock	Most valuable livestock owned | Ordinal | '3'= cattle, '2'= pigs, sheep, goat, '1'= poultry, fish, rabbits, '0'= none	HHS	Literature
Perception of fertile land availability	Perception of access to enough fertile land to meet household needs | ordinal | 0 = don't know 5 = completely agree	HHS	Literature/Local context

5.8.2.2 Spearman's rank correlations

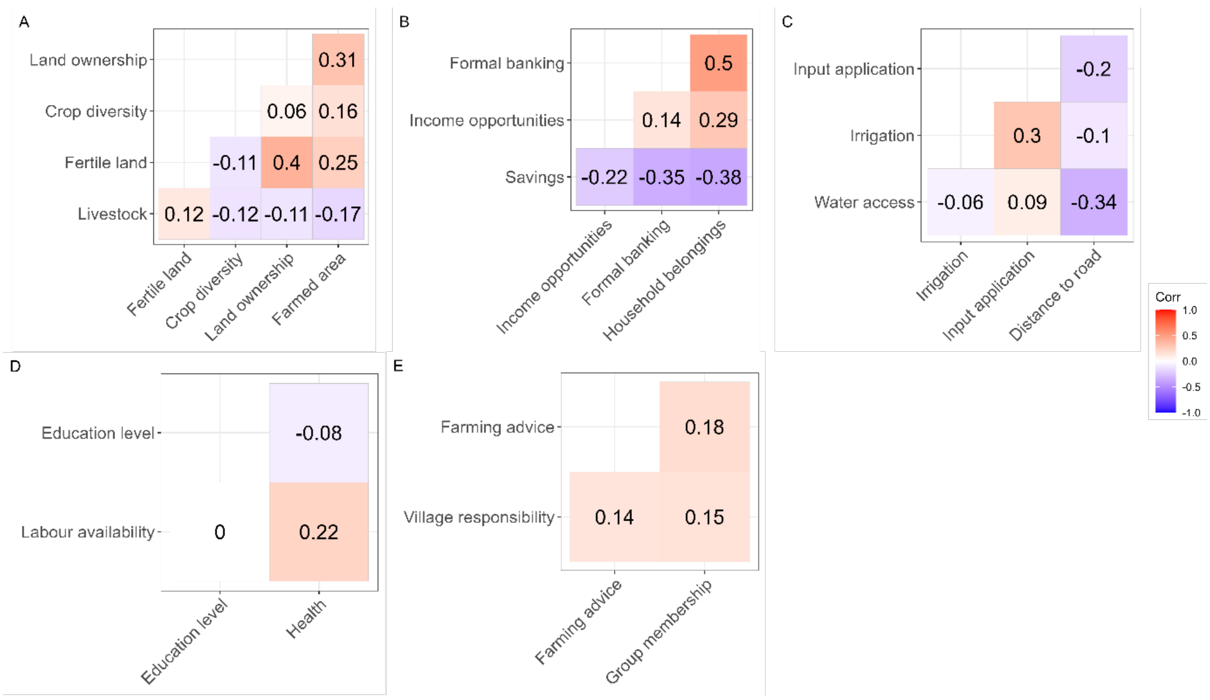

Figure S5.1 Spearman's rank correlations between variables within each capital asset category based on the household livelihood resilience approach. (A) natural capital, (B) financial capital, (C) physical capital, (D) human capital, (E) social capital.

5.8.3 Results

5.8.3.1 Household and homegarden characteristics

Table S5.4 Summary of household and homegarden characteristics

Characteristics n=65	Median	Mean	Min	Max	Range	SD
Household size (# of people)	4	4.46	1	9	8	2.26
Age of respondent (years)	53	53.7	22	84	60	13.76
Length sugarcane farming (years)	2	6.1	0	37	37	9
Number of livelihood activities practised	4	4.3	1	10	9	1.99
Distance to tarmac road	349.9	2044.4	13.3	6128.7	6115.4	2559.5
Number of plots farmed	2	2.2	1	5	4	0.96
Number of plots owned	1	1.4	0	5	5	1.18

Home plot size (ha)	0.05	0.066	0.04	0.29	0.29	0.06
Tree abundance	11	18.2	0	90	90	19.7
Tree species diversity	4	5.9	0	20	129	4.8
Tree density /ha	240	314	0	1413	1413	317.57
Carbon stocks t C ha-1	29.4	53.1	0	290.9	290.9	61.33
Livelihood resilience latent variable						
Total farmed area (acres)	4	6.2	0.25	60	59.75	10.23
Number of belongings or services	4	4.5	1	9	8	2.17
Education	2.7	3 (Primary (Standard 5-7)	0	6 (college)	6	1.28
Access to inputs	3	3.9	0	17	17	3.63
Access to information	0	0.4	0	1	1	0.49

5.8.3.2 Species abundance across homegardens

Table S5.5 Species abundance across plots measured

Species Latin	Species local name	Total abundance	Number of plots present
Acacia mangium	Mzanzibari	73	11
Acacia melanoxylon	Mzanzibari	17	8
Albizia lebbeck	Mtanga	7	3
Allophylus rhus		1	1
Anacardium occidentale	Nkorosho	1	1
Annona muricata	Mstafeli	30	16
Anthocleista grandiflora	Mbala	5	2
Antiaris toxicaria	Msenda	4	2
Artocarpus altilis	Mshelisheli	2	2
Artocarpus heterophyllus	Mfenesi	35	19
Averrhoa bilimbi	Mbilimbi	4	4
Azadirachta indica	Mwarubaini	7	6

Bauhinia thonningii	Mgobwali/Mkomba	1	1
Blighia unijugata	Msebele/Mchebele	1	1
Borassus aethiopum	Mhama	1	1
Breonadia unijugata	Unijugata	1	1
Bridelia micrantha	Mwija	7	1
Cedrela odorata	Mnukanuka	16	4
Citrus aurantiifolia	Mdimu	5	5
Citrus aurantium	mdalanzi	3	1
Citrus clementina	mchenza	3	3
Citrus limona	Mlimao	53	26
Citrus sinensis	Mchungwa	62	28
Cocos nucifera	Mnazi	109	29
Codiaeum variegatum		2	1
Deinbollia borbonica	Mpilipili dume	2	1
Delonix regia	Mkakaya	2	1
Diospyros spp		1	1
Diospyros zombensis	Nyakatitu	1	1
Elaeis guineensis	Mchikichi	109	30
Eucalyptus spp	Mkaratusi	14	2
Ficus spp	Mkuyu	1	1
Ficus sycamorus	Mkuyu	7	3
Gmelina arborea	Mtiki mweupe	46	6
Grevillea robusta	Mgrivea	1	1
Gliricidia sepium		11	5
Khaya anthotheca	Mkangazi	11	8
Kigelia africana	Mwegea/Mwicha/Mvungwa	4	3
Leucaena glauca		2	2
Leucaena leucocephala	Mlusina	16	2
Mangifera indica	Muembe	275	51
	Mdamba	1	1
Milicia excelsa	Mvule	3	1
Moringa oleifera	Mlonge	3	2

	Mpemba duma	2	1
	Mpilipili dume	2	2
Muntingia calabura	Muharadali	4	2
Palm spp	Mchikichi	2	1
Persea americana	Mparachichi	14	8
Polyalthia longifolia	Mhashok	27	9
Psidium guajava	Mpera	34	15
Senna siamea	Mjohoro	79	22
Sorindeia madagascariensis	Mpilipili	2	2
Spondias dulcis		2	2
Syzygium cumini	Mzambarau	9	7
Syzygium guineense	Mzambarau pori	3	1
Tamarindus indica	Mkwaju	1	1
Tectona grandis	Mtiki	31	9
Theobroma cacao	Mkakao	1	1
Thespesia garckeana		1	1
Trichilia dregeana	Muhubasi	2	2
Vangueria infuasta	Msadasada	1	1
Vitex doniana	Mfuru	2	1
Voacanga africana	Mkongosa	4	1

5.8.3.3 Tabular overview of the standardized factor loadings and standard errors for the measurement model

Table S5.6 Standardized factor loadings for the latent variable livelihood resilience in the measurement model using Confirmatory Factor Analysis

Livelihood resilience	**Standardized factor loadings**	**Standard errors**
Financial: Number of belongings or services	0.789	0.317
Natural: Total farmed area (acres)	0.385	0.108
Human: Labour availability	0.559	0.506
Physical: Access to inputs	0.318	0.222
Social: Participation in groups	0.516	1.403

5.8.3.4 Tabular overview of structural equation model results

Table S5.7 Structural relations of drivers on livelihood resilience, carbon stocks per hectare, tree abundance, tree diversity and length of sugarcane farming. P values in bold are below 0.05 threshold.

Response	Predictor	Coefficient	Standardised coefficient	Standard error	Lower confidence interval	Upper confidence interval	Z	p-value
Livelihood resilience	Length sugarcane farmer	0.03	0.16	0.03	-0.03	0.08	0.89	0.37
	Home plot size	6.09	0.26	6.637	-5.01	22.1	0.92	0.36
	Homegarden tree abundance	-0.022	-0.30	0.026	-0.08	0.04	-0.83	0.41
	Tree species diversity	0.036	0.12	0.105	-0.18	0.24	0.35	0.73
	Distance to tarmac road	-0.00	-0.19	0.0	-0.0003	0.0001	-1.1	0.27
	Number of plots owned	0.65	0.54	2.7	0.13	1.12	2.7	**0.007**
	Number of livelihood activities	0.16	0.22	1.1	-0.16	0.45	1.05	0.29
	Respondent age	-0.014	-0.13	-0.63	-0.06	0.03	-0.64	0.53
	Homegarden tree abundance	0.008	0.003	0.01	-1.57	1.41	0.01	0.99

Carbon stocks per hectare	Tree species diversity	4.621	0.37	1.51	-1.44	10.6	1.51	0.13
Homegarden tree abundance	Number of livelihood activities	3.4	0.35	2.15	0.21	6.2	2.2	**0.031**
	Home plot size	115.9	0.36	2/06	52.23	272.22	2.06	**0.039**
	Age of respondent	0.23	0.16	1.26	-0.19	0.52	1.3	0.21
Tree species diversity	Homegarden tree abundance	0.22	0.88	13.32	0.18	0.25	13.3	**0.00**
Length sugarcane farmer	Age of respondent	0.20	0.3	2.58	0.06	0.37	2.6	**0.01**
	Distance to tarmac road	-0.001	-0.26	-2.56	-0.001	-0.0002	-2.56	**0.011**

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6-Conclusions

My thesis addresses the benefits and trade-offs of tree-cover restoration and how methods such as participatory scenarios can be used as a tool to explore these. I focussed on three scientific advancements needed to improve and scale restoration actions (Figure 6.1). *Chapter 1* introduced the contextual background, knowledge gaps and the research questions addressed within each chapter. I focussed firstly at the global scale on the evidence that exists on the use of participatory scenarios in restoration planning to explore trade-offs in restoration outcomes (*Chapters 2 and 3*). *Chapters 4 and* 5 then focussed on the Kilombero Valley, Tanzania. I used participatory scenario workshops to investigate perceptions, attitudes and desires farmers' associate with tree restoration, on the farm and in the wider landscape (*Chapter 4*). For the final data chapter (*Chapter 5*), I focussed on assessing how agroforestry and contract farming contribute to livelihood resilience to climate change and climate change mitigation.

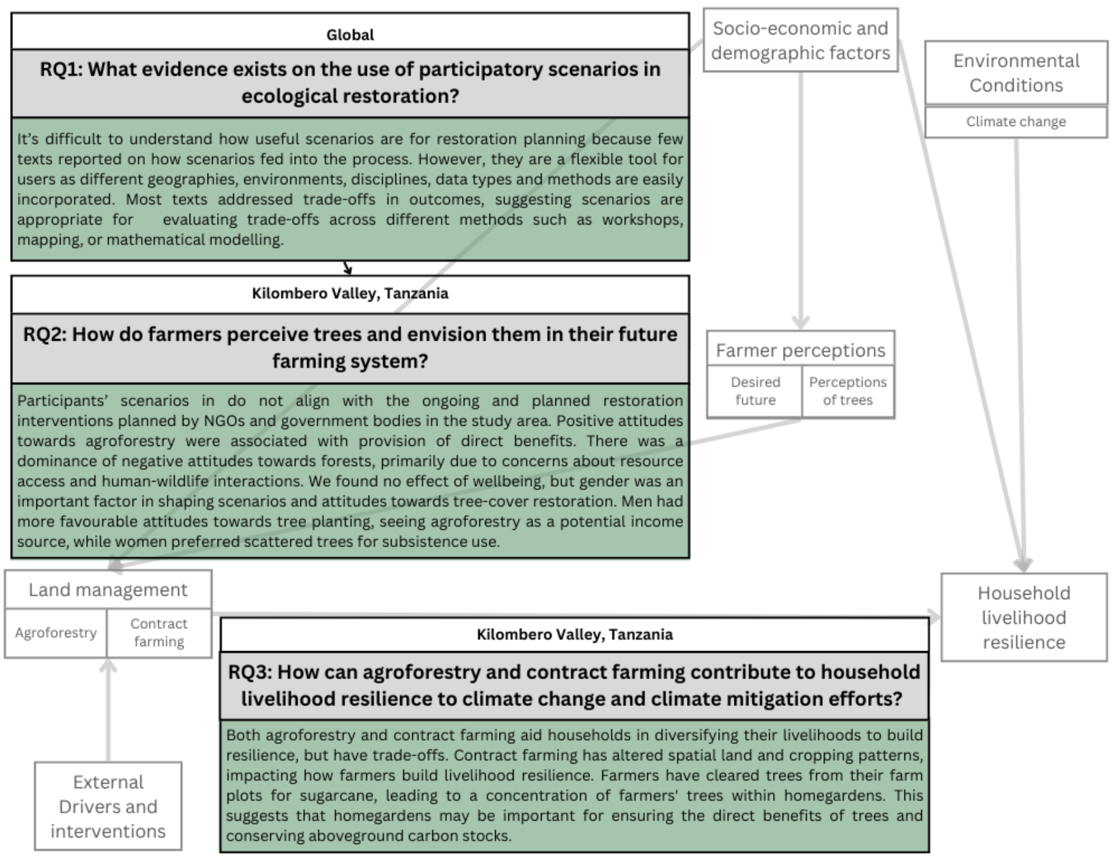

Figure 6.1 A summary of the key results from each scientific advancement addressed.

6.1 Conclusions, significance and novelty of the thesis

6.1.1 Conclusion 1 '*Participatory scenarios allow for the integration of method approaches and data across social and ecological sciences. This in turn allows for a more nuanced evaluation of value trade-offs in restoration planning'*

Conclusion 1 '*Participatory scenarios allow for the integration of method approaches and data across social and ecological sciences. This in turn allows for a more nuanced evaluation of value trade-offs in restoration planning'*

Findings	**Significance**	**Novelty**
Chapter 2 & 3: Different geographies, environments, disciplines, data types and methods are incorporated when using participatory scenarios. Most texts addressed trade-offs in outcomes across a variety of social, environmental, economic, and land-use categories. Chapter 4: Farmers primarily discussed the trade-offs related to social and economic outcomes from tree-cover restoration in their scenarios.	These results support the claims of Metzger et al., (2017), that participatory scenarios are suitable for evaluating diverse trade-offs across different knowledge domains and methods. They validate that participatory scenarios are a useful tool to integrate social considerations for 'people-centered' ecosystem restoration (Elias et al., 2022), allowing for integration of social dimensions which have been neglected in restoration planning in the past (Wortley et al., 2013).	Chapter 3 is the first study to systematically map the evidence on participatory scenarios in restoration planning according to the guidelines of the Collaboration for Environmental Evidence.

Figure 6.2 A summary of the findings, significance and novelty of the conclusion of this thesis that participatory scenarios allow for the integration of method approaches and data across social and ecological sciences.

***Novelty:** Chapter 3 is the first study to systematically map the evidence on participatory scenarios in restoration planning according to the guidelines of the Collaboration for Environmental Evidence.*

Findings: The finding across *Chapters 2,3 and 4* is that participatory scenarios are flexible and useful tool to evaluate restoration trade-offs. In *Chapters 2 and 3,* texts tended to list authors from multiple professions and address multiple restoration objectives. 92% of texts addressed trade-offs in restoration outcomes and 61% of studies took a mixed-methods approach and many built on or combined participatory scenarios with other scientific methods or frameworks such as multi-criteria analysis or InVEST ecosystem service models.

Moreover, *Chapter 3*, participatory scenario studies from a global set revealed that stakeholders consistently evaluated trade-offs across a variety of social, environmental, economic, and land-use categories. These studies demonstrated that participants valued diverse restoration outcomes, including improvements in water quality, sustainable production, recreation, and cultural values. Similarly, in *Chapter 4*, focused on the Kilombero Valley, Tanzania, farmers primarily discussed the trade-offs related to social and economic outcomes from tree-cover restoration, emphasizing household-level concerns such as food security and income diversification.

Significance: These results support the claims of Metzger et al., (2017), that participatory scenarios are suitable for evaluating diverse trade-offs across different knowledge domains and methods. They validate that participatory scenarios are a useful tool to integrate social considerations for 'people-centered' ecosystem restoration (Elias et al., 2022), allowing for integration of social dimensions which have been neglected in restoration planning in the past (Wortley et al., 2013).

Chapters 2 and 3 also highlighted knowledge gaps in the application of participatory scenarios for restoration planning. Moreover, while participatory scenarios can reveal areas of both alignment and conflict between stakeholder priorities, it is important to recognise that such processes are not inherently equitable. Trade-offs are often negotiated within existing power structures, where certain actors, such as government agencies, donors, or conservation NGOs, may hold more influence over final decisions than smallholder farmers or community representatives (Oteros-Rozas et al., 2015). This raises critical questions about who ultimately decides which trade-offs are acceptable, and who bears the consequences.

To address these imbalances, future restoration planning should incorporate deliberative mechanisms that explicitly foreground equity. Greater participation should be planned from the outset of restoration projects, including the co-definition of restoration objectives. Oteros-Rozas et al. (2015) noted that scenarios can be limited by the absence of both powerful and marginalised stakeholders. I therefore recommend the use of more systematic methods, such as stakeholder analysis, to support the inclusive selection of participants and ensure a diversity of perspectives and interests are meaningfully represented (Metzger et al., 2017; Reed et al., 2013).

6.1.2 Conclusion 2 'Tree-cover restoration interventions need to be tailored with smallholders to address their specific attitudes, concerns, motivations and trade-offs'

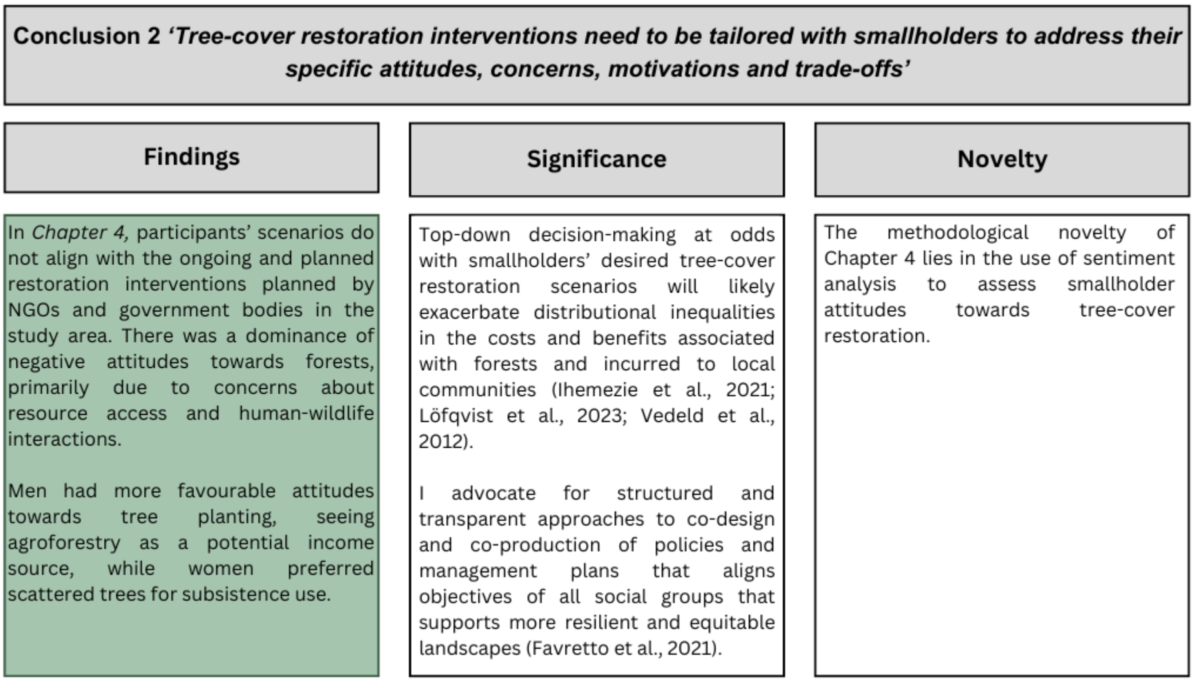

Figure 6.3 A summary of the findings, significance and novelty of the conclusion of this thesis that tree-cover restoration interventions need to be tailored with smallholders to address their specific attitudes, concerns, motivations and trade-offs

Novelty: *The methodological novelty of Chapter 4 lies in the use of sentiment analysis to assess smallholder attitudes towards tree-cover restoration.*

Findings: Farmers' scenarios do not align with the ongoing and planned restoration interventions planned by NGOs and government bodies in the Kilombero Valley (*Chapter 4)*. They are looking to expand and strengthen protected forest areas which would increase the number of farms bordering protected areas. However, participants wanted to be surrounded by neighbouring farms for safety from wild animals and pests and to minimise crop losses. There were strong negative attitudes towards forest driven by the perception that farmers no longer have access to the direct benefits of forests and mainly face challenges from fuel wood shortages and crop losses caused by wild animals from the surrounding forest areas. Negative attitudes towards agroforestry were most strongly associated with the perception that crops, particularly rice and sugarcane are negatively impacted by trees due to space, light and root competition. Within their ideal scenarios, trees were usually placed on the border or in separate small plantations to minimise this trade-off.

Moreover, the results of *Chapter 4* showed gendered differences in ideal tree-cover restoration scenarios. Men desired more intensive agroforestry systems and had more positive attitudes towards tree-cover restoration than women. They desired plantations for timber or sometimes fruit, perceiving the income from timber and hanging beehives for honey production as additional livelihood opportunities. Whereas women preferred a few scattered trees, more often wanting to expand their food crops and minimise the effects of trees on yields, relying on a smaller number of trees for shade and household use.

Significance: Scaling restoration of trees and tree cover at landscape scale within the Kilombero Valley will require the support of smallholder farmers. However, the current approach to restoration planning is driven by organisations with priorities different from those of local farmers, who control decision-making (Pfeifer et al., 2022; Southern Tanzania Elephant Program, 2024). This is reflected in the differences between smallholders' restoration scenarios and the reality on the ground. I advocate for structured and transparent approaches to co-design and co-production of policies and management plans that aligns objectives of all social groups as this has been shown to support more resilient and equitable landscapes in Africa (Favretto et al., 2021). These approaches can help ensure trade-offs are minimised to smallholders and that the needs of both men and women are addressed, promoting equitable access to resources and opportunities for participation (Kiptot & Franzel, 2011).

The current plans for expanding and strengthening protected areas within the study region while simultaneously restricting local use will likely exacerbate distributional inequalities in the costs and benefits associated with forests and incurred by local communities (Ihemezie et al., 2021; Löfqvist et al., 2023; Vedeld et al., 2012). Low benefits from conservation have been shown to trigger negative attitudes towards forest conservation in Sub-Saharan Africa (Ihemezie et al., 2021; Kideghesho et al., 2007), something that may also be at play within the Kilombero Valley. Not only does public opinion have the potential to shape conservation policy and implementation but, positive attitudes are essential for long-term conservation support (Massingham et al., 2023; Ihemezie et al., 2021). Moreover, modelling has predicted increasing forest area which subsequently will raise the overall probability of crop raiding risk and alter its spatial distribution, likely increasing human wildlife interactions in the future increasing crop damage and thus negative impacts on local livelihoods (Pfeifer et al., 2022). This modelling also highlights how scaling restoration is not only a spatial challenge but also a temporal one. Many benefits, such as shade, fruit, or carbon storage, take years to materialise. This time lag influences both farmer uptake and policy impact, and needs to be factored into restoration design, monitoring, and support structures (Chazdon et al., 2020).

Positive attitudes towards agroforestry have been shown to reinforce intentions to integrate and adopt trees into farming systems (Amare & Darr, 2024; Buyinza et al., 2020) and have been associated with positive benefits to livelihoods (Shennan-Farpón et al., 2022). While this chapter did not directly assess whether participants' attitudes translated into behavioural outcomes, the findings point to a clear gap between what farmers would like to do, such as growing more trees, owning larger farms, or investing in irrigation, and what they are currently able to do given their circumstances. This aligns with literature that highlights how structural barriers, including access to land, financial capital, and tenure security, can constrain the translation of intention into action (Emerton & Snyder, 2018; Lala et al., 2023). In this context, aspirations toward agroforestry may reflect not only environmental values but also desires for greater autonomy and control over productive resources (Ribot & Peluso, 2003). The broader literature on behavioural decision-making in agroecological systems reinforces that positive attitudes are necessary but not sufficient for practice adoption; enabling conditions are equally important (Meijer et al., 2015). Future research could explore this intention–action gap more explicitly, to identify which combinations of institutional, economic, and social factors allow farmers to act on their preferences.

6.1.3 Conclusion 3 'Agroforestry can diversify livelihoods and increase household livelihood resilience when integrated into broader livelihood strategies'

Conclusion 3 'Agroforestry can diversify livelihoods and increase household livelihood resilience when integrated into broader livelihood strategies''

Findings	Significance	Novelty
Chapters 4 and 5, indicate that agroforestry can diversify livelihoods and improve livelihood resilience. In *Chapter 4,* 80% of farmers wanted to include trees in their farming system in their ideal farming scenario, usually for the purpose of diversification alongside other crops. Homegarden agroforestry emerges as a strategy that ensure households can maintain diversity whilst also engaging in contract farming. While the primary benefits to household livelihood resilience of contract farming are a yearly income that can be transferred or used to build other capital assets, agroforestry paints a more holistic picture, providing direct and indirect benefits such as food, firewood, construction materials and a windbreaker from storms.	Farmers want diversified agricultural systems and it is a crucial strategy for resilience and adaptation (Ellis, 2000; Lala et al., 2023). Diversified farming systems with agroforestry have been documented to suffer fewer shocks and maintain a household's ability to adapt to changing conditions (Verchot et al., 2007; Thorlakson & Neufeldt, 2012), as they allow a household to expand their crops for market, space out production across the year and build redundancy into the agricultural system (McCord et al., 2015).	The novelty in the objectives and methods of Chapter 5 was using a systems model and mixed-method approach to examine how contract farming and agroforestry interact to build livelihood resilience to climate change.

Figure 6.4 A summary of the findings, significance and novelty of the conclusion of this thesis that agroforestry can diversify livelihoods and increase household livelihood resilience when integrated into broader livelihood strategies.

Novelty: *The novelty in the objectives and methods of Chapter 5 was using a mixed-method approach to examine how contract farming and agroforestry interact to build livelihood resilience to climate change, as these topics have traditionally been examined separately.*

Findings: *Chapters 4 and 5*, indicate that agroforestry can diversify livelihoods and improve livelihood resilience. Within Chapter *4,* 80% of farmers wanted to include trees in their farming system in their ideal farming scenario, usually for the purpose of diversification alongside other crops.

Chapter 5 shows how agroforestry and contract farming interact to produce co-benefits and trade-offs for livelihood resilience as part of a broader strategy of diversification. The concentration of trees within home gardens appears to be partially driven by the expansion of sugarcane contract farming in the landscape. Therefore, homegarden agroforestry emerges as a strategy ensures households can maintain diversity whilst also engaging in contract farming, enabling them to still receive livelihood benefits such as firewood, timber, and fruit. Agroforestry tree abundance increased with mean number of livelihood activities indicating that it forms part of a diversification strategy for farmers. While the primary benefits to household livelihood resilience of contract farming are a yearly income that can be transferred or used to build other capital assets, agroforestry paints a more holistic picture, providing direct and indirect benefits such as food, firewood, construction materials and a windbreak from storms.

Significance: The results reiterate that farmers desire diversified agricultural systems that include trees and that it is a crucial strategy for diversification is a crucial strategy for resilience and adaptation alongside enhancing future livelihood prospects (Ellis, 2000; Lala et al., 2023). Diversified farming systems with agroforestry have been documented to suffer fewer shocks and maintain a household's ability to adapt to changing conditions (Verchot et al., 2007; Thorlakson & Neufeldt, 2012), as they allow a household to expand their crops for market, space out production across the year and build redundancy into the agricultural system (McCord et al., 2015).

6.1.4 Conclusion 4 'Aggregated metrics to measure human wellbeing and household livelihood resilience have both benefits and limitations'

Conclusion 4 'Aggregated metrics to measure human wellbeing and household livelihood resilience have both benefits and limitations'

Findings	Significance	Novelty
Chapter 4 used an aggregated metric of human wellbeing that used 20 variables from Milheiras et al., (2022) based on the framework of Loveridge et al., (2020). Our analysis showed no influence of wellbeing on attitudes towards trees and forest. Within *Chapter 5* I took a structural equation modelling approach to construct a latent variable for household livelihood resilience. This method led to using five variables, one for each dimension of the livelihood capitals (social, financial, physical, nature and human).	Using aggregated metrics to measure concepts such as human wellbeing and livelihood resilience allowed me to simplify their complexity and incorporate them into my quantitative analysis that was complemented and enriched by qualitative analysis alongside. However, aggregating variables, like done when creating a single index to capture wellbeing or livelihood resilience, may have obscured the underlying factors shaping attitudes and perceptions toward trees on farms and in the landscape that could be useful for decision-making (Massingham et al., 2023). Future studies should examine individual dimensions of wellbeing or household livelihood resilience rather than relying solely on an aggregate metric to obtain more nuanced and insightful results.	The novelty in the objectives of Chapter 4 was achieved through using an aggregated metric to explore the influence of wellbeing on attitudes towards tree-cover restoration. The novelty in Chapter 5 was achieved methodologically through creating a latent variable for household livelihood resilience which could be used in the systems model framework.

Figure 6.5 A summary of the findings, significance and novelty of the conclusion of this thesis that aggregated metrics to measure human wellbeing and household livelihood resilience have both benefits and limitations

Novelty: *The novelty in the objectives of Chapter 4 was achieved through using an aggregated metric to explore the influence of wellbeing on attitudes towards tree-cover restoration. The novelty in Chapter 5 was achieved methodologically through creating a latent variable for household livelihood resilience which could be used in the systems model framework.*

Findings: *Chapter 4* used an aggregated metric of human wellbeing that used 20 variables from Milheiras et al., (2022) based on the framework of Loveridge et al., (2020). Our analysis showed no influence of wellbeing on attitudes towards trees and forest. Within *Chapter 5* I took a structural equation modelling approach to construct a latent variable for household livelihood resilience. This method led to using five variables, one for each dimension of the livelihood capitals (social, financial, physical, nature and human). I used the latent variable in my structural equation model to examine drivers of household livelihood resilience, of which number of plots owned was a significant driver.

Significance: Using aggregated metrics to measure concepts such as human wellbeing and livelihood resilience allowed me to simplify their complexity and incorporate them into my quantitative analysis that was complemented and enriched by qualitative analysis. However, my thesis also highlights the constraints and limitations associated with the use of composite metrics when trying to understand interactions between people and their environment. Primarily, aggregating variables, such as when creating a single index to capture wellbeing or livelihood resilience, can obscure patterns and differences between individual indicators that may be useful for decision-making.

In Chapter 4, the use of the wellbeing index as an aggregate measure for workshop participants may have obscured the underlying factors shaping attitudes and perceptions toward trees on farms and in the landscape. While two individuals might have the same overall wellbeing score, their scores across individual dimensions or specific components of wellbeing could differ (Massingham et al., 2023). Consequently, making specific recommendations to address prevalent attitudes without exacerbating existing inequalities in wellbeing was challenging due to the unclear localisation of these inequalities. Recognising that restoration interventions affect people differently and may enhance specific aspects of wellbeing while worsening others (Woodhouse et al., 2015), the aggregated metric lacks the information to provide such insights.

Despite aggregating fewer variables in *Chapter 5* to try and mitigate some of these constraints, this method also suffered from some of the same limitations as in *Chapter 4*. It is unclear specifically which variable the number of plots owned influenced the most, or whether aggregating the variables masked relationships between specific components of household livelihood resilience.

Therefore, I recommend that future studies examine individual dimensions of wellbeing or household livelihood resilience rather than relying solely on an aggregate metric to obtain more nuanced and insightful results.

6.2 Challenges and Future Research Steps

Although I have addressed three key science advancements for understanding the opportunities and trade-offs for tree-cover restoration in the Southern Agricultural Growth Corridor of Tanzania, this work has incurred challenges and has also revealed further avenues for research. Below, I describe some of the key challenges of this work and future research directions that could address some of challenges and build on the key results.

6.2.1 Key challenges across the thesis

(1) I had to design and implement the workshops for *Chapter 3* remotely in the UK due to COVID-19 travel restrictions which limited the application of findings from *Chapter 2* in the design and implementation.

(2) To quantitatively measure household livelihood resilience in *Chapter 5*, I took data from a household survey previously collected in 2019 by the Agrisys Tanzania project which aimed to understand wellbeing and agricultural practices. Although this then limited the variables that could be used, I considered this the best option to avoid participant fatigue and collection of more data from the same or a similar population.

(3) I only measured a single timepoint which was limited not only COVID-19 restrictions but also the short time frame of the PhD.

(4) Within *Chapter 4*, I was unable to link each participant back to their household survey and specific wellbeing score and therefore, I was unable to examine the influence of specific components of wellbeing on attitudes towards tree-cover restoration.

56.2.2 Future research steps

Key result	Future research directions
RQ1: What evidence exists on the use of participatory scenarios in ecological restoration?	
• Few texts reported on how scenarios fed into the restoration planning process.	• We need to evaluate the effectiveness of scenarios for restoration planning. • Future scenario research should evaluate and report on how using participatory scenarios aided restoration planning in their results.
• Few texts reported whether stakeholder participation succeeding in meeting the participatory objectives.	• We need to evaluate whether scenarios are successful in meeting their participatory objectives. • Future scenario research should evaluate and report on the outcomes of their participatory objectives.
RQ2: How do farmers perceive trees and envision them in their future farming system?	
• Positive attitudes towards agroforestry were associated with provision of direct benefits.	• Research should assess if positive attitudes towards trees make it more likely for farmers to adopt agroforestry.
• The dominance of negative attitudes towards forests were primarily due to concerns about resource access and human-wildlife interactions.	• Longitudinal sentiment analysis should be implemented to measure if attitudes towards forests improve with restoration interventions.
• Gender was an important factor in shaping scenarios and attitudes towards tree-cover restoration.	• Future workshops should be done with other stakeholders in the landscape such as pastoralists who may envision very different futures.
• In their ideal scenarios, farmers wanted to be surrounded by other farmers with different on-farm tree configurations.	• Quantitive modelling of scenario results should be used to examine predicted outcomes that are valued by farmers and other stakeholders.
RQ3: How can agroforestry and contract farming contribute to household livelihood resilience to climate change and climate mitigation efforts?	
• There are trade-offs for livelihood resilience influenced by wildlife-induced crop loss.	• Further research is needed to understand the intersection of wildlife-induced crop losses, contract farming and food security.
• Farmers recognise their climate is changing.	• Longitudinal research should be done on how livelihood resilience changes as the climate and livelihoods change.

Figure 6.6 A summary of future research directions grouped by the key outcomes from each scientific advancement and the challenges incurred during the thesis.

6.2.2.1 Systematically mapping the evidence on the use of participatory scenarios in ecological restoration

The following suggestions are applicable to global research studies using or examining participatory scenarios:

(1) Further research is needed to understand the effectiveness of participatory scenarios in restoration planning. This could be done by conducting primary research into the authors and participants of the studies included in my review.

(2) Future research that uses participatory scenarios should incorporate processes to evaluate their effectiveness in aiding restoration planning and report them in their outputs.

(3) Further research is needed to understand whether participatory scenarios in restoration planning are meeting their participatory objectives and how likely they are to achieve positive outcomes for restoration planning.

(4) Future research using participatory scenarios should incorporate processes to evaluate whether they have met their participatory objectives and report them in their outputs.

6.2.2.2 How do farmers perceive and envision trees in their farming systems?

The following suggestions are specific to the Kilombero Valley, Tanzania but would have relevance for the wider restoration research community:

(1) Further research could build on the results of *Chapter 4* to assess whether those with positive attitudes practice more agroforestry or whether they have a higher likelihood of planting trees.

(2) The data and results in *Chapter* 4 could be used as a baseline assessment to measure responses to, and help improve restoration interventions (Drijfhout et al., 2016).

(3) Further research on how actors besides smallholder farmers e.g. pastoralists, government leaders, conservation organisations, envision future farming landscapes would be beneficial to identify collaborative restoration solutions.

(4) The results from *Chapter 4* and the model from Pfeifer et al., (2022) could be used as the basis to continue participatory model building to quantitatively examine potential scenario outcomes.

6.2.2.3 How can agricultural strategies contribute to household livelihood resilience to climate change and climate mitigation efforts?

The following suggestions are specific to the Kilombero Valley, Tanzania but would have relevance for the wider restoration research community:

(1) Food insecurity as a function of sugarcane contract farming and wildlife induced crop losses needs further examination as farmers bear high start-up costs and all production risks in contract farming.

(2) A more extensive sample size and longitudinal research would be beneficial to understand how livelihoods are changing as more farmers adopt contract farming and the climate changes.

6.3 Concluding remarks

In this thesis, I have added to the growing scientific literature on the benefits and trade-offs of tree-cover restoration. Tree-cover restoration in rural tropical landscapes such as the Kilombero Valley provides the opportunity to meet international environmental commitments and deliver on multiple social and environmental outcomes. However, the realities for smallholder farmers are that tree-cover restoration represents a trade-off in how they build their farming systems and subsequent livelihoods.

While this research did not directly design or implement interventions to balance trade-offs across stakeholder groups, it identified several points of divergence between stakeholder objectives, such as farmers' preference for dispersed agroforestry systems versus policy efforts to expand protected forest areas. It also revealed some of the trade-offs farmers to build their livelihood resilience, such as by converting to sugarcane production and planting homegardens. These findings highlight a clear need for restoration planning approaches that can navigate and negotiate competing interests more transparently. In practice, this could involve embedding participatory scenarios, stakeholder analysis, and deliberative forums that include farmers into early stages of restoration programme design. Such tools can help identify trade-offs, assess who is likely to benefit or lose from certain outcomes, and support more equitable and inclusive decision-making. Therefore, while the thesis did not operationalise this balancing process, it provides empirical evidence that supports its necessity and offers insight into how it might be approached.

6.4 References

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