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Effects of forest proximity and socio-ecological determinants on tree species composition, diversity and carbon stocks in the Vhembe Biosphere Reserve in South Africa

By

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Dedication

To my lovely boys, Ntlakuso and Nkateko, I hope the sacrifices you have endured for me to pursue this dream will be repaid to you with many opportunities for joy and success. This research work is your foundation and stepping stone for your future.

Declaration

I, **Lucky Makhubele**, declare that this thesis, which I hereby submit for the degree of PhD in Forest Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary Institution.

Signature: …………………………

13 July 2023

Date: ………………………………

Summary

This study aimed to evaluate the effects of forest proximity, and socio-ecological determinants on tree species composition, diversity, and carbon stocks in traditional agroforestry landscapes. The study was crucial considering the importance of traditional agroforestry landscapes in an effort to halt the unprecedented rise of biodiversity loss and the effects of climate change at a landscape scale. The traditional agroforestry landscape in a rural set-up was divided into three distance levels that somehow mimic the biosphere reserve zones: the immediate distances (transitional zones), intermediate distances (buffer zones) and far distances (core areas). The paramount objective of conservation has been more focused on protected areas than any other forest resource areas. In the case of the Vhembe Biosphere Reserve (VBR), the legally designated protected areas are mainly the core areas of the biosphere. Therefore, considering the traditional agroforestry landscape, specifically, the transitional zone of the biosphere as complementary to the core areas for biodiversity conservation at large is necessary. Traditional agroforestry landscapes are earmarked to play a critical role in conserving biodiversity, climate change mitigation and adaptation, and sustaining rural livelihoods through multiple ecosystem goods and services. Previously, worldwide, studies assessed tree species diversity and carbon sequestration potential of traditional agroforestry landscapes. However, there has not been a study evaluating the potential of traditional agroforestry for provisioning ecosystem services, conservation of tree species diversity and carbon sequestration in South Africa.

The study was conducted in traditional agroforestry landscapes of four communities (Damani, Tshipako, Thenzheni and Tshiombo) situated in the transitional zone of Vhembe Biosphere Reserve in Thulamela Municipality, Limpopo Province. As described in biosphere zone classifications, transitional zones are characterised by multiple functions such as settlements, forestry plantations, agricultural farms and common resources use areas. To address the main objective of the study, five independent studies were conducted.

An unprecedented rise in the unsustainable extractions and use of provisioning ecosystem services from the landscapes poses a dilemma as to whether traditional agroforestry landscapes help to conserve tree species diversity while sustaining rural livelihood. Understanding these dynamics was essential in order to inform the harvesting behavioural change and management interventions. The study evaluated the link between distance and socio-ecological determinants

and the provisioning ecosystem services consumption behaviour. The following hypothesis was tested "*rural people's preferences and extent of Provisioning ecosystem services (PESs) harvesting decrease as the distance from the village to forest patches increase, regardless of the prevalent socio-ecological conditions"*. Consistent with the hypothesis, the results showed that local people harvest most of the provisioning ecosystem services at an immediate (1^{st}) level, followed by intermediate (2^{nd}) and far distance (3^{rd}) levels. This study further revealed the existence of 108 useful tree species in the study areas. The fact that there is a preference to use and harvest provisioning ecosystem services from the distance regime closest to the household, shows the need for a concerted effort to conserve and enhance the abundance of multipurpose tree species in homesteads and the immediate areas.

Anthropogenic disturbance has positive and negative effects on tree species richness and diversity. To ascertain and understand the effects, this study also tested the following hypotheses; first, ***"****Tree species diversity is expected to be the highest at an intermediate distance from the villages as predicted by the immediate disturbance hypothesis"*. Second, "*the turnover of tree species composition between distances levels increases as the distance from the community increases as predicted by the distance decay of community similarity hypothesis."* The findings are in consonant with distance decay of community similarity hypotheses, with estimated tree species richness of 76, 93 and 95 species in an immediate distance, intermediate distance and far distance, respectively. Moreover, the highest species variation was observed at an intermediate distance, which indicates that there is greater species composition at an intermediate distance compared to immediate and far distances. The results confirm that the distance and associated factors have major detrimental effects on tree species richness and biodiversity in traditional agroforestry landscapes. Harvesting of provisioning ecosystem services is found and known to be extremely high in the study area. Effective interventions such as planting native trees near to homesteads and conserving the existing vegetation must be implemented to reduce and halt overexploitation.

The defining features of traditional agroforestry landscapes (TALs) are species diversity, productivity, and complex functionality. Currently, there is a decline in endemic southern African tree species in TALs. This study, therefore, evaluated the impact of exotic species and socio-ecological determinants on endemic species diversity in these TALs. The study found that the endemic species diversity and richness were influenced by the distance level, exotic species richness, diversity, and abundance. In particular, the distance level was found to be the major driving factor of change in endemic species composition in TALs. The endemic species diversity increased as the distance increased from the epicentre of the village to the proximate forest. Conservation through endemic tree planting in traditional agroforestry landscapes would mitigate the impact of the introduction and spread of exotic species. This will ultimately enhance the traditional agroforestry biodiversity and production while benefiting people.

Little has been reported regarding the effects of socio-ecological determinants on the carbon sequestration potential of traditional agroforestry in South Africa, especially in the Vhembe Biosphere Reserve (VBR). The study assessed the tree carbon stocks in the VBR traditional agroforestry landscapes along the distance levels, immediate, intermediate, and far distance from villages to the forest. The results revealed that there were no differences in total carbon stocks between the distance levels, with the same amount of carbon stocks stored in the vegetation at all distance levels. While the carbon per distance remains the same, the species richness and composition differ along the distance regimes. Thus, while carbon sequestration may be the same, the conservation value for tree species differs along the distance regimes. In general, the results showed a greater potential for TALs to sequester high carbon. When all socio-ecological determinants were considered together, elevation, density and basal areas were the most important predictors of carbon stock. Hence, this study concludes that maintaining and enhancing species diversity in traditional agroforestry landscapes can be an effective strategy to achieve the climate change mitigation goals provided this is finely balanced with the livelihoods needs of the local communities.

Management practices in traditional agroforestry landscapes play a significant role in tree species conservation. The study aimed to investigate conservation strategies on tree species richness in traditional agroforestry landscapes. This study found that the local people have no conservation strategy and practices targeting the enhancement of tree species richness in the traditional agroforestry landscape. The study, therefore, advocates for the establishment of a conservation strategic framework for restoring tree species richness and composition by targeting traditional agroforestry landscapes.

The findings revealed that the transitional zones are neglected in terms of conservation, as demonstrated by extreme harvesting disturbances, low tree species richness and diversity, and high dominance of exotic species at an immediate distance from households. However, this study found a great potential for intermediate and distance levels in conserving indigenous species, including endemic species despite their comparable contribution to carbon sequestration with the immediate distance.

In sum, this thesis implies that human behavior and anthropogenic disturbances are linked to the decline of tree species diversity and landscape homogenization in immediate proximity to the settlement areas. If this behavioural pattern remains unchecked, the growing human population in the settlement areas may negatively affect the conservation of tree species diversity and the supply of ecosystem services that sustain rural livelihood. In addition, the possession of indigenous knowledge on conservation practices and management of native trees, may not be sufficient to tackle the fast-declining global biodiversity. Thus, there is a need to integrate scientific methods of conservation and behavioural change tools with indigenous knowledge at the local and landscape level to sustain global biodiversity while ensuring the provisioning of ecosystem service to rural livelihood.

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I thank God, He is a great God, and His love endures forever, I would never have completed this study if it was not for God's grace and divine plan. *"For I know the plans I have for you, declares the Lord, plans to prosper and not to harm you, plans to give you hope and a future"* Jeremiah 29:11.

I am immensely grateful to my most valuable asset, my mother (Midjadji). I thank you "Mhani" for making sure that you take care of us after the passing away of my father (Samuel) in 1995 (may his soul continue resting in peace) without any professional skill or job, you made sure that there was bread, water, education, and shelter for all of us.

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List of acronyms

AGB	: Above-Ground Biomass
AGC	: Above-Ground Carbon
ANOSIM	: Analysis of Similarity
BEF	: Ecosystem Functioning Hypothesis
BGC	: Below-Ground Carbon
BPH	: Biodiversity Productivity Hypothesis
CBD	: Convention on Biodiversity Diversity
CCM	: Concentric-Circles model
CCMS	: Climate Change Mitigation System
CO_2	: Carbon Dioxide
CPH	: Colonisation Pressure Hypothesis
COVID-19	: Coronavirus Disease
DBH	: Diameter at Breast Height
*db*RDA	: *distance-based* Redundancy Analysis
DISTLIM	: Distance-based Linear Modelling
ES	: Ecosystem Services
FGD	: Focus Group Discussion
FL	: Fidelity Level
GHG	: Green House Gases
GLM	: Generalised Linear Model
ICRAF	: International Centre for Research in Agroforestry
IDH	: Intermediate Disturbance Hypothesis

IK	: Indigenous Knowledge
IPBES	: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	: Intergovernmental Panel on Climate Change
IPLC	: Indigenous People and Local Communities
IVI	: Important Value Index
MLR	: Multinomial Logistic Regression
MMR	: Mixed-Method Research
nMDS	: non-Matric Multidimensional Scaling
OFT	: Optimal Foraging Theory
OUV	: Overall Use Value
PCO	: Principal Coordinate Analysis
PDH	: Productivity Diversity Hypothesis
PES	: Provisioning Ecosystem Services
PERMANOVA	: Permutational Based Multivariate Analysis of Variance
PERMDISP	: Test of Homogeneity of Dispersion
REDD+	: Reducing Emissions from Deforestation and forest Degradation
SADC	: Southern African Development Community
SEDS	: Socio-Ecological Determinants
SIMPER	: Similarity Percentage
SPSS	: Statistical Package for Social Science
TAL	: Traditional Agroforestry Landscapes
USD	: United of America Dollar
UN	: United Nation
UNESCO	: United Nations Educational, Scientific and Cultural Organization
UNFCCC	: United Nations Framework Convention on Climate Change

UV : Use Value

VBR : Vhembe Biosphere Reserve

ZAR : South African Rand

Chapter 1

Introduction

1.1 Background

World population growth, with the human population expected to be over 9 billion by the year 2050 (Nath *et al.,* 2022), increases the demand for natural resources such as land and ecosystem services (ESs). These projections raise a very critical question; will ecosystem services sustain human well-being in the near future? The Millennium Ecosystem Assessment (MEA) was meant to be a serious intervention in the form of awareness of the world in response to the aforementioned question. The world needs to maintain a balance between the demand and supply of ESs as a prerequisite for human well-being (Woodward & Bohan, 2015). Worldwide, people depend on ESs for goods and services (Mensah *et al.,* 2016). The ESs concept has been recognised by the international initiative such as MEA a few decades ago as a parasol of goods and services that are critical for human well-being (Sharme *et al.,* 2007; Mensah *et al.,* 2016; Cazalis *et al.,* 2018). Ecosystem services embody natural resources that are significant for human well-being, and the ESs are divided into four categories: provisioning ecosystem services (e.g. freshwater, timber and non-timber forests products), supporting ecosystem services (e.g. nutrients cycling and soil formation), regulating ecosystem services (e.g. climate regulation and water purification) and cultural services (e.g. spiritual and aesthetic) (Woodward & Bohan, 2015; Mensah *et al.,* 2016; Cazalis *et al.,* 2018; Huge *et al.,* 2020).

Ecosystem services are strongly rooted in the species' biodiversity; high biodiversity levels enhance the ecosystem service's function (Palacios Bucheli & Bokelmann, 2017). There has been a growing consensus on the need to conserve biodiversity, ecosystem services, sustainable development, and human well-being at the international level (Diaz *et al.,* 2015; Dunkley *et al.,* 2018). A recent international agreement such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) laments strongly the above-mentioned needs amid the recognition of human accelerated global biodiversity loss (Diaz *et al.,* 2015). The IPBES seeks to tackle the degradation of ecosystem services and loss of biodiversity through policy-relevant knowledge (Dunkley *et al.,* 2018). According to Diaz *et al.* (2015), the conceptual framework highlights the important role of human institutions as a source of nature challenges and solutions. The framework further highlights the contribution of indigenous knowledge to the sustainable use and conservation of ecosystems and biodiversity (Dunkley *et al.,* 2018).

South African ecosystems are significantly degraded (FAO, 2015; Sigwela *et al.,* 2017) and approximately 38% of the population inhabits ecologically degraded areas (Sigwela *et al.,* 2017). Ecological degradation largely affects indigenous communities, leading to reduced quality and quantity of essential natural resources such as water, soil, arable land, forest resources and fodder (Sigwela *et al.,* 2017). Limpopo Province is one of the provinces in the country that is experiencing a decrease in vegetation cover and changes in species composition (Sigwela *et al.,* 2017). However, the province has three biosphere reserves as declared by United Nations Educational, Scientific and Cultural Organization (UNESCO), Kruger to Canyons, Waterberg, and Vhembe biosphere reserves (Pool-Stainvleit *et al.,* 2018). The Vhembe biosphere reserve (VBR) is the second largest (3 million hectares) biosphere reserve of all nine reserves in South Africa (Pool-Stainvleit *et al.,* 2018). The VBR is in the northern part of Limpopo Province and was designated in 2009 by UNESCO (Evans, 2017). The biosphere reserves consist of three zones core area/s (protected areas), buffer zone/s (areas surrounding the core areas) and transitional zone/s (the areas surrounding the buffer zones) (Figure 1.1) (Evans, 2017; Pool-Stainvleit *et al.,* 2018). The national parks and provincial reserves are recognised as core areas in VBR (Evans, 2017). Agricultural farming, forest plantations, tea plantation, settlements, culturally protected areas, and Traditional Agroforestry Landscapes (TALs) are found in the transitional zone and buffer zones of the VBR.

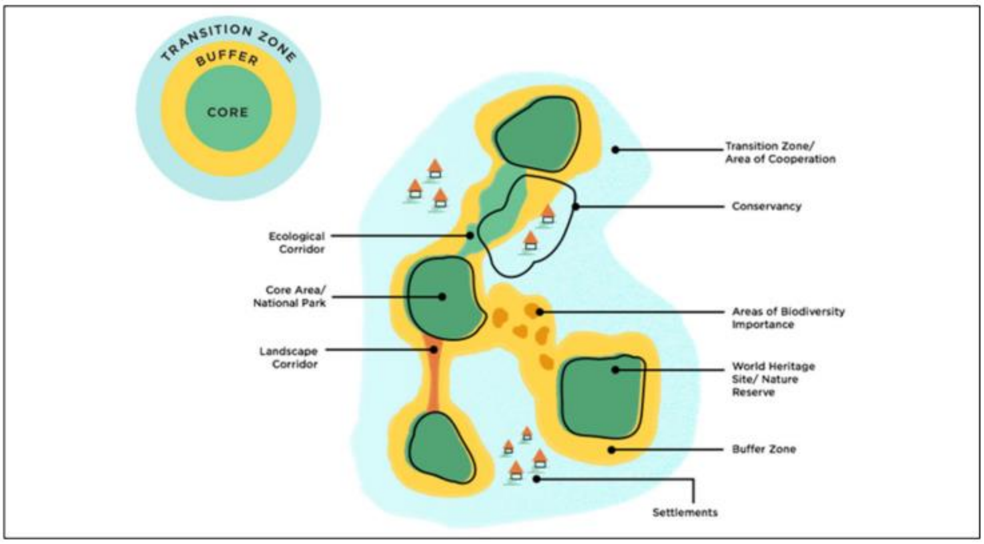

Figure 1.1: Schematic presentation of general biosphere reserve zones (Source: Pool-Stainvleit and Coetzer, 2020)

Ntshane and Gambiza (2016) found that in VBR, 28% of transitional and buffer zones were characterised by low biodiversity due to human threats. The zones were found close to human settlements, agricultural areas, mining, and plantations. The provisioning ecosystem services (PESs) can be potentially sustainably managed for both social benefit and nature conservation (Sigwela *et al.,* 2017). Planning for sustainable management of ESs requires evidence-based knowledge about social system demands and potential ecological systems to supply ESs (Sigwela *et al.,* 2017; Wisely *et al.,* 2018). According to Wisely *et al.* (2018), ecosystem value ultimately influences human behaviour and practices, such as overexploitation and selection of species to harvest. Therefore, evaluating consumption patterns and impacts of anthropogenic disturbance is paramount in understanding human consumption behaviour and causes of ESs loss (Wisely *et al.,* 2018). A key initial step in understanding the consumption of ESs is gathering the socio-ecological inventory of resource sources and human consumption patterns.

Many people in Limpopo Province depend on the forest ecosystem for their daily livelihoods (Rasethe *et al.,* 2013; Scheiter *et al.,* 2018). The heavy dependency on the forest ecosystem in the province is largely influenced by several factors such as socioeconomic and cultural factors (Rasethe *et al.,* 2013). The VBR, which is one of the tropical climatic zones in the Limpopo Province, is known for its richness of flora and fauna diversity (Scheiter *et al.,* 2018; Mugari & Nethengwe *et al.,* 2022). A larger portion of the population in the VBR is poor and lives in rural areas (Makhubele *et al.,* 2021). Consequently, they embark on a range of strategies to sustain their livelihoods by harvesting natural resources for subsistence or commercial purposes (Makhado *et al.,* 2009). Though the forest ecosystem is an epicentre of ES provision and species biodiversity (Santos *et al.,* 2019), forest ecosystems alone in human-dominated landscapes are not adequate to sustain biodiversity and ES provision (Santos *et al.,* 2019). Multifunctional landscapes that incorporate production and biodiversity conservation such as traditional agroforestry landscapes are important in human-modified landscapes (Santos *et al.,* 2019). These types of landscapes produced by socio-economic-driven transitions vary with context and the surrounding activities. Multi-functionality of the landscapes in VBR created multifunctional traditional agroforestry landscapes (TALs) that provide multiple benefits and livelihood options that people derive from them. Many indigenous communities depend on traditional agroforestry for multiple benefits such as food, medicines, fuels, handcrafts and building materials (Palacios Bucheli & Bokelmann, 2017; Afentina *et al.,* 2021). Multifunctional agroforestry landscapes were recognised many decades ago as the landscapes that have a greater potential to improve livelihoods, provide protection (e.g., protection of soil and water) and production (e.g., species biodiversity) in forest ecosystems (Sharma & Sharma, 2007; Nandy & Das, 2013). Traditional agroforestry landscapes in VBR are in closer proximity to the forest ecosystems as they provide exactly similar ecosystem services as the forest such as provisioning of non-timber forest products, regulating climate, supporting nutrients cycling and cultural services (Sharma & Sharma, 2007).

The biodiversity in the TALs is fundamental to the indigenous community's livelihoods (Palacios Bucheli & Bokelmann, 2017). Therefore, protection and conservation of the species' biodiversity in TALs are unnegotiable due to an inextricable link. Beyond traditional agroforestry multi-functionality, indigenous knowledge is the core root of the whole system. Indigenous knowledge or ethnobotany studies revealed that tribal rules and religious and socio-cultural beliefs play an important role in the sustainable management of natural resources and production (Nandy & Das, 2013; Velazguez-Rosas *et al.,* 2018). According to Velazquez-Rosas *et al.* (2018), TALs are established based on indigenous knowledge to complement cultural landscape preservation and enhance species biodiversity. In communities where culture and nature are intertwined, there is a high correlation between culture and species biodiversity (Velazquez-Rosas *et al.,* 2018). However, due to unprecedented political, social, ecological and economic challenges in rural communities, traditional ecological knowledge is gradually eroding (Dhanya *et al.,* 2014). Traditional agroforestry portrays a variety of human and natural relations and shows human creativity in dealing with forest resources (Nandy & Das, 2013). In TALs, ecosystem functions and production largely depend on indigenous knowledge (Erenso & Ademo, 2022).

Despite worldwide recognition of agroforestry practices, the adoption of agroforestry technologies in South Africa is moving at a slow pace due to little effort made to promote the practice locally and nationally (Oduniyi & Tekana, 2019). Compared to other countries in southern Africa, agroforestry in South Africa is not well developed though it is documented that the practice was introduced in the country in the 18th century (Zerihun *et al.,* 2014). Agroforestry practice has been well established and increasing in southern African countries such as Malawi, Namibia, Zambia, Zimbabwe, and Tanzania since their collaboration with the Southern African Development Community (SADC)- International Center for Research in Agroforestry (ICRAF) (Zerihun *et al.,* 2014). However, South Africa was not part of such an international partnership of efforts to promote agroforestry a few decades ago (Zerihun *et al.,* 2014).

Agroforestry practices at a local spatial scale range from traditional agroforestry to recent practices such as alley cropping, taungya, home gardens, live fences, shelterbelts, and windbreaks (Zerihun *et al.,* 2014). Traditional agroforestry has been practised over many centuries (Johansson, 2015; Ibrahim *et al.,* 2019). Worldwide, traditional agroforestry is the practice of indigenous communities and is culture-based farming since its earliest history (Palacios Bucheli & Bokelmann, 2017). It has also been practised at the spatial scale of a landscape with different combinations of local practices. The traditional agroforestry landscape benefits are co-produced by the interactions between the societies and ecosystem services (Balvanera *et al.,* 2017).

Through traditional agroforestry, indigenous communities met/meet their basic needs for fuelwood, medicine, food, building, etc. (Palacios Bucheli & Bokelmann, 2017). Traditional agroforestry landscapes provide a wide range of benefits related to ecosystem services at different spatial scales (Table 1.1). At the landscape scale, traditional agroforestry provides benefits to society at a larger scale (e.g., national, and global) (Jose, 2009).

Table 1.1: Traditional agroforestry landscape ecosystem services at different spatial scales (modified from Jose, 2009 and Balvanera *et al.*, 2017).

Types of ecosystems services		**Spatial scale**		
		Local/community	**Landscape/regional**	**Global**
Provisioning	• Fuelwood			
	• Food/Wild food			
	• Fodder			
	• Traditional medicine			
Regulating	• Climate change mitigation & adaptation			
	• Soil erosion control			
	• Flood regulation			
	• Air purification			
	• Water purification			
	• Pollination			
	• Carbon sequestration			
Cultural	• Spiritual			
	• Educational			
	• Heritage			
Supporting	• Nutrients cycling			
	• Primary production			
	• Soil formation			
	• Habitat formation			
	• Biodiversity			

Traditional agroforestry landscapes in the tropics are declining due to multiple reasons, including land-use change, anthropogenic disturbances, commercial farming, and land fragmentation (Sahilu, 2017). Worldwide, landscape ecosystems are on an unsustainable trajectory (Wu, 2013). Therefore, the current study focused on traditional agroforestry at a landscape level. Local scale-based ecosystem studies tend to be small to incorporate social, economic, and environmental factors, whereas at the global scale tends to be highly impossible to cover the necessary information to guide people at a local scale (Wu, 2013). At a landscape scale, the interaction between people and the ecosystem is more accurate and well-informed about what affects the landscape (Wu, 2013). In addition, the results explicitly link the local and global scale effectively and in a realistic manner.

1.2 Rationale and justification of the study

1.2.1 Traditional agroforestry landscape biodiversity and provisioning ecosystem services

Having vast biodiversity hot spots, South Africa is rich in biodiversity. However, large-scale forest exploitation which has been done for several decades has caused massive land degradation and deforestation, which in turn can reduce biodiversity (Scheiter *et al.,* 2018). Global biodiversity is significantly changing at an unprecedented alarming rate (Udawatta *et al.,* 2019). Consequently, biodiversity changes affect the multiple benefits sourced from forests. Indigenous communities' health care, food security, and ecosystem services are embedded strongly in the maintenance of biodiversity (Tahulela, 2016). The biodiversity in TALs that the rural communities maintain is very crucial to their livelihoods (Tscharntke *et al.,* 2010; Palacios Bucheli & Bokelmann, 2017). In rural communities, biodiversity conservation is a cultural goal and a means to improve livelihoods (Tscharntke *et al.,* 2010). Biodiversity within TALs allows the rural communities to reach high production in the short and long-term run, producing a variety of goods for subsistence and commercial purposes (Tscharntke *et al.,* 2010; Tahulela, 2016; Palacios Bucheli & Bokelmann, 2017). According to Muthee *et al.* (2022), rural people of sub-Saharan Africa depend on immediate ecosystems such as traditional agroforestry for survival. Traditional agroforestry landscapes provide and receive ecosystem services and disservices (Palacios Bucheli & Bokelmann, 2017).

Provisioning ecosystem services directly link people with nature and the actual use of PESs is determined by the social and ecological factors. Therefore, TALs deliver provisioning ecosystem services and the management of the traditional agroforestry ecosystems determines the delivery of those services (Tscharntke *et al.,* 2010). Ultimately, the biodiversity of TALs and provisioning ecosystem services production depends on how the landscape is being managed. As a result, indigenous communities play an integral part in biodiversity and provisioning ecosystem services of TALs within their communities. In Africa, traditionally managed agroforestry landscapes conserve biodiversity through in situ conservation (Bayu, 2019). For instance, in situ conservation of tree species is manifested in traditional agroforestry such as homegradens, live fences, parklands and farms in West, East and sub-Saharan Africa (Legesse and Negash, 2021; Muthee et al., 2022; Kassa et al., 2023).

Multifunctional landscapes such as traditional agroforestry play a significant role in biodiversity conservation and the provision of ecosystem services (Santos *et al.,* 2019). In human-dominated landscapes, agroforestry is an alternative option to recover degraded lands and enhance conservation and production. However, the benefits of agroforestry solely depend on the type of system. Traditional agroforestry landscapes with a higher vegetation diversity contribute to landscape production, soil conservation, nutrient cycling, and soil erosion reduction (Santos *et al.,* 2019). Hence, changes in the species biodiversity within a TAL result in the disruption of ecosystem services function and production (Rampheri *et al.,* 2022), consequently affecting human health and economic loss. Biodiversity is inextricably linked to ecosystem services because it influences their provisioning (Cotter *et al.,* 2017).

To respond to these above-mentioned serious challenges, international, regional, national, and local policies have been enacted and executed to combat and control the decline of biodiversity and ecosystem services (Di Minin *et al.,* 2017). According to Di Minin *et al.* (2017), countries affiliated with the Convention of Biological Diversity (CBD) adopted 20 Aichi targets in 2010 with target number 11 aimed to promote the expansion of the global protected area network to cover approximately 17% of all terrestrial land by 2020. To reach the target, each country committed to conserving between 3 to 50% of its land (Di Minin *et al.,* 2017). However, none of the Aichi targets have been achieved by the countries committed due to the following barriers: ineffective implementation at national level, lack of knowledge, poor conservation investments and lack of biodiversity conservation accountability (Xu *et al*., 2021).

South African ecosystem endured a significant change in vegetation and biodiversity loss in the past few decades (Scheiter *et al.,* 2018). Biodiversity and ecosystem services in Limpopo Province are under severe anthropogenic pressure, rural communities heavily depend on ecosystem services for their livelihoods (Rampheri *et al.,* 2022). In the same situation, rural communities are situated on historically marginal degraded land and land degradation is further increased by land-use intensification (Scheiter *et al.,* 2018). Land-use intensification in the province occurs through large commercial farming, small-scale farming, and subsistence farming (Scheiter *et al.,* 2018).

In a forest ecosystem, common natural disturbances include floods, wind, heavy rain, and wild animals, among others (Silva Pedro *et al.,* 2016). However, unprecedented climate change and anthropogenic disturbances are ever-rising agents of forest ecosystem changes in recent centuries. Increasingly, biodiversity loss worldwide has necessitated the need to understand the relationship between anthropogenic disturbances and biodiversity. Anthropogenic disturbances are events that disrupt the structure of an ecosystem, community, or population and change resource availability or the physical environment. Anthropogenic disturbance alters the function and production of ecosystems and affects the availability of flora and fauna (Patacca *et al*., 2023). Also, these disturbances are expected to further increase in the future forest (Silva Pedro *et al.,* 2016). In the context of species diversity, the disturbance is the stronger driver of diversity (Pedro *et al.,* 2016), and species biodiversity may increase or decrease along the disturbance gradients (Ikeda, 2003). Disturbance creates new forest forms and species diversity that is not usually found in undisturbed forests (Viljur *et al.,* 2022). Thus, along the disturbance gradient, there is a degree of disturbance that enhances species diversity and a degree of disturbance that causes species diversity loss.

The intermediate Disturbance Hypothesis (IDH) is the concept that tests and shows how disturbance influences species diversity. The intermediate Disturbance Hypothesis is one of the ecological hypotheses that predict the forest ecosystem response to a disturbance (Liu *et al.,* 2018). The intermediate disturbance hypothesis hypothesizes that species diversity maximises when a disturbance occurs at an intermediate frequency or with intermediate intensity (Silva Pedro *et al.,* 2016; Bendix *et al.,* 2017). In simple terms, the absence of disturbance or low-intensity disturbance causes species succession while the high-intensity disturbance destroys even the hardest tree species (Bendix *et al.,* 2017), and only the most resistant species subsist (Silva Pedro *et al.,* 2016). Understanding and predicting the species diversity disturbance in TALs is imperative in achieving the objective of sustainable use and management of forest provisioning ecosystem services in rural communities. Generally, conserving and protecting high-level biodiversity in TALs would ensure the provisioning of ecosystem services sustainability and productivity (Kershaw & Mallik, 2013) while ensuring the persistence of the same biodiversity to the future.

1.2.2 Carbon sequestration in a traditional agroforestry landscape

In Africa, South Africa is the largest carbon dioxide (CO_2) emitter, emitting approximately 400 million tons of CO_2 annually (O'Donoghue & Shackleton, 2013; Yessoufou, 2017). Biodiversity loss and vegetation landscape transformation have contributed to elevated CO_2 emissions in South Africa due to vegetation loss (Scheiter *et al*., 2018). Unfortunately, South Africa has a small forest land area, with a forest cover of less than 1% of the total land area (Leaver & Cherry, 2020), which require diverse strategies to reduce carbon emission and increase carbon sinks (O'Donoghue & Shackleton, 2013) such as agroforestry, reforestation, and afforestation to deal with the effects of climate change. According to Yessoufou (2017), more than 800 exotic plants have been introduced in South Africa for carbon initiatives. However, these exotic plants require more intensive management and control to prevent them from becoming invasive and other possible negative impacts on the environment and ecosystem, which is costing the country approximately R6.5 billion ($406 million) annually (Yessoufou, 2017).

In addition, agroforestry and natural regeneration have the potential to sequester CO_2 in the atmosphere and increase the carbon storage capacity of landscape vegetation (Murthy *et al.,* 2013; Chirwa *et al.,* 2023). Moreover, agroforestry has a greater potential for climate mitigation (Yasin *et al.,* 2019), and greater potential for carbon sequestration due to tree species' biodiversity and composition (Singh & Sahoo, 2015). Diverse tree species increase carbon sink in agroforestry landscapes (Poudel *et al.,* 2017). In an approach to mitigate Green House Gases (GHGs), the agroforestry land-use practice has been recognised under the Kyoto Protocol (Udawatta *et al.,* 2019; Yasin *et al.,* 2019). Kyoto Protocol, under United Nations Framework Convention on Climate Change (UNFCCC), is an agreement designed to reduce the release of GHGs into the atmosphere to prevent the projected effects of climate change and global warming (Dey & Masum, 2014). Two key processes have been adopted to deal with climate change and global warming, reducing anthropogenic emission of CO_2 and creating or enhancing carbon sinks (Gupta, 2012; Khaki *et al.,* 2016).

Integration of crops, livestock and trees in one landscape has been found to be more effective in carbon sequestration than any other monoculture land use. According to Yasin *et al.* (2019), agroforestry worldwide stores approximately 9, 21, 50 and 63 $MgCha^{-1}$ of carbon in semi-arid, sub-humid, humid, and temperate regions, respectively. Agroforestry with high tree biodiversity has a greater ability to adapt to climate change and sequester more CO_2 (Yasin *et al.,* 2019). The strong connection between aboveground biodiversity (vegetation) and belowground biodiversity (soil organisms) influences the provisioning ecosystem services (Paembonan *et al.,* 2018). Carbon accumulation in agroforestry is very high in both living biomass and soils (Poudel *et al.,* 2017; Chirwa *et al.,* 2023). According to Murthy *et al.* (2013) and Yasin *et al.* (2019), agroforestry landscape potentiality and effectiveness in storing carbon in above and below-ground biomass depend on both socioeconomic and environmental factors.

Forest ecosystems are major capturers of atmospheric carbon, which is then transferred to above- and below-ground biomass (Hanif *et al.,* 2019). Trees are the most significant fundamentals of the landscape, due to both diversity and biomass (Afzal & Akhtar, 2013). Tree wood and branches store atmospheric carbon that forms aboveground biomass. Trees are the most important sink of atmospheric carbon; it has been recorded that live tree biomass is 50 percent carbon (Afzal & Akhtar, 2013; Yessoufou, 2017). The aboveground biomass variation is influenced by several factors including environmental factors such as elevation, anthropogenic disturbance, and forest community such as plant taxonomic diversity and functional diversity (Yuan *et al.,* 2018; Chirwa *et al.,* 2023). According to Hanif *et al.* (2019), taxonomic and functional diversity have a link with aboveground biomass in forest ecosystems. In a forest ecosystem, species richness and diversity have been found to have a positive link with aboveground biomass.

Increasing or decreasing harvesting of provisioning ecosystem services in TALs would increase or decrease carbon sequestration. This would strongly depend on the frequency and intensity of harvesting. The most frequently harvested provisioning ecosystem services in South Africa include fuelwood, wild fruits, food, medicine, timber, and fodder (Lenfers *et al.,* 2018). Several factors contribute to the unsustainable use or harvest of provisioning ecosystem services in TALs, the most factors being climate change and anthropogenic activities (Lenfers *et al.,* 2018). Aboveground biomass removal through firewood, forage, timber, and other forest products exceeds the tree species resilience because they alter the ecosystem functionality and production (Souza *et al.,* 2019). The relationship between the aboveground biomass carbon and biodiversity is commonly disturbed by anthropogenic activities (Vizcaino-Bravo *et al.,* 2020).

An unsustainable harvest of provisioning ecosystem services could lead to the degradation of TALs and increased impoverishment of rural communities. The previous study by Wessels *et al.* (2013) hypothesised that biomass should be higher in distance areas compared to closer to communal areas due to the harvest of provisioning ecosystem services such as fuelwood. Biomass increases with increasing distance from the rural communities, confirming the intermediate disturbance hypothesis on highly disturbed areas. The hypothesis predicts that intermediate disturbance increases the species richness and diversity of an area (Araia & Chirwa, 2019). A Study conducted by Wessels *et al.* (2013) found that distance had a significant influence on communal landscape biomass, biomass increased as the distance to the forest increased (10 t h^{-1} at 0-1000 m to 25 t h^{-1} at 1000 m-2400 m). According to Wessels *et al.* (2013), provisioning ecosystem harvesters are not willing to travel more than 1000 m to the collection site. Therefore, species diversity, species richness and biomass are expected to increase at a distance beyond 1000 m. Due to excessive and heavy harvesting of provisioning ecosystem services at a 1000 m radius in TALs, the disturbance intensity affected the species diversity and subsequently reduce aboveground biomass and carbon sequestration (Wessels *et al.,* 2013). Aboveground biomass contributes significantly to the economic value of TALs as well as carbon sequestration (Owusu *et al.,* 2016). Agroforestry is the most recognised land-use system for both aboveground and belowground biomass carbon sequestration (Poudel *et al.,* 2017). Therefore, understanding the relationships between biodiversity and ecosystem functions such as aboveground biomass or carbon storage and productivity in TALs is very important for predicting the consequences of biodiversity loss on provisioning ecosystem services (Yuan *et al.,* 2018).

1.2.3 Conservation in traditional agroforestry

The paramount objective of conservation is still mainly to conserve the biodiversity of the natural forests (Soley & Perfecto, 2021) and protected areas (Ihemezie *et al.,* 2021). However, failure to visualise the traditional agroforestry landscapes within the conservation matrix has hindered their full conservation potential in South Africa. The question of how best to conserve biodiversity in modern societies would be answered in full consideration of traditional agroforestry and human-modified landscapes. The TALs are often excluded from conservation initiatives in South Africa, even though they harbour a diversity of tree species. Linking traditional agroforestry landscapes with conservation initiatives would create matrices that produce greater biodiversity conservation. If traditional agroforestry landscapes are placed in an appropriate conservation context, their effects on biodiversity could be substantial (Soley & Perfecto, 2021). The inclusion of TALs in the conservation agenda will scale up conservation gains worldwide (Urruth *et al.,* 2022).

Traditional agroforestry landscapes have a greater potential to promote conservation efforts worldwide by harbouring a diversity of tree species in different systems. Whether it is trees on farms, home gardens, live fences, silviopastural systems or more integrated systems. In TALs, native and endangered tree species of desirable benefits (e.g., traditional medicine) can be planted or conserved (Soley & Perfecto, 2021). However, changes in ecological (e.g., biodiversity, climate) and social factors (e.g., population, poverty) put more pressure on TAL's ability to provide livelihoods and environmental needs. Losing the ability to provide these TAL-based benefits can increase the vulnerability of the local people and have devastating effects on the society and environment. As part of conservation, the TALs of VBR within the landscape also have significant cultural value sites (e.g., sacred sites), these sites are very important for identity and local culture (Shackleton, 2020; Sinthumule & Mashau, 2020). The sacred sites within TALs are the key areas of local natural resources management (Sinthumule & Mashau, 2020). Deforestation and forest loss have led to a loss of biodiversity which has debilitated the capacity of forest landscapes to provide ecosystem services (Sinthumule & Mashau, 2020). As a result, the TALs as the adjacent landscapes to the forest landscapes are also affected by the same activities, these landscapes are simultaneously providing ecosystem services to local people, specifically in the VBR.

The lack of agroforestry policy in South Africa becomes a legal and regulatory constraint to traditional agroforestry promotion, management, and practice, and is still a common challenge worldwide (Urruth *et al.*, 2022). The legal constraints include restrictions or prohibitions on harvesting native trees, land, and tenure policies (Urruth *et al.*, 2022). For instance, like in many other countries, land ownership issues in South Africa hamper agroforestry development (Urruth *et al.*, 2022). Agroforestry is not getting full attention of policymakers as other land uses such as forestry and agriculture (Urruth *et al.*, 2022). Although there is no clear policy in the enhancement and management of agroforestry systems and practices, the Department of Agriculture, Land Reform and Rural Development, and Department of Forestry, Fisheries and Environment are the custodians of agroforestry implementation. Tree species conservation in agroforestry highly depends on forestry policies that impose restrictions or prohibitions on timber extraction and harvesting of trees under the grab of protecting the native trees. To strengthen and support conservation in agroforestry in South Africa, developing an agroforestry policy must be an unnegotiable action. It is necessary to develop a policy that will create conditions and incentives beyond the legislative scope to translate the legal provisions into actions (Urruth *et al.*, 2022).

1.3 Purpose and objectives of study

The purpose of this study was to evaluate the effects of distance levels and socio-ecological determinants on tree species composition, diversity, and carbon stocks in traditional agroforestry landscapes in order to address the biodiversity loss and enhnce conservation of the landscapes. This study had five objectives with a series of hypotheses for each.

Objective 1: To evaluate the influence of distance and socio-ecological determinants on provisioning ecosystem services (PESs) consumption in the traditional agroforestry landscapes (TALs).

Hypothesis: The extent of rural people's preferences and extent of provisioning ecosystem services (PES) harvesting decrease as the distance from the village to forest patches increases, regardless of the prevalent socio-ecological conditions.

Objective 2: To investigate the effects of distance on tree species diversity in traditional agroforestry and its contribution to tree species conservation.

Hypothesis one (1): Tree species diversity is expected to be the highest at an intermediate distance from the villages as predicted by the intermediate disturbance hypothesis.

Hypothesis tow (2): The turnover of tree species composition between distance levels increases as the distance from the community increases as predicted by the distance decay of the community similarity hypothesis.

Objective 3: To evaluate the impact of exotic species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes.

Hypothesis: There is a higher number of exotic tree species in community proximate areas and exotic species decrease as distance to the forest increases.

Objective 4. To investigate the effects of tree species richness, diversity and socio-ecological determinants on carbon stocks in traditional agroforestry.

Hypothesis one (1): Tree carbon accumulation increases as the distance from the community to the forest increases.

Hypothesis two (2): High tree carbon accumulation is expected at an intermediate distance.

Objective 5. To investigate the conservation strategies on tree species richness in traditional agroforestry landscapes.

Hypothesis: Management and conservation practices influence the conservation of tree species in traditional agroforestry landscapes.

1.4 Study conceptual framework

Traditional agroforestry resembles natural forests with fully stocked multi-strata species (Ali & Mattsson, 2019). Traditional agroforestry landscapes are characterised by production systems that combine socioeconomic well-being with ecological ecosystem functions to deliver a diverse landscape mosaic (Ali & Mattsson, 2019). The TALs have a greater potential to provide diverse and higher-level ecosystem services and functions due to higher biodiversity (Tadesse *et al.,* 2021). This has compelling support from Biodiversity and Ecosystem Functioning Hypothesis (BEF hypothesis), the BEF hypothesis predicts that a more diverse ecosystem delivers higher ecosystem functions than a less diverse one (Schwarz *et al.,* 2021).

Despite the potential of agroforestry to conserve biodiversity, biodiversity is threatened by anthropogenic disturbances in agroforestry landscapes (Koelemeijer *et al.,* 2021). At this current rate of anthropogenic disturbances, there is a need to optimise agroforestry biodiversity conservation. This could be achieved by identifying the major drivers of biodiversity loss in TALs. Previous studies suggested that tree species richness and diversity increase with increasing distance to the forest from the human communities (e.g., Singh *et al.,* 2021). In addition, it is also plausible that the tree species richness and diversity, and disturbances are positively related, as an intermediate disturbance leads to higher landscape productivity and tree species diversity (Araia & Chirwa, 2019; Escobedo *et al.,* 2021). For instance, communities with intermediate disturbance of biodiversity have higher biodiversity and productivity (Araia & Chirwa, 2019; Escobedo *et al.,* 2021). As such, the distance could be positively related to the disturbances that determine the biodiversity and productivity of the TALs.

Therefore, these relations are the driving factor of a question on whether the distance is a potential indicator for driving positive relationships between biodiversity, disturbance, productivity, and socio-economic well-being in the context of TALs management. Distance is fundamental in harvesting provisioning ecosystem services (e.g., fuelwood, fodder, traditional medicine, wild fruits, and food) extraction, as it determines the amount, frequency, time and choice of the extraction site (Ciccuzza & Kessler, 2011 Mohammed & Inoue, 2017; Kyaw *et al.*, 2020). Previous studies show that local people prefer to save time and energy when extracting PESs (Suleiman *et al.*, 2017; Feitosa *et al.*, 2018). Therefore, this study was guided by the link and relationship of the following ecological and social hypothetical framework (Figure 1.2).

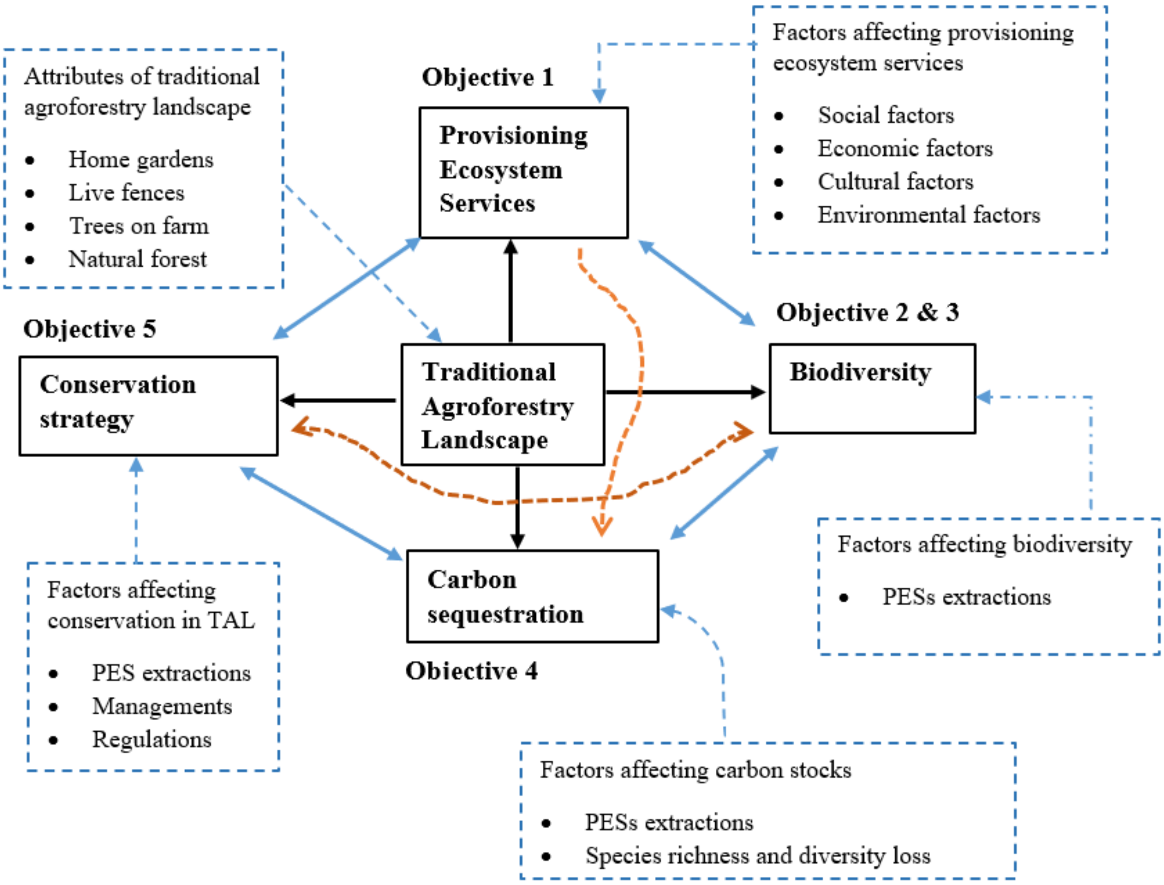

Figure 1.2: Conceptual framework of the study.

The conceptual framework relied on Optimal Foraging Theory (OFT) which predicts that human beings will maximise energy and time when extracting PESs (Soldati *et al.*, 2017). The OFT revealed that resources harvesters consider effort and time in harvesting natural resources, thus proximate areas are subjected to high harvesting activities (Schweik, 1999). The harvesting pressure at proximate areas surrounding the settlements causes lower tree species diversity and affects vegetation structure (Schweik, 1999). The repeated PESs extraction at an immediate distance reduces tree growth, productivity, and regeneration capacity (Thapa *et al.*, 2010). This affects tree species richness, density, and diversity and in the long run, this may cause local extinction. However, a different magnitude of PESs extraction may have different levels of either positive or negative impact (Thapa *et al.,* 2010). Thus, this study linked OFT with Intermediate Disturbance Hypothesis (IDH) as a guiding theoretical framework. As predicted by IDH, tree species diversity is expected to be higher at an intermediate distance due to minimal disturbances. In accordance with the OFT in TALs and IDH, the species richness and diversity were expected to be high at an intermediate distance of the TALs than at immediate and far distances.

Anthropogenic disturbances such as extraction of PESs are generally accompanied by negative effects on tree species richness and diversity (Araia *et al.,* 2019). In turn, these have been shown to affect the biodiversity and productivity in the landscape (Araia *et al.,* 2019; Banag-Maron *et al.,* 2021). In accordance with the OFT and IDH in the TALs of VBR, lower landscape biodiversity, productivity and tree regeneration were expected. This also links with the introduction of exotic species in TALs (Thapa *et al.,* 2010). The exotic trees (e.g., *Mangifera indica*, *Psidium guajava*, etc.) are introduced in TALs of VBR for different purposes including subsistence and economic gains (Ayisi *et al.*, 2018). The exotic species may capacitate the landscapes to meet the socio-economic demands of the local people. However, at the same time could also bring a detrimental effect such as the colonisation of the landscape due to higher preference by local people and disturbance tolerance (Thapa *et al.,* 2010), and plasticity characteristics (Walsh *et al.,* 2012).

At the immediate distance of TALs, as predicted by the OFT and IDH, higher disturbance reduces tree species diversity, thus providing a niche that favours exotic species colonisation and dominance. In contrast with monocultures landscapes, TALs have a greater potential to sequester higher atmospheric carbon due to the higher biodiversity (Mayele *et al.,* 2020; Yasin *et al.,* 2021). This study hypothesised that above-ground carbon accumulation increases as the distance to the forest increase as predicted by the OFT and the biodiversity productivity hypothesis (BPH). Previous studies show that in a biodiversity abundant landscape, there is higher level of production and carbon sinks (e.g., Dhyani *et al.,* 2021; Melone *et al.,* 2021). The above-ground carbon accumulation is positively related to the biodiversity and disturbances in TALs of VBR. The proximity to the forest by the communities has a fundamental impact on PESs (Thapa *et al.,* 2010). As it influences the extraction amount and frequency (Mohammed & Inoue 2017; Kyaw *et al.,* 2020). It is very critical to understand the impact of extraction drivers of PESs on the biodiversity and vegetation structure of TALs. As human livelihood needs significantly impact vegetation structure, diversity, and composition (Thapa *et al.*, 2010).

1.5 Limitations of the study

It is important to note that due to the COVID-19 pandemic, it was very difficult for researchers to enter and access communities. For the qualitative investigation, it was observed that during the FGDs, the availability of the desired participants was problematic, especially the elder participants, as they were classified as the most vulnerable group to the pandemic. Those who participated were elders who were deemed fit and knowledgeable about the traditional agroforestry landscape. Apart from that, the whole exercise of FGDs data collection was successful and provided valuable information that was in line with the aim of the study. The use of quantitative techniques was exempted from problems. Furthermore, due to limited finance or funding, the study could not be extended to many communities around VBR, hence only covered four communities.

1.6 Structure of the thesis

The thesis is comprised of eight (8) chapters as follows; Chapter 1 presents the introduction to the research, rationale of the study, research objectives, hypothesis, questions, and study conceptual framework. Chapter 2 sets out the research methodological approaches applied in the study. Chapter 3 investigated the influence of forest proximity on harvesting and use of provisioning ecosystem services from tree species in traditional agroforestry landscapes (Objective 1). Chapter 4 assessed the harvesting distance effect on tree species diversity in traditional agroforestry landscape: A case of Vhembe Biosphere Reserve in South Africa (Objective 2). Chapter 5 assessed the effects of exotic tree species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes of Vhembe Biosphere Reserve, South Africa (Objective 3). Chapter 6 assessed the effects of socio-ecological determinants on carbon accumulation in traditional agroforestry: A Case of Vhembe Biosphere Reserve, South Africa (Objective 4). Chapter 7 investigated the conservation of tree species richness in a traditional agroforestry landscape in the Vhembe Biosphere Reserve, South Africa (Objective 5). Chapter 8 presents the discussion and conclusion of the proceeding chapters and summarises the contribution of the study to the traditional agroforestry global knowledge and management of traditional agroforestry in South Africa, and globally.

In regard to publications, this thesis contains two published articles (Chapters 3 and 7) and three manuscripts (Chapters 4, 5 and 6) that are under peer review.

Chapter 3 has been published by the *International Journal of Sustainable Development & World Ecology;*

Lucky Makhubele, Paxie W Chirwa and Mulugheta G Araia. (2022). The influence of forest proximity to harvesting and use of provisioning ecosystem services from tree species in traditional agroforestry landscapes. *International Journal of Sustainable Development & World Ecology*. https://doi.org/10.1080/13504509.2022.2107104

Chapter 4 has been published by the *Journal of biodiversity and conservation;*

Lucky Makhubele, Mulugetha G Araia, and Paxie W Chirwa. (2023). Harvesting distance effect on tree species diversity in traditional agroforestry landscape: A case of Vhembe Biosphere Reserve in South Africa. Biodiversity and Conservation https://doi.org/10.1007/s10531-023-02671-2

Chapter 5 has been accepted for review by the *Journal for Nature Conservation;*

Lucky Makhubele, Mulugheta G Araia, Paxie W Chirwa. (Under review). The effects of exotic tree species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes of Vhembe Biosphere Reserve, South Africa

Chapter 6 has been accepted for review by the *Forestry: An International Journal of Forest Research;*

Lucky Makhubele, Paxie W Chirwa, Mulugetha G Araia. (Under review). Effects of socio-ecological determinants on carbon accumulation in traditional agroforestry: A Case of Vhembe Biosphere Reserve, South Africa.

Chapter 7 (Supplementary chapter, results of conservation strategies published with land use data within the traditional agroforestry landscape) has been published by the *MDPI: Forests*;

Makhubele, L.; Chirwa, P.W.; Sheppard, J.P.; Tshidzumba, R.P.; Araia, M.G.; Kahle, H.-P. (2022). Conservation of Tree Species Richness in a Traditional Agroforestry Landscape in the Vhembe Biosphere Reserve, South Africa. Forests, 13, 1766. https://doi.org/10.3390/f13111766

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Chapter 2
Methodology

2.1 Introduction

This section presents and describes the study's research methodological approaches, research design, sampling framework, data collection techniques, data analysis techniques, pilot study, and ethical considerations. This study used primary data collected in four communities of Vhembe Biosphere Reserve to address the research objectives outlined in Chapter 1. The presented methodology helped to collect socio-economic and vegetation (ecological) data. Different methodological approaches were applied in five different chapters based on the objective set-up, however, some of the chapters applied similar approaches as guided by the conceptual framework (Chapter 1). The conceptual framework helped to interlink the methodological approaches to address the main objective of the study.

2.2 Study area

Limpopo Province is classified as one of the underdeveloped provinces in South Africa (Statistics South Africa, 2016), characterised by a persistently high unemployment rate and extreme poverty (Uhunamure *et al.,* 2019). The majority of the 5.7 million people in the province live below the poverty line (Statistics South Africa, 2016), and heavily depend on PESs (Makhubele *et al.*, 2021), agriculture and social grants (Shackleton, 2020). The population growth in the province subsequently increases the demand for PESs and land for agriculture farming and settlements (Makhubele *et al.*, 2021). The use of forest products is deeply rooted in the culture, customs, and beliefs of the local people (Araia & Chirwa, 2019). The prevalence of a high degree of forest biodiversity is one of the prominent characteristics of the traditional agroforestry landscape of the VBR. The VBR has tremendous potential as a forest genetic resource for the conservation and support of the local people's livelihood. However, the PESs have been overexploited by local people to maintain their livelihoods. Therefore, it will be of immense importance if the use, species diversity and human behaviour are understood to inform future strategies of biodiversity conservation in the landscape. The present study was conducted from November to December 2020 in four villages, Damani (22°.50' 45 S, 30°.31'38 E), Thenzheni (22°.49' 54 S, 30°.28' 57 E), Tshiombo (22°.48' 30 S, 30°.30' 53 E) and Tshipako (22°.51' 14 S, 30°.28' 59 E) situated Thulamel Municipality in the Vhembe District of the Limpopo Province (Figure 2.1). The land area of the study sites is approximately 4,92 km^2 in Tshiombo, Damani (3.23 km^2), Tshipako (5.12 km^2) and Thenzheni (3.22 km^2). The household's population was 2600 in Tshiombo, Damani (400), Tshipako (320) and Thenzheni (400).

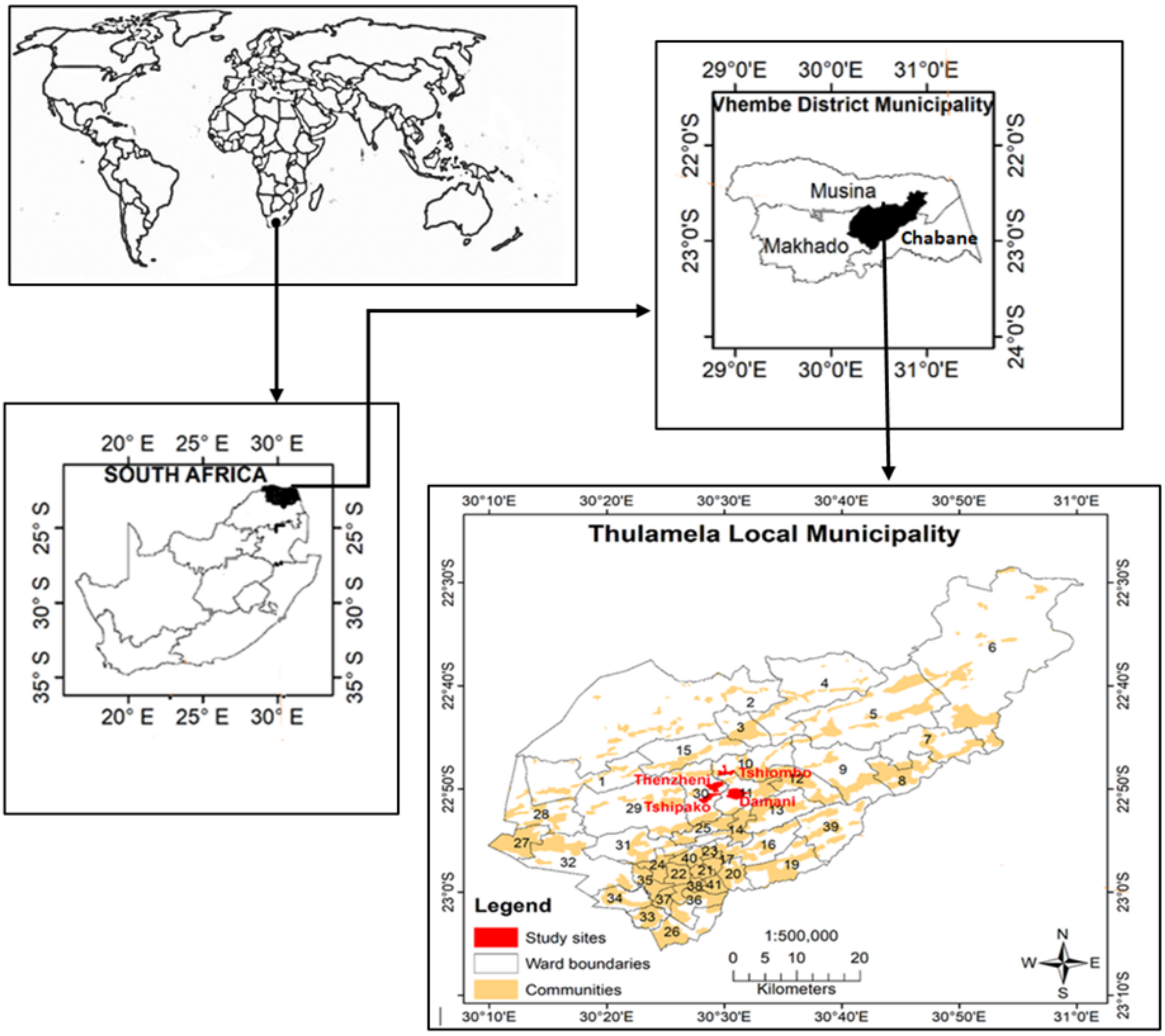

Figure 2.1: Map of the study sites.

The Vhembe District covers approximately 21 407 km^2 of land and has a population of 1.3 million people (Statistics South Africa, 2016). The ethnic groups of Vhembe District included Africans, Whites, Indians and Coloureds. The Thulamela Municipality covers approximately 2 893 936 m^2 of land which translates to 289 393 hectares. The annual rainfall of this area is above the threshold of both agriculture and forestry (500 mm-1000 mm per annum), as a result, this rainfall trend offers good climatic conditions for both agriculture and forestry production (Maponya *et al.*, 2019). Due to its climatic suitability, the slopes of the south-eastern part of the mountain range are dominated by various farming activities such as agriculture, forestry, and tea plantations (Kori *et al.*, 2018). The VBR landcape is characterised by different land uses (Figure 2.2), mostly dominated by natural vegetation and cultivated land (Ntshane, 2016). Land degradation is prevailing in VBR especially in human settlements and cultivated areas (Figure 2.2).

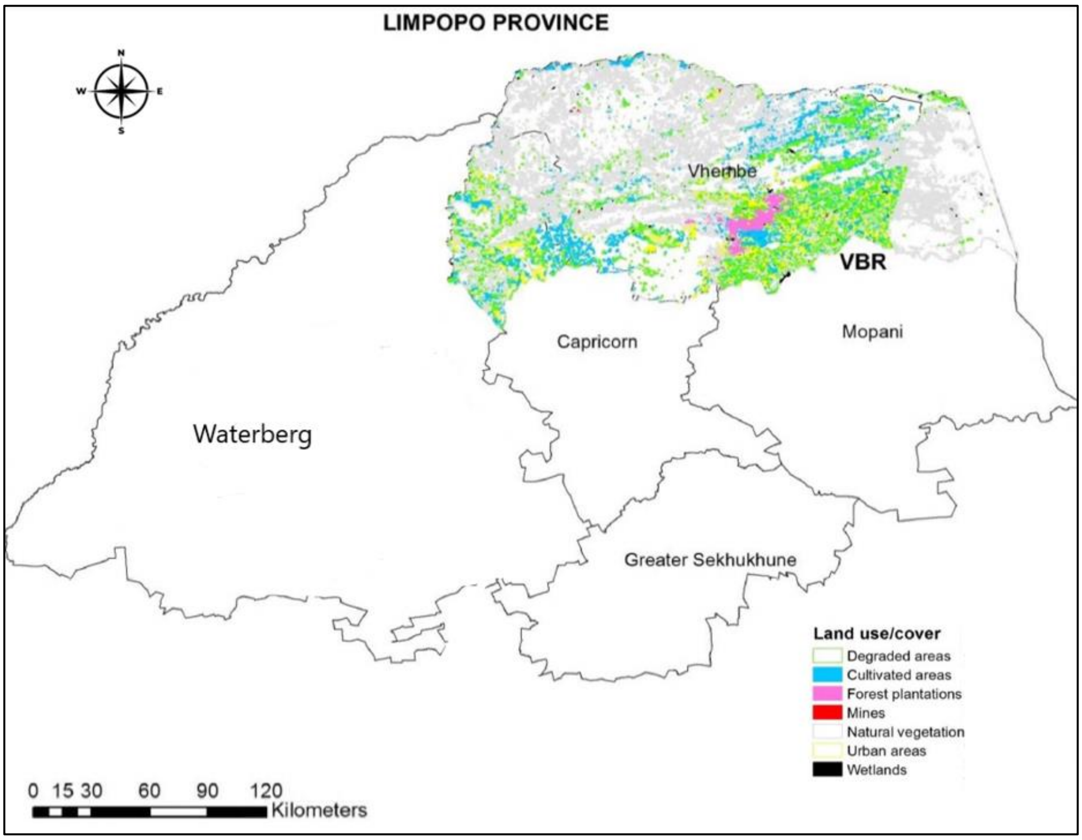

Figure 2.2: Land uses in VBR (Source: Ntshane, 2016).

The VBR consists of three biomes, grassland, forest, and savannah. The VBR vegetation classification includes (Figure 2.3); north vegetation, vhavenda miombo, musina mopane bushveld; west vegetation, limpopo sweet bushveld, makhado sweet bushveld; south vegetation, tzaneen sour lowveld, granite lowveld; east vegetation, mopane shrubland, makuleke sandy bushveld; middle vegetation, soutpansberg mountain bushveld, soutpansberg summit sourveld (Ntshane, 2016). Native tree species are retained in both homesteads and outside of the homestead in this area. At the same time, people plant diverse exotic species in their homesteads for different utilities. In VBR, tree species diversity in TAL provides a wide range of uses and PESs which include fuelwood, medicine, wild fruits, fodder, wild food, timber, soil improvement, fencing and building materials. Similar to many parts of the world (Ibhrahim *et al.*, 2019). The vegetation in traditional agroforestry landscapes is a habitat for indigenous trees, exotic trees and endemic trees. The provisioning ecosystem services commonly used are wild fruits and food, traditional medicines, firewood, building and livestock fodder (Constant & Tshisikhawe, 2018; Araia & Chirwa, 2019). Harvesting of PESs constitutes a primary source of income for most of the population (Makhubele *et al.*, 2021). The VBR vegetation primarily consists of grasslands, savannahs, wetlands, and forests (Evans, 2017).

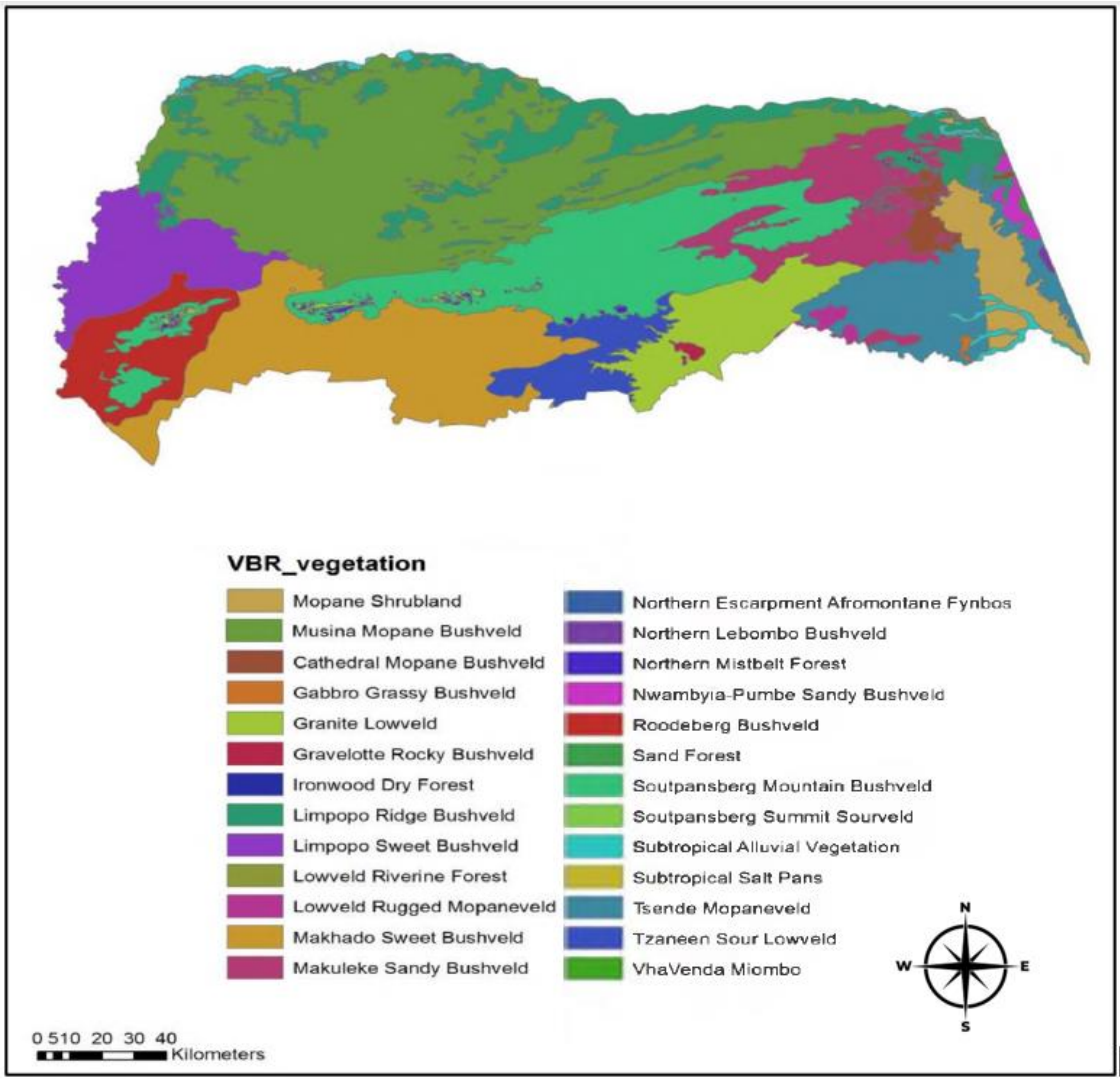

Figure 2.3: Vhembe Biosphere Reserve classification (Source: Ntshane, 2016).

2.3 Research design

Mixed-Method Research (MMR) was applied to provide a complete and comprehensive understanding of the context in which the VBR communities operate in TALs and to minimise methodological bias by integrating quantitative and qualitative methods. The MMR approach was applied to combine deductive and inductive designs to generate quantitative and qualitative data, and integrated the datasets (Migiro & Magangi, 2011; Alavi & Habek, 2016; Leavy, 2017). The MMR approach was appropriate for this study because the study investigated the social and behavioural science of the study communities (Edmonds & Kennedy, 2017; Leavy, 2017), and seeks to prompt community change and social action. Moreover, studies that seek to address social and environmental issues often use MMR (Kindon *et al.,* 2007). Furthermore, applying the MMR approach provided an opportunity to verify the findings. The MMR approach enhanced the validity and credibility of the study findings (Hesse-Biber, 2010). The MMR approach was considered appropriate because of the following reasons, the MMR was used for the integration of results in different ways including;

1. Merging the data: The quantitative and qualitative results were brought together and compared.
2. Embedding the data: One data set was used to augment or support the other data set.

In this study, MMR convergent or concurrent design was applied (Figure 2.4). This approach allowed the collection of both quantitative and qualitative concurrently, analysing both datasets to integrate both results in order to validate and compare the findings (Leavy, 2017). The data were collected simultaneously; firstly, forest inventory; secondly, households survey; lastly, focus group discussion.

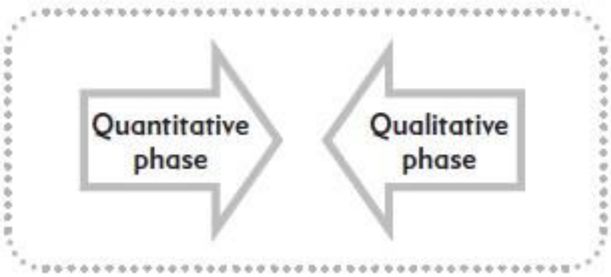

Figure 2.4: Convergent or concurrent MMR design (Source: Leavy, 2017).

2.4 Sampling and data collection framework

2.4.1 Household survey

Purposive sampling was used to select the study sites based on the premise that the study communities are in traditional agroforestry landscapes that are proximate to VBR biodiversity hot spot, the Soutpansberg mountain (Leavy, 2017; Lune & Berg, 2017). The purposive sampling approach is typically used in mixed-methods research (Leavy, 2017). Four communities were selected during the preliminary visit to VBR, Damani, Thenzheni, Tshipako and Tshiombo. The household population of each community was sourced from the community's leadership and the community register of the households was provided for the household's random selection. The sample size was determined at a 95% confidence level and 5% margin of error, using the following equation (Equation 1.1) in the computerized survey system.

$$S = \frac{X^2 NP(1-P)}{d^2(N-1)+X^2 P(1-P)} \qquad (1.1)$$

The S= sample size required, X= Z value of 1, 96 for 95% of the confidence interval, N= population size, d= degree of accuracy (0.05), a margin of error (Lune & Berg, 2017). The calculated sample sizes were 172 for Damani, Tshipako (177), Thenzheni (198) and Tshiombo (335). The household respondents were selected using a random sampling computerised program (random number generator), and the numbers were selected in the community households register (Krosnick, 2018).

The semi-structured questionnaires (Appendix 9) were used to collect data. The questionnaires were administered by the researcher and research assistants to the randomly selected households in each community. Prior to data collection, research assistants were trained to orient them about sampling design and administration of the questionnaires. Predetermined questions with a limited range of possible answers (Leavy, 2017), such as those ranging from dichotomous (yes and no), checklist, Likert scale (e.g., low to high) and Likert scale (e.g., increased to decreased), were used to interview the respondents. The questionnaires were translated into Tshivenda local language (Appendix 10) because is the spoken language in the study communities and to ease the administration of the questionnaires.

2.4.2 Focus Group Discussions

Focus Group Discussion (FGD), a qualitative data collection approach, was used in this study. The FGDs were conducted in each of the four (4) study communities in December 2020. Each FGD comprised youth and older participants with a minimum of 10 to a maximum of 35 respondents per FGD. Quota sampling (Figure 2.5) was used to select the participants because of the notion that older people poses vast traditional ecological knowledge (Araia & Chirwa, 2019), therefore, having mixed FGDs opened an opportunity for the older and younger generations to share knowledge and ideas about the subject under investigation.

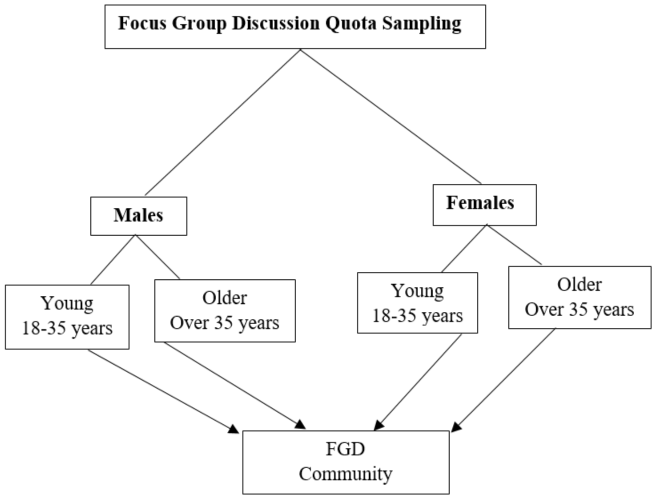

Figure 2.5: Schematic presentation of quota sampling of FGD participants.

FGDs provided an opportunity for the respondents to express the issues they think are important, explaining their experiences and knowledge in detail (Edmonds & Kennedy, 2017). The FGD also provided rich data through researcher facilitation, guiding the discussion, asking key questions, and allowing the respondents the freedom of expression at their discretion (Leavy, 2017). Each FGD lasted about two (2) hours, and the discussions were recorded by the researcher and later transcribed (Balza *et al.*, 2021).

2.4.3 Forest Inventory

The forest inventory was conducted in the Autumn and Summer seasons (November-December) 2020. The Concentric-Circles model (CCM) was used to describe the harvesting distances approach that describes the local people's use of provisioning ecosystem services (Hall & Farrell, 2001; Gorresen & Willig, 2004). Within this model, the distances are described as a set of concentric circles. As shown in figure 2.6, set A represents the community and immediate distance, set B denotes the community boundary and intermediate distance (less than 5km away from the community centre) and set C denotes the far distance measured at 5-10km from the community boundary. The assumption is that PESs harvesting decreases as the distance to the forest increases or is visa-verse as indicated by arrows in the CCM. Distance acts as a natural barrier to the harvesting of provisioning ecosystem service with the frequency of harvesting declining significantly as the distance from communities to the forest increases (Mensah, 2016; Ramarumo & Maroyi, 2020). The PESs in the immediate distance (adjacent or surrounding communities) have been reported to be depleting and vulnerable to local elimination (Makhado *et al.*, 2012). For this study, the data collection sites within each community were classified based on the distance travelled to collect or harvest PESs based on information obtained from local communities. The distances were thus grouped into three levels as follows, immediate (0-1km), intermediate (1-5km) and far distance (5-10km). The immediate distance was charatarised by live fences, homegardens, remant forest patches, intermediate and far distances are characterised by silvopastoral practice, trees on farm, and forests. Vegetation sampling and data collection methods are detailed in Chapters 4, 5, 6 and 7. The vegetation data were collected using the forestry inventory form (Appendix 11). The forest inventory form captured vegetation data (DBH, scientific and local names), grazing incidents, elevation, gradient, fire occurrence and human disturbances. However, there was an apparent duplication of methods between the Chapters.

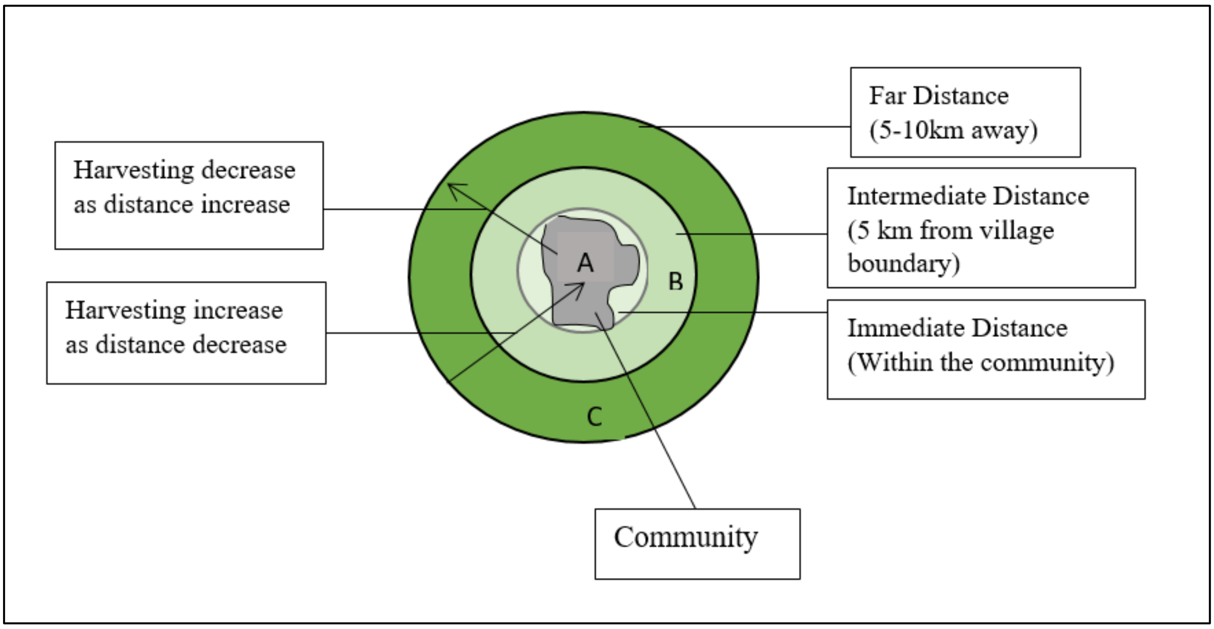

Figure 2.6: Concentric-circles model of distances levels.

2.4.4 Pilot study

Prior to actual data collection, a pilot study was conducted in one community with a small number of participants (community members), this was done to test the reliability of the questionnaire (Ramarumo & Maroyi, 2020). In line with Vercruyssen and Hendrick (2012), the pilot study serves as a preliminary test of the study hypothesis and tests whether it is the right tool to collect data. The findings from the pilot study were used as an aid in refining the questionnaire and the research approach (Vercruyssen & Hendrick, 2012). In a pilot study for forest inventory, the transect walk was conducted to have a look at the community settings, measuring the distance between the planned transects and observing the traditional agroforestry landscape and testing the forest inventory instrument's applicability.

2.5 Data analysis

The data analytical approach was executed based on the type of datasets (quantitative and qualitative data) and the specific objectives of the study. Several steps were followed in the preparation for data analysis, exploring the data, validating the data, and testing data analysis techniques. The biological data was analysed using Plymouth Routines in Multivariate Ecological Research (PRIMER) version 7.0.21 and added to PERMANOVA + 1 software. The quantitative data for social surveys were analysed using the Statistical Package for Social Science (SPSS) software, version 23.0. Detailed specific analytical approaches and statistical techniques applied for each specific objective in this study are presented in Appendix 1.

2.6 Study ethics

This study involved human participants and considered the protection of the research participants by applying for ethical approval before the data collection (Leavy, 2017; Lune & Berg, 2017). The study assessed the possible risks to research participants, risks which may include emotional, psychological, and physical harm (Edmonds & Kennedy, 2017; Leavy, 2017), and none were identified for this study. However, the study ensured that all the risks that may arise, the research ensured that they should be prevented (Lune & Berg, 2017). Permission to conduct the study was granted by the communities' leadership during the preliminary visit to the study sites. The informed consent form was signed by the researcher and community leadership as a permission token (Lune & Berg, 2017). The informed consent ensured that the research participants participated with their willingness, voluntarily and they were free to withdraw from the study project (Edmonds & Kennedy, 2017). The ethical clearance was applied at the University of Pretoria ethics committee and granted in 2020. The Ethical clearance reference number is NAS317/2020.

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Chapter 3

The influence of forest proximity to harvesting and use of provisioning ecosystem services from tree species in traditional agroforestry landscapes

Abstract

Traditional agroforestry landscapes play a critical role in conserving biodiversity and sustaining rural livelihoods through multiple products and services. However, an unprecedented rise in the unsustainable utilisation and management of provisioning ecosystem services from these landscapes contributes to forest biodiversity loss and impacts livelihood efforts. The objective was to evaluate the link between distance and socio-ecological determinants and the provisioning ecosystem services consumption behaviour. This study tested whether "*rural people's preferences and extent of PESs harvesting decrease as the distance from the village to forest patches increase, regardless of the prevalent socio-ecological conditions"*. Using a structured questionnaire survey, data were collected in 882 households in four villages of Thulamela Municipality, Limpopo Province in South Africa. The data were analysed using Chi-square, Fidelity level, Use-value, Friedman test, and Generalised linear model. Consistent with the hypothesis, the results showed that local people harvest most of the provisioning ecosystem services at an immediate (1^{st}) level, followed by intermediate (2^{nd}) and far distance (3^{rd}) levels. This study further revealed the existence of 108 useful tree species in the study areas. This study also found that although socio-ecological determinants influence consumption behaviour, the influence of specific socio-ecological determinants was not consistent across the different regimes of distance from the forest resources. The fact that local people use and harvest provisioning ecosystem services from the distance regime closest to the household, shows the need for a concerted effort to conserve and enhance the abundance of multipurpose tree species in homesteads and the immediate areas.

Keywords: Harvesting Distance Level, Optimal Foraging Theory, Provisioning ecosystem service, Traditional Agroforestry Landscape, Concentric-circle model, Use-value

3.1 Introduction

With the growing dominance of humanity in natural ecosystems, forests and woodlands are widely utilised by most rural communities around the world for provisioning ecosystem services (PESs) such as medicine, fuelwood, fodder, and wild food (Zhyla *et al.,* 2018; Hong & Sazien, 2019; Hussain *et al.,* 2019; Mushi *et al.,* 2020; Shackleton, 2020). The world population depending on PESs for survival has proportionally increased in recent years by over 2 billion people (Sinthumule & Mashau, 2020). However, the sources of PESs are currently subjected to intense collection pressure, resulting in the modification of natural landscapes and decline of life-supporting ecosystem services (Vitousek *et al.,* 1997). Hence, we see evidence of the negative impact of over-harvesting and/or use, such as decreased biodiversity including loss of important tree species (Hong & Saizen, 2019; Sinthumule & Mashau, 2020; Hoveka *et al.,* 2020).

Globally, over 2 billion hectares of forest have been degraded, posing a serious threat to species biodiversity, thus reducing PESs and inadvertently impacting human well-being (Feng *et al.,* 2021). This has stimulated research aimed at understanding the socio-ecological determinants (SEDs) of PESs harvesting and use (Augustynczik *et al.,* 2020; Hoveka *et al.,* 2020; Musakwa *et al.,* 2020), specifically to investigate factors that influence the harvesting of PESs (Kutal *et al.,* 2021). Some of these studies have shown, for example, that elevation, accessibility, socio-economic status, availability, culture, and distance are major socio-economic ecological determinants that influence the extent of harvesting of PESs (Araia & Chirwa, 2019; Ofoegbu & Chirwa, 2019; Kutal *et al.,* 2021; Gomes *et al.,* 2020; Musakwa *et al.,* 2020; Araia *et al.,* 2020). Recently, many studies have applied the Optimal Foraging Theory (OFT) to disentangle the contribution of different socio-ecological determinants on user behaviour. The OFT suggests that human beings will maximise their gains, whether economic or energy demanding when extracting PESs (Soldati *et al.,* 2017; Feitosa *et al.,* 2018). The theory is applied to understand the fundamental choices of resources harvesters, such as where to harvest, what to harvest, and how long to spend on harvesting (Kefa *et al.,* 2018).

The resources harvesters require time and energy to search for PESs, and the availability of resources influences the choice of the harvesting site. This leads resources harvesters to choose harvesting sites that combine availability and quantity with minimal distance (Feitosa *et al.,* 2018). If resources harvesters choose their harvesting site based on the distance to the forest, perhaps to minimise the collecting energy and travelling time, distance becomes endogenous to PESs harvesting and use. The study by Suleiman *et al.* (2017) confirmed that the greater the distance from the household to the forest, the less likely the forest will be targeted for collection by the household. However, to our knowledge, there have not been any local studies that investigated how other SEDs influence the harvesting and use-behaviour of households within a specific distance regime of forest resources in human-modified landscapes.

Furthermore, studies show that resources harvesters do not select harvesting sites randomly, but rather that harvesting distance may be an indicator of availability (Scales & Fries, 2019; Luswaga & Nuppenau, 2020), scarcity (Kegode *et al.,* 2017) and use-value (Etongo *et al.,* 2017) of the PES in a given harvesting site. Availability and use-value of species may compel resources harvesters to travel a long distance to the forest (Luswaga & Nuppenau, 2020). Depleting PESs in the forest adjacent to the communities compels resources harvesters to travel a relatively long distance to collect PESs (Makhado *et al.,* 2009). Resources harvesters may have to bridge some distance in space and time to collect PESs necessary for survival. For instance, women and youth resources harvesters may prefer to travel a short distance. Such preference for short-distance areas for harvesting saves energy and time for other productive activities (Uhunamure *et al.,* 2017). Araia and Chirwa (2019) further argued that there is a weak correlation between the specific category utility and use-value of tree species and their ecological abundance. Collection and use of tree species do not imply equal knowledge of the different uses of the trees. Local people do not value and use all the tree species equally because not all species used are known and valuable to everyone in a given area (Camou-Guerrero *et al.,* 2008; Etongo *et al.,* 2017). Hence, understanding the knowledge of forest resources in general and tree species used for a specific utility category, is a socio-ecologically complex issue that may not be fully explained by household distance from the forest resources (Makhado *et al.,* 2012).

The unprecedented rise in the unsustainable utilisation and management of PESs in the Traditional Agroforestry Landscape (TAL) of South Africa has contributed to forest degradation and consequently impacts livelihoods efforts (Ofoegbu & Chirwa, 2019). A detailed understanding of resources harvesters' behaviour will likely be the key to successful forest utilization planning and management in traditional agroforestry landscapes. The main objective of this study was to evaluate the influence of distance and other socio-ecological determinants on PES consumption behaviour in the TAL. Thus, this study tested the hypothesis that "*The extent of rural people's preferences and extent of PESs harvesting decrease as the* *distance from the village to forest patches increases, regardless of the prevalent socio-ecological conditions"*. The following associated research questions were developed to answer the objective: (a) At which distance do local people harvest PESs in TALs? (b) Which tree species are important for different PESs in TALs? (c) What factors determine the extent of PESs harvesting at different distance levels?

3.2 Research methods

3.2.1 Data collection

Data was collected using the procedure discussed in Chapter 2 (Sections 2.4.1 and 2.4.2). In the context of this study, the questionnaire explored the respondents' harvesting behaviour, knowledge, and experience in relation to PESs use, harvesting distance levels, and tree biodiversity in the TAL. In parallel, FGDs were conducted using semi-structured questions to ensure that there was flexibility in questioning and to allow follow-up questions. This approach helped to check the reliability of responses and to validate the data (Lune & Berg, 2017; Balza *et al.*, 2021). The FGDs in each community were conducted with a group of young and old participants, including the communities' leadership. The FGD size ranged from 15 to 35 participants and the sessions lasted about 2 hours. A digital audio recorder was used to capture the data during FGD sessions and responses were later transcribed (Balza *et al.*, 2021). The following questions were asked in order to lead the discussions: Where do local people harvest the PESs such as fuelwood, fodder, medicinal plants, and wild fruits/food? Which tree species are mainly used for food, medicine, fuelwood, and livestock fodder? What are the SEDs influencing the use of certain tree species?

3.2.2 Data analysis

The quantitative data were analysed using the Statistical Package for Social Science (SPSS) software, version 23.0. Firstly, the Kolmogorov-Smirnov normality test was performed to check the normal distribution of the data (Mishra *et al.*, 2019; Khatun, 2021). The results of the test of the variables were significant ($p < 0.05$). Therefore, the null hypothesis of normal distribution was rejected. Since the results showed no normal data distribution, the non-parametric analysis was applied. Then, demographic variables were analysed using cross-tabulation in percentiles and means.

3.2.2.1 The homogeneity of the harvesting distance level of provisioning ecosystem services

The homogeneity of the harvesting distance level of PESs among the communities was analysed using the Friedman test of whether there are differences in harvesting distances of PESs among study communities. The results were considered significant at $p < 0.05$. When the significant difference in harvesting distances of PESs was detected in the Friedman test, it was critical to determine which distance level was mostly preferred by the local people. Therefore, the Wilcoxon rank test was used to test the significant difference of mean total.

3.2.2.2 Association of the extent of harvesting distance levels and their socio-ecological determinants

A Generalised Linear Model (GLM) with an ordinal logistic distribution (Schmettow, 2021) was used to examine the association between the PESs harvesting distance levels and their SEDs. SEDs were used as independent variables and the extent of harvesting distance levels as the dependent variables. The following GLM formula (Equation 3.1) was used:

$$Link_{(\Upsilon ij)} = \theta j - (\beta_1 X_{i1} + \beta_2 X_{i2} \ldots + \beta_p X_{ip} \beta p) \qquad (3.1)$$

Where *Link* (γ_{ij}) is the link function, γ_{ij} is the cumulative probability of the j^{th} category for the i^{th} case, θj is the threshold for the j^{th} category, p is the number of regression coefficients, X_{i1}, X_{i2}, X_{ip} are the values of the predictors (age, gender, household income, education, cultural value, use-value, elevation, accessibility and availability) for the i^{th} case, $\beta_1 \ldots . \beta_p$ are regression coefficients.

3.2.2.3 Importance of tree species based on use-value.

To assess tree species use-value, the fidelity level (FL) technique was adopted (da Silva *et al.*, 2014; Araia & Chirwa, 2019). The following FL formula (Equation 3.2) was used to calculate the tree species use-value:

$$FL\ (\%) = (I_p \ / \ I_u\ ) \times 100\% \qquad (3.2)$$

Where *FL (%)* is the fidelity level or use-value in percentile, I_p is the mention of tree species for a particular use, and I_u is the total number of respondents. The fidelity level (use-value) was calculated by dividing the number of mentioned tree species by the total number of respondents in percentiles. The total use-value of tree species was the summation of the use-value of all categories of utility. An Overall Use-Value (OUV) was calculated as the summation of all use-values of four categories. Based on the high use-value score, the top 30 tree species were selected for utility and community comparison categories. The following formula (Equation 3.3) was used to calculate the OUV:

$$OUV = \sum(Food_{uv} + Fuel_{uv} + Medicine_{uv} + Fodder_{uv}) \quad (3.3)$$

Where OUV is the overall use-value, $Food_{uv}$ is the total food category use-value, $Fuelwood_{uv}$ is the fuelwood category use-value, $Medicine_{uv}$ is the medicine category use-value and $Fodder_{uv}$ is the fodder category use-value.

3.3 Results

3.3.1 Demographics

Table 3.1 shows that the most prevalent age group of the respondents ranged from 36 to 60 years, representing 58% in Tshipako, 51% in Damani, 38% in Thenzheni and 43% in Tshiombo. Overall, most of the respondents were elderly people in all the communities. The study areas were predominated by females, with 74% in Tshipako, 59% in Damani, 55% in Thenzheni and 73% in Tshiombo. Except for Thenzheni where the majority (46%) are self-employed, the main source of income in the study area was a social grant, with 52% in Tshipako, 31% in Damani, and 47% in Tshiombo dependent on an old-age grant, child support, disability or foster grants. The most prevalent level of education was secondary education with 63% of people in Tshipako, 48% in Damani, 46% in Thenzheni and 43% in Tshiombo, who attended secondary school.

Table 3.1. Socio-economic and demographic profile of the study area.

	Proportions of respondents (%)			
	Tshipako	Damani	Thenzheni	Tshiombo
Socio-economic	(n=177)	(n=172)	(n=198)	(n=335)
Age of respondent				
18-25	4.52	8.14	7.07	7.76
26-35	17.51	20.35	30.30	16.72
36-60	58.19	50.58	37.88	42.99
>61	19.77	20.93	24.75	32.54
Gender				
Male	25.99	40.70	44.95	26.87
Female	74.01	59.30	55.05	73.13
Household source of income				
No formal income	14.69	27.91	7.58	15.82
Employed	12.99	18.02	14.14	10.45
Self-employed	19.21	20.93	45.45	24.48
Pensioner	1.13	2.33	7.58	2.09
Social grant	51.98	30.81	25.25	47.16
Level of education				
No schooling	4.52	10.47	12.12	15.22
Primary	19.77	21.51	12.12	18.51
Secondary	62.71	48.26	45.45	43.28
Tertiary	12.99	19.77	30.30	22.99

3.3.2 The homogeneity of the harvesting distance level of provisioning ecosystem services

As depicted in Table 3.2, the results show that there was a statistically significant difference ($\chi^2 = 109.9, p < 0.05$) in harvesting distance of wild food and fruits across the study areas. The wild food and fruits are harvested at an intermediate distance by 92% in Tshipako and 91% in Thenzheni communities, while 94% in Damani and 85% in Tshiombo harvest wild food and fruits at an immediate distance. The harvesting distance of fuelwood was significantly different ($\chi^2 = 123.4, p < 0.05$) across the study areas. About 90% of people in Tshipako and 91% in Thenzheni harvested the fuelwood at an intermediate distance, while 90% in Damani and 86% in Tshiombo harvested fuelwood at an immediate distance. There was a significant association

($\chi^2 = 150.9, p < 0.05$) in harvesting distance of traditional medicine across the study areas. Traditional medicine was harvested at an intermediate distance by 89% of people in Tshipako and 87% in Thenzheni, while 89% in Damani and 69% in Tshiombo harvested traditional medicine at an immediate distance. The collection of fodder and grazing distance was statistically significantly associaation ($\chi^2 = 121.9, p < 0.05$) across the study areas. About 83% in Damani and 73% in Tshiombo collected fodder and grazed their livestock at an immediate distance, while 88% in Thenzheni grazed and collected fodder at a far distance, and 87% in Tshipako harvested at an intermediate distance.

Table 3.2. The proportion of communities' provisioning ecosystem services harvesting from distance regimes.

Provisioning ecosystem services	**Distance levels**	**The proportion of respondents (%)**				**Chi-square**	
		Damani (n=172)	**Thenzheni (n=198)**	**Tshiombo (n=335)**	**Tshipako (n=177)**	χ^2	***p*-value**
Food & Fruits	Immediate	94.20	88.40	85.20	90.80	109.85	0.01
	Intermediate	69.20	90.90	47.80	92.00		
	Far	45.30	86.40	39.80	79.90		
Fuelwood	Immediate	90.10	86.40	86.10	86.20	123.40	0.00
	Intermediate	71.50	91.40	45.40	90.20		
	Far	41.90	85.40	36.50	85.00		
Traditional medicine	Immediate	89.00	82.80	68.80	82.90	150.94	0.00
	Intermediate	62.20	87.40	39.50	89.10		
	Far	44.80	86.40	28.20	81.70		
Fodder	Immediate	83.10	66.20	73.30	66.30	121.96	0.00
	Intermediate	62.20	84.80	43.60	87.40		
	Far	44.80	87.90	36.20	85.70		

Table 3.3 shows the Friedman test of significant differences in harvesting distances of PESs. The Chi-square results revealed a significant difference in harvesting distance across the communities. There were significant differences in the distance levels for wild food and fruits ($\chi^2 = 363.8, p < 0.05$), fuel wood ($\chi^2 = 300.9, p < 0.05$), traditional medicine ($\chi^2 = 185.7, p < 0.05$) and fodder ($\chi^2 = 29.1, p < 0.05$) (Table 3.3). The Friedman results showed that overall, the local people mostly harvest PESs at an immediate distance. The immediate distance was highest ranked (1), followed by an intermediate distance (2) and far distance (3)

in three of the PESs categories, but not in the grazing and fodder collection category (Table 3.3).

Table 3.3. Friedman's means ranking of the PESs harvesting distance levels.

Distance levels	All communities (n=882)			
	Food & fruits	Fuelwood	Traditional medicine	Fodder
	Mean Rank	Mean Rank	Mean Rank	Mean Rank
Immediate distance	2.38^{1}	2.37^{1}	2.27^{1}	1.88^{3}
Intermediate distance	1.87^{2}	1.88^{2}	1.91^{2}	2.07^{1}
Far distance	1.74^{3}	1.76^{3}	1.82^{3}	2.05^{2}
Chi-Square	363.80	300.78	185.65	29.08
Df	2	2	2	2
Asymp. Sig.	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}

$^{1, 2, 3}$Ranking ranging from highest (1) to (3), $^{a}p < 0.05$

3.3.3 Importance of tree species based on use-value.

Local people used 108 tree species for the selected four categories (food, fuel, medicine, and fodder) of use (Table 3.4). The leading category of use was medicine. An average of 55 tree species was reported as trees that are used for medicine, comprising 29% of all useful tree species. The second category was fuelwood with an average of 52 tree species (27%), followed by 44 tree species (23%) used for fodder and 40 tree species (21%) for edible trees.

Table 3.4. Average number of tree species per category of use

Category of use	**The average number of species[a]**	**Percentage (%)**
Food & fruits	40.20	21.02
Fuelwood	52.00	27.15
Traditional medicine	55.25	28.85
Fodder	44.00	22.98

[a]Includes all tree species mentioned (n=108 species)

The use-value for the selected species showed that the most important species in the four categories in Thenzheni were as follows (Appendix 2): food (UV=0.858, *Englerophytum magalismontanum*), fuel (UV=0.515, *Xylopia odoratissima*), medicine (UV=0.510, *Combretum molle*) and fodder (UV=0.267, *Bridelia micrantha*). Based on the total use-value in the community, *E. magalismontanum* spp. has multiple uses in Thenzheni (UV=1.005). The most important tree species of the four categories in Tshipako: food (UV=0.734, *E. magalismontanum*), fuel (UV=0.672, *Parinari curatellifolia*), medicine (UV=0.451, *Clematis brachiata*) and fodder (UV=0.282, *Persea americana*). Based on the total use-value in the community, *E. magalismontanum* spp. has multiple uses in Tshipako (UV=1.056). The most important tree species of the four categories in Damani: food (UV=0.430, *E. magalismontanum*), fuel (UV=0.412, *Albizia adianthifolia*), medicine (UV=0.267, *Zanthoxylum capense*) and fodder (UV=0.232, *Dichrostachys cinerea*). Based on the total use-value in the community, *Sclerocarya birrea* spp. has multiple uses in Damani (UV=0.903). The most important tree species for the four categories in Tshiombo: food (UV=0.450, *E. magalismontanum*), fuel (UV=0.179, *Dichrostachys cinerea*), medicine (UV=0.200, *C. molle*) and fodder (UV=0.149, *Mangifera indica*). Based on the total use-value in the community, *M. indica* spp. has multiple uses in Tshiombo (UV=0.582).

Based on the OUV results (Appendix 2), the top 10 species were selected and considered to be the most important multiple-use tree species within and across the four categories. In descending order (OUV=3.089-1.290), Munombelo (*E. magalismontanum)*, Muvhungo (*Landolphia kirkii*), Mufula (*S. birrea*), Muvhula (*P. curatellifolia*), Mugwiti (*C. molle*), Muungo (*M. indica*), Muelela (*A. adianthifolia*), Muvhulavhusiku (*X. odoratissima*), Muzwilu (*Vangueria esculenta*) and Muafukhada (*P. americana*).

3.3.4 Association of harvesting distance levels and their socio-ecological determinants

3.3.4.1 Wild food and fruits harvesting distance level.

Table 3.5 presents the GLM odds ratios and their 95% confidence intervals for each harvesting distance level and the associated SEDs. The results showed that the harvesting of wild fruits and food at an immediate distance was significantly more likely to be influenced by the cultural value (Wald= 4.883, $p< 0.05$), use-value (Wald=17.848, $p< 0.05$), accessibility (Wald=3.687, $p < 0.05$) and availability (Wald= 4.972, $p < 0.05$) of the wild fruits and food. On the other hand, household income was significantly less likely to influence (Wald=5.348, $p < 0.005$) the harvesting of wild fruits and food at an immediate distance. During FGD, Tshiombo participants indicated that they survive by collecting wild fruits in the forest close to their community and selling them along the streets. The 95% confidence interval depicts no significant ($p > 0.05$) difference in the association of age, gender, education, and number of household members of harvesting wild food and fruits at an immediate distance. The model analysis at a 95% confidence interval showed that age, gender, household income, education, number of household members, cultural value, use-value, accessibility, and availability are not statistically significant determinants of harvesting wild food and fruits at intermediate and far distance levels.

Table 3.5. The influence of socio-ecological determinants on the extent of harvesting of wild food and fruits at different distance levels

Wild food & fruits harvesting			95% Confidence Interval			
Distance level	Socio-ecological determinants	B	Lower	Upper	Wald	Sig.
Immediate	Age	.041	-.135	.217	.204	0.651
	Gender	.217	-.060	.495	2.353	0.125
	HH Income	-.112	-.206	-.017	5.348	0.021[a]
	Education	-.035	-.198	.128	.177	0.674
	No.HM	-.013	-.070	.043	.215	0.643
	Culture value	.056	.006	.106	4.883	0.027[a]
	Use-value	.100	.053	.146	17.848	0.000[a]
	Elevation	.032	-.009	.079	2.299	0.129
	Accessibility	.047	-.001	.096	3.687	0.005[a]
	Availability	.056	.007	.105	4.972	0.026[a]
Intermediate	Age	-.041	-.216	.135	.205	0.651
	Gender	-.230	-.508	.048	2.621	0.105
	HH Income	-.035	-.130	.061	.507	0.476
	Education	-.039	-.201	.123	.223	0.637
	No.HM	.032	-.024	.088	1.225	0.268
	Culture value	.039	-.033	.111	1.139	0.286
	Use-value	.034	-.034	.101	.952	0.329
	Elevation	-.024	-.084	.037	0.590	0.442
	Accessibility	5.569	-.070	.070	0.000	0.999
	Availability	.063	-.008	.134	2.989	0.084
Far distance	Age	-.090	-.257	.078	1.100	0.294
	Gender	-.133	-.396	.130	.985	0.321
	HH Income	-.037	-.126	.053	.640	0.424
	Education	-.083	-.235	.069	1.152	0.283
	No.HM	.001	-.053	.055	.002	0.961
	Culture value	.038	-.039	.116	.940	0.332
	Use-value	.021	-.051	.094	.328	0.567
	Elevation	-.016	-.081	.049	.243	0.622
	Accessibility	.006	-.069	.081	.024	0.876
	Availability	-.032	-.109	.045	.667	0.414

[a]Sig. = Significance at p value < 0.05, HH Income=Household income, No.HM= Number of Household Members

3.3.4.2 Fuelwood harvesting distance level.

Based on the GLM model results in Table 3.6, harvesting of fuelwood at an immediate distance was significantly less likely to be influenced by education (Wald=4.508, $p < 0.05$). However, the harvesting of fuelwood was more likely to be influenced by the use-value (Wald=6.209, $p < 0.05$) and elevation (Wald=4.755, $p < 0.05$). On the other hand, age, gender, household income, number of household members, cultural value, accessibility, and availability were not statistically significant ($p > 0.05$) determinants of harvesting fuelwood at an immediate distance. The model showed that age, gender, household income, education, number of household members, cultural value, use-value, accessibility, and availability are not statistically significant determinants ($p > 0.05$) of harvesting fuelwood at an intermediate level. However, the likelihood of harvesting fuelwood at a far distance was significantly more likely to be influenced by household income (Wald=4.034, $p < 0.05$) and use-value (Wald=4.493, $p < 0.05$). On the other hand, gender was significantly less likely (Wald=5.603, $p < 0.05$) to influence the harvesting of fuelwood at a far distance. Furthermore, the results showed that age, education, number of household members, cultural value, accessibility, and availability are not statistically significant determinants ($p > 0.05$) of harvesting fuelwood at a far distance.

Table 3.6. The influence of socio-ecological determinants on the extent of harvesting of fuelwood at different distance levels

Fuelwood harvesting			95% Confidence Interval			
Distance level	Socio-ecological determinants	B	Lower	Upper	Wald	Sig.
Immediate	Age	-.141	-.316	.034	2.491	0.114
	Gender	.009	-.266	.283	.004	0.951
	HH Income	-.006	-.101	.089	.015	0.901
	Education	-.173	-.334	-.013	4.508	0.034[a]
	No.HM	-.026	-.082	.030	.810	0.368
	Culture value	.046	-.008	.099	2.831	0.092
	Use-value	.063	.013	.113	6.209	0.013[a]
	Elevation	.049	.005	.094	4.755	0.029[a]
	Accessibility	.029	-.022	.081	1.249	0.264
	Availability	.026	-.027	.078	.929	0.335
Intermediate	Age	-.087	-.252	.079	1.051	0.305
	Gender	-.084	-.347	.179	.390	0.532
	HH Income	.073	-.019	.164	2.444	0.118
	Education	-.037	-.191	.116	.225	0.636
	No.HM	.013	-.040	.066	.223	0.637
	Culture value	.063	-.010	.135	2.895	0.089
	Use-value	.028	-.040	.096	.663	0.416
	Elevation	.003	-.057	.064	.011	0.917
	Accessibility	.028	-.043	.098	.598	0.439
	Availability	.022	-.050	.094	.367	0.545
Far distance	Age	-.043	-.205	.120	.264	0.607
	Gender	-.313	-.571	-.054	5.603	0.018[a]
	HH Income	.091	.002	.179	4.034	0.045[a]
	Education	.024	-.126	.173	.095	0.757
	No.HM	.038	-.014	.091	2.097	0.148
	Culture value	.036	-.042	.114	.824	0.364
	Use-value	.079	.006	.151	4.493	0.034[a]
	Elevation	-.023	-.088	.043	.458	0.498
	Accessibility	-.004	-.079	.072	.008	0.928
	Availability	-.003	-.080	.074	.006	0.939

[a] Sig.= Significance at p value < 0.05, HH Income=Household income, No.HM= Number of Household Members

3.3.4.3 Traditional medicine harvesting distance level.

Table 3.7 presents the GLM odds ratios and their 95% confidence intervals for each harvesting distance level and the interactions of SEDs. The GLM results showed that the harvesting of traditional medicine at an immediate distance was significantly less likely to be influenced by education (Wald=8.744, $p < 0.05$), cultural value (Wald=8.117, $p < 0.05$), use-value (Wald=10.700, $p < 0.05$) accessibility (Wald=9.180, $p < 0.005$) and availability (Wald=8.424, $p < 0.05$). The age, gender, household income, number of household members and elevation are not statistically significant ($p > 0.05$) determinants of harvesting traditional medicine at an immediate distance in the communities. The model analysis at a 95% confidence interval showed that age, gender, household income, education, number of household members, cultural value, use-value, accessibility, and availability are not statistically significant determinants ($p > 0.05$) of harvesting traditional medicine at an intermediate and far distance level.

Table 3.7. The influence of socio-ecological determinants on the extent of harvesting of traditional medicine at different distance levels.

Traditional medicine harvesting			95% Confidence Interval			
Distance level	Socio-ecological determinants	B	Lower	Upper	Wald	Sig.
Immediate	Age	-.030	-.198	.138	.123	0.726
	Gender	.027	-.239	.293	.039	0.843
	HH Income	-.023	-.116	.069	.246	0.620
	Education	-.236	-.392	-.079	8.744	0.003[a]
	No.HM	-.033	-.088	.022	1.419	0.234
	Culture value	-.526	-.887	-.164	8.117	0.004[a]
	Use-value	-.571	-.913	-.229	10.700	0.001[a]
	Elevation	-.229	-.553	.095	1.924	0.165
	Accessibility	-.545	-.898	-.193	9.180	0.002[a]
	Availability	-.530	-.888	-.172	8.424	0.004[a]
Intermediate	Age	-.096	-.263	.071	1.276	0.259
	Gender	-.138	-.400	.125	1.056	0.304
	HH Income	.077	-.012	.167	2.885	0.089
	Education	-.046	-.197	.106	.354	0.552
	No.HM	-.024	-.076	.029	.778	0.378
	Culture value	.018	-.313	.348	.011	0.917
	Use-value	-.252	-.556	.053	2.626	0.105
	Elevation	.193	-.083	.470	1.886	0.170
	Accessibility	-.063	-.382	.257	.147	0.701
	Availability	.033	-.294	.360	.039	0.843
Far distance	Age	-.116	-.278	.046	1.961	0.161
	Gender	-.074	-.332	.184	.319	0.572
	HH Income	.076	-.012	.165	2.894	0.089
	Education	.003	-.146	.151	.001	0.970
	No.HM	-.007	-.059	.045	.073	0.787
	Culture value	.062	-.256	.380	.144	0.704
	Use-value	.032	-.265	.329	.045	0.832
	Elevation	.154	-.112	.420	1.290	0.256
	Accessibility	.149	-.161	.459	.885	0.347
	Availability	.170	-.146	.485	1.112	0.292

[a] Sig.= Significance at p value < 0.05, HH Income=Household income, No.HM= Number of Household Members

3.4 Discussion

3.4.1 Provisioning ecosystem services and the harvesting distance

This study provides valuable information regarding patterns of PESs utilisation in relation to harvesting distance level. Rural communities demonstrated optimal choices that maximise utility when deciding whether or not to harvest PESs from forest sources, and the distance (proximity) to the forest resources influenced these choices. The findings reveal that the PESs such as wild food and fruits, fuelwood and traditional medicine are widely utilised by rural people from immediate distances followed by intermediate and far distances, respectively. However, rural people rely more highly on intermediate and far distances for livestock fodder (grazing) than immediate distance. Overall, this study found that rural people rely on 108 tree species for various PESs that are crucial to maintaining their livelihood demands. These include several useful tree species for traditional medicine, fuelwood, livestock fodder (grazing) and wild food in descending order.

Though several studies demonstrate that PESs harvesting behaviour is influenced by different SEDs, such as (i) availability (Hora *et al.*, 2021), (ii) socio-economic factors, (iii) culture (Hora *et al.,* 2021), and (iv) species-level (Leaver & Cherry, 2020), this study also found that the influence of a given socio-ecological factor was not consistent across the different distance regimes from the forest resources. The finding implies that distance regimes may highly influence human behaviour in forest resource harvesting consistent with the Optimal Foraging Theory (Soldati *et al.,* 2017; Feitosa *et al.*, 2018). Our finding is consistent with Mohammed and Inoue (2017) reported that as the distance from communities to the forest resources increases, there is less likelihood that communities will harvest the PESs at far distance depending on the prevalent socio-ecological factors that differ from one community to other.
For instance, while the PESs such as wild food and fruits, fuelwood and traditional medicine were harvested at the immediate harvesting distance level at Damani and Tshiombo, in the other communities (Tshipako and Thenzheni), these were harvested at a far distance level. This may be attributed to the fact that Damani and Tshiombo communities had more forest trees at their immediate distance compared to the other communities. Furthermore, the FGD with communities at Tshipako and Thenzheni revealed that overharvesting of wild fruits and fuelwood at an immediate distance caused a decline in the availability of forest trees. Thus, forest degradation becomes severe in the near distance. Hence, the residents are compelled to

travel relatively long distances in search of PESs. As resources become scarce, people may infringe on the relatively intact forests in distant areas. To avoid this, forest conservation and tree planting in the near distance become crucial. However, during FGDs, local people reported lack of technical knowledge (silviculture operations) of planting indigenous tree species. Though, ecological assessment results showed that the Tshiombo community harvest fuelwood at an immediate distance, evidence of high fuelwood harvesting at a far distance was observed in Tshiombo (Figure 3.1, right photo).

In the context of tree species, scarcity, and community leadership (traditional authorities) restrictions on harvesting and cutting down live trees (green trees), directly influence the choice of harvesting distance level and the quantity of harvested fuelwood. Unlike in Tanzania, the restrictions on harvesting green trees had no effect on the harvesting site choice and quantity harvested (Kegode *et al*., 2017). As depicted in Figure 3.1, large stacks of fuelwood were harvested illegally and hidden in the forest in Thenzheni and Tshiombo. Similarly, Kyaw *et al.* (2020) reported that an increase in distance from the human residents to the forests increased the quantity of the fuelwood harvested in the forest. Evidently, due to an increase in harvesting distance, the traditional medicine harvesters in some parts of Limpopo Province harvest large quantities (Semenya *et al.*, 2013).

Figure 3.1: Left photo: *Parinari curatellifolia* tree species fuelwood left to dry in the forest (Thenzheni). Right photo: stacks of fuelwood (mixed species, including *X. odoratissima, Pteleopsis myrtifolia, Parinari curatellifolia*, etc.) left to dry in the forest (Tshiombo).

On the contrary, several studies indicated that an increase in harvesting distance decreases the number of PESs harvested (Singh *et al.*, 2021). These harvesting behaviours may lead to a high incidence of forest degradation in the proximate forest, and degraded forests would impede the rural people's livelihood. The rate of fuelwood extraction in southern Africa is unsustainable (Rasimphi & Tinawaro, 2020). The findings of this study demonstrate that, although OFT may be used as a guide, the local-level SEDs need to be integrated with conservation strategies and the sustainable harvesting practice in the TAL. Sustainable utilisation of PESs is pivotal to ensuring sustainable forest production of goods and services for current and future generations (Mohammed & Inoue, 2017; Amadu *et al.*, 2021).

3.4.2 Importance of tree species based on the use-value.

The local people within the study sites were found utilising various tree species for various use categories. The highest percentage of the cited tree species were being used for traditional medicine. Unsurprisingly, the studies conducted by Ramarumo and Maroyi (2020), and Ndhlovu *et al.* (2019) reaffirmed that most of the tree species in VBR are utilized for medicinal purposes. This shows the knowledge and great dependence of rural people on traditional medicine for health care. This high number of tree species used for traditional medicine is greatly influenced by the direct contact of local people with PESs and the rural communities' closeness to the forest (Gomes *et al.*, 2020).

This study found that fuelwood was the second highly cited use category for the number of important tree species. In contrast, a study conducted in Himalayan traditional agroforestry systems reported that the leading use category for most tree species was fuelwood (Pangging *et al.*, 2017). This implies that fuelwood harvesting in traditional agroforestry is equally critical to people’s livelihood. During FGD in Damani, Tshipako and Thenzheni, the participants indicated that they harvest fuelwood for both household consumption and commercial purposes. Female participants at Tshipako said, "*We survive by selling fuelwood and sometimes wild fruits because we are not employed, people come with bakkies (pick-ups) from far places every week to buy our fuelwood*". In addition, during the survey, large stacks of fuelwood for sale were observed along the streets within the communities, and fuelwood stacks selling in Damani as per Figure 3.2. According to the respondents at Damani and Tshipako, one stack of fuelwood normally sells from 350ZAR (24.9USD) to 600ZAR (42.8USD); the prices depend on the quality of the wood, while in Thenzheni, processed fuelwood is sold and priced using a small scale of three sections (Figure 3.2). One stack of the processed fuelwood costs 400 ZAR (28.54USD).

Figure 3.2. Right photo: On-market fuelwood stack (Damani). Left photo: Fuelwood sales measuring the scale at Thenzheni village.

The harvesting of fuelwood and traditional medicine poses a serious threat to tree species diversity in the TAL, which could lead to forest degradation (Specht *et al.*, 2015). In South Africa, commercial exploitation of traditional medicine and fuelwood caused a decline in tree species in some parts of the country (Leaver & Cherry, 2020). Though several studies reported that availability, socio-economic factors, distance, and cultural factors (Araia & Chirwa, 2019) influence tree species utilisation, human behaviour and harvesting decision-making based on distance also play a role (Lenfers *et al.*, 2018).

The most important tree species used by the local people in the study communities differ considerably, despite living in the same cultural landscape. However, the *E. magalismontanum* species is a predominantly used wild fruit tree species within the study sites. This might be an indication of the high value, abundance, and extent of knowledge of the tree species in VBR. Araia and Chirwa (2019) reported that the user preference for *E. magalismontanum* species in VBR is more due to the traditional ecological knowledge that exists, rather than the abundance of the species. Tree species used for fuelwood, traditional medicine and fodder were differently valued in the study sites. The results illustrate that despite living in the same cultural landscape, the user preference for tree species differs. This may indicate that the local preference of species differs from site to site (Kunwar *et al.*, 2020), and this may override the predominance of culture over preference in use decision-making. This study revealed that the multipurpose tree species, *E. magalismontanum* (Figure 3.3) has several different uses, such as fuelwood, fruits, medicine, and fodder in Thenzheni and Tshipako.

Figure 3.3: Englerophytum magalismontanum tree species.

However, the multiple uses of a single tree species have a negative impact on the tree species' abundance due to high demand and harvesting intensity, thereby posing a threat to the tree species (Rasethe *et al.*, 2013; Sinthumule & Mzamani, 2019). Tshipako respondents reported a decline in *E. magalismontanum* species in the forest adjacent to the community. Surprisingly, the multiple-use tree species in the Damani community is *S. birrea*, which is one of the protected tree species in terms of the National Forests Act of 1998 (Act 84 of 1998) in South Africa. A recent study by Sinthumule and Mzamani (2019) reported the multiple uses of *S. birrea* in rural communities though it is a protected tree species. According to the Forest Act, *Sclerocarya birrea* is not supposed to be cut, damaged, removed or disturbed unless a license has been granted by the forestry department. The multiple-use tree species in the Tshiombo community is interestingly a domesticated tree species, *M. indica* species. The *M. indica* species is one of the dominant fruit species in homesteads of VBR traditional agroforestry landscapes (Ayisi *et al.*, 2018). In rural communities, *M. indica* is used for multiple purposes such as fuelwood, shade, and fruits. The multiple uses of domesticated or cultivated trees could perhaps ease the pressure on PESs as they could serve as an alternative. However, from the top 10 multiple-use tree species found in this study, *E. magalismontanum*, *Landolphia kirkii*, *S. birrea*, *P. curatellifolia*, *C. molle*, *M. indica*, *A. adianthifolia*, *X. odoratissima*, *Vangueria esculenta* and *P. americana*, only two domesticated species were found, the *M. indica* and the *P. americana*. It is clear from the fact that a protected tree species (*Sclerocarya birrea*) is within the top 10 multiple-use tree species, that there is a need for effective policy enforcement and for communities to plant more multipurpose indigenous trees, including protected trees such as *S. birrea*.

3.4.3 Correlation of socio-ecological determinants and extent of harvesting of provisioning ecosystem services

Similar to Rasethe *et al.* (2013), the results of this study showed that although distance influences the PESs user behaviour, the extent of resource harvesting at each distance is also influenced by different SEDs. In particular, the study found that the extent of PESs harvesting was influenced by a larger number of SEDs (gender, household income, education, cultural value, use-value, elevation, accessibility, and availability) in almost all use categories, depending on the distance level.

The results showed that people with low income are more likely to harvest wild food or fruits at an immediate distance compared with high-income people. Similarly, low-literacy people are more likely to harvest fuelwood at an immediate distance compared with educated people. Unsurprisingly, females are less likely to harvest fuelwood at a far distance compared to their male counterparts. Harvesting of fuelwood at an immediate distance by females reduces the hardship in fuelwood collection, by minimising the travelling distance, time, and possible encounter with wild animals. Thus, perhaps the majority of females may prefer to harvest in the forest adjacent to the communities.

Fuelwood is an affordable, accessible, and available source of energy in rural communities (Semenya & Machete, 2019). Therefore, the rural people would harvest at an immediate distance, avoiding attaching the cost of travelling, time, and transport to collecting fuelwood. It is a common strategy of the lower-income communities to utilise forest resources adjacent to their communities to make savings for other needs (Temudo *et al.,* 2020), while higher-income people are more likely to harvest fuelwood at a far distance. The FGD participants at Tshiombo indicated that harvesting fuelwood at a far distance is a challenge if you do not have transport or money to pay for transport; therefore, they harvest from the forest around or within their community. Also, harvesting fuelwood at a close distance reduces the burden of walking a long distance with a heavy fuelwood load (Uhunamure *et al.,* 2017).

The results showed that local people with higher qualifications are less likely to harvest traditional medicine at an immediate distance compared to people with low qualifications. Mostly, higher educated people are working class, and can therefore afford healthcare centres, while the lower qualification classes are compelled to use traditional medicine found at their homestead or in adjacent forests for their primary healthcare (Kunwar *et al.,* 2020). During an interview, participants indicated that they use Tshiumbeumbe (*Clematis brachiate*) to treat flu and COVID-19 (SARS-CoV-2) related symptoms, harvested in their homestead and forests adjacent to their community. Regardless of households' SEDs, this study's results show that local people's harvest of PESs decreases as the distance to the forests increases. Similar findings were reported by Singh *et al.* (2021) regardless of socio-economic status.

3.5 Conclusion

PESs form the pillar of livelihood strategies of local people, with a huge part of the population highly depending on PESs for survival in most developing countries. This study was an attempt to understand the human harvesting behaviour in obtaining PESs in TALs in relation to distance. This study found that distance determines harvesting behaviour. However, the extent of harvesting at each distance is also influenced by prevailing local socio-ecological conditions. The results showed that when the distance from the communities to the forest increases, the harvesting decreases as projected by the results ranking in this sequence: immediate, intermediate, and far distance. The results are consonant with the assumption and advanced support to the applicability of optimal foraging theory to human PESs harvesting behaviour. Despite local people living in the same cultural landscape with different socio-ecological conditions, their livelihood strategies and harvesting patterns of PESs are similar.

From ethnobotanical analysis, there are many tree species used multi-purposely such as for fuelwood, traditional medicine, fodder and wild food or fruits. However, there is a scarcity of indigenous species used for multiple purposes. Perhaps, for the conservation of tree species biodiversity, planting indigenous tree species for multiple uses could ease the demand and pressure in the natural forest adjacent to TALs. There is a need for speedy research on the multi-use of *E. magalismontanum* species and the associated importance of taking necessary measures for the conservation of this species. Furthermore, research on protected tree species in the TAL is very important, as *S. birrea* species was found in multi-use categories such as fuelwood, while according to forest policy, the tree species is protected for such use. This study underscores the importance of harvesting distance and the extent of the use of PESs in conservation strategies in TALs. The fact that there is a preference to use and harvest provision ecosystem services from the nearest distance to the household, means that a concerted effort to conserve and enhance the abundance of multi-purpose tree species in homesteads and the immediate areas is crucial. This may alleviate use pressure on the relatively intact forest patches in the intermediate and far distance. At the same time, any conservation intervention should consider the local socio-ecological conditions that do have an influence on the extent of PESs at different distance regimes in TALs.

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Chapter 4

Harvesting distance effect on tree species diversity in traditional agroforestry landscape: A case of Vhembe Biosphere Reserve in South Africa

Abstract

Traditional agroforestry has been recognised to contribute to biodiversity conservation; however, biodiversity strategies often lack information about drivers of tree species diversity loss, which is crucial for decision-making. Anthropogenic disturbance has positive and negative effects on tree species richness and diversity. This study was conducted in Vhembe Biosphere Reserve, Limpopo Province, and used distance from the nucleus of the community to the forest as a parameter to assess tree species richness and diversity. Vegetation data were collected using three transects of 150 m in each distance level and sampled a total area of 1000 m^2 by sampling five rectangular plots of $20m^2$ x $10m^2$ ($200m^2$). Data analysis was conducted using Chao1, PERMANOVA, *n*MDS, PERMDISP, DISTLIM, *db*RDA and SIMPER. The findings are consonant with distance decay of community similarity hypotheses, with estimated tree species richness of 76, 93 and 95 species in an immediate, intermediate, and far distance, respectively. Moreover, the highest species variation was observed at an intermediate distance, indicating greater species assemblage at an intermediate distance compared to immediate and far distances. The results confirm that the distance and associated factors have major detrimental effects on tree species richness and biodiversity in traditional agroforestry landscapes. Harvesting of provisioning ecosystem services is found and known to be extremely high in the study area. Effective interventions such as planting indigenous trees and conserving the existing vegetation must be implemented to reduce and halt overexploitation.

Keywords: Biodiversity, Distance, Intermediate disturbance hypothesis, Traditional agroforestry, Provisioning ecosystem services

4.1 Introduction

Over the past decades, agroforestry practice has gradually increased with over 1.2 billion people worldwide practising agroforestry (Islam *et al.*, 2021). Agroforestry is a system that includes traditional and modern practices integrating crops, animals, and woody plants (e.g., trees, palms, and bamboo) into the same land management unit (FAO, 2019). The agroforestry practice provides cultural, socioeconomic, and environmental benefits (Dhanya *et al.*, 2014). In particular, traditional agroforestry has played a critical role in conserving biodiversity and sustaining rural livelihoods through the provision of multiple products and services (Tadesse *et al.*, 2021). In South Africa, native tree species are well integrated into traditional agroforestry landscapes due to their use value and capacity to tolerate both environmental and anthropogenic disturbances (Starke *et al.*, 2020).

South Africa, like many developing countries, is saddled with a high population (60.6 million), high unemployment rates (34.9%) (Statistics South Africa, 2021), and high levels of poverty (Shackleton, 2020). Moreover, the country is enduring severe land degradation and poor land productivity, particularly in rural communities (*Ayisi et al.*, 2018). Hence, most poor people live in rural areas and heavily depend on provisioning ecosystem services (PESs e.g., fuelwood, medicinal plants, wild food and fruits) (Scheiter *et al.*, 2018; Shackleton, 2020). High dependence on PESs has resulted in a loss of biodiversity and forest degradation (Mensah *et al.*, 2016). Human dependence on PESs is directly linked to human disturbance in the forest, which is considered among the main drivers of tree species loss (Ramarumo & Maroyi, 2020; Rampheri *et al.*, 2020). Native tree species loss has a negative impact on the stability of the ecosystem services in traditional agroforestry landscapes (Rampheri *et al.*, 2020). However, traditional agroforestry landscapes have been recognised as one of the effective ways to conserve biodiversity and improve the livelihoods of rural people (Asase & Tetteh, 2016). Agroforestry is widely promoted as an effective and equitable forest biodiversity restoration strategy (Duffy *et al.*, 2021; Lelamo, 2021; Melone *et al.*, 2021). Species diversity plays a critical role in the function of the traditional agroforestry ecosystem and productivity (Rampheri *et al.*, 2020). Hence, planting more indigenous trees help in restoring fragmented natural forests (Gemechu *et al.*, 2021). Specifically, multipurpose indigenous trees provide several benefits (Appendix 8) (Lelamo, 2021). However, even though planting indigenous trees is effective in restoring the forest, people prefer planting exotic tree species with economic value (Gemechu *et al.*, 2021).

Successful traditional agroforestry systems are a function of the management of the system (Islam *et al*., 2021), and environmental, social, and economic parameters. These parameters have been assessed in the past in villages in Bangladesh (e.g., Islam *et al*., 2021). Among the change variables, the distance to the forest areas was shown as a significant driver of species richness in a traditional agroforestry landscape (Yashmita-Ulman *et al*., 2021). According to Yashmita-Ulman *et al*. (2021), tree species richness increases as the distance to the forest increases, and the tree species assemblage are closely similar. Indeed, distance has a significant influence on tree species diversity because it is directly linked to human disturbances (Cicuzza *et al*., 2011). There have been many studies that disturbance affects species diversity by changing local species richness, mean similarity of local assemblage, variance (homogeneity of dispersion) of local assemblages or all at the same time (e.g., Bendix *et al*., 2017; Araia & Chirwa, 2019)

As predicted by optimal foraging theory, human beings will save time and energy when searching and collecting PESs (Soldati *et al.*, 2017; Feitosa *et al*., 2018). Therefore, local people are expected to intensively harvest PESs at an immediate distance, moderate harvest at an intermediate distance, and minimal harvest at far distances in the landscape. Subsequently, as predicted by the intermediate disturbance hypothesis, tree species diversity is expected to be high at an intermediate distance from the traditional agroforestry landscape to indigenous forests. The intermediate disturbance hypothesis hypothesizes that the species diversity maximises when a disturbance occurs at an intermediate frequency or with intermediate intensity (Silva Pedro *et al*., 2016; Bendix *et al*., 2017). In simple terms, the absence of disturbance or low-intensity disturbance causes predominance of few species over the others. This results in species succession while the high-intensity disturbance decreases trees species richness and diversity (Bendix *et al*., 2017) only the most resistant species persist (Silva Pedro *et al*., 2016; Araia & Chirwa, 2019). Despite distance being an important tree species driver, little is known in South Africa about the influence of distance on tree species diversity in traditional agroforestry systems.

The main objective of the present study was to understand the effect of distance on tree species diversity in traditional agroforestry and its contribution to tree species and biodiversity conservation. This study, therefore, tested two hypotheses; first, *"Tree species diversity is expected to be the highest at an intermediate distance from the villages as predicted by the immediate disturbance hypothesis"*. Second, "*the turnover of tree species assemblage between* *distance levels increases as the distance from the community increases as predicted by the distance decay of community similarity hypothesis"*. The distance decay of community similarity hypothesis predicts that geographically close communities or habitats tend to be like those that are far apart (Soininen *et al*., 2007; Dias *et al*., 2021). This study used distance as an environmental predictor to understand species turnover. A distance to the forest is defined as the distance from the community settlements to the proximate forest within the traditional agroforestry landscape.

4.2 Materials and methods

4.2.1 Tree species inventory

Traditional agroforestry landscape distances levels were categorised as immediate, intermediate, and far distances (Figure 4.1). Distance levels were determined based on the walking distance from the community epicentre to the proximate forest for PESs harvesting (Shova & Hubacek, 2011; Araia, 2019), and then kilometres were estimated with the key informants of the community (Sheil *et al*., 2006). Immediate distance; nearest distance within the homestead intermediate distance; a distance of less than 5km from the community boundary and far distance, a distance greater than 5km to 10km from the community boundary. Tree species inventory was conducted in late spring (November) and early summer (December) during the growing season when leaves, fruits and flowers can be recognized (Herrera *et al.,* 2018). In each traditional agroforestry landscape in the village, using systematic sampling, the distances were selected based on the distance levels highlighted in figure 4.1. Previous studies demonstrated that 100 m (Teshome *et al.,* 2019) and 250 m (Mir *et al*., 2021) long transects are appropriate for tree species diversity. However, in this study, three (3) transects of 150 m in length each were established for vegetation assessments in three distance levels, immediate, intermediate, and far distance levels, defined by increasing distance from the epicentre of the village community to the forest. At each distance level in each community, three (3) transects of 150 m each were established (Figure 3) and sampled for a total area of 1000 m^2 by sampling five rectangular plots of $20m\ x\ 10m\ (200m^2)$ each, separating each plot by 25 m. The rectangular plots are less vulnerable to measurement errors in the field and tend to cover a large area (Kangas & Maltamo, 2006; Araia *et al*., 2020). The three transects were separated from each other by at least 200 m. On each plot, all individual plant species with a diameter ≥ 5cm at breast height (DBH) were considered trees and measured using a calliper (e.g., Jegora *et al*., 2019; Zequeira-Larios *et al*., 2021). The scientific and vernacular names of the tree species were captured (Araia *et al*., 2020). Tree species identification was carried out using a tree identification expert and a trees field guidebook (van Wyk & van Wyk, 1997). The Field guide to trees of Southern Africa was used to identify the indigenous, endemic, and exotic species (van Wyk & van Wyk, 1997). The trees were classified as indigenous to South Africa, endemic to Southern Africa and exotic if originated from outside Southern Africa.

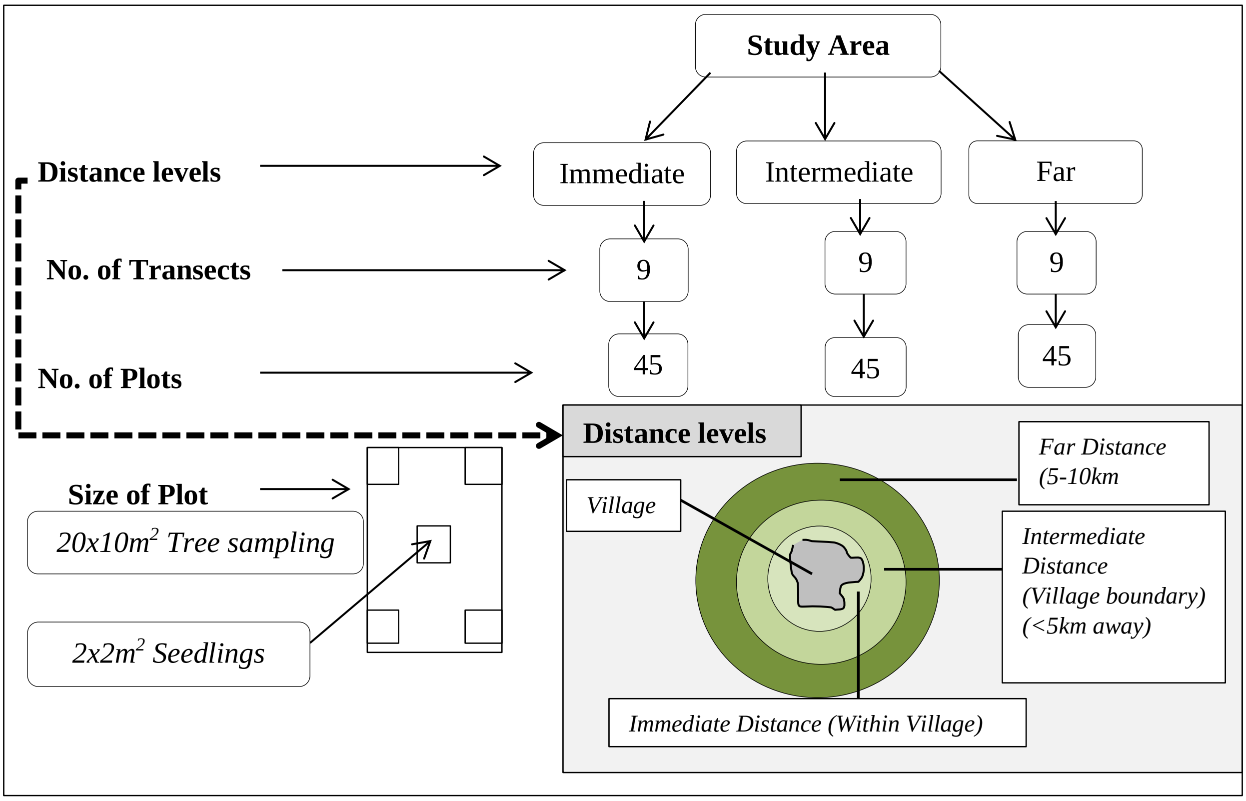

Figure 4.1: Outline of sampling design for biological data collection.

4.2.2 Statistical analysis

The biological data was analysed using Plymouth Routines in Multivariate Ecological Research (PRIMER) version 7.0.21 and added to PERMANOVA + 1 software. Firstly, the original abundance-based species-sample matric was prepared and followed by the analysis of the Bray-Curtis similarity coefficient matrix (Clarke & Gorley, 2015). This was then followed by the Jaccard similarity coefficient matrix by transforming the original abundance-based species-sample matrix into presence/absence data. Jaccard similarity coefficient calculates the likelihood of a single species picked at random from two sites without considering the joint absence (Anderson *et al*., 2008). Then both matrices were subjected to RELATE routine to test the correlation between the two matrices. The Spearman's rho correlation value was found to be very high ($\rho=0.97$; $p=0.001$) indicating the two matrices contained almost identical information. Hence, the Jaccard similarity coefficient matrix was used to test the similarity in mean local assemblage among different distance regimes (Clarke & Gorley, 2015).

4.2.2.1 Sampling effectiveness and vegetation description

The sampling effort sufficiency was evaluated to observe the effectiveness of the sampling effort of observed species (Devkota *et al*., 2020). A sufficient sampling effort captures as many species as possible, with ≥ 80% estimated species richness (Araia *et al*., 2020). This species richness estimate was performed using Chao 1 (Equation 4.1), Chao1 is a non-parametric species richness estimator (Gotelli & Chao, 2013; Chao & Chiu, 2012; Clarke & Gorley, 2015; Chao & Chiu, 2016). Then, the species accumulation curve was computed to demonstrate the species observed and the estimated species. These indices help to compare a variety of species richness at different distance levels (Equation 4.1).

$$S_{Chao\,1} = S_{obs} + \frac{f_1^2}{2f_2} \qquad (4.1)$$

Where S_{obs} is the number of species in the sample, $f\,1$ is the number of species with only a single occurrence and $f2$ is the number of species with two occurrences in the sample (Chao & Chiu, 2012; Chao & Chiu, 2016). Similarities percentages analysis (SIMPER) was used to identify dominant tree species (cut off 70%) using Jaccard similarity matrix using dummy variables on original abundance data and their contribution in dissimilarity in species assemblage to each distance level (Anderson *et al.,* 2008). Then, the dominance of each tree species was visualised in the shade plots. The visual impact of grey-scale intensities in a shaded plot gives a strong idea of which species are highly dominated at each distance level. White denotes the absence of that species at that distance level and full black represents the maximum abundance at the distance level (Anderson *et al*., 2008).

The distribution of the species similarity was calculated using the Jaccard similarity coefficient or Jaccard index in Primer-E version 7 (Clarke & Gorley, 2015). The Jaccard index measured the similarity for three distance levels, ranging from 0-100%. The Jaccard similarity index was calculated as follows (Equation 4.2);

$$S_{jk} = 100\ [\frac{(a+d)}{(a+b+c\,+\,d)}] \qquad (4.2)$$

Where, S represents the probability (x100) of a single species picked at random (from the full species list) being present in both samples or absent in both samples, *a* = the number of species which are present in both samples; b = the number of species present in sample j but absent from sample k; c = the number of species present in sample k but absent from sample j; d = the number of species absent from both samples (Clarke *et al*., 2014). The species richness was determined using the Margalef index (d) of the DIVERSE index in Primer-E. Margalef index was calculated as follows (Equation 4.3);

$$d = \frac{(S-1)}{\log N} \tag{4.3}$$

Where S= represents the number of species counts, and N= represents the total number of individuals (Clarke *et al*., 2014). Then, the resemblance matrix of the Margalef index was developed using Euclidean distance (Araia *et al*., 2020). Based on the species richness data, the significant differences in species richness among different distance levels (immediate, intermediate, and far distances) were tested with permutational multivariate analysis of variance (PERMANOVA) (Anderson *et al*., 2008). Pairwise comparison tests with PERMANOVA 999 permutations and t statistics were conducted to investigate the significant difference in distances pairs "Immediate x Intermediate, Intermediate x Far, Immediate x Far" for species richness data.

4.2.2.2 Analysis of mean similarity of local species assemblage among different distance levels

To assess the significance of the mean similarity of local assemblages, the Jaccard coefficient matrix was subjected to non-parametric multidimensional scaling (*n*MDS) in Primer-E 7. *n*MDS helps to visually inspect the mean similarities of local assemblages within a distance level and among different distance levels. This was then subjected to PERMANOVA to discriminate if the similarity is statistically significant. Pairwise comparison tests with PERMANOVA 999 permutations and t statistics were conducted to investigate the significant difference in species assemblage in distances pairs "Immediate x Intermediate, Intermediate x Far, Immediate x Far".

4.2.2.3 The variation of local species assemblage among different distance levels

To assess the significance of variance in the identity of species that are locally co-existing among the distance levels, homogeneity of dispersion (PERMDISP) was tested using the Jaccard coefficient matrix with 999 permutations (Anderson *et al*., 2008). A pairwise comparison of levels of distance was conducted to show variance between distance level groups. Then, SIMPER dissimilarity analysis of species was conducted to assess the species contributing to variation in the landscape. The shade plots analysis was conducted for predominant species using original abundance data.

4.2.2.4 Drivers of turnover of species composition of local assemblages among different distance levels

The inter-correlations among the change drivers were tested using Primer's Draftsman plot's Multicollinearity test of the correlation matrix. The pairs of all variables (drivers) correlation were below the threshold ($|r|\geq 0.95$); therefore, they contain effectively different information and are not redundant (Anderson *et al*., 2008). Then, the link between the drivers (elevation, gradient, fire occurrence, grazing, PESs harvesting and distance) and distance levels was tested using distance-based linear modelling (DISTLM), and visually inspected using distance-based redundancy analysis *(db*RDA*)* (Araia *et al*., 2020). The relationships between each environmental factor were analyzed separately in the marginal test. Then, the factors were subjected to a sequential test, the R^2 selection criterion which explained each factor's contribution to the changes. A *db*RDA plot obtained from PERMANOVA using DISTLM was used to visualize the patterns of the DISTLM results.

4.3 Results

4.3.1 Sampling effectiveness and vegetation description

Altogether, this study recorded 2578 individual trees, of which 634 are recorded at an immediate distance, 862 at an intermediate distance and 1082 at a far distance. The Chao1 species accumulation curve indicated that species sampled in the whole study area and at different distance levels captured the total number of tree species within a different number of sample plots. The tree species curve continued to increase up to 150 and 40 sample plots in the whole study area and all different distance levels, respectively (Figure 4.2). The curve did not reach the asymptote which indicates that an increase in sample plots would increase the capture of the number of tree species. The Chao l species accumulation estimator curve slightly exceeds the observed species in the whole study and all distance levels.

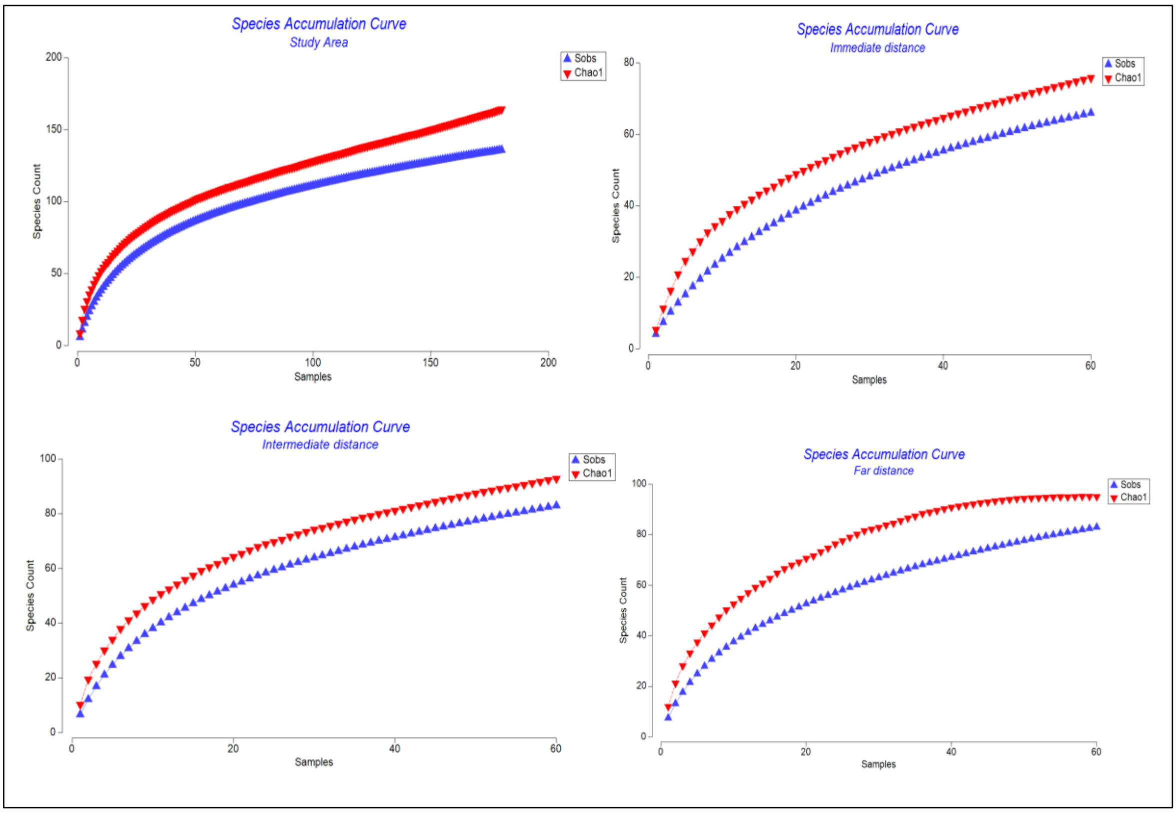

Figure 4.2: Estimation of actual and estimated total species richness.

The total number of tree species was 136, the number of tree species was significantly smaller at an immediate distance (66 species) than at the intermediate distance and far distance (83 species) (Table 4.1). The sampling effectiveness of the whole study was 82.84% and differed slightly across distance levels, and was significantly higher in an intermediate distance (89.40%) followed by 87.33% in a far distance and 87.07% in an immediate distance. The Chao l species estimation indicated that far distance had a higher number of species (95.04 species) followed by an intermediate distance (92.84 species) and an immediate distance (75.80 species) (Table 4.1). Out of 136 tree species, 114 were indigenous species, of which 22 were endemic species to Southern Africa. This study recorded a substantive high number of exotic tree species in an immediate distance (18 species) and relatively low in both intermediate and far distances.

Table 4.1: Total Species richness in different distance levels.

Distance levels	Number of species		Sampling effectiveness
	S_{Ob}	S_{Chao1}	(%)
Immediate	66	75.80	87.07
Intermediate	83	92.84	89.40
Far	83	95.04	87.33
Overall	136	164.17	82.84

S_{Ob}= Species observation. S_{Chao1}= Species richness estimator (Chao1)

The SIMPER results revealed the dominating species and the contribution of each species at different distance levels (Appendix 3). Exotic tree species have largely dominated and contributed to the similarity of an immediate distance, *Mangifera indica* (57%) and *Persea americana* (18.28%). The intermediate distance was dominated by a wide range of indigenous tree species including *Pteleopsis myrtifolia* (20.1%), *Tabernaemontana elegans* (13.2%), *Bridelia micrantha* (12.4%), *Pseudolachnostylis maprouneifolia* (7%), *Combretum molle* (6.03%), *Albizia adianthifolia* (4.3%), *Afzelia quanzensis* (3%) *Parinari curatellifolia* (3%) and *Senegalia ataxacantha* (3.4%). Dominating species in the far distance were *Pteleopsis myrtifolia* (36%), *Albizia adianthifolia* (13%), *Tabernaemontana elegans* (7%), *Parinari curatellifolia* (7%), *Englerophytum magalismontanum* (7%), and *Combretum molle* (6%).

4.3.2 Local species richness among different distance levels

The PERMANOVA test for species richness found that there was a significant difference among the distance levels (F_2=17.147, P=0.01) (Table 4.2). The immediate distance had lower tree species richness than an intermediate and far distance. Then, the pairwise comparison of species richness detected significant differences between (Immediate & Intermediate) and (Immediate& Far), (t=6.8345, P=0.027) and (t=5.6622, P=0.03) respectively (Table 4.3). However, there was no statistical significance difference between intermediate and far distances (t=0.933, P=0.444).

Table 4.2: PERMANOVA results of species richness of different distance levels.

Source	Df	SS	MS	Pseudo-F	P(perm)	Unique terms
Vi	3	0.33367	0.11122	0.246	0.858	997
Di	2	24.052	12.026	17.147	0.01	998
Vi x Di	6	4.2081	0.70136	1.5512	0.177	999
Res	168	75.959	0.45214			
Total	179	104.55				

Di= Distance (Random factor), Vi= Village (Fixed factor), SS= Sum of species, MS= Mean of species, F ratio (Pseudo-F), P= Permuted probability values, df= Degree of freedom'

Table 4.3: PERMANOVA pairwise comparison for species richness.

Pairwise distance levels	T	P(perm)
(Immediate & Intermediate)	6.8345	0.027
(Immediate& Far)	5.6622	0.03
(Intermediate& Far)	0.93301	0.444

4.3.3 Mean similarity of local species assemblage among different distance levels

The results of the non-metric multidimensional scaling ordination (*n*MDS) showed a greater overlap between an intermediate (2) and far distance (3), indicating no distinct species assemblage between the two distances (Figure 4.3). The *n*MDS ordination showed a slight separation between immediate (1) and intermediate (2) distances. The results further show evidence of separation of species assemblage between an immediate (1) and a far distance (3), indicating a greater distinction of species assemblage. The results show the intermediate distance as the centre of the species assemblage.

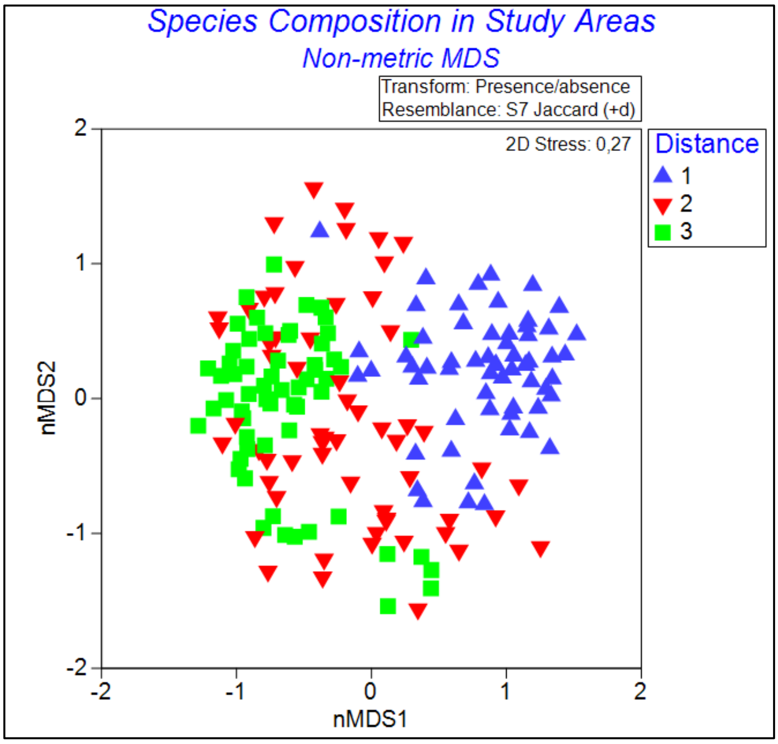

Figure 4.3: Multi-dimensional scaling of the local assemblage of different distance levels (1= Immedaite, 2= Intermediate and 3= Far distance).

The PERMANOVA test confirmed a significant effect of distance on species assemblage ($F_{5.8938}; p < 0.001$), indicating different species assemblages in different distance levels (Table 4.4). Pairwise comparisons further supported this finding, underlining that species assemblage differed between the distances (Immediate & Intermediate; $t = 2.7, p < 0.05$) and (Immediate & Far; $t = 2.9, p < 0.05$), but not across all the distances (Table 4.5). The pairwise comparison supported the nMDS results of showing no significant difference in species assemblage between an intermediate and the far distance ($t = 1.3, p = 0.144$).

Table 4.4: PERMANOVA results of local species assemblage of different distance levels.

Source	Df	SS	MS	Pseudo-F	P(perm)	Unique terms
Vi	3	32025	10675	3.5699	0.001	997
Di	2	72256	36128	5.8938	0.001	998
Vi x Di	6	36779	6129.9	2.0499	0.001	998
Res	174	539160	3098.6			
Total	179	643440				

Di= Distance (Random factor), Vi= Village (Fixed factor), SS= Sum of species, MS= Mean of species, F ratio (Pseudo-F), P= Permuted probability values, df= Degree of freedom

Table 4.5: PERMANOVA pairwise comparisons for species composition.

Pairwise distance levels	T	P(perm)
(Immediate & Intermediate)	2.7025	0.031
(Immediate& Far)	2.9889	0.028
(Intermediate& Far)	1.3888	0.144

4.3.4 The variation of local species assemblage among different distance levels

Homogeneity of multivariate dispersion (PERMDISP) results showed a significant difference in co-existing species identity of local assemblages among the distance levels ($F = 10.771, p < 0.001$). The PERMDISP pairwise comparisons support the significant difference in the distance levels (Table 4.6). The species variation at an immediate distance differed significantly from the intermediate distance ($t = 4.3297, p < 0.001$). Likewise, the species variation at an intermediate distance differed significantly from the far distance ($t = 4.2181, p < 0.001$). However, species variation of an immediate distance and far distance was not statistically distinct ($t = 0.9088, p = 0.409$). The species assemblage variation within the distance levels was 59% at an intermediate distance, far (55%) and immediate (54%) descending.

Table 4.6: PERMDISP pairwise comparison of species composition.

Pairwise distance levels	T	P (perm)
(Immediate& Intermediate)	4.3297	0.001
(Immediate& Far)	0.9088	0.409
(Intermediate& Far)	4.2181	0.001

An average dissimilarity of 95% species assemblage was observed between the immediate and intermediate distances (Appendix 4). SIMPER analysis showed that about 32 out of the 136 shared species between the immediate and intermediate distance contributed above 70% to the average dissimilarity between the two distances. The most dominating species in dissimilarity were *Mangifera indica* (7%), *Persea americana* (4%). *Pteleopsis myrtifolia* (5%), *Tabernaemontana elegans* (4%), and *Bridelia micrantha* (4%). Exotic species such as *Mangifera indica*, *Persea americana*, *Citrus sinensis*, and *Musa acuminata* were completely absent in the intermediate distance and indigenous species such as *Vitex ferruginea* and *Hexalobus monopetalus* were completely absent in the immediate distance. An average dissimilarity of 83% species assemblage was observed between the intermediate and far distances. About 30 out of the 136 shared species between the intermediate and far distances contributed above 70% to the average dissimilarity between the two distances. The most dominating species in dissimilarity were *Pteleopsis myrtifolia* (5%), *Tabernaemontana elegans* (4%), *Bridelia micrantha* (4%), *Combretum molle* (4%), *Albizia adianthifolia* (5%), and *Parinari curatellifolia* (4%). Indigenous species *Vitex ferruginea* was completely absent at a far distance. An average dissimilarity of 95% species assemblage was observed between the immediate and far distances. About 29 out of the 136 shared species between the immediate and far distance contributed above 70% to the average dissimilarity between the two distances. The most dominating species in dissimilarity were *Mangifera indica* (6%), *Persea americana* (4%), *Pteleopsis myrtifolia* (7%), *Albizia adianthifolia* (5%), and *Englerophytum magalismontanum* (4%). Indigenous species such as *Scolopia mundii, Brachylaena huillensis* and *Pavetta lanceolata* were completely absent in the immediate distance, while exotic species such as *Mangifera indica*, *Persea americana*, and *Citrus sinensis* were completely absent in the far distance. Likewise, *Trichilia emetica* was absent at a far distance. The immediate distance is predominated by exotic tree species and the far distance is predominated by indigenous and endemic species (Figure 4.4). The predominance of most species, for example, *Pteleopsis myrtifolia, Parinari curatellifolia, Englerophytum magalismontanum, Albizia adianthifolia* and *Bridelia,micrantha* seemed to increase from the immediate to the far distance.

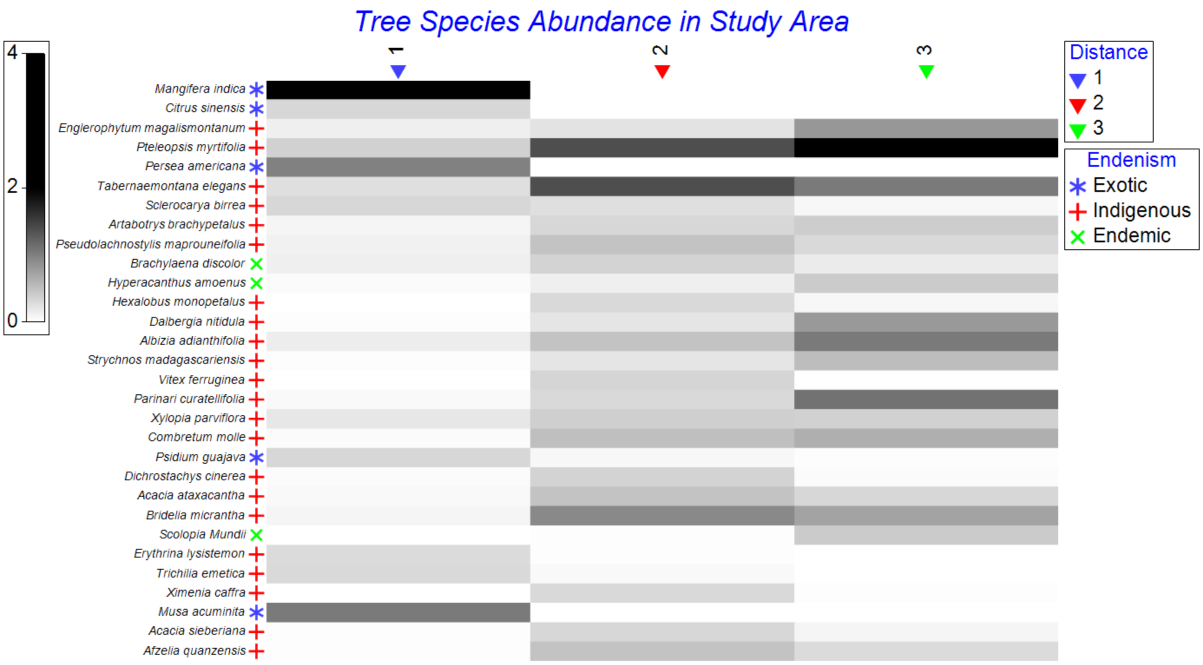

Figure 4.4: Species dominance across distance levels.

4.3.5 Drivers of species turnover of local assemblages in different distance levels

The DISTLM results showed that there was a significant correlation between species assemblage and most of the environmental variables examined ($R^2 = 0.155, P < 0.001$). The marginal test showed a significant relationship ($p < 0.001$) between species assemblage (all distances) and most environmental variables (elevation, gradient, PESs harvesting and distance), except fire occurrence ($p = 0.182$) and grazing, ($p = 0.002$). The variation explained by each variable (Table 4.7) was as follows: distance contributed 9%, elevation (2.4%), gradient (2.2%), fire occurrence (0.6%), grazing (1.3%) and PESs harvesting (1.5%). The change of the total marginal contribution of each variable in the sequential test may indicate the dominance of the variable or interaction of distance levels and other change variables in determining the species assemblage of a landscape. The distance (15%) explained the highest variability, followed by PESs harvesting (7%), grazing (6%), fire occurrence (5%), gradient (4%) and elevation (2%). The first two axes of *db*RDA captured 75.6% of the variability in the fitted model and 11.8% of the total variation in the data cloud (Figure 4.5).

Table 4.7: DISTLM Marginal test and sequential test of change variables.

	Marginal Test		Sequential Test	
Variable	**P**	**Prop. (%)**	**P**	**Cum. (%)**
Elevation	0.001	2.443	0.001	2.44
Gradient	0.001	2.214	0.001	4
Fire occurrence	0.182	0.620	0.188	4.6
Grazing	0.002	1.3045	0.001	5.8
PESs harvesting	0.001	1.5525	0.004	7
Distance	0.001	8.7104	0.001	15.4

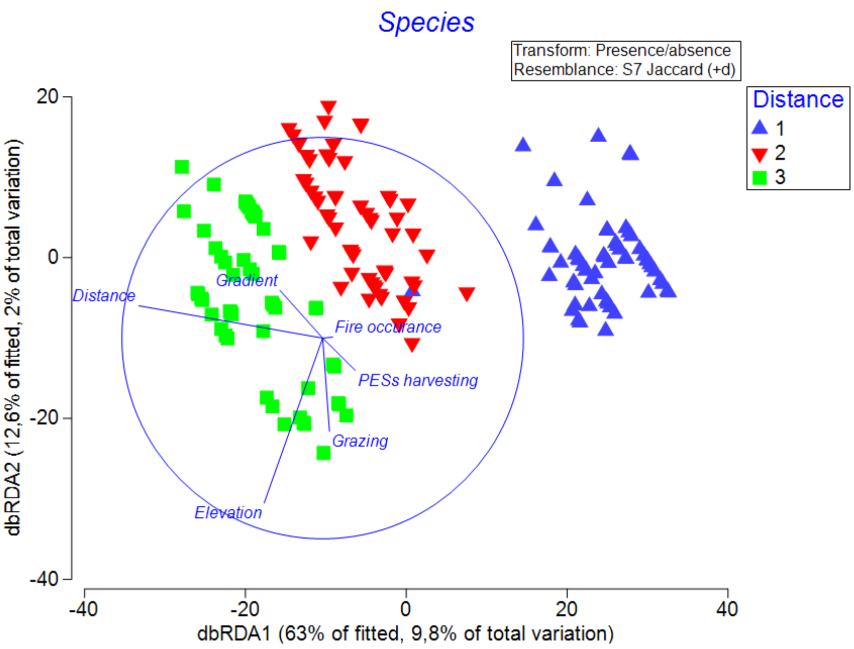

Figure 4.5: *db*RDA (Distance-based redundancy analysis) on the association of distance levels and change variables.

4.4 Discussion

4.4.1 Sampling effectiveness, vegetation description and species richness

A high species diversity is often associated with intermediate disturbance (Escobedo *et al.*, 2021), and anthropogenic pressure resilience (Araia *et al.*, 2019; Tadesse *et al.*, 2019). As predicted by the intermediate disturbance hypothesis (IDH), lower species diversity was expected at a high disturbance (Araia *et al.*, 2019; Escobedo *et al.*, 2021). This study finding confirmed one hypothesis, the turnover of local tree species assemblages increases as the distance from the community increases as predicted by the distance decay of community similarity hypothesis (Soininen *et al.*, 2007; Dias *et al.*, 2021). The immediate disturbance hypothesis was rejected as the species richness and diversity at intermediate and far distances were similar.

In this study, 66, 83 and 83 species were counted in an immediate distance, intermediate distance and far distance, respectively. The Choa1 predicted that 76, 93 and 95 species would be recorded for an immediate distance, intermediate distance and far distance, respectively, suggesting that an immediate distance is more likely to be lower in species richness compared to intermediate and far distances. These findings are in agreement with Escobedo *et al*. (2021) that large disturbance results in high dominance of disturbance-tolerant species and decreased species richness. Therefore, low species richness is expected in a highly disturbed area (Araia *et al*., 2019). Moreover, these study findings are in agreement with Yashmita-Ulman *et al*. (2021) that tree species richness in agroforestry increases with an increase in distance to the natural forest. The number of indigenous tree species is decreasing in the traditional agroforestry landscape (Lelamo, 2021). The decumulation of a greater number of species in immediate distance compared to intermediate and far distances may be attributed to the extensive harvesting of provisioning ecosystem services (Banag-Moran *et al*., 2020) and human behaviour (e.g., harvesting area preference) (Singh *et al*., 2021a; Ihemezie *et al*., 2021), as predicted by the optimal foraging theory. Provisioning ecosystem services harvesting usually are impacted by the increase in distance to the forest, for example, fuelwood collection distance increase is perceived to reduce the collection of fuelwoods from the forest (Singh *et al*., 2021a). An increase in harvesting distance influences the PESs harvesters as they would prefer to harvest in proximity to save time and energy (Bahru *et al*., 2021). Similarly, Roy *et al*. (2022) found that local people harvest fuelwood in traditional agroforestry to avoid travelling a long distance to the forest.

Local people would maximise energy and time when searching and harvesting PESs. This results in a significant decline of tree species at an immediate distance as the distance from the community to the forest increases (Cicuzza *et al*., 2011; Tadesse *et al*., 2019). Studies confirmed that high species richness drives the multifunction of the ecosystem (Basile *et al*., 2021; Li *et al*., 2021), for example, the traditional agroforestry landscape. Then, low species richness in the immediate distance probably affects the proximate ecosystem functionality. Therefore, it significantly affects the products and benefits derived from a multifunctional ecosystem (Madonsela *et al.,* 2018).

High disturbance can affect the capacity of traditional agroforestry to provide protection from natural hazards (Stritih *et al.*, 2021). Though the immediate distance has lower tree species richness compared to intermediate and far distance, the immediate distance had 48 indigenous tree species out of 118 total indigenous species. Considerable diversity of tree species (41%) is retained and/or deliberately planted and maintained by the local people within traditional agroforestry. The higher percentage of tree species richness in the immediate distance in the present study suggests that traditional agroforestry, despite being intensively disturbed, has a high potential in preserving and conserving indigenous tree species (Yashmita-Ulman *et al.*, 2021). For example, in Indonesia and Mexico, Rendon-Sandoval *et al.* (2020) reported that a traditional agroforestry system contains over 50% of adjacent indigenous forests tree species and has therefore the capacity to conserve indigenous species. A study conducted in central Ethiopia found that traditional agroforestry has 64 tree species compared to the proximate forest with 31 species (Asfaw & Lemenih, 2010). The high number of indigenous tree species in traditional agroforestry confirms the importance of the trees to people's livelihood (Lokonon *et al.*, 2017); and the potential to provide a variety of resources for human livelihood (Bahru *et al.*, 2021).

The study revealed *Mangifera indica* and *Persea americana* to be more dominant species in an immediate distance. *M. indica* and *P. americana* are exotic fruit tree species that are widely distributed in traditional agroforestry landscapes (Vibhuti & Bargali, 2019). However, these are naturalised exotic tree species in South Africa (Constant & Tshisikhawe, 2018). In fact, *M. indica* and *P. americana* are home garden indicators, the occurrence of which signifies the use-value of the tree species (Gemechu *et al.*, 2021). Along with this finding, Lokonon *et al.* (2017) found that *M. indica* is the dominating exotic species in Benin's traditional agroforestry. Similar to traditional agroforestry in India (Vibhuti & Bargali, 2019), *M. indica* is a dominating tree species in traditional agroforestry systems. Their dominance confirms the fact that, within traditional agroforestry, many exotic trees exist due to anthropogenic disturbances (Escobedo *et al.*, 2021) and socio-economic benefits (Gemechu *et al.*, 2021). Recently, local people had a tendency of promoting exotic tree species for different uses (Lelamo, 2021). This is due to the fact that most of the exotic tree species in traditional agroforestry have economic value (Gemechu *et al.*, 2021), hence, they plant more exotic species compared to indigenous species. *Pteleopsis myrtifolia*, *Tabernaemontana elegans*, *Combretum molle*, *Albizia adianthifolia,* and *Parinari curatellifolia* are found to be dominant in both an intermediate and far distance. The dominance of indigenous tree species in the intermediate and far distance indicates that harvesting levels decay with an increase in distance. Thus, distance becomes a limiting factor. However, *Englerophytum magalismontanum* species are more dominant in the far distance and *Bridelia micrantha, Pseudolachnostylis maprouneifolia, Afzelia quanzensis,* and *Senegalia ataxacantha* species are more dominant in an intermediate distance.

The most dominating species in intermediate and far distances are multiple-purpose trees, mostly used for traditional medicine; tree species such as *Combretum molle*, *Albizia adianthifolia, Parinari curatellifolia, Pseudolachnostylis maprouneifolia, Afzelia quanzensis* (Tshisikhawe *et al*., 2012), and *Tabernaemontana elegans* (Ndhlovu *et al*., 2019; Setshego *et al*., 2020). A recent study found that *Elaeodendron transvaalense* is a near-threatened species in a far-distant area. The same species has been reported to be in high demand for bark and root medicine in Limpopo Province (Tshisikhawe *et al*., 2012). The *E. transvaalense* species treat sexually transmitted diseases (Semenya *et al*., 2013). However, *E. transvaalense* is a protected species in South Africa (Semenya *et al*., 2013). Tree species such as *E. magalismontanum, C. molle* and *Bridelia micrantha* are protected from being cut by cultural rules (Constant & Tshisikhawe, 2018). The dominance of fruit tree species like *E. magalismontanum* was expected in the far distance because of the high demand and use in the study areas (Araia & Chirwa, 2019). Dissimilarities in species abundance in traditional agroforestry increased with increasing distance. The present study found higher species dissimilarities of 95% between an immediate and intermediate, an immediate and far distance; this could be due to human disturbances and management decisions at an immediate distance (Zequeira-Larios *et al*., 2021). However, all the distances shared nearly the same indigenous species. Previous studies indicated that the tree species in traditional agroforestry are nearly the same as species in the indigenous forest (Yashmita-Ulman *et al*., 2021).

4.4.2 The variability of local species assemblage among different distance levels

PERMDISP showed a narrow range of species variation among different distance levels, ranging from 54% to 59%. The species assemblage significantly differs among the distance levels. The highest species variation was observed at an intermediate distance, which indicates that there is greater species assemblage at an intermediate distance compared to immediate and far distances. These findings agree with previous studies, that tree species assemblage increases with an increase in distance to the natural forest and a large variation is found at an intermediate distance (Zwiener *et al*., 2020). Tree species assemblage and assemblage in traditional agroforestry vary based on the distance to the natural forest (Yashmita-Ulman *et al*., 2021).

There are two potential explanations for the greater species variation in an intermediate distance. First, validation of the intermediate disturbance hypothesis, the intermediate disturbance strongly influences the species assemblage (Zwiener *et al*., 2020). The disturbance at an intermediate distance positively influences the species diversity, while the immediate distance negatively influences species diversity by encouraging the dominance of certain tree species and affecting regeneration (Zwiener *et al*., 2020). As reported by Banag-Moran *et al*. (2020), disturbance can positively and negatively influence species diversity. Furthermore, anthropogenic disturbance could lead to homogeneity in species assemblage in the proximate areas (Banag-Moran *et al*., 2020; Michalet *et al.,* 2021). This kind of disturbance also threatens biodiversity through the reduction of species assemblage and the introduction of exotic species (Banag-Moran *et al*., 2020). Secondly, the harvesting of PESs is higher in the immediate distance as the hypothesis predicted that the harvesting of PESs increases as the distance from the community to the forest increases. Yashmita-Ulman *et al*. (2021) indicated that tree species assemblage and assemblage variation decrease as the distance from the forest to the community decreases. This finding suggests that distance plays a very critical role in species richness and assemblage in local communities proximate to the forest (Yashmita-Ulman *et al*., 2021). Even though traditional agroforestry has rich tree species diversity through retained and planted tree species (Villanueva-Lopez *et al*., 2019), the number of tree species is decreasing in the traditional agroforestry landscape.

4.4.3 Drivers of turnover of species assemblage in different distance levels

This study confirms that there is a correlation between species assemblage and change variables such as elevation, gradient, distance and PESs harvesting. The drivers of species assemblage significantly differ among the distances. The difference could be due to human behaviour arising from change variables such as elevation, gradient, distance and PESs harvesting (Zwiener *et al*., 2020). These drivers are determining factors in species assemblage dissimilarity in traditional agroforestry landscapes in distance levels. The distance from the traditional agroforestry to the natural forest is an important parameter determining tree species assemblage and diversity (Cicuzza *et al*., 2011).

The immediate distance in close vicinity to local people had different tree species drivers compared to an intermediate and far way distance. The harvesting of PESs was found to be the driver of tree species assemblage at an immediate distance. The most likely reason for such a trend is that a relatively high number of local people prefer to utilize tree species at an immediate distance than an intermediate and far distance. Subsequently, this mediates the tree species in traditional agroforestry. In India, distance to the forest was shown to determine the consumption of fuelwood. Approximately 75% of the fuelwood is extracted in traditional agroforestry and was understood to save people's time travelling to the forest (Singh *et al.*, 2021b). Moreover, an intermediate distance could be an option or alternative source for the local people to harvest the PESs. Locals could neglect to maintain tree species assemblage at an immediate distance since they can fulfil their demands for PESs from an immediate distance (Getachew *et al.*, 2022). In this case, the presence of such behaviour would result in high species assemblage at an intermediate distance because of minimal disturbance. Consequently, the tree species assemblage in an immediate distance and far distance would decline due to high disturbance and succession, respectively. The distance, elevation and gradient were found to be the factors determining species assemblage in the far distance of the traditional agroforestry. These study results agree with the findings of the previous studies that indicated that gradient had a contribution to tree species assemblage (e.g., Getachew *et al.*, 2022).

4.4.4 Conservation implications

Traditional agroforestry plays a critical role in reducing pressure on the natural forest for medicine, fuelwood, timber extraction, and fodder (Asase & Tetteh, 2016; Phondani *et al.*, 2020). The sustainable management of traditional agroforestry would balance the cultural, ecological, economic, and social needs of present and future generations (Phondani *et al.*, 2020). However, this could be achieved through the direct integration of attitudes, perceptions, and preferences (Phondani *et al.*, 2020) and the behaviour of local people. Resources preferences and use in traditional agroforestry are more likely to be influenced by many factors; harvesting distance is not an exception. It is very critical to conserve tree species in traditional agroforestry than in undisturbed forest ecosystems when conservation resources are limited (Araia *et al.*, 2020). It has been argued that undisturbed and protected areas are not sufficient to protect all tree species (Sharma & Vetaas, 2015). In addition, traditional agroforestry contributes to reducing deforestation and mitigating the loss of biodiversity (Villanueva-Lopez *et al.*, 2019). It is crucial for traditional agroforestry management practices to have the ability to restore ecosystem structure and functions. While tree species richness has been well documented in traditional agroforestry, a decrease in tree species richness must be empirically evaluated. As far as conservation is concerned, traditional agroforestry could not be an absolute substitute for natural forests. Therefore, tree species diversity must be conserved in both traditional agroforestry and natural forests (Asfaw & Lemenih, 2010). The recent study found a near-threatened *Elaeodendron transvaalense* tree species in VBR. The planting of indigenous tree species could contribute to the conservation of biodiversity. In Bangladesh, traditional agroforestry biodiversity is conserved through the local planting of indigenous trees (Baul *et al*., 2021). Likewise, the local people of Ethiopia plant indigenous tree species in their traditional agroforestry systems (Gemechu *et al*., 2021). This study found few endemic tree species in the traditional agroforestry landscape. The occurrence of some endemic tree species in traditional agroforestry makes the argument for conservation even stronger. The conservation strategies must be designed and coordinated at a local level in balance with the need of people's livelihoods. If people's livelihood is excluded from conservation strategies, no conservation intervention is likely to be effective. Multipurpose trees in traditional agroforestry should be promoted to supplement other tree species. This study confirms that traditional agroforestry integrates biodiversity with socio-economic needs and hence reduces forest degradation, deforestation, and overexploitation of natural resources. Unfortunately, the South African national agroforestry strategic framework (Agroforestry Strategic Framework 2017) currently emphasises mainly modern agroforestry systems and largely overlooks traditional agroforestry as a component of agroforestry.

4.5 Conclusion

This study's results confirm that the distance and associated factors have major detrimental effects on tree species richness and biodiversity in traditional agroforestry landscapes. The tree species richness increases as the distance from the traditional agroforestry to the natural forest increases. Contrary to expectations, species diversity at intermediate and far distances has similar higher species diversity compared to an immediate distance. The intermediate disturbance hypothesis was not applicable in this study, however, confirmed the effect of high disturbance on species richness and diversity in the immediate distance. As the tree species richness in the study area is distance-dependent, this study identifies a strong decline in tree species richness in proximity to traditional agroforestry. The provisioning ecosystem services harvesting is known to be extremely high in the study area. Effective solutions must be implemented to reduce and halt overexploitation, including planting indigenous trees and conserving the existing vegetation. Through this intervention, the immediate distance can accumulate more tree species.

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Chapter 5

The effects of exotic tree species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes of Vhembe Biosphere Reserve, South Africa

Abstract

Traditional agroforestry has been recognised as a potential species diversity conservation practice. The defining features of traditional agroforestry landscapes (TALs) are species diversity, productivity, and complex functionality. However, currently, there is a decline in endemic species and a loss of biodiversity in TALs. This study, therefore, evaluated the impact of exotic species and socio-ecological determinants on endemic species diversity in these TALs. The vegetation inventory was conducted in the TALs of the Vhembe Biosphere Reserve communities. The data were analysed using SIMPER, PERMANOVA, dbRDA and DISTLM. The results showed that there was a significant difference between exotic $(df = 2, F = 44.974, p = 0.004)$ and endemic $(df = 2, F = 1.9396, p = 0.001)$ tree species diversity across the distance levels. The Shannon diversity means plot showed that there was a higher endemic species diversity in the far distance ($\bar{X}$= 0.198, SD= 0.332) than in the intermediate ($\bar{X}$= 0.119, SD= 0.303) and immediate distance ($\bar{X}$= 0, SD = 0). In contrast, there was a higher exotic species diversity in the immediate distance ($\bar{X}$= 0.523, SD= 0.527) than in the intermediate ($\bar{X}$= 0, SD= 0) and far distance ($\bar{X}$= 0, SD= 0). The study found that the endemic species diversity and richness were influenced by the distance level, exotic species richness, diversity, and abundance. However, the distance level was found to be the major driving factor of change in endemic species composition in TALs. The endemic species diversity increased as we moved from the epicentre of the village to the forest. The study found that endemic species diversity and richness were influenced by the distance level, exotic species richness, diversity, and abundance. Conservation through indigenous tree planting in traditional agroforestry landscapes would mitigate the introduction and spread of exotic species. This will ultimately enhance the traditional agroforestry biodiversity and production while benefiting people.

Keywords: Endemic species, Exotic species, Distance, Colonisation pressure hypothesis, Biodiversity, Traditional agroforestry

5.1 Introduction

Traditional agroforestry is a complex and dynamic ecosystem that contributes to biodiversity conservation, provision of ecosystem services and improving livelihoods (Chirwa & Mala, 2016; Hamawa *et al.,* 2018; Rendón-Sandoval *et al.,* 2020). The long-term viability and conservation value of traditional agroforestry are sustained by conserving genetic diversity which is largely dependent on the effort of local people (Subba *et al.,* 2017). Traditional agroforestry plays a critical role in conserving endangered tree species by reducing pressure on native forests (Mylliemngap, 2021). The tree species diversity in traditional agroforestry has been enhanced by the local people through retaining endemic species, and indigenous species and planting exotic tree species (Kelso & Jacobson, 2011; Nath *et al.,* 2016). The local people promote and/or domesticate exotic plant species that provide food security and economic value (Gemechu *et al.,* 2021). However, planting exotic tree species has been globally observed as a threat to traditional agroforestry diversity as the dominance of exotic tree species is transforming diverse traditional agroforestry into homogenous landscapes (Nath *et al.,* 2016). Hence, the value of traditional agroforestry for biodiversity conservation is questionable if the introduced exotic tree species are dominating endemic tree species (Kehlenbeck *et al.,* 2011).

An exotic tree species often tends to increase species similarity and homogenisation in different ecosystems (Qian & Ricklefs, 2006). The challenge of increasing the dominance of exotic tree species in traditional agroforestry landscapes has been reported in many tropical and subtropical countries such as Ghana, Brazil, and Costa Rica (Nath *et al.,* 2016). The increased dominance of exotic tree species has a threat to ecosystem services and biodiversity (Herrera *et al.,* 2018), due to competition, predation, and disruption of natural ecosystem functions and processes (Walsh *et al.,* 2012). These impacts of exotic species often lead to the direct or indirect extinction of endemic species locally or globally (Walsh *et al.,* 2012). The threat of exotic species to biodiversity drew the attention of international institutions' attention, resulting in the Convention on Biodiversity Diversity (CBD) to eradicate and control exotic tree species. Despite global attention and international agreements, the rate of biodiversity loss due to the introduction of exotic tree species into a landscape has not changed (Walsh *et al.,* 2012).

South Africa has rich species diversity and has been ranked third in terms of biological diversity globally with over thirteen thousand (13 000) endemic tree species (Hoveka *et al.,* 2020). The biodiversity and ecosystem loss in South Africa is a growing concern (Lukey *et al.,* 2017; Scheiter *et al.,* 2018). Maema *et al.* (2016) reported that South Africa has approximately 750 and 800 exotic tree species and shrubs, respectively. The exotic tree species cover approximately 10 million hectares (8.28%) of South African land (Maema *et al.,* 2016). The most dominating exotic species include *Pinus, Eucalyptus, Lantana, Opuntia* and *Acacia* species (Ruwanza & Thondhlana, 2022). Exotic tree species were introduced in South Africa in the 18th century during colonisation by the British colonies (Bennett, 2010). The introduction of exotic species and the subsequent invasiveness in South Africa have resulted in stream level reduction, attributed to species such as *Pinus radiata* D.Don, *Eucalyptus camaldulensisi* Dehnn and *Acacia mearnsii* De wild (Ruwanza & Thondhlana, 2022). In the Vhembe Biosphere Reserve, exotic invasive species such as *Eucalyptus* spp., *Lantana camara* L., Australian *Acacia's* spp. and *Caesalpinia decapatela* (Roth) Alston are reported to have caused biodiversity loss and forest structure change (Ruwanza & Thondhlana, 2022). The exotic species are considered invasive species when gwoing in unwanted areas or locations.

In traditional agroforestry landscapes, native tree species were reasonably abundant decades ago and played a significant role in protecting the environment and improving the local people's livelihoods (Foroughbakhch *et al.,* 2001). The retained and planted endemic tree species in traditional agroforestry landscapes reflected the value, experience, and culture of indigenous people (Jose, 2011). However, the expansion of exotic tree species in traditional agroforestry landscapes characterizes the human perception that exotic tree species provide more benefits than endemic tree species (Gemechu *et al.,* 2021). According to Nath *et al.* (2016), exotic tree species possess more useful attributes than endemic trees, such as higher economic value, fast growth rate, competitiveness, and ability to withstand pests. van Heezik *et al.* (2014), argued that preference for exotic tree species shows the socioeconomic importance and history of colonisation in some countries. Traditional agroforestry landscapes have been and/or are still being modified to promote economic exotic tree species due to socio-economic dynamics (Chirwa & Mala, 2016). Thus, the presence of exotic species confers economic benefits (Sahoo *et al.,* 2020), with the traditional agroforestry practice quickly eroding in rural community landscapes (Kelso & Jacobson, 2011).

Introducing exotic tree species makes endemic tree species diversity complex (Omoro *et al.,* 2010). Exotic species have a higher tendency to tolerate a wide range of disturbances than endemic tree species and therefore can colonise the area (Wainwright & Cleland, 2013). As noted in the literature, local people plant more exotic tree species than endemic tree species in traditional agroforestry (Kelso & Jacobson, 2011; Nath *et al.,* 2016). A recent study by

Gemechu *et al.* (2021), reported that in some parts of Ethiopia, people are planting more exotic tree species of economic value in traditional agroforestry than indigenous trees. As predicted by the optimal foraging theory (OFT), local people harvest provisioning ecosystem services at an immediate distance (Makhubele *et al.,* 2022); thus, with extensive harvesting, the tree species disturbance is likely to be very high at an immediate distance (Bendix *et al.,* 2017; Liu *et al.,* 2018). These human disturbances favour the exotic tree species over endemic tree species due to the exotic tree species' characteristics such as high competitiveness and adaptability (Walsh *et al.,* 2012). Human management and disturbances cause huge changes in tree species composition and abundance in traditional agroforestry (Adjossou *et al.,* 2019). However, the endemic tree species and exotic tree species respond differently to human disturbances (Adjossou *et al.,* 2019). In an ecosystem, the exotic tree species often benefit from human disturbances while the endemic tree species suffer (Adjossou *et al.,* 2019). Disturbances facilitate exotic species' invasion of a landscape (Cordeiro *et al.,* 2020). The higher exotic tree species population homogenise the landscape and reduces the endemic tree species population (Qian & Ricklefs, 2006). In many parts of the world, over 80% of endemic species are endangered and threatened due to the presence and pressure of exotic species (Jose, 2011).

Nevertheless, there is a lack of information on the interaction of exotic and endemic species in traditional agroforestry in South Africa. The main objective of the study was, therefore, to evaluate the impact of exotic species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes (TAL). To quantify the impact of exotic tree species and associated socio-ecological determinants, this study tested two hypotheses; (1) There is a higher colonisation by exotic tree species in proximate areas. (2) Exotic species decrease as the distance to the forest increases, affecting the endemic species. As predicted by the colonisation pressure hypothesis (CPH), the high colonisation by exotic species makes an ecosystem more vulnerable to further invasion and impact of exotic species (Walsh *et al.,* 2012). The following questions were assessed to answer the objective: (a) Does exotic tree species diversity correlate with endemic species diversity and socio-ecological determinants? (b) What are the major driving factors of endemic species diversity at TAL?

5.2 Materials and methods.

5.2.1 Tree species inventory

Data collection was conducted with the procedure discussed in Chapter 2 (section 2.4.3) and Chapter 4 (section 4.2.1). In context of this study, the exotic and endemic tree species were separated from the indigenous tree species and recorded. The Field guide to trees of Southern Africa was used to identify the indigenous, endemic, and exotic species (van Wyk and van Wyk 1997). The trees were classified as indigenous to South Africa, endemic to Southern Africa and exotic, if originated from outside Southern Africa.

5.2.2 Statistical analysis

The adequacy of the sampling effort was tested using a species accumulation curve. The different distance levels are represented as 1=immediate distance, 2=intermediate distance and 3=far distance. Endemic and exotic tree species richness was estimated by the Bootstrap index (Clarke & Gorley, 2015) for sampling effectiveness. The diameter class of tree diameters at breast height (DBH) was tested as an indicator of the growth and regeneration of exotic and endemic species in Microsoft Excel, using percentage. The diameter classes were established based on 10 cm amplitude (Bayala *et al.*, 2011; Mir *et al.*, 2021) and the following five classes were established in centimetres (cm): (5-15, 16-26, 27-37, 38-48, 49-59, and ≥ 60). Plymouth Routines in Multivariate Ecological Research (PRIMER) (Primer-E, version 7.0.21) with add-on PERMANOVA+ software was used to analyse the data. PERMANOVA was used to run a univariate ANOVA. The P-values are obtained by permutation, and therefore it avoids the assumption of normality (Anderson *et al*., 2008). The Bray-Curtis similarity index was used through SIMPER to analyse the similarity in tree species composition (Cut-off 70%) (Clarke & Gorley, 2015). To determine tree species composition, endemic tree species and exotic tree species composition in different distance levels, the permutational multivariate analysis of variance (PERMANOVA) was performed in the Bray-Curtis assemblage similarity index (Anderson *et al.*, 2008). When a significant difference was detected in PERMANOVA, a pairwise comparison test was performed to assess the difference in species composition among and between the distance levels (Clarke & Gorley, 2015). When the differences were detected, Bray-Curtis dissimilarity index analysis in SIMPER was applied to determine the individual species' contribution to the dissimilarity among and between the distance levels (Clarke *et al.*, 2014). The species assemblage patterns were visualised using non-metric multidimensional scaling (nMDS), also in the Bray-Curtis similarity index (Anderson *et al.*, 2008).

Exotic and endemic species diversity was analysed using the Shannon diversity index in the DIVERSE matrix in Primer-E (Anderson *et al.*, 2008). Then, the diversity of distance levels was computed in a split means plot analysis. To determine the significance of the change in species diversity distribution, the K-dominance curve was used in Primer-E (Clarke & Gorley, 2015). The K-dominance curve uses the cumulative dominance (%) and species rank to illustrate the species diversity variation at different distance levels. The links between the drivers of species diversity of endemic species and socio-ecological determinants were tested using distance-based linear modelling (DISTLM) (Anderson *et al.,* 2008). The socio-ecological determinants considered in this study were elevation, gradient, grazing, forest fires, provisioning ecosystem services (PESs) harvesting, exotic species richness, exotic species diversity, exotic species abundance and distance. PESs harvesting includes traditional medicine, fuelwood, fodder and wild fruits, and wild vegetables (Makhubele *et al.*, 2022). The influence of determinants on endemic species was analysed separately in the marginal test. Then, the determinants were further subjected to a sequential test, the R^2 selection criterion which explained each driver's contribution to the changes (Anderson *et al.,* 2008; Clarke *et al.,* 2014).

5.3 Results

5.3.1 Landscape structure and characteristics

Based on bootstrap species richness estimation and accumulation curve, all the distance levels presented an adequate sampling effort with sample coverage of more than 80% in both exotic and endemic species (Figure 5.1). This study recorded a total of 39 tree species, which 17 were exotic and 22 endemic species from a total of 2578 measured individual trees in the whole landscape. The dominant families in exotic species were Fabaceae, Rutaceae, and Euphorbiaceae with each presenting two species. In endemic species, the dominant family was Rubiceace with 5 tree species. The stand density of combined endemic and exotic species was higher at an immediate distance ($386.87\ m^2 ha$) compared to intermediate ($96.81\ m^2 ha$) and far distance ($70.54 m^2 ha$) (Table 5.1). The immediate distance is dominated by exotic species with an average DBH of 22.2 cm and an average height of 9.16 m (Tables 5.1& 5.2). The most abundant species that contributed about 90% of the stand at an immediate distance were exotic species- such as *Mangifera indica* L. (69%) and *Persea americana* Mill. (21%). While the intermediate and far distances were dominated by endemics with an average DBH of 9.48 cm and an average height of 5.42 m. Figure 5.2 demonstrated that an immediate distance had higher regeneration of exotic species (DBH class 5-15cm >50%), while intermediate and far distances had higher regeneration of endemic species (DBH Class 5-15cm >80%). SIMPER analysis indicated that 7 species contributed to the 70% cut-off group, 5 species being endemic species and 2 exotic species, while the most abundant at an intermediate distance were endemic

Brachylaena discolor DC. (36%), *Grewia microthyrsa* K.Sachum. ex Burret (65%), *Hyperacanthus amoenus* (Sims) Brisdon (52%) and *Zanthoxylum davyi* (I.Verd) P.G.Waterman (78%) and at the far distance were *H. amoenus* (55%) and *Scolopia mundii* (Eckl. & Zeyh.) Warb (73%) (Appendix 5).

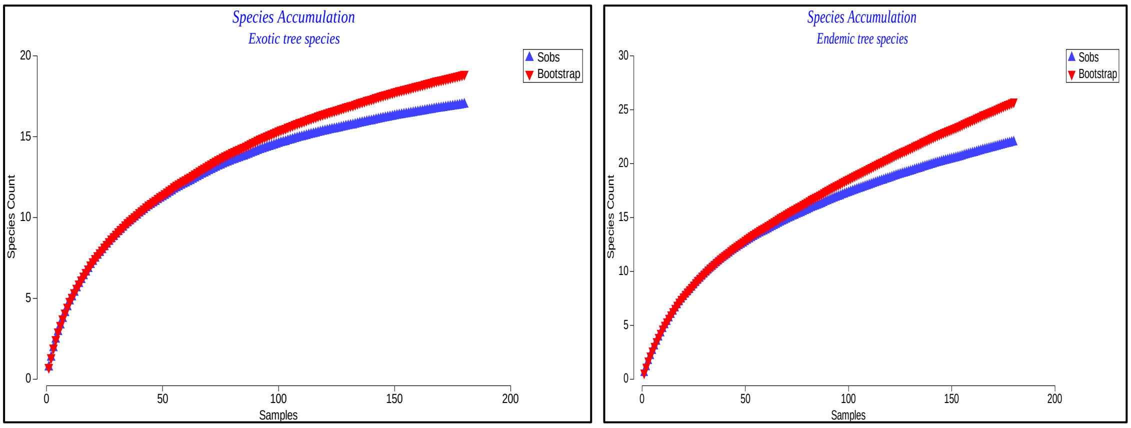
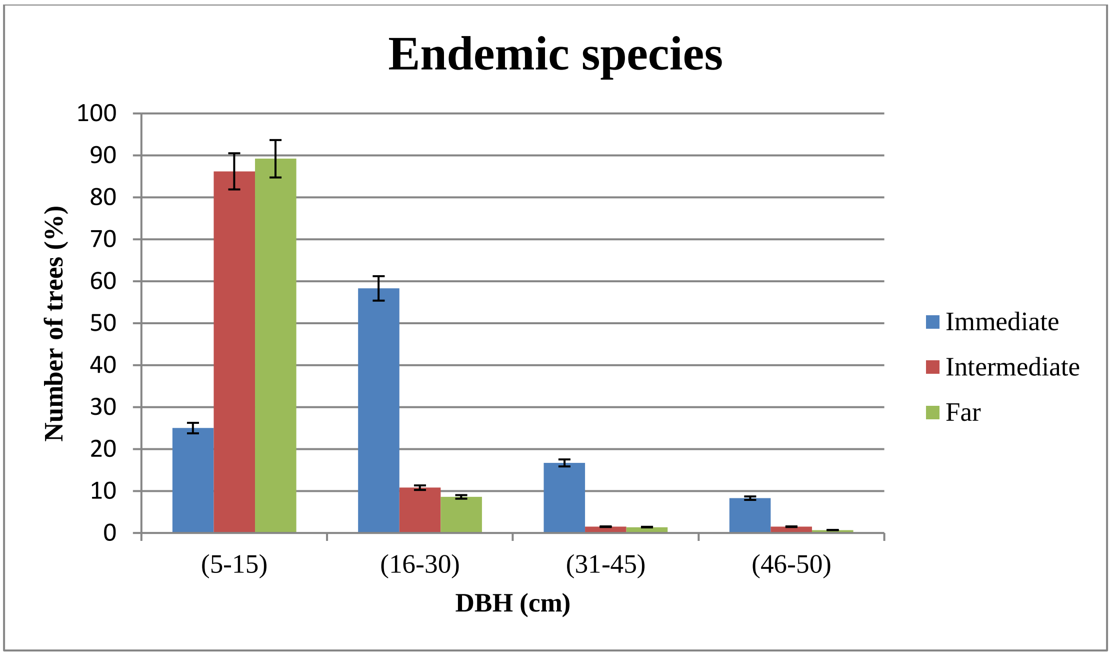


Figure 5.1: Exotic and endemic tree species accumulation curves.

Table 5.1: Stand structure and characteristics.

Distance level	Av. Basal area (m^2ha)	Av. DBH (cm)	Av. Height (m)
Immediate	386.87	22.20	9.16
Intermediate	96.81	11.11	4.73
Far	70.54	9.48	5.42



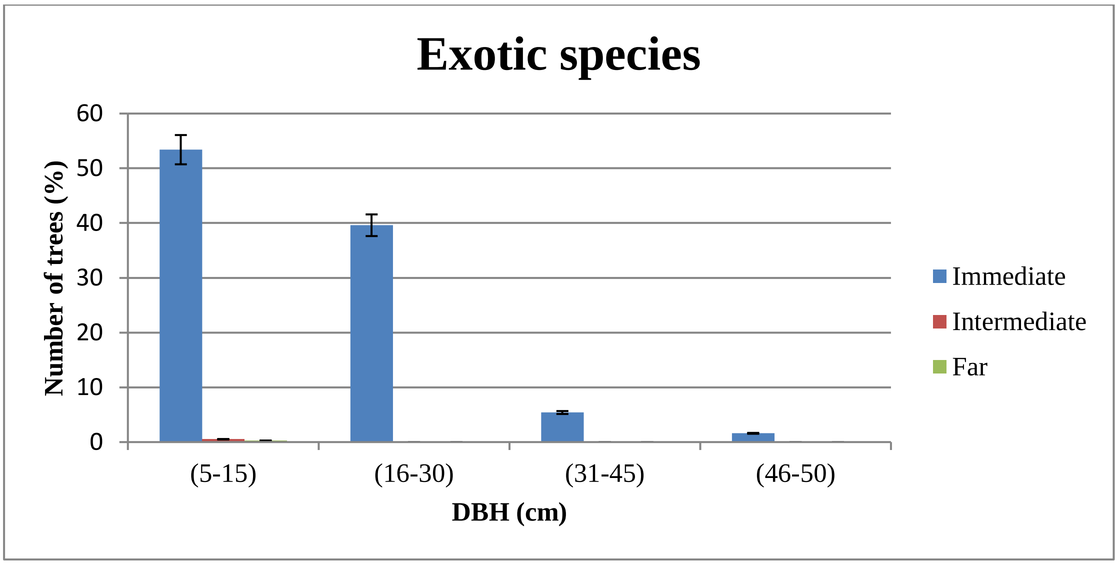


Figure 5.2: DBH classes of exotic and endemic species in traditional agroforestry landscape.

5.3.2 Species composition of endemic and exotic trees across distance levels

PERMANOVA tree species composition analyses found a significant difference in exotic tree species ($df = 2, F = 44.974, p = 0.004$) and endemic tree species ($df = 2, F = 1.9396, p = 0.001$) species diversity across the distance levels. Pairwise comparison of distance levels in terms of overall species composition indicated that, in exotic species, there were significant differences between immediate and intermediate distance ($t = 6.6111, p < 0.05$), and between immediate and far distance ($t = 6.9628, p < 0.05$). However, there was no significant difference detected between intermediate and far distances (t =1, p = 0.550). In endemic species, significant differences were between immediate and far distances ($t =$ $1.7278. p < 0.05$) (Table 5.2). However, a non-significance difference existed between immediate and intermediate (t = 1.3252, p = 0.327) and between intermediate and far (t = 1. 0989, p = 0.352). The species abundance dissimilarity (Appendix 6) was 99% between immediate and intermediate, with *M. indica (26%)* followed by *P. americana (13*%). Species dissimilarity between immediate and far distances was 99% with *M. indica* (24%) being the highest contributing species and *P. americana* with a high abundance average dissimilarity (13%). The species abundance dissimilarity was 96% between far distance and intermediate distance, with *H. amoenus* (19%) being the highest contributing species and *B. discolor* with high species abundance average dissimilarity (12%). The nMDS showed tree species assemblage patterns in exotic and endemic species, with 1 representing immediate, 2 = intermediate and 3 = far distance levels (Figure 5.3). The nMDS showed a distinct exotic species assemblage, while the endemic species showed similar assemblage patterns.

Table 5.2: PERMANOVA pairwise comparisons for exotic and endemic species composition.

	Exotic species		Endemic species	
Pairwise distance levels	**T**	**P(perm)**	**t**	**P(perm)**
(Immediate & Intermediate)	6.6111	0.022	1.3252	0.327
(Immediate& Far)	6.9628	0.033	1.7278	0.043
(Intermediate& Far)	1	0.550	1.0989	0.352

t= pairwise statistics value, P= Permuted probability values

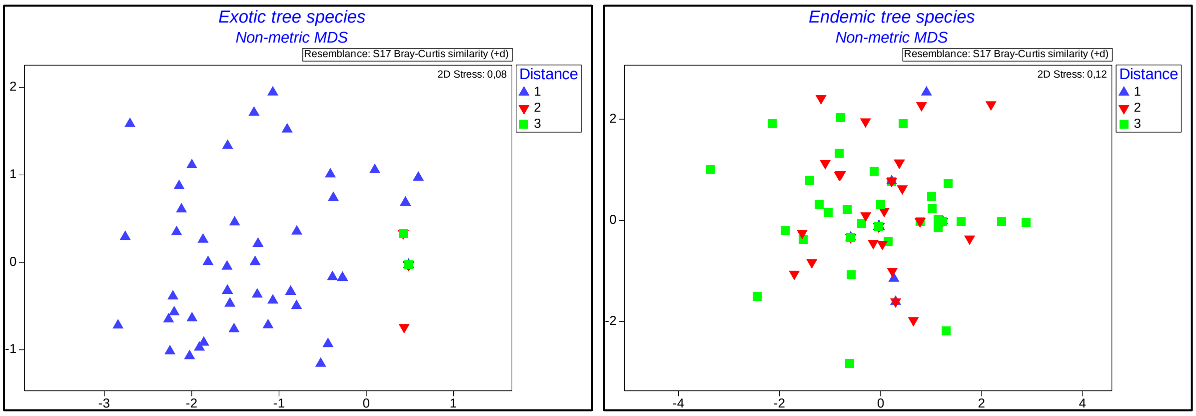


Figure 5.3 Multi-dimensional scaling showing exotic and endemic tree species composition patterns across distance levels, Distance (1= Immediate, 2= Intermediate and 3= far distance).

5.3.3 Diversity of endemic and exotic species at distance levels

The Shannon diversity means plot showed that there was higher endemic species diversity in the far distance ($\bar{X}$= 0.198, SD= 0.332) than in intermediate ($\bar{X}$= 0.119, SD= 0.303) and immediate distance ($\bar{X}$= 0, SD= 0). In contrast, there was higher exotic species diversity in the immediate distance ($\bar{X}$= 0.523, SD= 0.527) than in intermediate ($\bar{X}$= 0, SD= 0) and far distance ($\bar{X}$= 0, SD= 0). The K-dominance curve (Figure 5.4) showed that the traditional agroforestry landscape had contrasting patterns of exotic and endemic species diversity, evenness, and richness across the distance levels. In exotic species, species richness and evenness of diversity increased in the immediate distance but were constant in an intermediate and far distance. In contrast, in endemic species, the decline in evenness of species diversity was slightly different in the intermediate and far distance but largely different in the immediate distance. The intermediate and far distances had almost equal species richness except for the immediate distance, which had a slightly vertical increase in species richness.

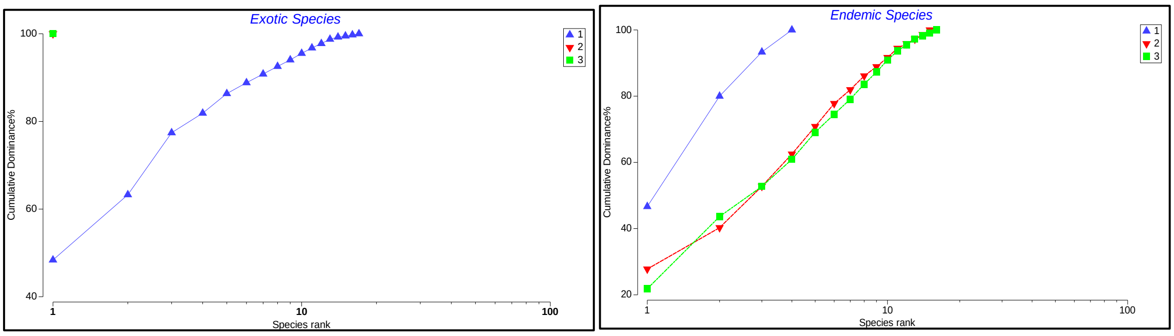


Figure 5.4: Species dominance curves of exotic and endemic species, Distance (1= Immediate, 2= Intermediate and 3= far distance).

5.3.4 Drivers of endemic and exotic species composition change

DISTLM marginal (test $R^2 = 0.36, P < 0.001$) and sequential test ($R^2 = 0.23, P < 0.001$) results showed that there was a significant correlation between endemic species turnover and most of the socio-ecological factors examined (Table 5.3). The marginal test leading factors were distance (14%) followed by exotic abundance (7%), exotic richness (7%) and exotic diversity (7%). The change of the total marginal contribution of each variable in the sequential test may indicate the dominance of variable or interaction of distance levels and other change variables in determining the endemic species turnover of a landscape. The sequential test showed that when all factors considered, they could only explain 23% of the variation on endemic species composition change, which was lower than marginal test. The sequential test showed that distance level ($p < 0.05$) was the major contributing determinant of endemic species diversity in the traditional agroforestry landscape.

Table 5.3: DISTLM Marginal and sequential tests of driving factors of exotic and endemic tree species.

	Marginal test			Sequential test	
Species	**Determinants**	**P**	**Proportion (%)**	**p**	**Cumulative (%)**
Endemic	Elevation	0.307	0.5	0.324	0.5
	Gradient	0.775	0.03	0.300	1.2
	Forest fires	0.802	0.2	0.619	1.4
	Grazing	0.612	0.1	0.456	1.7
	PESs harvesting	0.482	0.3	0.728	1.8
	Distance	0.001[a]	14.5	0.001[a]	22.5
	Exotic Abundance	0.003[a]	6.5	0.844	22.5
	Exotic Richness	0.003[a]	6.7	0.478	22.7
	Exotic Diversity	0.003[a]	7.2	0.850	22.7
Total			36.03		22.7

[a] Significant at $p < 0.05$

5.4 Discussion

5.4.1 Vegetation structure and characteristics

The exotic tree species richness of traditional agroforestry was very high at an immediate distance compared to a far distance, while the endemic tree species richness was very high at a far distance compared to an immediate distance. The traditional agroforestry landscapes are expected to have higher exotic species and lower endemic species because of the high introduction of exotic species and over-harvesting of native species. Exotic tree species are introduced or planted for economic value in traditional agroforestry (Silas Semenya & Maroyi, 2020) hence they are mostly preferred over endemic species (Nath *et al.,* 2016; Gemechu *et al.,* 2021). It is believed that exotic species provide food security (Nath *et al.,* 2016), household income, shade, and environmental benefits such as soil fertility (Muche *et al.,* 2020). According to Semenya and Maroyi (2020), many exotic species are required for the local people's livelihoods and play an integral part in most of the rural communities of Africa, such as South Africa, Lesotho, Nigeria, Cameroon, etc.

The exotic species contribute to the provision of ecosystem services and goods which are essential for human livelihoods (Ruwanza & Thondhlana, 2022). Most of the exotic species integrated into traditional agroforestry include *P. americana, M. indica* and *Psidium guajava* L. Similarly, in most of the traditional agroforestry in Ethiopia, they integrate exotic species such as *P. americana*, *M. indica*, *Musa accuminata* Colla. and *P. guajava* (Muche *et al.,* 2020; Gemechu *et al.,* 2021). These species are perceived to pose more useful attributes such as pests and disease tolerance, disturbance tolerance, faster grower rates (Nath *et al.,* 2016) and high production rate (Cordeiro *et al.,* 2020) than endemic species. These exotics are multipurpose species with uses including fuelwood, fruits, and medicine (Silas Semenya & Maroyi, 2020). Ultimately, this has made the propagation of endemic species less attractive than economic exotic species (Nath *et al.,* 2016). However, the continued domestication of exotic species is transforming the traditional agroforestry landscape into a homogenous landscape, which affects the traditional agroforestry heterogeneity (Nath *et al.,* 2016).

The exotic species tend to alter the ecosystem function, structure, community assemblage and species interaction (Harrea *et al.,* 2018). The immediate level had a higher density of exotic tree species than intermediate and far distance. The high density of exotic trees in the immediate distance in traditional agroforestry is attributed to trees (mainly exotics *M. indica* and *P. americana*.) planted in very high densities for economic value (Gemechu *et al.,* 2021). However, high reduction of endemic species automatically leads to higher relative abundance of the exotic species even without planting any more exotics. The exotic tree species are rarely harvested and/or pruned for their dense canopies and are allowed to grow big. These species such as *M. indica* and *P. americana* are not yet considered invasive, however, *P. americana* is considered a poisonous plant to animals such as goats (van Wyk *et al.,* 2005). The *P. americana* leaves contain a chemical called persin that causes breathing difficulties and cardiotoxic effects that can lead to the death of animals (van Wyk *et al.,* 2005). However, the *P. americana* is widely spread in Limpopo Province through planting in home gardens and farms for consumption and commercial purposes (Silas Semenya & Maroyi, 2020). On the other hand, *P. guajava* which has been found at all distance levels is classified as an invasive plant in South Africa (Bromilow, 2010; Ruwanza & Thondhlana, 2022). *P. guajava* is a very aggressive invasive species that can displace endemic species and transform the ecosystem (Bromilow, 2010).

The *P. guajava* is known to withstand disturbance and has a strong root system that enables the plant to geminate (Bromilow, 2010) easily and quickly. According to Ruwanza and Thondhlana (2022), *P. guajava* has displaced the endemic species in Kenya. Therefore, it is very important to evaluate the negative impact of invasive species on biodiversity and humankind (Silas Semenya & Maroyi, 2020). On the other hand, highly dense retained endemic species such as *Ficus tettensis* Hutch. and *B. discolor* in an immediate distance are also rarely harvested. Though, Ruwanza and Thondhlana (2022) reported that *B. discolor* species has more uses than some exotic species such as *P. guajava*. The immediate distance had higher regeneration (DBH 5-15cm trees) of exotic species, whereas the intermediate and far distance had high regeneration (DBH 5-15cm trees) of endemic species. The introduced exotic species often maintain a high constant germination rate compared to endemic species regardless of environmental conditions (Wainwright & Cleland, 2013). These variations of species regeneration reflect the ecological adaptation of the exotic species to disturbances while the endemic species are negatively impacted by intensive exploitation. In a disturbed landscape, endemic species are prone to extinction while exotic species easily adapt (Wainwright & Cleland, 2013; Adjossou *al.*, 2019).

It is more appropriate to state that local people have been/or are replacing the endemic species regeneration with exotic species regeneration, as there appears to be very little regeneration of endemic species at an immediate distance. The endemic displacement is happening at the juvenile level. The results are congruent with studies conducted by Nath *et al.* (2016) in India who found that in agroforestry, endemic trees of >10 cm DBH are mostly harvested more than exotic species which caused a decline in the regeneration of endemic species. As predicted by the foraging theory, the local people will maximise time, gains and energy in harvesting ecosystem services (Feitosa *et al.*, 2018; Makhubele *et al.*, 2022). This simply means that instead of harvesting at a far distance, the local people harvest at an immediate distance to save time and energy. Therefore, endemic species at an immediate distance are close targets for PESs such as fuelwood, medicine, and fodder (Makhubele *et al.*, 2022). The *P. guajava* species was the only exotic species found at the intermediate and far distance. Exclusively found *P. guajava* species in intermediate and far distances could be dispersed by livestock grazing (goats) and/or wildlife (e.g., birds, baboons) (Ruwanza & Thodlana, 2022). *P. guajava* is one of the exotic species highly preferred diet by livestock and/or wildlife and quickly dispersed through dung. However, the introduction was still at a very low level but steadily increasing. Over time, if the invasion and disturbances at intermediate and far distances intensify, their invasion will increase as the disturbance will favour their regeneration and distribution (Florens *et al.,* 2017; Adjassou *et al.,* 2019). Thus, this exotic species will probably colonise and homogenise the landscape (Qian & Ricklefs, 2006). Exotic species are fast-growing trees with a tendency to replace endemic species in highly colonised area (Boinot *et al.,* 2022). Nonetheless, a lack of knowledge of threats of exotic species to the ecosystem and the need to address people's livelihood needs will have a detrimental impact on traditional agroforestry (Ruwanza & Thondhlana, 2022).

5.4.2 Species composition and diversity of endemic and exotic trees across distance levels

There are many common tree species in the traditional agroforestry of Vhembe Biosphere Reserve, but differences occur in the composition of the species. The differences are mainly attributed to the distance levels, immediate, intermediate, and far distance to the forest. A recent study by Makhubele *et al.* (2022) found that distance is an important factor to show variation in the composition and diversity of species in traditional agroforestry landscapes. For instance, in the immediate and intermediate distance, endemic species such as *B. discolor* are common but *Z. davy* is absent in the immediate distance. On the other hand, endemic species *H. amoenus* is common in the immediate, intermediate, and far distance, while *S. mundi* and *Pavetta lanceolata* Eckl. are rare or absent in an immediate distance. While exotic species such as *M. indica*, *P. americana* and *P. guajava* are common species in an immediate distance. On the other hand, *M. indica* and *P. americana* are rare or absent at intermediate and far distances. These exotic species are planted for their edible fruits (Silas Semenya & Maroyi, 2020), and have higher economic value in the Vhembe area (Semenya *et al.,* 2012; Ruwanza & Thondhlana, 2022).

These variations of species reflect the adaptation of species at the different species levels. The diversity of endemic species in traditional agroforestry decreases as a result of local people focusing on exotic species (Abebe *et al.,* 2013). The comparison of the composition indices among the different distance levels of the traditional agroforestry landscape indicated a clear difference in exotic tree species composition between the immediate and intermediate, and between immediate and far distances. However, the tree species composition between the intermediate and the far distance was similar. On the other hand, the endemic tree species composition difference was between the immediate and far distance. The diversity indices constructed to compute the diversity of the species generally showed that immediate distance had higher exotic diversity while the far distance has higher endemic species diversity. The endemic diversity increases as the distance to the forest increases, while the exotic species decrease as the distance to the forest increases. The change in exotic species composition is highly associated with distance and reflects the proximity of human disturbances and the spread (Qian & Ricklefs, 2006). These results support the colonisation hypothesis, which states that high colonisation by exotic species makes an area or ecosystem more vulnerable with an increased likelihood of further invasion and impact of exotic species. In agreement, studies conducted by Florens *et al.* (2017) found that in an exotic-dominated ecosystem, the regeneration of endemics is very low or stopped because of the suppression by the exotic species. This serves to confirm the importance of the interactions between exotic and endemic species in the traditional agroforestry landscape. However, various factors contribute to these interactions such as competition and human disturbance (Byun *et al.,* 2018).

The evenness of exotic species had a uniform distribution. Such distribution is expected in traditional agroforestry since local people have preferences for more valuable species (Abebe *et al.,* 2013). On the other hand, endemic species' evenness was uneven. The difference in composition and diversity is largely the effect of disturbance through harvesting of provisioning ecosystem services. Literature has shown that increased overharvesting of PESs leads to changes in the composition and diversity of species in traditional agroforestry landscapes (Batisteli *et al.,* 2020). The proximity of the forest in itself did not affect the species diversity and composition because of the effects of foraging theory, local people harvest the provisioning ecosystem services at an immediate distance.

5.4.3 Distance and socio-ecological drivers of endemic diversity change

The present study found that endemic species diversity and richness depended on the distance, exotic species richness, diversity, and abundance. However, the distance was found to be the major driving factor of resources use pattern in TAL. The endemic species richness increased as the distance to the forest increased. This implies that at an immediate distance, endemic species were affected by human disturbance. Local people prefer to collect or harvest PESs at an immediate distance (Makhubele *et al.,* 2022). These findings are congruent with studies conducted by Herrera *et al.* (2018), which reported that endemic species assemblages were associated with anthropogenic disturbances and environmental gradients. Thus, from a far distance, there were a few exotic species and high-endemic species. As reported by Qian and Ricklefs (2006), exotic species may be excluded in the intact forest as they are closely associated with the disturbed ecosystem. Additionally, the efficiency of biological resistance by the native species eventually reduces the niche for exotic species (Byun *et al.,* 2018; Waddell *et al.,* 2020; Li *et al.,* 2021).

The immediate distance had more exotic tree species and fewer endemic species. This is because local people concentrate on endemic species for provisioning ecosystem services and allocate more energy and time to an immediate distance (Makhubele *et al.*, 2022), the effect of optimal foraging theory (Feitosa *et al.,* 2018). Harvesting indirectly and directly affect tree species diversity, richness, and structure (Herrera *et al.,* 2018). The pattern of increasing tree species richness and diversity with increasing distance to the forest was also reported by several studies (e.g., Abebe *et al.,* 2013). Distance influences the patterns of resource use that drive change in species diversity and composition (Qian & Ricklefs, 2006). The high harvesting of endemic species results in densely stocked exotic species in the traditional agroforestry landscape. As result, exotic species colonise the landscape. Disturbances disrupt ecological function and consequently limit the efficacy of biotic resistance (Batisteli *et al.*, 2020).

5.4.4 Implictions for biodiversity conservation

Distance influences the resource use pattern along the drivers of change in tree species composition. A deliberate planting of exotic tree species was evident in traditional agroforestry. While local people plant economic value exotic species, conservation of the endemic species remains important for species diversity in TAL, especially in the immediate distance. The species conservation value of traditional agroforestry is questionable if the landscape is dominated by exotic species and thus threatens endemic species and indigenous trees' genetic loss (Kehlenbeck *et al.,* 2011). Selection and breeding of endemic or indigenous species for a specific use or multiple-use species are the first steps in conserving species diversity in traditional agroforestry (Jose, 2011). The indigenous tree species planted for multipurpose use presumably would buffer the remaining endemic species to be further exploited at immediate and intermediate distances (Gemechu *et al*., 2021). It is of great importance to identify suitable indigenous species for agroforestry promotion. Those with high multiple-purpose value and relatively fast growth rates. These multipurpose species may include *Bridelia micrantha* (Hocht.) Bill., *Parinari curatellifolia* Planch. Ex Benth and *Englerophytum magalismontanum* (Sond.) T.D. Penn. in Vhembe Biosphere Reserve TAL (Araia & Chirwa, 2019). Local people are most likely to positively respond to traditional agroforestry strategies that are aligned with their interests and needs (Nath *et al.,* 2016). While they may oppose the strategies that may control or deprive them of benefits from exotic species (Silas Semenya & Maroyi, 2020). Therefore, the National Agroforestry Strategic Framework and Policy should promote harvesting, replanting and conservation strategies that accommodate the local people's interests and needs. It is worth noting that local people are most unlikely to plant indigenous species that are of no economic value (Nath *et al.,* 2016).

5.5 Conclusion

The study has found that traditional agroforestry has high diversity and richness of exotic species than endemic species in proximate areas to the households. The dominance of exotic species depends on four factors that altogether determine the outcome of low endemic species diversity in traditional agroforestry: distance, exotic species diversity, exotic species richness and exotic species abundance. This recent study presumes that over time, the introduction and colonisation of exotic species will further spread and diminish the traditional agroforestry biodiversity. As result, the heterogeneity of the traditional agroforestry landscape could be transformed into a homogenous landscape, which will result in a serious threat to human well-being, livelihoods, and biodiversity. Interventions through capacitating the local people on the negative impacts of exotic species and promotion of endemic or indigenous species planting in traditional agroforestry would mitigate the introduction and spread of exotic species. This will ultimately enhance the traditional agroforestry biodiversity for the benefit of people and the environment.

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Chapter 6

Assessing carbon stocks and carbon determinants in traditional agroforestry landscape: implications for tree species conservation and carbon sequestration

Abstract

Traditional agroforestry has been explicitly recognised worldwide for its positive contribution to biodiversity conservation, climate change mitigation, and improving socio-economic livelihood. Little has been reported regarding the effects of ecological determinants on the carbon accumulation potential of traditional agroforestry in South Africa, especially in the Vhembe Biosphere Reserve (VBR). The main objective was to quantify the tree carbon stock in the VBR traditional agroforestry landscapes along three distance levels from villages to the forest. The vegetation data were collected using forestry inventory tools in VBR traditional agroforestry landscapes. Diversity indices, Important value index, and Carbon stocks were calculated from the data and then analyzed using PERMANOVA, ANOVA, Spearman's correlation, and Linear regression model. Tree species richness and diversity had no significant effect. Tree density increase and elevation decrease were found to be the determinants of carbon stocks in traditional agroforestry landscapes. The results showed no statistically significant differences in total carbon stocks ($F= 0.888$, $p= 0.413$) between the distance levels, with the same amount of carbon stocks stored in the vegetation. The fact that the carbon stock per hactare remains the same in all distance levels implies that carbon sequestration alone cannot be used as a guiding criterion for setting conservation priority areas. Instead, the prevalence of the higher species diversity in the intermediate and far distance levels than intensively managed immediate distance levels shows that the agroforestry landscape may remain stable and productive even under recurrent disturbance. Hence, its contribution to the species diversity conservation and mitigation of climate change may also be considered sustainable.

Keywords: Above-ground biomass, Below-ground biomass, Carbon stock, Traditional agroforestry, Diversity index, Distance level

6.1 Introduction

Traditional agroforestry has been explicitly recognised worldwide for its positive contribution to biodiversity conservation, climate change mitigation, sustainable land use and improving socio-economic livelihood (Dhyani *et al.,* 2021; Pantera *et al.,* 2021). Over 1.2 billion people worldwide are practising agroforestry (Islam *et al.,* 2021; Yasin *et al.,* 2021). The traditional agroforestry landscape (TAL) deliberately integrates crops, woody trees, and/or animals into the same land management unit (Nöldeke *et al.,* 2021; Shrestha *et al.,* 2018). With such management practice, TAL provides a wide range of direct and indirect benefits; the direct benefits include, for example, crops, fuelwood, traditional medicine, livestock fodder, timber, wild food and fruits, etc. (Mukhlis *et al.,* 2022; Ghale *et al.,* 2022). The indirect environmental benefits embrace for example biodiversity conservation, soil conservation, sustainable land use, carbon sequestration, etc. (Kokkora *et al.,* 2022; Mukhlis *et al.,* 2022). These benefits from the TAL originate from the interaction of the system components, and the outcomes are directly linked to landscape management (Islam *et al.,* 2021). Moreover, these benefits may depend on the ecological and socio-economic conditions of the landscape (Atreya *et al.,* 2021; Islam *et al.,* 2021; Makhubele *et al.,* 2022). These include a variety of factors such as elevation, slope, tree species composition, climate, soil properties, grazing, culture, and poverty, among others (Araia and Chirwa 2019; Araia *et al.,* 2020; Gomes *et al.,* 2020; Makhubele *et al.,* 2022).

Worldwide, anthropogenic activities such as burning fossil fuels, clearing of forests and land use change are directly linked with the emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4) (Usman *et al.,* 2022; Ghale *et al.,* 2022). Amongst all, CO_2 has been found to be the leading GHG in global warming (Ghale *et al.,* 2022; Usman *et al.,* 2022), contributing approximately 70% (Yasin *et al.,* 2021). Recently, several studies have demonstrated the impact of global warming on the reduction of species diversity which in turn has an impact on the global environment (e.g., Sun *et al.,* 2021; Holz *et al.,* 2022). In this regard, agroforestry has been recognised as a mitigation strategy for climate change by contributing to the conservation of tree species diversity (Dhyani *et al.,* 2021; Melone *et al.,* 2021) and the reduction of GHG through carbon sequestration (CS) (Ghale *et al.,* 2022; Shrestha *et al.,* 2018).

Tree components in TAL play a very significant role in carbon sequestration (Mayele *et al.,* 2020), with woody vegetation storing about 75% of the carbon (Yasin *et al.,* 2021). Tree species sequester and store carbon in different quantities and rates depending on the tree's characteristics such as age, type of species, size, and growth rate (Cyamweshi *et al.,* 2021; Stoffberg *et al.,* 2010). However, anthropogenic disturbances are a threat to ecological factors (e.g., species richness) that are essential for carbon accumulation (Tesfay *et al.,* 2022). Anthropogenic disturbances in TAL of East Africa were reported to emit about 4.07- 17 Mg C ha^{-1} of carbon (Cyamweshi *et al.,* 2021). Despite TAL playing a significant role in reducing anthropogenic pressure on natural forests (Ghale *et al.,* 2022), the number of indigenous tree species is decreasing in the traditional agroforestry landscape in Africa (Lelamo, 2021). The increasing demands for provisioning ecosystem services (PESs) such as fuelwood, fodder, traditional medicine, wild fruits, and food are usually associated with biodiversity loss (Makhubele *et al.,* 2022). In addition, local people's tendency of preferring exotic species over indigenous species has a negative impact on indigenous species (Lelamo, 2021).

South Africa has been practising traditional agroforestry since the late 18th century (Oduniyi & Tekana, 2019). Thus, TAL has been used by rural communities to improve their livelihood (Mukhlis *et al.,* 2022). However, the recognition of traditional agroforestry in South Africa remains very low (Oduniyi & Tekana, 2019). Considering the significance of agroforestry in addressing socio-economic, ecological and climate adaptation and mitigation, South Africa has developed an exclusive Agroforestry Strategic Framework (ASF) (2017) to promote agroforestry. The ASF aimed to improve traditional agroforestry by identifying indigenous species that can be genetically improved to enhance agroforestry production (DAFF, 2017). This will probably also enhance agroforestry adoption as a climate change mitigation strategy in South Africa. However, in many developing countries including southern African countries, there is a slow pace in terms of adopting and promoting carbon projects due to barriers such as lack of government support, organisational capacity, policies (Chirwa, 2015), and institutional framework (Koh *et al.,* 2021). These barriers hinder the participation of many African countries in carbon markets while Africa remains the most climate change-vulnerable continent (Chirwa, 2015).

South Africa earmarked climate-smart agriculture, agroforestry, and other environmental projects to achieve the global goal (DEA, 2016). Previous studies across the globe have assessed the potential of agroforestry in carbon sequestration (e.g., Siarudin *et al.,* 2021; Dyhani *et al.,* 2021; Bertsch-Hoermann *et al.,* 2021; Cyamweshi *et al.,* 2021). The Intergovernmental Panel for Climate Change (IPCC) reported that agroforestry has great potential for carbon sequestration in developing countries and is a suitable practice for reducing emissions from deforestation and degradation (REDD+) projects (Negash & Starr, 2015). In the South African context, little has been done to assess the carbon sequestration potential of agroforestry in the region. This could have been influenced by the fact that the implementation of agroforestry in South Africa is at a low level (Oduniyi & Tekana, 2019).

Here, we examine the C accumulation potential for TAL practice in the VBR. This study was led by the following hypotheses *"Tree carbon accumulation increases as the distance from the community to the forest increases due to tree species disturbances"*. Due to disturbances caused by resource use patterns, the Optimal Foraging Theory (OFT) predicts that people will maximize energy and time when searching for and harvesting PESs (Makhubele *et al.,* 2022; Soldati *et al.,* 2017; Feitosa *et al.,* 2018). Effectively, this results in frequent harvesting events at an immediate distance that significantly affect the tree species diversity (Makhubele *et al.,* 2022). In addition, overharvesting affects landscape productivity and function (Mir *et al.,* 2021), and carbon sequestration as it depends on a high species diversity (Jahman *et al.,* 2021). Therefore, this study's main objective was to quantify the tree carbon stock in VBR traditional agroforestry landscapes along three distance levels. The study addresses the following questions: (1) What are the tree carbon stocks along the distance levels in TAL? (2) What are the ecological determinants of tree carbon accumulation? (3) What are the dominant tree species contributing to carbon accumulation? (4) What is the tree species diversity along the distance levels in TAL?

6.2 Materials and Methods

6.2.1 Data collection

Data collection was conducted with the procedure discussed in Chapter 2 (section 2.4.3) and Chapter 4 (section 4.2.1). In context of this study, the measured trees DBH were used to estimate the trees carbon biomass.

6.2.2 Statistical analysis

6.2.2.1 Tree composition, characteristics, and structure of the landscape

Plymouth Routines in Multivariate Ecological Research (PRIMER) (Primer-E, version 7.0.21) with add-on PERMANOVA+ software was used to analyse the data. The permutation number to estimate the probabilities were set at 999 (Anderson *et al*., 2008). The effectiveness of the sampling effort on species observed (S_{ob}) was evaluated using a species accumulation curve based on Chao2 estimators in Primer-e (Chao & Chiu, 2016). This was done for the whole landscape and each distance separately. A sampling effort that captures ≥80% of the estimated species richness can be considered effective. To determine the traditional agroforestry landscape characteristics, the DIVERSE function in Primer-E (Clarke *et al*., 2014) was used to analyse the species diversity using the Shannon diversity (H^1) index (Equation 6.1) and species richness used Margalef's (*d*) richness index (Equation 6.2).

$$H^I = -\sum_i Pi \log (Pi) \tag{6.1}$$

Where *pi* is the proportion of the total species count arising from the *i*th species.

$$d = \frac{(S-1)}{\log N} \tag{6.2}$$

Where *S*= represents the number of species counts, and *N*= represents the total number of individual species (Clarke *et al.,* 2014). Then, a resemblance matrix of *H* and *d* richness indices sample plots was developed using the Euclidean distance (Araia *et al.,* 2020). The resemblance matrices were then subjected separately to permutation-based multivariate analysis of variance (PERMANOVA) to test if there were significant differences in species diversity and richness among different distance levels (immediate, intermediate, and far distances) (Anderson *et al.,* 2008). The effect of distance on species richness and diversity was then tested and followed by a post hoc pairwise t-test (hereafter referred to as pairwise comparison) to compare the effect of distance on local species richness using the PERMANOVA pseudo-t-test. When PERMANOVA is used to do a univariate ANOVA, the P-values are obtained by permutation, therefore avoiding the assumption of normality (Anderson *et al.*, 2008). In a model design, the random factor was distance, and the fixed factor was the village. Traditional agroforestry landscape tree composition and structure were analysed to describe the landscape characteristic (Swangjang & Panishkan, 2021). The tree species composition and structure were described in terms of relative frequency (Equation 6.3), relative density (Equation 6.4) and relative dominance (Equation 6.5) (Bhandari *et al*., 2021; Swangjang & Panishkan, 2021). Then, the important value index of each species was determined (Equation 6.6) (Bhandari *et al*., 2021)

$$Relative\ frequecency\ (RF) = \frac{Frequecny\ of\ a\ species}{Frequency\ of\ all\ species}\ x\ 100 \tag{6.3}$$

$$Relative\ density\ (RDe) = \frac{Density\ of\ a\ species}{Density\ of\ all\ species} x\ 100 \tag{6.4}$$

$$Relative\ dominance\ (RDo) = \frac{Basal\ area\ of\ a\ species}{Basal\ area\ of\ all\ species} x\ 100 \tag{6.5}$$

Therefore;

$$Important\ value\ index\ (IVI) = RF + RDe + RDo \quad (6.6)$$

6.2.2.2 Biomass carbon stock estimation

Generally, above-ground biomass assessment is either conducted through destructive measurements of the tree (Sheppard *et al.,* 2020) or by using non-destructive AGB allometries which typically predict the AGB of a tree using its DBH and in some cases height (Stoffberg *et al.,* 2010). Various allometric equations have been developed for different forest types in southern Africa, however, there's no allometric equation for agroforestry systems in southern Africa (Sheppard *et al.,* 2020). This study adopted an allometric equation developed for agroforestry systems by Kuyah *et al.* (2012) which was also adopted by Jose and Bardhan (2012), and Reppin *et al.* (2020). This allometric equation has been used to assess the AGB of agroforestry systems in Kenya (Kuyah & Rosenstock, 2015; Reppin *et al.,* 2020) and adopted in agroforestry studies conducted in Ethiopia (Manaye *et al.,* 2021). The allometries suggested by Kuyah *et al.* (2012) seemed appropriate for this current study because the tree species measured to develop the allometric equation are the same as the species measured in this current study {e.g., *Combretum molle*, *ficus sp*, *Mangifera indica*, *Persea americana*, *Syzygium cordatum*, etc. (Kuyah & Rosenstock, 2015)} and applied in the same continent, and close regions (east and south region). The applied allometry (Equation 6.7) is:

$$AGB = 0.091DBH^{2.472} \quad (6.7)$$

Where AGB is the aboveground biomass of an individual tree and DBH is the diameter at breast height of a tree. After calculating the AGB per tree, the total biomass was calculated per hectare (Mg ha) using the following formula (Equation 6.8) (Salas Macias *et al.,* 2017);

$$AGB = (\sum AU/1000)\ x(\frac{10000}{Plot\ area}) \quad (6.8)$$

Where AGB is the above-ground biomass (Mgha), $\sum AU$ is the sum of tree biomass of all the trees in the plot, and the plot area (200 m^2). The estimated AGB was converted to carbon stock by multiplying the AGB by the default carbon fraction value of 0.47 (Equation 6.9) developed by the Intergovernmental Panel on Climate Change (IPCC, 2006).

$$\Delta AGC = ABG\ (Mgha)\ x\ CF \quad (6.9)$$

Where AGC is above-ground carbon (Mgha) and CF is the carbon fraction (0.47). Subsequently, below-ground biomass was estimated using a root-shoot ratio method developed by IPCC (for tropical regions, where 0.24 of AGB was assumed to be BGB) (IPCC, 2006). Finally, the total tree carbon stock was estimated by summing the above-ground carbon (AGC) and below-ground carbon (BGC). This was then subjected to a One-way ANOVA to establish if the carbon stock significantly varies within a distance level. Based on the output of Spearman's correlation of ecological factors, the multicollinearity test of correlation between all pairs of the ecological factors was found to be below the acceptable cut-threshold (R^2= 0.95) except for species richness and diversity. This was followed by correlation scatter plots and a regression line. The output showed that the R^2 value in all ecological factors was still very low. If the R^2 was high, we would assume that the model has a predictive value (Gogtay *et al.*, 2017). Then, the Linear Regression Model (LRM) was used to explore whether the carbon stocks in the traditional agroforestry landscape could be related to measured ecological factors. The total carbon stock was modelled as a dependent variable while ecological factors were independent variables.

6.3 Results

6.3.1 Tree density and carbon stocks in distance levels

As depicted in Table 1, there was a statistically significant difference in tree density (F= 1.017; p< 0.001) among the distance levels. The far distance had a higher mean tree density ($\bar{X}$ = 20.03 t h^{-1}, SD= 7.31) than the intermediate ($\bar{X}$= 15.83 t ha^{-1}, SD= 7.55) and immediate distance ($\bar{X}$= 11.74 t ha^{-1}, SD= 7.04). Distance levels did not significantly influence aboveground carbon (F= 0.888, p= 0.413), and belowground carbon (F= 0.888, p= 0.413). However, the aboveground carbon, belowground carbon and total carbon stock mean for immediate distance was generally higher than that in the intermediate and far distance levels (Table 6.1). The tree species that contributed the most carbon stock at immediate, intermediate, and far distance levels were *Mangifera indica* (1153.92 $Mgha^{-1}$), *Syzygium cordatum* (506.37 $Mgha^{-1}$), and *Pteleopsis myrtifolia* (648.48 $Mgha^{-1}$), respectively (Table 6.2).

Table 6.1: ANOVA of tree density and carbon stocks in distance levels.

Distance	Density (t/ha)	AGC ($Mgha^{-1}$)	BGC ($Mgha^{-1}$)
Immediate	11.74± 7.04	1923.63 ± 3052.32	461.67 ± 732.56
Intermediate	15.83± 7.55	1349.73 ± 2627.32	323.93 ± 630.55
Far	20.03± 7.31	1490.37 ± 1387.13	357.68 ± 332.91
ANOVA			
p-value	0.000	0.413	0.413
F	19.353	0.888	0.888

The stand density at the immediate distance was lower than the intermediate and far distances (Figure 6.1 and 6.2). During fieldwork, it was observed that at the intermediate distance, most of the large trees were removed due to past disturbance (e.g., over-harvesting of fuelwood) and the vegetation is at recovering stage (Figure 6.1).

Damani intermediate distance vegetation (↑)

Tshipako intermediate distance vegetation (↑)

Figure 6.1: Vegetation at intermediate distance levels (young vegetation)

Mixed indigenous old growth with a large girth at an immediate distance at Damani (↑)

Protected species with large girth (*Sclerocarya birrea*) at an immediate distance at Damani (↑)

Figure 6.2: Large trees at immediate distance level.

Table 6.2: List of the top five most carbon-productive species in traditional agroforestry.

Distance	Species	Carbon Stock ($Mgha^{-1}$)
Immediate	*Mangifera indica*	1153.92
	Sclerocarya birrea	829.32
	Trichilia emetica	736.09
	Persea americana	445.14
	Diospyros mespiliformis	398.36
Intermediate	*Syzygium cordatum*	506.37
	Pteleopsis myrtifolia	459.39
	Afzelia quanzensis	437.90
	Albizia adianthifolia	426.66
	Bridelia micrantha	358.02
Far	*Pteleopsis myrtifolia*	638.48
	Albizia adianthifolia	314.15
	Parinari curatellifolia	304.24
	Bridelia micrantha	155.08
	Ficus sur	141.02

6.3.2 Determinants of carbon stocks in a traditional agroforestry landscape

The total carbon stocks were significantly positively correlated with density ($r= 0.431$, $p< 0.05$), species richness ($r= 0.181$, $p< 0.05$) and species diversity ($r= 0.247$, $p< 0.05$). However, the total carbon stocks were significantly negatively correlated with elevation ($r= -0.22$, $p< 0.05$) (Table 6.3). As depicted in Table 6.4, the linear regression analysis for TAL detected that a decrease in elevation (odds= -9.38, $p< 0.05$) was most likely to decrease the carbon stocks in the TAL, while an increase in tree density (odds= 131.14, $p < 0.05$) was most likely to increase the carbon stocks. Species richness ($p= 0.697$) and species diversity ($p= 0.712$) had no significant impact on carbon stocks in the TAL.

Table 6.3: Correlation coefficients matrix of ecological determinants and carbon stock.

	Elevation	Density	Carbon	Species richness	Species diversity
Elevation					
Density	0.221				
Carbon	-0.222	0.431			
Species richness	0.254	0.368	0.181		
Species diversity	0.279	0.499	0.247	0.953	

Table 6.4: Determinants of carbon stock in a traditional agroforestry landscape.

eterminants	B	Sig.
Constant	6714.79	0.039
Elevation	-9.377	0.000[a]
Species richness	422.540	0.697
Species diversity	-858.152	0.712
Density	131.153	0.011[a]

[a]Significant at $p < 0.05$)

6.3.3 Vegetation diversity and structure

A total of 136 tree species were recorded in the traditional agroforestry landscape, of which 66 were captured at an immediate distance and 83 tree species at both intermediate and far distances. As depicted in Table 6.5, the PERMANOVA test for species richness and diversity found that there was a significant difference between the distance levels (F_2=17.2, $p < 0.05$ and F_2= 22.9, $p < 0.05$). The pairwise comparison of species richness detected a significant difference between (Immediate and Intermediate) and (Immediate and Far), (t=6.8, $p < 0.05$) and (t=5.7, $p < 0.05$) distances, respectively. Similarly, the pairwise comparison of Shannon diversity (Table 6.6) detected significant differences between (Immediate and Intermediate) and (Immediate and Far), (t=9.1, $p < 0.05$)) and (t=6.0, $p < 0.05$) distances, respectively. However, there was no statistically significant difference between (Intermediate and Far) both in species richness (t=1.1, P=0.432) and Shannon diversity (t=0.9, p= 0.444). There were considerable dissimilarities in the species composition at three distance levels (Appendix 7). The top five dominating species in terms of IVI at an immediate distance were *Mangifera indica* (87%), *Persea americana* (27%), *Musa acuminata* (23%), *Sclerocarya birrea* (16%) and *Ficus sur* (14%). At an intermediate distance, the five tree species were *Pteleopsis myrtifolia* (30%), *Tabernaemontana elegans* (22%), *Bridelia micrantha* (21%), *Afzelia* *quanzensis* (16%) and *Albizia adianthifolia* (15%). At a far distance, the five tree species were *Pteleopsis myrtifolia* (67%), *Albizia adianthifolia* (22%), *Parinari curatellifolia* (21%), *Bridelia micrantha* (13%) and *Englerophytum magalismontanum* (12%).

Table 6.5: Species richness and Shannon diversity across distance levels.

	Source	Df	SS	MS	Pseudo-F	P(perm)	Unique terms
Species richness	Vi	3	0.33	0.11	0.25	0.858	997
	Di	2	24.05	12.03	17.15	0.010[a]	998
	Vi x Di	6	4.21	0.70	1.55	0.177	999
	Res	168	75.95	0.45			
	Total	179	104.55				
Shannon diversity	Vi	3	0.78	0.26	1.55	0.200	999
	Di	2	12.89	6.45	22.98	0.010[a]	999
	VixDi	6	1.68	0.28	1.68	0.141	998
	Res	168	28.14	0.17			
	Total	179	43.49				

[a]Significant at $p< 0.05$, Di= Distance (Random factor), Vi= Village (Fixed factor), SS= Sum of species, MS= Mean of species, F ratio (Pseudo-F), P= Permuted probability values, df= Degree of freedom'

Table 6.6: PERMANOVA pairwise comparison for species richness and shannon diversity.

	Species richness		Shannon diversity index	
Pairwise distance levels	T	P(perm)	T	P(perm)
(Immediate & Intermediate)	6.83	0.027[a]	9.08	0.029[a]
(Immediate & Far)	5.66	0.030[a]	6.00	0.037[a]
(Intermediate & Far)	0.93	0.444	1.14	0.432

[a]Significant at $p< 0.05$

6.4 Discussion

6.4.1 Vegetation diversity and structure in a traditional agroforestry landscape

Our results showed a variation in species diversity indices along the distance levels, especially species richness and Shannon diversity index. The species richness and diversity index were comparably low at an immediate distance and increased as the distance from the homesteads to the forest increased. In line with previous studies, highly disturbed areas are characterised by low species richness and diversity (Bentsi-Entchill *et al.,* 2022; Chaundhury *et al.,* 2022; Mir *et al.,* 2021). Also, these results are inconsistent with the study's hypothesis that species richness and diversity increase as the distance increases to the forest as predicted by the optimal foraging theory. Proximity enhances the anthropogenic disturbance of indigenous tree communities for various ecosystem services (e.g., fuelwood, traditional medicine, etc.), and frequently replaced by economically important and fast-growing exotic species at an immediate distance (Bentsi-Entchill *et al.,* 2022). Our findings are also in agreement with a recent study from Ethiopia, which reported that the indigenous vegetation structure was replaced by exotic species such as *Mangifera indica* and *Persea americana* at immediate distances from villages due to their high economic value for the local communities (Sahoo *et al.,* 2020; Gemechu *et al.,* 2021). However, local people also preserve *Sclerocarya birrea* in their immediate vicinity which is a protected species by national forest policy. *S. birrea* is one of the most domesticated indigenous tree species either by propagation (High & Shackleton, 2000; Sinthumule & Mzamani, 2019) or retained (Sinthumule & Mashau, 2019) because of the socio-economic benefits to local livelihood (Shackleton, 2004). The benefits include traditional medicine, shade, fodder, and traditional beer. Hence, cutting down (harvesting) the *S. birrea* in rural communities of VBR is strictly taboo (Sinthumule & Mashau, 2019).

We expected a higher species diversity at an intermediate distance as predicted by the intermediate disturbance hypothesis; however, the present study found that species richness and diversity were the same at the intermediate and far distances. This could be due to comparably higher use of both distance levels for livestock grazing and browsing than at immediate distances (Makhubele *et al.*, 2022). The low-intensity disturbance that continues for a longer period may have a detrimental effect on species diversity even at intermediate distances (Chaundhury *et al.,* 2022). The intermediate and far distances are highly dominated by indigenous species such as *Syzygium cordatum* and *Pteleopsis myrtifolia*, respectively. PESs harvesting is prevalent in the Vhembe region and human disturbance intensity negatively influenced the species composition and vegetation structure in the landscape. This could lead to biodiversity loss, land degradation and loss of ecosystem services in TAL (entsi-Entchill *et al.,* 2022; Chaundhury *et al.,* 2022).

As mandated by the Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES), society must be well informed about the impacts, drivers and solutions of biodiversity loss, ecosystem service loss and land degradation (Kay *et al.,* 2019). However, it is more achievable with a clear connection with indigenous knowledge (IK) because local people possess detailed knowledge about the landscapes, species diversity and climate conditions (Haeggman *et al.,* 2020). The integration of IPBES mandates and IK in TAL will strengthen and promote conservation, sustainable use of biodiversity, and sustainable human-wellbeing and development (Kay *et al.,* 2019).

6.4.2 Carbon stocks in a traditional agroforestry landscape

Carbon storage is primarily influenced by tree species composition and vegetation structure (Bentsi-Enchill *et al.,* 2022). Tree species attributes such as age, height and diameter determine the carbon storage potential (Dangai *et al.*, 2021; Bentsi-Enchill *et al.*, 2022). The analysis of variance exhibited that the tree density significantly increased from the immediate distance to the far distance. As predicted by the OFT that translates to a massive anthropogenic disturbance at the immediate distance and replacement by economically important tree species, the tree density is expected to be low at a proximate distance. The low-density vegetation at an immediate distance may be due to continuous disturbances in proximate areas. The higher disturbances due to the extraction of PESs have an impact on the vegetation population (Chaunhury *et al.*, 2022). It may also affect the regeneration of the trees. In this study, individual trees at an immediate distance had a high basal area which decreased as the distance to the forest increased. However, the stand density at the immediate distance was lower than the intermediate and far distances (Figure 6.1 and 6.2). A higher AGB and carbon stocks are expected in forest vegetation that has higher species density, basal area, richness, and diversity (Jaman *et al.,* 2020; Rahman *et al.,* 2021; Semere *et al.,* 2022). However, the present study exhibited that the vegetation at all distance regimes stored the same carbon stocks. This was mostly due to a trade-off between a few trees with large diameters at immediate distances (Figure 6.2) and numerous trees with smaller diameters at intermediate and far distances (Figure 6.1).

Studies around the world asserted that large trees contribute approximately 50% of AGB and carbon in the landscape (Mir *et al.,* 2021; Chaundhury *et al.,* 2022). The presence of tree species characterised by a large girth hence accounts for a massive share of the AGB and carbon of the landscape (Hussein, 2022). The present findings demonstrate that in traditional agroforestry, besides species composition, the AGB and carbon stocks are mainly determined by the girth distribution of individual trees, which is like the situation in forest ecosystems (Mir *et al.,* 2021). This study revealed that, despite the low species richness and diversity at the immediate distance, the vegetation was dominated by exotic and protected species which grow into large diameter classes and are thus notably contributing to carbon storage. This means that increased species richness and diversity along with maintaining tree girth in proximate areas in TAL all contribute to sequestering of more carbon.

It has been reported that the majority of VBR people are poor and unemployed living in rural areas (Makhubele *et al.*, 2022). Therefore, the development of carbon markets has the potential to improve local people's lives and mitigate climate change (Neya *et al.*, 2020; Chirwa, 2015). Carbon revenue could be an important incentive for restoring degraded landscapes, mitigating climate change, and adopting sustainable management of TAL (Walden *et al.*, 2020). Kay *et al.* (2019) found that an increase in the value of stored carbon increased the economic performance of agroforestry. Moreover, an average of 80$ and 120$ carbon price by 2030 would be adequate to limit global warming to 1.5 and 5ºC (Nyberg *et al.*, 2020). This could help many countries including South Africa to achieve the Paris Agreement goal to keep global warming below 2ºC by the end of 2030. In addition, carbon revenue has a great potential to increase the profit of agroforestry by 5 to 70% depending on the carbon sequestration rate (Nyberg *et al.*, 2020). This opportunity for carbon revenue would encourage the conservation, planting of trees and sustainable management of TAL.

6.4.3 Determinants of carbon stocks in a traditional agroforestry landscape

Given the rise of climate change effects worldwide, understanding the determinants of carbon stocks in the traditional agroforestry landscape is critical for carbon sequestration and sustainable management of the landscape. Many studies have focused on the effects of species richness and diversity on carbon stock storage (e.g., Dangai *et al.*, 2021; Jaman *et al.*, 2020). However, information regarding how ecological determinants influence carbon stock storage in the traditional agroforest landscapes in VBR is scarce. This study assessed how and whether the ecological determinants differ across the distance levels of the TALs. The study found that carbon stocks in traditional agroforestry landscapes were correlated to several ecological determinants. However, against the expectation of this study, distance did not have a significant correlation with carbon stock at TAL. Instead, carbon stocks were positively correlated to tree density. In line with other studies, carbon stocks increased with increasing density (Dellasala *et al.*, 2022). The carbon stocks and density were very strongly correlated; thus, the density is a good indicator of carbon sequestration in TAL. Similar findings were reported in Ethiopia, where the carbon stocks were shown to be strongly influenced by tree density (Negash & Starr, 2015; Betemariyam *et al.*, 2020). Although there was no difference detected in carbon socks along distance levels, the lower tree density in the immediate distance would have a negative effect in the future. The recent study by Makhubele *et al.* (2022) found that immediate distance in the TAL of VBR is subjected to high anthropogenic disturbance due to PES harvesting and reduced tree density. Previous studies found that anthropogenic disturbance has a negative influence on tree carbon stocks (McNicol *et al.,* 2018; Saimun *et al.,* 2018).

Studies conducted in Cameroonian agroforestry systems found that elevation had a great effect on carbon stocks (Phillips *et al.,* 2019). In India's agroforestry, above- and below-ground biomass increased with increasing elevation (Yadav *et al.,* 2019). The negative correlation of elevation on carbon stocks in TAL implies that a decrease in elevation decreases the carbon stocks in TAL. Higher elevation favours the higher biomass for accumulation of carbon stocks (Dellasala *et al.,* 2022). Hgh elevation, therefore, limits accessibility and shields forest vegetation against human disturbances (Phillips *et al.,* 2019). However, exotic species in higher basal areas balanced the carbon stocks. In agreement with previous studies, elevation and slope were found to be positively correlated with tree carbon as they influence the tree species composition (Wondimu *et al.*, 2021; Saimun *et al.*, 2018). The amount of carbon stocks in TAL depends on the structure and function of the landscape, which is mainly determined by ecological determinants (Dellasala *et al.,* 2022).

6.4.4 Conclusion and implications for conservation, and climate change

The fact that the carbon stock per ha remains the same in all distance levels implies that carbon sequestration alone cannot be used as a guiding criterion for setting conservation priority areas. Instead, the prevalence of the higher species diversity in the intermediate and far distance levels than intensively managed immediate distance levels, while having the same carbon stock, shows that the agroforestry landscape may remain stable and productive even under recurrent minimal or intermediate disturbance. Hence, its contribution to the species diversity conservation and mitigation of climate change may also be considered sustainable. Moreover, it can provide a multitude of ecosystem services that are crucial for the sustainability of local livelihood. The present study, therefore, asserts the need for sustainable management practices in the traditional agroforestry landscape of VBR, which have a greater potential in contributing to climate change mitigations through sequestering atmospheric CO_2 and contributing to improving the livelihood of the local communities (alleviating poverty). Management that promotes tree species richness should be prioritized and focus on the multipurpose tree species. The results of our study show that the traditional agroforestry landscape has a high potential to mitigate climate change. Policies that promote agroforestry as an intervention in the adaptation and mitigation to the impact of climate change should be implemented.

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Chapter 7

Local people perception of conservation of tree species diversity in a traditional agroforestry landscape in South Africa: A case of the Vhembe Biosphere Reserve.

Abstract

Tree species richness is a critical element to support biodiversity and socio-economic livelihoods in traditional agroforestry landscapes. Tree species richness is directly linked to the use of provisioning ecosystem services, and to management practices in traditional agroforestry landscapes. The study aimed to investigate the conservation strategies on tree species richness in traditional agroforestry landscapes. The study was conducted in Damani, Thenzheni, Tshiombo and Tshipako villages located in Thulamela Municipality of the Vhembe Biosphere Reserve, South Africa. The data were collected using a mixed method approach combining a structured questionnaire and focus group discussion. The findings revealed that local people deliberately conserve native tree species and manage the TALs using indigenous knowledge. However, the participants also acknowledged and highlighted the lack of awareness of conservation policies; others highlighted the lack of knowledge of planting native trees in the landscape. This study found that the local people have limited scientific knowledge and conservation strategy and practices targeting the enhancement of tree species richness in the traditional agroforestry landscape. The study, therefore, advocates for the establishment of a conservation strategic framework for restoring tree species richness by integrating traditional knowledge and scientific tools in traditional agroforestry landscapes.

Keywords: Indigenous knowledge, traditional agroforestry, traditional rules, conservation, tree species richness, provisioning ecosystem services

7.1 Introduction

Many people in the Limpopo Province in South Africa depend on forest ecosystems for their daily livelihoods (Rasethe *et al.,* 2013; Scheiter *et al.,* 2018). This close dependency on the forest ecosystem is largely influenced by socio-economic and cultural factors (Rasethe *et al.,* 2013). The Vhembe Biosphere Reserve (VBR) is one of the tropical climatic zones in the Limpopo Province and is known for its few remaining forest patches and its richness of floristic diversity (Turpie *et al.*, 2017). A larger portion of the population in the biosphere lives in rural areas (Scheiter *et al.*, 2018) and sustain their livelihoods by relying on provisioning ecosystem services (PES) such as harvesting of natural resources for subsistence or commercial purposes (Makhado *et al.*, 2012). The forest ecosystem itself is an epicentre of ecosystem services (ES) provision and species biodiversity (Santos *et al.,* 2019), nevertheless, the forest ecosystem alone within human-dominated landscapes is not adequate to sustain biodiversity and ES provision simultaneously (Santos *et al.*, 2019). Multifunctional landscapes that incorporate production and biodiversity conservation objectives especially those that have shaped the rural landscape over the long term can be defined as Traditional Agroforestry Landscapes (TAL), such areas therefore, have become increasingly important in landscapes dominated by human activity (Santos *et al.*, 2019; Araia *et al.,* 2020).

Traditional Agroforestry Landscapes in VBR provide multiple services that are crucial for the sustenance and maintenance of livelihood to communities. These include the provision of food, medicines, fuels, handcrafts and building materials (Palacios Bucheli *et al.,* 2017; Makhubele *et al.,* 2022). However, the sustainability of PESs relies on the level of biodiversity retained in multifunctional agroforestry landscapes. In addition, supporting and regulating services are important in all associated ecosystems, such as protection (e.g., protection of soil and water) and landscape productivity (e.g., species biodiversity) in associated forest ecosystems within the region (Viswanath *et al.*, 2018; Plieninger *et al.,* 2020). Moreover, TALs provide almost similar ecosystem services as the forest such as provisioning of non-timber forest products, regulating climate, supporting nutrients cycling and cultural services (Sheppard *et al.*, 2020a). Thus, the biodiversity in the TALs is fundamental to the livelihoods of the indigenous community (Palacios Bucheli *et al.,* 2017). Therefore, the protection and conservation of species biodiversity within these systems are indispensable for the sustenance of biodiversity and rural welfare (Pinard *et al.*, 2014).

Traditional agroforestry landscape is a historic landscape management practice that deliberately integrates multipurpose trees, shrubs, livestock, crops, and horticulture crops in a single land management unit (Rendon-Sandoval *et al.,* 2020; Chavan *et al.,* 2021). The benefits of TALs are well documented (Viswanath *et al.,* 2018; Sheppard *et al.,* 2020a), yet from a research and development point of view, traditional agroforestry in South Africa is seldomly, recognised and promoted, nor applied. Little effort has been made in the study and promotion of traditional agroforestry in South Africa. In general, agroforestry information and research in South Africa is limited and fragmented, in terms of functioning and dynamics (DAFF, 2017; Ayisi *et al.*, 2018).

South Africa's agroforestry strategic framework primarily focuses on upscaling and promoting modern agroforestry systems rather than acknowledging and upholding traditional agroforestry practices (Ayisi *et al.,* 2018). Nonetheless, the framework emphasised support for rural agroforestry systems and emphasised the identification of indigenous tree species that can further be developed for integration in agroforestry applications (DAFF, 2017). The potential of agroforestry to improve people's livelihoods, mitigate climate change and provide resilience to the environment has elicited world adoption (Viswanath *et al.*, 2018). Accounting for the benefits delivered by agroforestry systems, such as those reviewed by Sheppard *et al.* (2020a) alongside South Africa's agroforestry strategic framework (DAFF, 2017), calls for the need to clearly identify potential agroforestry interventions for testing and promotion in South Africa.

In developing and least developed countries such as those found in southern Africa, approximately 20% of indigenous communities derive livelihoods and basic needs from trees and forests (Sheppard *et al.*, 2020b). Billions of people around the world live within or in proximity to forests and depend on natural resources for survival (Sheppard *et al.,* 2020b), agroforestry systems can supplement that necessity. High dependence on natural resources affects both TALs and forests (Ayisi *et al.,* 2018). Similar to the global trends, the unprecedented rise of poverty and unemployment in rural communities of South Africa has undoubtedly enabled a huge reliance on natural resources for survival and massive exploitation of PESs.

Millions of South Africans in areas of limited economic activities harvest fuelwood, wild food, medicines, and other forest resources for both commercial and subsistence purposes (Turpie *et al.,* 2017; Scheiter *et al.,* 2018; Musakwa *et al.,* 2020). Approximately 47 billion rand (2.8 billion USD) per year of provisioning ecosystem resources are harvested for household consumption by the rural inhabitants of South Africa (Turpie *et al.*, 2017). Furthermore, a huge dependency on forest resources by rural communities in South Africa is exerting more pressure on TALs, indigenous forests and woodlands (FAO, 2015). However, the extent of resources used and the impact thereof on biodiversity within TALs are not well documented. The main objective of the study was to investigate the conservation strategies on tree species richness in traditional agroforestry landscapes. The leading questions were, (i) Do local institutions effectively manage and conserve tree species diversity in TAL? (ii) What are the tree management practices in the traditional agroforestry landscape? (iii) What are the conservation strategies?

7.2 Materials and Methods

7.2.1 Data collection

7.2.1.1 Questionnaire

Data were collected using the procedure discussed in Chapter 2 (Sections 2.4.1). In the context of this study, the questionnaire explored the respondents' conservation practices, management, and institutions responsible for conservation in the TAL.

7.2.1.2 Focus Group Discussion

Focus Group Discussions (FGDs) were conducted to obtain more data that would help to understand the community members' perceptions concerning tree species richness and conservation strategies. This allowed participants to provide a wide range of information. The FGD participants were a combined group of community leaders and community members. Four FGDs were conducted with four communities, Damani (n = 15), Tshipako (n = 23), Thenzheni (n = 16) and Tshiombo (n = 13). Each FGD session lasted for about 1 hour. The leading questions were structured as follows: i) what are the tree species used for fodder, fuelwood, traditional medicine, and food? ii) what are the conservation strategies for traditional agroforestry and other tree-based systems? Each participant was given an opportunity to discuss and raise questions under the facilitation of the researcher. The discussions from the FGDs were recorded for content analysis.

7.2.2 Household survey analysis

Data analysis was conducted using the procedure discussed in Chapter 3 (Sections 3.2.2). In the context of this study, after testing data normality, the Likert scale data were analysed using the Chi-square inferential statistics (Boone & Boone, 2012; Zhang *et al.*, 2019).

7.2.3 Focus group discussion.

To understand local people and community leadership perceptions, use and management of the tree species richness in TALs, a comprehensive qualitative analysis of focus group discussion data was performed. Focus group discussion participants and informants' consensus on utility categories were analysed using fidelity level (da Silva *et al.*, 2014) and calculated as follows in equation 7.2:

$$FL = \left(\frac{I_p}{I_u}\right) x\ 100\% \qquad (7.1)$$

Where, FL= fidelity level, Ip = number of participants that cited the principal use of the species and Iu = Total number of participants that cited the species for any purpose.

Content analysis was performed for themes or subjects discussed with participants (Roller, 2019). Categorising of themes or subjects was used through manifest analysis (Bengtsson, 2016). The variability and reliability were assessed through crossing evaluation of the participant’s responses.

7.3 Results

7.3.1 Landscape management

The results showed that the communities significantly ($p < 0.001$) agreed that they are responsible for managing (86%) and deliberately conserving trees (81%) in the traditional agroforestry landscape (Table 7.1). Table 7.2 depicted that the leading institutions managing the TALs very effectively are Tribal Council (community committee) (45%), individual households (32%) and community (28%). The government and non-profit organisations are not effective. In addition, the communities are strongly willing (70%) to support and participate in conservation initiatives in the TALs (Table 7.1).

Table 7.1: Landscape management perspectives.

Management	Responses	Percentage (%) (n=882)	Chi-square
Q1: Community managing landscape	Yes	86.1	$\chi^2 = 898.844$
	No	13.9	$d = 2$
			$p = 0.000$
Q2: Deliberate conservation of trees	Yes	80.8	$\chi^2 = 460.578$
			$d = 1$
	No	19.2	$p = 0.000$
Q3: Support conservation initiatives	Strongly willing	70.4	$\chi^2 = 1013.927$
	Willing	18.7	$d = 3$
	Undecided	7.4	$p = 0.000$
	Not at all	3.5	

Table 7.2: Trees species conservation institutions effectiveness.

Landscape managing institutions	Responses	Proportion (%) (n=882)	Chi-square
Government	Not effective	50.6	$\chi^2 = 132.272$
	Effective	29.9	$d = 2$
	Very effective	19.5	$p = 0.000$
Community	Not effective	19.7	$\chi^2 = 152.816$
	Effective	52.4	$d = 2$
	Very effective	27.9	$p = 0.000$
Non-profit organization	Not effective	57.7	$\chi^2 = 301.339$
	Effective	32.0	$d = 2$
	Very effective	10.1	$p = 0.000$
Tribal Council	Not effective	14.4	$\chi^2 = 145.150$
	Effective	40.5	$d = 2$
	Very effective	45.1	$p = 0.000$
Household	Not effective	21.5	$\chi^2 = 83.226$
	Effective	46.5	$d = 2$
	Very effective	31.9	$p = 0.000$

7.3.2 Landscape management practices

Table 7.3 shows that communities were significantly ($p < 0.001$) effective in sustainable harvesting of PESs, reporting of illegal harvesting of PESs and conserving indigenous trees. The communities practice sustainable harvesting of PES (75%), reporting illegal harvesting (58%) and conserving indigenous trees (63%) at an immediate distance in TALs.

Table 7.3: Landscape management practices.

Practices	Distance	Percentage (%) (n=882)	Chi-square
Sustainable harvesting of PESs	Immediate distance	74.7	$\chi^2 = 957.102$
	Intermediate distance	9.2	$d = 2$
	Far distance	3.2	$p = 0.000$
Reporting illegal harvesting	Immediate distance	58.4	$\chi^2 = 414.586$
	Intermediate distance	20.3	$d = 2$
	Far distance	8.4	$p = 0.000$
Conserving indigenous trees	Immediate distance	62.7	$\chi^2 = 535.227$
	Intermediate distance	17.7	$d = 2$
	Far distance	6.7	$p = 0.000$

7.3.3 Tree species use and conservation strategies.

In FGDs, the participants listed the important tree species based on the utility categories such as fuelwood, fodder, wild food, and traditional medicine. Based on species nomination within FGDs, the most important tree species in each category were evaluated using the fidelity level formula. The overall number of citations of the most important tree species varied between 4%-62% in the use categories (Figure 7.6). The indigenous species *Englerophytum magalismontanum* was the most reported tree species (62%) for wild fruits in the study sites, while also highly reported for fuelwood utilisation (43%). *Pteleopsis myrtifolia* was the most described (57%) tree species for fuelwood, while *Combretum molle* was the most cited (36%) tree species for traditional medicine. *Albizia adianthifolia* was most frequently given (12%) as a species for fodder. From 29 tree species, eight tree species were cited as multiple purpose species such as *Englerophytum magalismontanum* and *Parinari curatellifolia* both appearing in wild food and fuelwood utility categories. *Peltophorum africanum* Sond. and *Combretum molle* were suggested in both traditional medicine and fuelwood utility categories. *Artabotrys brachypetalus* Benth. and *Annona senegalensis* in both wild food and traditional medicine utility categories, *Diplorhynchus condylocarpon* in both fodder and wild food utility categories and *Albizia adianthifolia* recorded in both fuelwood and fodder utility categories.

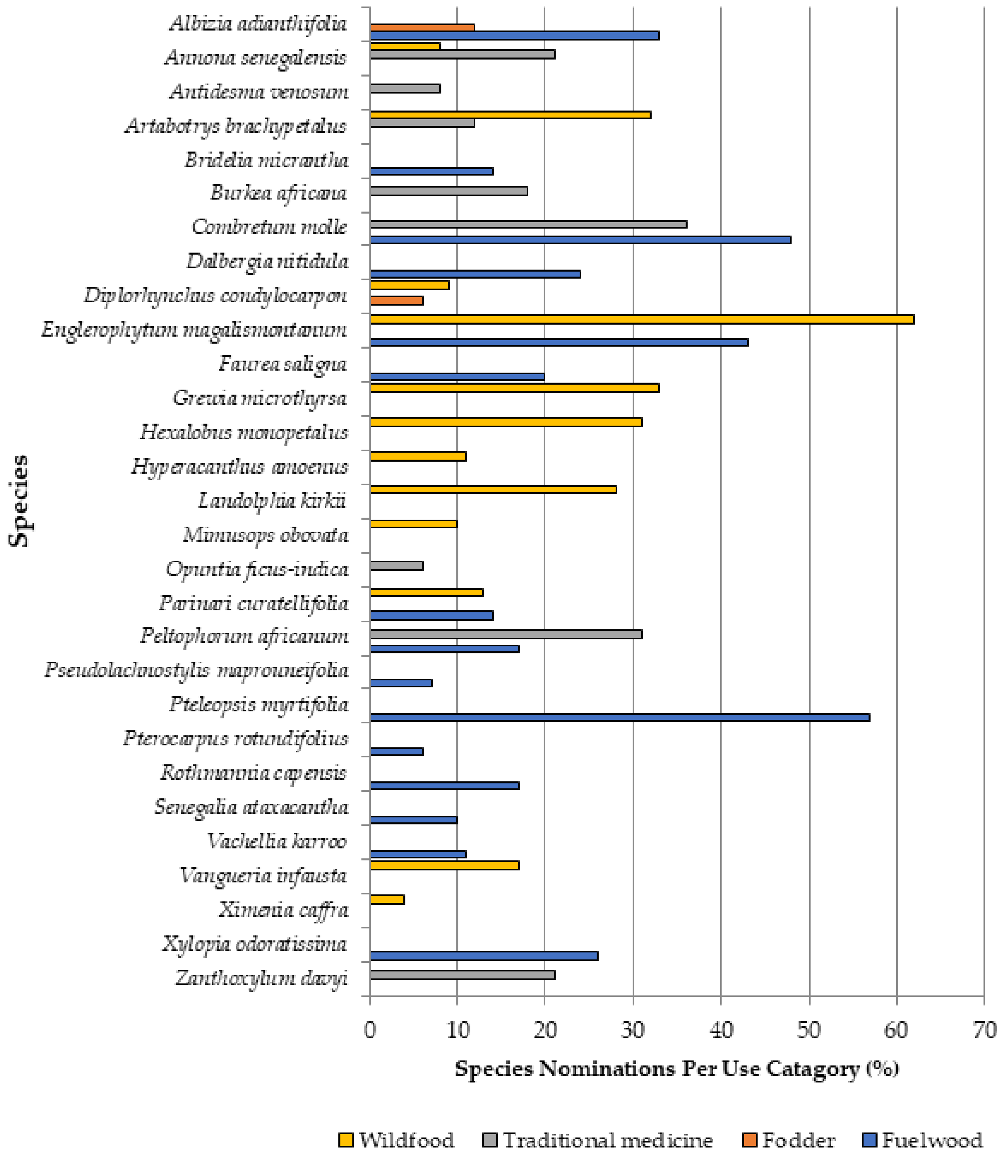

Figure 7.6: Nominated important tree species per defined utility category as cited by participants in the focus group discussions.

Overall, in the FGDs sessions, three themes (National conservation policy, community conservation policy, and conservation practices) were selected for an in-depth understanding of the conservation strategies.

Theme 1: National conservation policy

In all study sites, the participants are not aware of conservation policies. However, they knew that the government protects natural forests and trees. From a participant at Damani village; "*A few decades ago, there were forest guards in our communities employed by the government to* *protect forests and trees. But they are no longer there, and our forests are overexploited*". The challenge of lacking knowledge of conservation policies was further emphasised by the chief of one of the communities. Chief: "*We just hear that are some of the trees which are protected by government policies, but we don't know these trees*"

Theme 2: Community conservation policy

In all the study sites, the Chiefs or community leadership reported that it is their responsibility to protect the forest trees within their jurisdiction. Though there is no documented policy or rules by the traditional leaders, the message is conveyed through word of mouth during the communities' gatherings. From an FGDs participant, "*Our leadership always reminds us to protect and report a person who fells live trees*" Furthermore; "*People from outside our communities are not allowed to harvest or collect forest re-sources in our forests*". The leadership said, "*We have people who harvest fuelwood for selling, we always advised them not to harvest in bulk and they should frequently change harvesting sites to allow regeneration*".

Theme 3: Conservation practices

In all the study sites there is no formal project implementing conservation practices. The participants indicated; "*We are protecting the existing trees on our homesteads and communal farms, and plant non-native trees such Mangifera indica".* Leadership: *"We manage indigenous trees in our farms and homesteads by doing minimal harvesting instead of felling the whole tree*". Furthermore, "*We are interested in planting indigenous trees in our communal land. However, we do not know how we can plant indigenous trees*". Trees within the community are highly managed by the community members because of the benefits provided by the trees. Participants: "*Trees help us during natural disasters floods, storms and drought*".

7.4 Discussion

7.4.1 Traditional agroforestry landscape management and practices

Management of the traditional agroforestry landscape depends on indigenous knowledge and cultural practices of the local people (Araia & Chirwa, 2019; Wana et al., 2022). The local indigenous knowledge of managing traditional agroforestry landscapes evolves over time (Wana et al., 2022). Thus, constant reviewing and understanding of the complex management and practices of traditional agroforestry landscapes is a prerequisite for sustainable management. In order to scale up traditional agroforestry landscape practices and management, understanding the indigenous knowledge of management and practices is very critical (Madalcho & Tafera, 2016). The current study found the following traditional agroforestry landscape management and practices: deliberate conservation of indigenous trees, reporting of illegal harvesting and sustainable harvesting of PESs. The results showed that the native tree species are deliberately conserved at an immediate distance by local people. In line with Tadesse et al. (2021), the TALs are characterised by traditional management and native tree species diversity being deliberately conserved by local people. It is very rare that local people deliberately conserve trees far away from their immediate distance. In addition, tree species conservation in VBR seems to be the culture of the local people (Araia & Chirwa, 2019). Hence, recognising the indigenous knowledge and culture of TALs management and practices could be a prudent approach to adapting to changing social, economic and climate conditions (McNeely & Schroth, 2006). The results showed that local people practice sustainable harvesting of PESs and are effective in conserving tree species at an immediate distance. However, they seemed to have little interest in conserving tree species far away from the immediate distance. These results were supported by FGD results, where participants indicated that they practice brunch harvesting and pruning for fuelwood in the immediate distance. Pollarding, pruning, and brunch harvesting are the common sustainable harvesting and management practices of native trees in TALs (Maldacho & Tefera, 2016). However, some of the FGD participants confirmed and were concerned about the escalating incidents of the unsustainable harvesting of trees in TALs, "*Traditional medicine harvesters are uprooting trees (whole tree or shrub) and cutting down the whole tree for fuelwood and poles for commercial markets at intermediate and far distances*".

Overexploitation of PESs with unsustainable management leads to the loss of tree species diversity and landscape productivity (Tadesse et al., 2021). Recent literature shows biodiversity loss due to the unprecedented rise of the unsustainable harvesting of PESs (e.g., Yamashina et al., 2021). The results further showed that government institutions are not effective in conserving native tree species at an immediate distance while the Tribal councils (community committees) are very effective. In VBR, cultural rules, traditional rules and norms play a significant role in conserving tree species diversity (Araia & Chirwa, 2019). However, these traditional rules and norms seem insufficient in conserving biodiversity without the support of national policies of the country and proper implementation of the rules and policies. Traditional agroforestry land use systems have been overlooked in the national agroforestry strategic framework. Clear traditional agroforestry policies and frameworks are very important in supporting traditional rules and norms (McNeely & Schroth, 2006).

7.4.2 Tree species use and conservation strategies.

This study found that the TAL of VBR host up to 29 of the most appreciated tree species of which 15 tree species are used for fuelwood, 14 tree species for wild food, seven tree species for traditional medicine and two tree species for fodder. On the contrary, studies conducted in traditional agroforestry systems in India found that most tree species are used for fuelwood followed by traditional medicine uses (Mylliemngap, 2021). Unsurprisingly, most of the tree species in TALs have high value to the local people (Ayisi *et al.,* 2018), as determined by human needs such as food, energy, and shelter. Concerning trees on farms, the non-native species contributed the greatest number of tree species, which were represented by two species *Mangifera indica* and *Persea americana.* These findings coincide with the results of the study conducted by Singh *et al.* (2021), who reported that farmers in India plant *Mangifera indica* along the farm boundaries or within the farms. A study conducted by Borsari (2022) reported that *Mangifera indica* is one of the iconic tree species in agroforestry practices such as silvopasture and trees on farms. Both communal land and traditionally protected area were dominated by several indigenous tree species such as *Pteleopsis myrtifolia*, *Albizia adianthifolia*, *Tabernaemontana elegans*, *Parinari curatellifolia*, *Englerophytum magalismontanum*, *Bridelia micrantha*, *Pseudolachnostylis maprouneifolia* and *Combretum molle*.

This study found that the local people have no clear and sufficient conservation strategy and conservation practices to enhance the tree species richness for sustainable functionality of the traditional agroforestry landscape. The study conducted by Duriaux-Chavarria *et al.* (2021) highlighted that in Niger and Ethiopia, rural communities and farmers restored tree species richness through the planting of native tree species and subsequently, improved tree species richness and ecosystem services. Considerable, restoration practices such as planting native tree species in traditional agroforestry land reduce disservices by human beings.

7.5 Implications for conservation

The findings revealed that local people deliberately conserve native tree species and manage the TALs using indigenous knowledge. The participants acknowledged and highlighted the lack of awareness of conservation policies; others highlighted the lack of scientific knowledge of planting native trees in the landscape. This may have an overall negative impact on rural forest tree conservation and enhancement of tree species richness in traditional agroforestry landscapes. Therefore, enhancing sustainable management and practices is paramount in the traditional agroforestry landscapes of VBR. The Climate Smart Agriculture Strategic Framework for Agriculture, Forestry and Fisheries in South Africa developed actions to increase the forest cover or tree species in agroforestry systems by identifying agroforestry species for different agro-ecological zones and supporting farmers to increase tree cover on their land (DAFF, 2017). However, practically nothing has been achieved as local people are still only depending on the existing tree species. An additional constraint is that the developed Agroforestry Strategic Framework largely promotes modern agroforestry systems over traditional agroforestry. Interdepartmental collaboration in enhancing traditional agroforestry tree species diversity would play a key role in conserving and improving the local people's livelihoods. Moreover, implementing the actions and strategic frameworks would fast-track the mitigation of biodiversity loss in South Africa. Government institutions should scale up conservation efforts in traditional agroforestry landscapes to supplement the effective Tribal Councils and community efforts.

7.6 Conclusions

The results of this study confirmed that local people are deliberately conserving native tree species within traditional agroforestry landscapes and conserving existing native tree species governed by local and traditional rules. Tribal councils and communities are more effective in conserving tree species in TALs than government institutions. Local people traditionally conserve tree species in TALs through sustainable harvesting by reporting illegal harvesting and deliberately conserving existing tree species. However, they lack scientific knowledge of planting native trees and there is no clear legislative conservation framework. An inadequate legislative framework on conservation in rural communities has contributed to biodiversity loss and forest degradation. This study advocates for the adoption of native tree species planting and conservation in traditional agroforestry landscapes to enhance landscape productivity and functionality. There is, therefore, a need to establish a conservation strategic framework for restoring tree species richness targeting traditional agroforestry in the VBR region and beyond.

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Chapter 8: Overview

8. Introduction

There has been a good effort and progress to identify and arrest the drivers of biodiversity loss by international organisations, for instance, IPBES. Despite the efforts, reports show that biodiversity loss is increasing (e.g., Carmen *et al.,* 2015; IPBES, 2019; Helseth *et al.*, 2022). The effort to reduce biodiversity loss has been generally poor (IPBES, 2019). Due to insufficient effort, natural habitats and species abundance are precipitously declining (Johns *et al.*, 2022), and trends of species extinctions are alarming (IPBES, 2019). The drivers associated with forest biodiversity loss are increasing and negatively affecting ecosystem services (IPBES, 2019). Human beings are at the forefront of the major drivers of biodiversity loss and threats to the environment. The IPBES identified indigenous local knowledge (ILK) and indigenous people and local communities (IPLC) practices as relevant approaches for the sustainable use of natural resources (IPBES, 2019). The ILK provides a wide range of indicators of interaction between people and nature, indicators such as resource use and behaviour (IPBES, 2019). Human behaviour is the major cause of biodiversity loss and conservation challenges (Johns *et al.,* 2022). In human-dominated landscapes such as traditional agroforestry landscapes, protected areas of the few remaining intact forests alone are insufficient for biodiversity conservation (Haggar *et al.*, 2019; Santos *et al.*, 2019; Araia *et al.,* 2020). Therefore, managing the whole agroforestry landscape is crucial for biodiversity conservation and plays a complementary role in protected areas (Haggar *et al.,* 2019). However, recent studies reporting a decline in tree species diversity in agroforestry landscapes are not different from the other biodiversity hotspots (Mellisse *et al.,* 2018). The TALs face threats of over-exploitation, climate change, invasive species, biodiversity loss and structural disruption by human settlements expansion.

Ecosystem services from the traditional agroforestry landscapes have emerged as an important concept that substantiates and underpins conservation efforts (Bremer *et al.*, 2015). Traditional agroforestry is one of the most important ecosystems in terms of providing goods and services for human livelihood (Das *et al.,* 2022). The ecosystem services comprise four components provisioning, regulating, cultural and supporting services (Bakar *et al.,* 2022). Ecosystem services from TALs to human beings depend on both supply and demand of such services (Jiang *et al.,* 2021). However, ecosystem services are crucial for human survival and development (Jiang *et al.,* 2021). Ecosystem services provide direct and indirect benefits to human beings (Totino *et al.,* 2023). Due to the unprecedented rise in human population and consumption, the behaviour and the demand for ecosystem services have increased (Das *et al.,* 2022). The unprecedented rise in the world population signifies the high demand for provisioning ecosystem services, particularly by poor people in developing countries (Bakar *et al.,* 2022). In developing countries, provisioning ecosystem services determine the livelihood of the poor population (Bakar *et al.,* 2022). Due to people's high dependence on provisioning ecosystem services, the PESs are the most important ecosystem services for local people's livelihood in rural communities (Das *et al.,* 2022), however, not to neglect the role and interrelation of other services.

Anthropogenic disturbances (Araia *et al.,* 2019) and human behaviour (IPBES, 2019) are linked to the biodiversity of agroforestry ecosystems. Biodiversity is a major driver of ecosystem functioning and production (Brockerhofff *et al.,* 2017), including traditional agroforestry ecosystems. The provisioning ecosystem services commonly used are wild fruits and food, medicines, firewood, building material and livestock fodder in the VBR (Constant & Tshisikhawe, 2018; Araia & Chirwa, 2019). Distance acts as a predictor of the harvesting of provisioning ecosystem service with the frequency of harvesting declining significantly as the distance from communities to the forest increases (Mensah, 2016; Ramarumo & Maroyi, 2020). The PESs in the immediate distance (adjacent or surrounding communities) have been reported to be depleting and could disappear (Makhado *et al.,* 2012).

The presence of exotic tree species in traditional agroforestry landscapes is one of the human-induced impacts on the landscape (Herrera *et al.,* 2018). The occurrence of exotic tree species in the ecosystem alters the functioning, structure, and community assemblage, and affects the interactions of the native species (Lazzaro *et al.,* 2020), thus threatening landscape productivity (Herrera *et al.,* 2018). Exotic tree species are capable of developing morphologies and reproductive behaviour that enable the species to compete and adapt to new habitats (Qian & Ricklefs, 2006; Schnitzler *et al.,* 2007). Exotic species mostly occur at higher vegetative densities and exhibit other vegetation growth due to impenetrable structures (Schnitzler *et al.,* 2007). Local people plant useful exotic tree species mostly in their home gardens for economic gains without considering the ecological implications (Gemechu *et al.,* 2021). Then the question remains, how to balance exotic species and indigenous provisioning ecosystem services without compromising the sustainability and maintenance of biodiversity and ecosystem services? Exotic tree species provide a very critical benefit to the local people such as economic value (Nath *et al.,* 2016).

Generally, exotic species possess disturbance tolerance and fast growth rates attributes than some of native tree species (Nath *et al.,* 2016). Hence the exotic species may colonize the indigenouses tree species in a landscape. The increasing dominance of exotic tree species in traditional agroforestry has a negative impact on landscape biodiversity, and the dominance of exotic tree species transforms the heterogeneity of the landscape into homogeneity (Batistel *et al.,* 2020). Continuation of this trend would hinder the objective and targets of using traditional agroforestry landscapes as a strategy to reduce biodiversity loss. Exotic tree species affect the biodiversity of agroforestry and species conservation (Adjossou *et al.,* 2019). Besides being the responsibility of human practice, understanding the interaction and impacts of exotic tree species in TALs is very critical for biodiversity conservation and sustainable production of the landscape. The relationship between exotic species, anthropogenic drivers and ecological factors is still poorly understood (Herrera *et al.,* 2018).

The effects of climate change are projected to be more severe in the next decades, with climate change increasingly becoming a direct driver of changes in nature and human well-being (IPBES, 2019). Human beings will suffer the indirect and direct consequences of climate change (Manes *et al.,* 2022) and global warming in the near future. Climate change and global warming are escalating due to rising atmospheric carbon dioxide (CO_2) (Ghale *et al.,* 2022; Heryandi *et al.,* 2022; Sarkar & Das, 2022). Rising concerns about climate change and global warming have intensified efforts to reduce the CO_2 in the atmosphere and from emissions. Carbon sequestration has been recognised as a mechanism to reduce CO_2 in the atmosphere (Ghale *et al.,* 2022). Worldwide, forests and agroforestry are the leading strategies for reducing atmospheric carbon emissions through carbon sequestration (Soazafy *et al.,* 2021). Trees in the forest and agroforestry landscapes capture carbon and transform it into plant biomass (Sarkar & Das, 2022).

Agroforestry plant biomass and soils are terrestrial carbon pools and long-term carbon stores (Ghale *et al.,* 2022). Considering the significance of agroforestry in carbon sequestration, international organisations, or institutes such as IPCC and IPBES promote agroforestry as a holistic approach to mitigating carbon emissions. Traditional agroforestry has a greater potential than other land uses to store carbon while providing other essential services such as social, economic, cultural and environmental services (Nath *et al.,* 2022). It is evident from the literature that agroforestry has an immediate solution to challenges such as carbon emissions. Therefore, it was paramount to determine tree biomass and carbon accumulation to quantify the ability of trees in the traditional agroforestry landscapes (TALs) of the Vhembe Biosphere Reserve (VBR) to store carbon. This also quantifies to what extent the TALs could contribute to mitigating climate change. Thus, this study addressed the effects of forest proximity, and socio-ecological determinants on tree species composition, diversity, and carbon stocks in traditional agroforestry landscapes.

8.1 Addressing research objectives

This section provides a summary of each chapter's key findings (Chapters 3-7) and provides general concluding remarks on areas for future research. This research conducted five autonomous studies to address the main aim, specific objectives, and hypotheses. The following studies were conducted: Chapter 3 (The influence of forest proximity on harvesting and use of provisioning ecosystem services from tree species in traditional agroforestry landscapes); Chapter 4 (Tree species diversity and harvesting distance correlation in traditional agroforestry landscape); Chapter 5 (The effects of exotic tree species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes); Chapter 6 (Effects of socio-ecological determinants on carbon accumulation in traditional agroforestry), and Chapter 7 (Conservation of Tree Species Richness in a Traditional Agroforestry Landscape).

8.1.1 The influence of forest proximity on harvesting and use of provisioning ecosystem services from tree species in traditional agroforestry landscapes.

This study investigated the influence of forest proximity on harvesting and the use of provisioning ecosystem services from tree species in traditional agroforestry landscapes. The methodological approaches used in the study include the household questionnaire survey and focus group discussions to investigate the respondents' harvesting behaviour and uses of provisioning ecosystem services. This study used distance as an environmental predictor to understand the inextricable link between provisioning ecosystem services use, anthropogenic disturbances and harvesting intensity in TALs. A distance to the forest is defined as the distance from the community settlements to the proximate forest within the traditional agroforestry landscape. The distance measurements were done based on the established concentric circle (Figure 2.4) and informed by the guidance of local key informants (Sheil *et al.*, 2006). Findings show that local people harvest fuelwood, traditional medicine, and wild vegetables and fruits at an immediate distance while feeding livestock at an intermediate distance (Table 3.3). Forest proximity influence may be positive or negative, depending on the factors involved (Singh *et al.,* 2021). This study also found that although socio-ecological determinants influence consumption behaviour, the influence of specific socio-ecological determinants was not consistent across the different distance regimes from the forest resources. The fact that there is a preference to use and harvest provision ecosystem service from the nearest distance to the household, is a concerted effort to conserve and enhance the abundance of multipurpose tree species in homesteads and the immediate areas. This may alleviate use pressure on the relatively intact forest patches in the intermediate and far distance. At the same time, any conservation intervention should consider the local socio-ecological conditions that do influence the extent of provisioning ecosystem services at different distance regimes in Traditional Agroforestry Landscapes.

In Chapter 4, the study revealed that an immediate distance has poor species richness. These findings link with higher preferences for harvesting PESs at an immediate distance (Table 3.3). Supported by Chapter 5, the study revealed that there is poor regeneration of native tree species at an immediate distance (Figure 5.4). Concurrently, the findings of this series of studies imply that anthropogenic disturbances such as PESs harvesting resulted in the local elimination of some of the tree species at an immediate distance and few species survive due to their ability to adopt severe disturbances (Escobedo *et al.,* 2021). Elevation and accessibility vary systematically with distance from the edge of the community to the proximate forest. In Chapter 6, the study revealed that higher elevation plays a significant role in limiting access to the forest vegetation and shielding forest vegetation against anthropogenic disturbances (Philips *et al.,* 2019). However, this does not favour the immediate distance PESs in TALs, as Chapter 6 found that most of the communities are located at lower elevations in TALs. This also links well with the results in Table 3. 4, showing that local people harvest almost all the PESs at an immediate distance.

As a result, forest proximity will not be significant in reducing anthropogenic disturbances at an immediate distance as the immediate distance is more accessible and vulnerable to anthropogenic disturbances (Chapter 6). However, re-establishing biodiversity through tree planting would supplement the existing vegetation. Major factors more likely to contribute to and influence the re-establishment of biodiversity and conservation in TALs include socioeconomic factors (e.g., improving the living conditions) and cultural practice (Singh *et al.,* 2021). All these factors may interact and influence the response of a person in re-establishing and conserving biodiversity. However, other factors that may be included in local people's foraging behaviours not associated with tested factors are the desire for leisure, status, and accumulation of wealth. The higher competition in selling fuelwood in TALs was recorded in TALs (Figure 3.4). These activities contribute to the high pressure of foraging in TAL as everyone would desire a capital gain from these open-access resources. Changes in forager behaviour are unnegotiable in current situations.

A forager behavioural model that compels individuals to behave in ways beneficial to the biodiversity and the entire TALs community is crucial. It is conceivable to conserve resources for the benefit of the entire society. When categories of use were considered separately, it becomes clear that some of the species are more likely to be multipurpose species (Table 3. 5). For example, Munombelo (*E. magalismontanum)*, Muvhungo (*Landolphia kirkii*), Mufula (*S. birrea*), Muvhula (*P. curatellifolia*), Mugwiti (*C. molle*), Muungo (*M. indica*), Muelela (*A. adianthifolia*), Muvhulavhusiku (*X. odoratissima*), Muzwilu (*Vangueria esculenta*) and Muafukhada (*P. americana*). Soldati *et al.* (2016) argue that people validate the uses of common species and confirm the correlation of UV with the availability of resources. Due to the correlation between UV and the availability of resources (Soldati *et al.,* 2016), the availability encourages the optimal behaviour of the resources harvesters and results in the overexploitation of the resources (Soldati *et al.*, 2016). The UV of tree species increases the probability of resources to be collected in random extraction events and leads to optimal behaviour (Soldati *et al.*, 2016), and higher disturbances. In this sense, it is critical to incorporate the most important (multipurpose trees) into the knowledge production process. This may provide acquisition in sustainable extraction of PESs (Soldati *et al.,* 2016), thereby ensuring that individual trees and forest biodiversity are conserved. It is plausible in the context of biodiversity loss, that the likelihood of the collection of the most important (High UVs) tree species will result in the elimination of some of the in the landscape. Findings in Chapter 3, confirm the optimal behaviour of local people in TALs (Table 3.3). The optimal behaviour expanded by the PESs harvesting activities affected the landscape tree species diversity as low tree species richness at an immediate distance was reported in Chapter 4.

8.1.2 Tree species diversity and harvesting distance correlation in traditional agroforestry landscape: A case of Vhembe Biosphere Reserve in South Africa.

This study investigated the effects of distance on tree species diversity in traditional agroforestry and its contribution to tree species conservation. The methodological approach used in the study entailed vegetation inventory, measuring tree species richness and diversity in different distance levels in TALs. The main aim was to understand the inextricable link between human behaviour and tree species diversity in TALs, tree species diversity was assessed using the environmental indicator (distance) as the predicting factor. As predicted by the OFT in Chapter 3, the study hypothesised that there was an increase in tree species richness with increasing distance to the proximate forest. The findings revealed that there were significant differences in tree species richness between the distance levels (Table 4.4), with the intermediate and far distances being the most similar. The intermediate and far distances shared very similar species assemblage (Figure 4.5). The results agree with the tested hypothesis of the intermediate disturbance hypothesis, implying the negative effects of a higher disturbance to tree species diversity at an immediate distance. In highly disturbed areas, disturbance eliminates local species and only disturbance-tolerant species remain (Escobedo *et al.,* 2021).

The anthropogenic disturbances were very high at an immediate distance because most of the PESs are harvested at an immediate distance in TALs (Table 3. 3). Poor species richness was reported in an immediate distance because it was a highly disturbed area and affected the regeneration of native trees (Chapter 5). The TALs in some parts were highly fragmented, heavily exploited for fuel wood, and in some cases are young primary forests emerging. Consequently, they may have already lost some of the important species and the remaining species, are species that can tolerate disturbance. Nevertheless, despite being disturbed, the immediate distance in the TALs still maintained the native tree species (e.g. *Pteleopsis myrtifolia*, *Tabernaemontana elegans*, *Combretum molle*, *Albizia adianthifolia, Parinari curatellifolia,* and *Englerophytum magalismontanum*) (Figure 4.8). These species form part of 41% of native tree species recorded in the immediate distance (Chapter 4). The question then remains, whether these species were remnant individuals from the original forest or were introduced. However, other studies reported that traditional agroforestry harbours a high number of indigenous tree species (e.g., Singh *et al.,* 2021). While species may be shared between agroforestry systems and forests, their relative abundance may be different as indicated by the SIMPER similarities index (Tables 4.2 and 4.8). In particular, the lower proportion of shared trees at an immediate distance was due to the presence of disturbance and planted non-native tree species. Findings in Chapter 5 revealed that the immediate distance is dominated by non-native tree species (Figure 5.5 and Table 5.2). This was similar to the findings of Haggar *et al.* (2019) showing that almost 55% of the individual trees were non-native tree species in agroforestry landscapes. Overall, the top leading driving factors of tree species richness in the TALs are PESs harvesting and distance (Table 4.9). The results of the Chao 1 species richness index (Table 4.1) showed that tree species richness increases as the distance to the forest increases, while the results of PESs extractions (Table 3.3) show that PESs extraction decreases as the distance to the forest increases. Concurrently, both findings explain the reason for distance and PESs harvesting being the major drivers of species richness in the TALs. Amongst other drivers, distance from the forest to the community influences tree species diversity (Singh *et al.*, 2021). A study by Singh *et al.* (2021) found that forest resources (e.g., fuelwood) were harvested in agroforestry systems to avoid the long distance of travelling to the forest. Moreover, PESs harvesting is reported to be the driving factor for biodiversity loss in TALs (Yamashina *et al.*, 2021). These factors lead to an integration of human behaviour to achieve biodiversity conservation in TALs. Distance is an environmental factor that could not be changed or controlled. However, human behaviour can be changed. The solutions to biodiversity loss and greater efforts in conservation reside within changing human behaviour (Johns *et al.*, 2022). The remaining key part of reducing biodiversity loss is initiating changes in human behaviour (Carmen *et al.*, 2015). The effectiveness of TALs to support forest biodiversity conservation appeared to rest on the degree of behavioural change of PESs harvesters.

8.1.3 The effects of exotic tree species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes of Vhembe Biosphere Reserve, South Africa.

This study investigated the effect of exotic tree species and socio-ecological factors on endemic species diversity. The methodological approach used in the study entailed vegetation inventory, measuring endemic and exotic tree species richness and diversity in different distance levels in TALs. The results showed that the immediate distance was dominated by exotic tree species while the far distance was dominated by the endemic species (Figure 5.5). The occurrence of exotic species decreased as the distance to the forest increased while the endemic species increased as the distance to the forest increased. These results correlate with the findings of the PESs harvesting distance levels in Chapter 3. Previous research showed the impacts of anthropogenic disturbances in reducing the native species diversity in the landscapes

(Byun *et al.,* 2018). Also, Chapter 4 showed the impact of PESs magnitude on the native tree species richness. However, some studies showed that anthropogenic disturbances favour the occurrences and establishment of exotic tree species (e.g., Batistel *et al.,* 2020). Due to exotic tree species' plasticity, exotic tree species are tolerant to common disturbances such as anthropogenic disturbance (Adjossou *et al.,* 2019). This explains the higher dominance of exotic tree species at the immediate distance and the poor diversity of endemic species. Furthermore, exotic tree species are mostly useful for economic value (Gemechu *et al.,* 2021) than subsistence. Therefore, they are not frequently harvested like the native species and thus increase the growth and dominance of exotic species in the landscape; while the endemic species are mostly harvested for PESs and become vulnerable to local elimination.

Chapter 3 showed that most of the PESs are extracted at an immediate distance, continuation of this trend will have a detrimental impact on the TALs heterogeneity because it will promote the occurrence of exotic tree species and transforms the TALs into a homogenous landscape. The exotic tree species found to dominate the immediate distance are *Persea americana Mill.* and *Mangifera indica* Wall. (Chapters 4-5). These species are classified as neutralized exotic tree species in South Africa (Silas Semenya & Maroyi, 2020). Similar exotic tree species are found in agroforestry landscapes of Ethiopia (Muche *et al.,* 2020). However, exotic species such as *Psidium guajava L.* have been found in the intermediate and far distance in less density. This species has been classified as invasive species in the natural landscape of South Africa (Bromilow, 2010; Ruwanza & Thondlana, 2022), and is an aggressive invasive species that can transform the landscape (Bromilow, 2010). Due to its plasticity, this species can tolerate disturbance and has a strong root system that enables the plant to easily adapt and geminate fast (Bromilow, 2010). The *Psidium guajava L.* species is widely planted by local people of VBR for fruit benefits (Semenya *et al.,* 2012). However, poor control of this exotic tree species has resulted in a serious spread to forests. The occurrence of this species in the proximate forest is through dispersal by human beings, livestock (e.g., goats) and wild animals (e.g., baboons and monkeys) (Chapter 5).

The *Psidium guajava L.* species require immediate intervention in the proximate forest and TALs because it has attributes to displace the native species and transforms the landscape. A recent study in Kenya reported that *Psidium guajava L.* displaced endemic species (Ruwanza & Thondlana, 2022). In Chapter 5, findings revealed that distance, exotic species richness, abundance and diversity drive the endemic species diversity in the TALs (Table 5.5). The exotic species diversity index affects native species diversity (Qian & Ricklefs, 2006; Adjossou *et al.,* 2019). Across the immediate distance levels in TALs, the understory plants were mainly the exotic tree species which shows the establishment of exotic species' dominant landscape (Table 5.2). This transformation will threaten the landscape ecosystem services and food security that the TALs provide (Mellisse *et al.,* 2018). Endemic tree species represented the intermediate and far distance component of plant assemblages, which maintained their naturalness and intactness at an increased distance from the community. The PESs harvesting changed the TALs structure, allowing rapid development of the exotic tree species development. This poses a serious threat to TALs biodiversity (Herrera *et al.,* 2016) and increases the pressure of biodiversity loss. The TALs biodiversity cannot be maintained if the ongoing occurrence of exotic species continues unabated. The better indicator of biodiversity conservation in agroforestry is the diversity of native species (Adjossou *et al.,* 2019). TALs require redesigning the management options such as the identification of multipurpose species (e.g., species identified in Chapter 3 and Chapter 7), planning, and balancing the integration of exotic and native species in a landscape and establishing native tree species nurseries.

8.1.4 Effects of socio-ecological determinants on carbon accumulation in traditional agroforestry: A Case of Vhembe Biosphere Reserve, South Africa.

This study determined carbon accumulation at various distance levels in the traditional agroforestry landscape. The methodological approach used in the study entailed vegetation inventory, measuring tree biomass (DBH) in different distance levels in TALs. The findings revealed that carbon storage was similar in all distance levels (Table 6.4) regardless of significant differences in species richness and diversity between distances (Table 6.2). These results contradict the findings by Natalia *et al.* (2017), who reported that there was no correlation between carbon stocks and the diversity index, but rather that a correlation was influenced by the basal area.

It was found that the immediate distance had lower tree density compared to the intermediate and far distances. These results correspond with the reported effects of anthropogenic disturbances on tree species richness and diversity in Chapters 3-5. Preference for extracting PESs at an immediate distance had a negative effect on tree density. Anthropogenic disturbances change vegetation structure and cause substantial loss of tree species richness and diversity (Mir *et al.,* 2021). A similar effect was observed on the tree basal area, immediate distance had higher basal areas compared to intermediate and far distance. This implies that

PESs harvesting from native species resulted in a big diameter remnant tree species and allowed high growth of the exotic species (Figure 5.4). In Chapter 5, the results showed that the immediate distance is dominated by exotic trees of larger diameter. The higher tree basal area at an immediate distance and higher tree density at a far distance balanced the amount of carbon accumulation in the TALs. A study by Cardozo *et al.* (2022) found that the structural diversity of vegetation (e.g., different tree sizes) is an important driver of carbon accumulation in agroforestry systems.

The higher complexity of vegetation structure contributes to higher carbon stocks (Guillemot *et al.,* 2018). Equally so, this suggests that augmentation of tree species richness and diversity at an immediate distance would probably increase the capacity and potential of TALs to sequester atmospheric carbon. The literature emphasizes that higher tree species richness and diversity contribute to higher carbon sequestration (e.g., Shirima *et al.,* 2015; Guillemot *et al.,* 2018). In the immediate distance, mixed tree species (native and non-native species) contributed to carbon accumulation, while in intermediate and far distances only native species contributed (Table 6.5). The economically important non-native species, *Mangifera indica* contributed higher biomass-carbon followed by native species such as *Sclerocarya birrea* and *Trichilia emetica.* Mixed tree species (native and non-native species) in agroforestry systems have multifunctional use including carbon sequestration and local livelihood (Batsi *et al.,* 2021). Unsurprisingly, exotic species are dominating in the immediate distance (Chapters 2 and 3). Studies by Nath *et al.* (2022) in India found that *Mangifera indica* contributed higher biomass-carbon in traditional agroforestry systems. It was discovered that, in addition to the tree distance levels, elevation, density and basal area were the leading drivers of carbon accumulation in TALs (Table 6.5).

An increase in elevation and the basal area is associated with an increase in carbon accumulation in TALs, while a decrease in density was associated with a decrease in carbon accumulation. Kumar *et al.* (2021) previously reported that lower elevation is associated with easy access to forest resources while high elevation is associated with difficult access. Moreover, tree growth decline with increasing altitude which affects the biomass (Birhane *et al.,* 2020; Kumar *et al.,* 2021). Therefore, at a lower elevation, PESs harvesting would be higher due to accessibility, which in turn affects carbon accumulation due to anthropogenic disturbances of tree species (Bajigo *et al.,* 2015). Due to limited forest land in South Africa (which constitutes approximately 1.2% of the total land), traditional agroforestry serves as a pivotal tool to mitigate carbon emissions and carbon sequestration in the country.

8.1.5 Conservation of Tree Species Richness in a Traditional Agroforestry Landscape in the Vhembe Biosphere Reserve, South Africa

Biodiversity conservation is not confined to protected areas, natural forests and woodlands but also extended to agroforestry landscapes (Doddabasawa *et al.,* 2018). The role of TALs in biodiversity conservation is well-recognised worldwide. However, traditional agroforestry landscapes are declining gradually (Doddabasawa *et al.,* 2018; Plieninger *et al.,* 2020; Telwala, 2023). The traditional agroforestry landscapes are changing at an unprecedented rate, exposing many of the ecosystem services such as PESs to a high risk of elimination. These PESs are essential for human well-being. The PESs are considered among the most important ecosystem services derived from biodiversity (Getachew *et al.,* 2022). The TALs contribute more or equal to the forest ecosystems to social, cultural, economic and environmental benefits (Singh *et al.,* 2021).

Despite TAL's substantial support for biodiversity loss reduction (Abdul-Salam *et al.,* 2022), climate change mitigation (Heryandi *et al.,* 2022) and food security (Plieninger *et al.,* 2020), traditional agroforestry practices are not well recognised in policies, for instance, the agroforestry strategic framework of South Africa (DAFF, 2017). The lack of an agroforestry policy in South Africa will hinder the objectives and targets of using agroforestry as a strategy for biodiversity loss reduction. The methodological approach used in the study entailed vegetation inventory and focus group discussions. The study findings revealed that local people lack knowledge of conservation practices (Chapter 7). Anthropogenic disturbances at an immediate distance caused a detrimental impact on tree species diversity (Chapters 2 and 3), and tree species richness was reduced. Tree species richness measures the relationship between biodiversity and ecosystem functionality (Buffa *et al.,* 2018; Li *et al.,* 2021;). Loss of tree species richness results in a decrease in ecosystem functionality (Li *et al.,* 2021).

The continuation of these trends will directly transform the TALs in VBR by reducing the tree species diversity. In Chapter 3, the protected species *Sclerocarya birrea* was recorded as one of the multipurpose species by the local people. This clearly showed ineffective protection of the protected species because the species is restricted for uses such as fuelwood by the national policy of biodiversity conservation. In Chapter 7, local people reported that they are not familiar with the protected tree species in their area. This suggests that the exploitation of the protected tree species is because of the lack of knowledge and awareness by the local people. The report by IPBES (2019) indicated that increasing awareness will open opportunities for actions of biodiversity conservation and sustainable use of the resources in local communities. Chapter 4 revealed that the TALs still contain 41% of the native tree species at an immediate distance. These are the remnant species as the local people reported that they maintain the existing tree species, however, they are not planting native species. Unlike in some parts of Ethiopia, native tree species are planted in agroforestry systems (Lelamo, 2021). However, the TALs of VBR require augmentation of tree species richness to maintain the provision of ecosystem services and landscape functionality.

Multipurpose tree species are vulnerable to high disturbance intensity due to the multi-use attributes and therefore, are vulnerable to local elimination and extinction in the region. Planting more multipurpose species will augment the tree species richness in TALs and provide a wide range of benefits including socio-economic, ecological, and environmental benefits (Uwera *et al.*, 2023). Then the question rises, which multipurpose tree species are to be planted? The results in Table 3.5 and Figure 7.7 provide a clear idea of which tree species local people would prefer to plant in their landscape. The remaining questions are: (1) how to propagate these species for quality seedlings? (2) how to introduce these species to other areas?

8.2 Implications to society and conservation institutions

8.2.1 Provisioning ecosystem services harvesting in a traditional agroforestry landscape.

Trees in traditional agroforestry landscapes denote an investment in an ecological community that diversifies landscape production, increases landscape functionality, and provide valuable ecosystem services. However, the high consumption level is a serious constraint for the TALs to provide ecosystem services. Harvesting the PESs at an immediate distance is an irreplaceable benefit of TALs to the local people. The challenge arises when consumption surpasses the supply of PESs in the landscape. The clear indicator of the impact of overharvesting of PESs in the landscape was the lower tree species richness in proximate areas (Chapter 4), with tree species richness being directly associated with landscape production and functionality (Santos *et al.*, 2019). Therefore, the PESs harvesting behaviour by the individual and communities of VBR is due for a change or adjustment to promote sustainability. Local people have a vast traditional ecological knowledge (TEK) which is very essential for resource use and biodiversity conservation (Araia & Chirwa, 2019; Erenso & Ademo, 2022). However, the TEK is eroding, and this has a negative influence on people's association with nature (Dhanya *et al.*, 2014). As a result, resource use behaviour is partially or no longer informed by the TEK resulting in overexploitation that needs immediate intervention through educational programmes. The interventions will benefit both ecological infrastructure and local people's livelihood because sustainable management will enhance biodiversity and landscape production (Legesse & Negash, 2021; Schwarz *et al.*, 2021). Sustainable harvesting of PESs in TALs must be prioritized and communicated across different levels of society (e.g., educated, and uneducated, young and old generation, rich and poor group). Education and awareness programmes should promote sustainable consumption behaviour as ultimately, human behaviours are the underlying driver of anthropogenic disturbance drivers.

8.2.2 Tree species diversity and conservation in a traditional agroforestry landscape

Tree species diversity is the central attribute of traditional agroforestry, and the function and production depend on it. The social, economic, cultural, and environmental benefits of TALs are derived from the tree species diversity. However, the services of tree species diversity in TALs are threatened by disturbance. Anthropogenic disturbances are the major driver of tree species diversity (Haggar *et al.*, 2019). Higher disturbance eliminates some species and only disturbance-tolerant species survive (Haggar *et al.*, 2019). The proximate areas of TALs require ecological restoration through tree species richness augmentation. The findings in Chapter 3 showed that most of the PESs are derived from multipurpose tree species. This implies that these are the most harvested or utilised tree species in the TALs of VBR. Therefore, tree species richness augmentation should prioritize or focus on the multipurpose tree species, this will align the augmentation with local people's needs. Focus group participants indicated that they like planting native tree species but lack silvicultural knowledge. This suggests that programs supplying native tree species seedlings would enhance TALs tree species diversity. This study developed a tree species richness augmentation schematic framework (TSRAF) to assist the local people to restore the TAL's ecological infrastructure at an immediate distance (Figure 8.1).

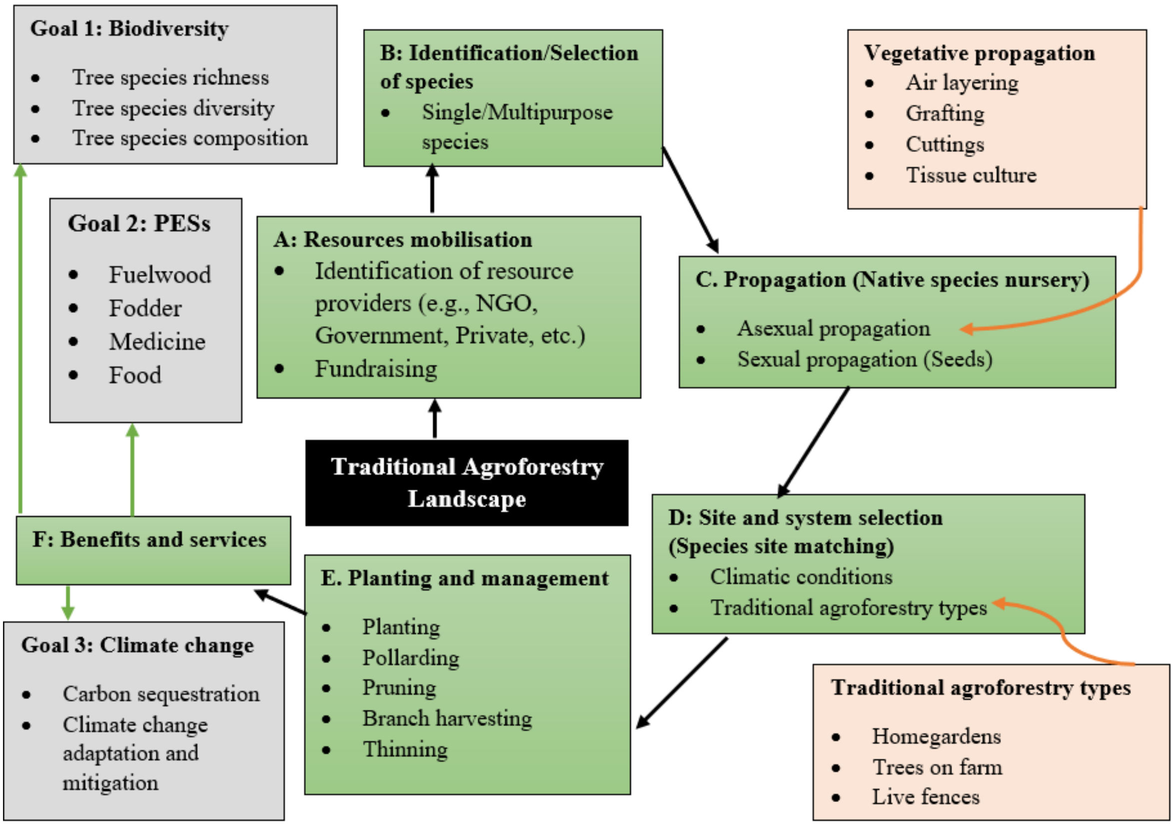

Figure 8.1: Tree species richness augmentation schematic framework.

The TSRAF consists of five steps, (A) resources mobilisation. In this step, different mechanisms (e.g., fundraising, donations, etc.) may be used to get resources from resource providers (e.g., Government, Private, NGO, etc.). (B) identification/selection of multipurpose tree species from the existing vegetation. This step must be done through consultation with the local people to achieve ecological and local livelihood goals. For VBR, some of the multipurpose tree species are already identified in Chapters 1 and 5. (C) native species nursery, propagation of the species using both asexual and sexual propagation. (D) tree species site and system matching and identification of integration components of agroforestry (e.g., crops or animals). (E) planting and maintenance, and proper management of the TALs. The effective implementation of TSRAF is expected to achieve at least three goals; first goal, high tree species richness and diversity; second, provisioning ecosystem services; third goal, climate change mitigation and adaptation. Therefore, TALs will compensate for and continue reducing anthropogenic disturbances and pressure on the proximate forest (Meragiaw *et al.*, 2022).

The traditional agroforestry landscape distance levels could somehow mimic the biosphere reserve zones: the immediate distances (transitional zones), intermediate distances (buffer zones) and far distances (core areas). The findings revealed that the transitional zones are neglected in terms of conservation, as demonstrated by extreme harvesting disturbances, low tree species richness and diversity, and high dominance of exotic species at an immediate distance. As reported by Ihemezie *et al.* (2021) the paramount objective of conservation is mainly on protected areas than any other areas of forest resources areas. In the case of the VBR, the protected areas are mainly the core areas of the biosphere. The highly protected areas in VBR include provincial and national reserves and parks (Evans, 2017). However, protected areas are insufficient to achieve local, regional and global biodiversity conservation (Haggar *et al.,* 2019; Santos *et al.,* 2019; Araia *et al.,* 2020). Local people do not have scientific knowledge of conservation practices and management of native tree species except the long held traditional practices. In addition, government institutions are not effective in conserving tree species in traditional agroforestry landscapes, therefore, government institutions should scale up conservation efforts in traditional agroforestry landscapes to supplement the effective Tribal Council and community conservation efforts. The effectiveness of all these institutions will improve conservation in the TALs, specifically, the transitional zone of the biosphere and it will complement the core zone as the main targeted area of biodiversity conservation (Haggar *et al.,* 2019).

8.2.3 Homogenization of traditional agroforestry landscape by exotic tree species

Traditional agroforestry landscape transformation from heterogeneous to homogeneous tree species landscape is an emerging issue. Evidently, exotic tree species are dominating the proximate areas of the TALs of VBR (Chapter 3). In fact, exotic tree species are expected to increase due to a higher preference for planting over native tree species (Nath *et al.,* 2016; Gemechu *et al.,* 2021). Previous studies reported that exotic tree species provide high economic value to local people than native species (Silas Semenya & Maroyi, 2020). For example, exotic tree species such as *Mangifera indica* and *Persia americana* have higher economic value for local people (Silas Semenya & Maroyi, 2020). In VBR, almost every household has one or two exotic tree species and limited native tree species or none. Therefore, to ensure that TALs sustain production and functionality, the existence of exotic and native tree species must be balanced. At an immediate distance, exotic tree species management must be established focusing on integrating both native and exotic species. Landscape management such as pruning and thinning of tree species should be applied to both exotic and native species. Furthermore, native tree species augmentation should be prioritised to restore the TAL's ecological infrastructure. The TALs homogenization needs to be avoided, and instead, promote heterogeneity to maintain landscape function and production for ecological and socio-economic benefits. Moreover, the exotic tree species' invasion of the proximate forest must be prevented (Cordero *et al.,* 2023).

8.2.4 The capacity of traditional agroforestry landscape to sequester carbon.

The potential of TALs and/or agroforestry systems to contribute to climate change mitigation has been getting increasing attention in scientific investigations (Graham *et al.,* 2022; Quandt *et al.,* 2023). Given the critical importance of agroforestry in regulating climate change (Meragiaw *et al.,* 2022) and biodiversity conservation (Schuler *et al.,* 2022), traditional agroforestry landscapes are crucial in climate change adaptation and mitigations in rural community settings (Heryandi *et al.,* 2022; Graham *et al.,* 2022). Despite the prevalence of anthropogenic disturbances in immediate distance, the traditional agroforestry landscapes still harbour a relatively high number of carbon stocks comparable to the proximate forest. This is a clear indication that the immediate distance area has a reasonably useful species mix including both exotic and native species for carbon sequestration. Regardless of poor species richness and diversity, the immediate distance sequesters an equal amount of carbon as a high species diversity proximate forest. Therefore, augmentation of tree species richness and diversity at an immediate distance will enhance the carbon sequestration capacity of the TALs. Previous studies reported that higher species richness and diversity contribute to high carbon accumulation (e.g., Heryandi *et al.,* 2022). It is critical that the local people of VBR enhance tree species richness at an immediate distance as most of the PESs are derived at an immediate and contribute to climate change mitigations.

8.3 Reflecting on the conceptual framework and future research direction.

Human behaviour is critical to future scenarios of PESs harvesting and biodiversity conservation in TALs. The overexploitation of PESs is due to behavioural norms, and therefore, behavioural change is the driving force of overexploitation change (IPBES, 2019). Understanding the relationship between human behaviour, drivers of biodiversity loss and PESs use is very critical in biodiversity conservation. This study was conducted at a landscape spatial scale, the traditional agroforestry landscape of VBR. Ecosystem services at the landscape scale provide a clear and more accurate interaction between people and ecosystems than at a local scale (tends to be small) and global scale (tends to be large to inform local people) (Wu, 2013). This study used environmental predictors (Distance) and socio-ecological factors relying on social and ecological theories and hypotheses. Considering that human behaviour change requires underlying individual and social behaviour (IPBES, 2019), this study addressed the effects of socio-ecological factors and distance in relation to harvesting behaviour. However, the study majorly focused on the socio-ecological factors at the expense of human demographic factors, especially the human population. Growth of the human population has been linked with biodiversity loss (Cafaro *et al.,* 2022). Considering the high population growth in South Africa, a failure to address the association between the human population and PESs harvesting in TALs will compromise conservation efforts. The human population, biodiversity loss and anthropogenic disturbances are intimately connected (Cafaro *et al.,* 2022). Therefore, future research should focus on investigating the influence of the human population on PESs harvesting and tree species richness decline in traditional agroforestry landscapes. According to Cafaro *et al.* (2022), the higher the population, the lower the ecological population.

Based on the conceptual framework, the results confirmed the interlinkage between PESs harvesting disturbances, tree species richness and diversity, exotic species, and conservation strategies. The higher disturbance at an immediate distance corresponded with low tree species richness and diversity, high dominance of exotic species and a lack of conservation strategies and approaches. The tree species diversity declines in TALs and the report of no strategies for restoring and conserving tree species diversity in VBR is a critical issue that needs attention considering the challenges of climate change and biodiversity loss in the future. However, the ecological restoration approaches and practices were not assessed and found as a gap to achieve the goal of biodiversity conservation. Moreover, the growth rate of exotic species has been reported to be very fast and these species are more preferred by local people compared to native species due to their economic value (e.g., Nath *et al.,* 2016). Future studies could assess whether exotic species provide better provisioning ecosystem services without compromising the sustainability and maintenance of biodiversity and other ecosystem services.

Interestingly, there was no interlinkage as predicted in the conceptual framework between carbon accumulation, PESs harvesting disturbance, tree species richness and diversity, and exotic species and conservation strategies. The current study applied a single method of carbon stock assessment, biomass carbon accumulation. To complement these findings, future research could also assess the soil organic carbon, which has been reported to be very important for climate change mitigation in TALs (Schwarz *et al.,* 2021; Chirwa *et al.,* 2023). According to Negash *et al.* (2022), around 40% of developing countries aimed to use agroforestry to contribute to the Paris Agreement on climate change mitigation. South Africa committed to Paris Climate Agreement held under the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 to take necessary decisions and steps to reduce carbon emissions and a low-carbon future (DEA, 2016). The results from this study have shown greater potential for TALs to sequester carbon sequestration (Chapter 6). Hence, future research should focus on assessing the practical application of carbon projects in TALs as a strategy to enhance biodiversity conservation and carbon sequestration while incentivising the local people with non-carbon benefits. Notwithstanding, a study by Chirwa (2015) found that the challenge of adopting tree-based voluntary carbon projects in southern Africa is the lack of institutional capacity to manage the projects and establish international markets. Therefore, there is a need to determine how voluntary carbon projects in TALs can be rolled out with consideration for benefits for the local people. Indeed, for example, a recent study in India showed that local families received carbon revenue amounting to an approximately 800, 000 USD, which was shared among the families based on the survival rate of the planted trees (carbon stocks) in their fields. Evidently, incentives increased the number of participants in tree planting, in two decades an increase of 94% of participating families was recorded (Telwala, 2023). This case study provides a typical successful scenario of voluntary carbon projects and tree species richness augmentation.

8.4 Concluding remarks

Firstly, the study investigated the influence of distance on PESs harvesting behaviour in traditional agroforestry landscapes. The findings lead to the conclusion that distance influences PESs harvesting behaviour. The PESs (e.g., fuelwood, medicine, wild fruits, etc.) are highly harvested at an immediate distance compared to intermediate and far distances. The harvesting intensity decreased as the distance to the proximate forest increased. These results confirmed the two hypotheses of the study: (1) PESs harvesting decreases as the distance to the proximate forest increases; (2) Optimal foraging theory, which hypothesizes that local people behave optimally when harvesting PESs by maximising energy and time by harvesting PESs at an immediate distance. From a biodiversity conservation perspective, frequent or higher events of harvesting of resources in one location have a detrimental impact. Higher anthropogenic disturbance leads to the elimination of some of the tree species and only disturbance-tolerant species survive. Therefore, the harvesting behaviour of local people must change to serve the remnant species. Sustainable harvesting behaviour would encourage the regeneration and grow back of disturbed tree species in the landscape.

Secondly, the results revealed that tree species richness was very low at an immediate distance compared to intermediate and far distances. The results agreed with the tested hypothesis of the intermediate disturbance hypothesis. However, it confirmed the effect of higher disturbance on tree species in the immediate distance in the landscape. The lower tree species at an immediate distance were due to higher anthropogenic disturbance through harvesting of PESs and other activities. It has been proven that disturbance has a negative and positive effect on tree species diversity, however, this study showed that the disturbance caused a decrease in tree species richness as compared to proximate forest. There is a need for ecological restoration in the TALs of VBR. Tree species richness augmentation through planting native species will enhance the landscape's productivity and functions. The multipurpose tree species of TALs should be prioritised to augment the TALs through joint planning and decisions with the local people.

Thirdly, the results revealed that TALs were predominated by exotic tree species such as *Mangifera indica* and *Persea americana*. These species are regarded as commercial value species in local community settings. Historically, traditional agroforestry landscapes are known for rich native tree diversity. The findings confirm the hypothesis that a high population of exotic tree species displaces native tree species. Moreover, high anthropogenic disturbance favours exotic tree species regeneration and colonisation. The continuation of diversity transformation in the TALs will result in a homogenous landscape. This will affect both TAL's ecological infrastructure and local people's livelihood. Balancing the ecological infrastructure of TALs through native tree species augmentation is unnegotiable at this stage.

Fourthly, the findings revealed that regardless of distinct tree species diversity between distance levels, biomass and/or carbon accumulation was equal at all distance levels. The results contrast with the study hypothesis; carbon accumulation increases as the distance from the communities' increases to the proximate forest and the higher carbon accumulation was expected at an intermediate distance due to high tree species diversity. The carbon accumulation was equal in three distance levels. The different vegetation structures in distance levels contributed to equal carbon sequestration. The tree diameter compensated for the biomass carbon accumulation at an immediate distance, while the tree density compensated for the carbon accumulation at intermediate and far distances. These results confirmed that vegetation structure has a significant role in carbon sequestration. Moreover, these results show the higher potential and capacity of TALs in contributing to a larger problem, climate change. Furthermore, tree species richness augmentation in TALs will increase the production and function capacity of the landscape.

Lastly, the results revealed that no conservation policies and practices were being implemented by the local people in TALs. The results imply that there is a lack of support and promotion of traditional agroforestry in South Africa thus, allowing the over-exploitation of PESs without guidance. The only rules being applied in the study area are of the traditional leaders which are also not documented for referencing and promotion. The local people lack knowledge of the protected tree species and skills for propagating native tree species. However, local people are willing to learn how to propagate native tree species as was emphasised in focus group discussions. Recognising traditional agroforestry in local and national policy will enhance landscape sustainable management. Overall, the findings demonstrated that TALs are viable landscapes to balance biodiversity conservation, mitigating climate and providing essential services (e.g., PESs) depending on wise human behaviour decisions.

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Appendices

Appendix 1: Data analytical approaches

Research objective	Data set	Data type	Analytical approaches
Objective 1 (Chapter 3): To evaluate the influence of distance and other socio-ecological determinants on provisioning ecosystem services (PES) consumption in the traditional agroforestry landscape (TAL).	• Household Surveys • Focus Group	• Quantitative • Qualitative	• A Generalised Linear Model (GLM) with an ordinal logistic distribution. • Friedman ranking test. • Fidelity level • Use-value. • Content analysis
Objective 2 (Chapter 4): To investigate the effects of distance on tree species diversity in traditional agroforestry and its contribution to tree species conservation.	• Forest Inventory	• Quantitative	• Similarities percentages analysis (SIMPER). • PERMANOVA • PERMDISP • Non-parametric multidimensional scaling (nMDS). • Distance-based linear modelling (DISTLM). • Distance-based redundancy analysis (dbRDA). • Primer's Draftsman plot.
Objective 3 (Chapter 5): To evaluate the impact of exotic species and socio-ecological determinants on endemic species diversity in traditional agroforestry landscapes (TAL).	• Forest Inventory	• Quantitative	• K-dominance curve. • Shannon diversity index. • PERMANOVA • PERMDISP • Non-parametric multidimensional scaling (nMDS). • Distance-based linear modelling (DISTLM).
Objective 4 (Chapter 6): To investigate the effects of tree species richness, diversity and socio-ecological determinants on carbon stocks in traditional agroforestry.	• Forest Inventory	• Quantitative	• Important Value Index • Allometric equation • One-way ANOVA • Multiple Linear Regression (MLR) • Shannon diversity index. • PERMANOVA
Objective 5 (Chapter 7): To investigate the link between socio-ecological factors and conservation strategies on tree species richness in traditional agroforestry landscapes.	• Forest Inventory • Household Surveys • Focus Group Discussion	• Quantitative • Qualitative	• ANOSIM • Fidelity level • Content analysis • PERMANOVA • PERMDISP • Non-parametric multidimensional scaling (nMDS). • Distance-based linear modelling (DISTLM).

Appendix 2: Use-value of tree species

Tree species (Top 30 of 108 tree species)	Thenzheni (n=198)					Tshipako (n=177)					Damani (n=172)					Tshiombo (n=335)					Overall Use Value
	Food	**Fuel**	**Medicine**	**Fodder**	**Use V**	**Food**	**Fuel**	**Medicine**	**Fodder**	**Use V**	**Food**	**Fuel**	**Medicine**	**Fodder**	**Use V**	**Food**	**Fuel**	**Medicine**	**Fodder**	**Use V**	
Annona senegalensis	0.101	0	0	0.005	**0.106**	0.028	0.005	0.045	0.022	**0.101**	0.081	0.034	0.186	0	**0.302**	0.011	0.056	0.068	0.032	**0.170**	**0.680**
Tabernaemontana elegans	0.030	0.015	0.025	0	**0.070**	0.005	0.033	0.141	0	**0.180**	0.023	0.238	0.104	0	**0.366**	0.002	0.071	0.089	0	**0.164**	**0.781**
Englerophytum magalismontanum	0.858	0.075	0.010	0.060	**1.005**	0.734	0.271	0.039	0.011	**1.056**	0.430	0.063	0	0.017	**0.511**	0.450	0.059	0.005	0	**0.516**	**3.089**
Landolphia kirkii	0.778	0.045	0	0.015	**0.838**	0.728	0.011	0	0.028	**0.768**	0.325	0.005	0.005	0	**0.337**	0.358	0.032	0.005	0.005	**0.402**	**2.346**
Hexalobus monopetalus	0.252	0	0	0	**0.252**	0.248	0.005	0	0	**0.254**	0.186	0	0	0	**0.186**	0.149	0.005	0	0.002	**0.158**	**0.851**
Vangueria esculenta	0.373	0.015	0.005	0	**0.393**	0.293	0.011	0.005	0.016	**0.327**	0.284	0.029	0.011	0	**0.325**	0.250	0.008	0	0	**0.259**	**1.306**
Psidium guajava	0.121	0.015	0	0.055	**0.191**	0.197	0	0.084	0.011	**0.293**	0.139	0.005	0.023	0.046	**0.215**	0.110	0.002	0	0.017	**0.131**	**0.832**
Pterocarpus angolensis	0.156	0.010	0.045	0.005	**0.217**	0.067	0.248	0.056	0.011	**0.384**	0	0.104	0.075	0	**0.180**	0.077	0.083	0.044	0	**0.205**	**0.987**
Mangifera indica	0.056	0.025	0	0.237	**0.318**	0.237	0.039	0	0.248	**0.525**	0.273	0.058	0	0.104	**0.436**	0.367	0.065	0	0.149	**0.582**	**1.861**
Persea americana	0.025	0.025	0	0.257	**0.308**	0.096	0	0.005	0.282	**0.384**	0.127	0.029	0	0.145	**0.302**	0.167	0.008	0	0.119	**0.295**	**1.290**
Grewia microthyrsa	0.040	0.005	0	0.040	**0.085**	0.124	0.062	0	0.045	**0.231**	0.220	0.052	0	0	**0.273**	0.277	0.152	0.005	0	**0.435**	**1.026**
Citrus sinensis	0.030	0	0	0.045	**0.075**	0.107	0.005	0	0.084	**0.197**	0.255	0	0	0.034	**0.290**	0.214	0.008	0	0.008	**0.232**	**0.797**
Sclerocarya birrea	0.030	0.101	0.111	0.141	**0.383**	0.045	0.112	0.372	0.090	**0.621**	0.215	0.366	0.174	0.145	**0.901**	0.008	0.089	0.137	0.056	**0.292**	**2.199**
Bridelia micrantha	0.085	0.181	0	0.267	**0.535**	0.016	0.056	0.005	0.084	**0.163**	0	0.075	0	0	**0.075**	0	0.026	0.023	0.011	**0.062**	**0.837**
Albizia adianthifolia	0	0.232	0.015	0.065	**0.313**	0	0.214	0	0.163	**0.378**	0	0.412	0.046	0.151	**0.610**	0	0.047	0.005	0	**0.053**	**1.355**
Parinari curatellifolia	0	0.363	0.020	0.101	**0.484**	0.084	0.672	0.079	0.062	**0.898**	0.104	0.319	0.075	0.011	**0.511**	0.038	0.170	0.026	0.002	**0.238**	**2.133**

Acacia ataxacantha	0	0.207	0.015	0.075	**0.297**	0	0.067	0	0.067	**0.135**	0	0.058	0.005	0	**0.063**	0	0.032	0	0	**0.032**	**0.530**
Dichrostachys cinerea	0	0.050	0.025	0.090	**0.166**	0	0.011	0.016	0.197	**0.225**	0	0.180	0.038	0.232	**0.447**	0	0.179	0.011	0	**0.191**	**1.031**
Xylopia odoratissima	0	0.515	0.015	0.005	**0.535**	0	0.423	0.016	0.028	**0.468**	0	0.104	0.127	0.011	**0.244**	0	0.083	0	0	**0.083**	**1.332**
Heteropyxis natalensis	0	0.191	0.075	0.015	**0.282**	0	0.107	0.005	0.101	**0.214**	0	0.063	0	0	**0.063**	0	0.023	0	0.002	**0.026**	**0.588**
Peltophorum africanum	0	0.050	0.030	0.035	**0.116**	0	0.022	0.220	0.101	**0.344**	0	0.209	0.052	0.034	**0.296**	0	0.119	0.086	0.017	**0.223**	**0.981**
Combretum molle	0	0.106	0.510	0.030	**0.646**	0	0.305	0.446	0.056	**0.807**	0	0.087	0.110	0	**0.197**	0	0.083	0.200	0	**0.283**	**1.935**
Pteleopsis myrtifolia	0	0.005	0	0	**0.005**	0	0.237	0	0.186	**0.423**	0	0.273	0.017	0.040	**0.331**	0	0.158	0	0.017	**0.176**	**0.936**
Faurea saligna	0	0.156	0	0	**0.156**	0	0.282	0	0.005	**0.288**	0	0.011	0	0	**0.011**	0	0	0	0	**0**	**0.456**
Zanthoxylum capense	0	0.005	0.085	0	**0.090**	0	0.005	0.367	0	**0.372**	0	0	0.267	0.005	**0.273**	0	0	0.143	0.005	**0.149**	**0.886**
Securidaca longepedunculata	0	0	0.500	0	**0.500**	0	0	0.225	0	**0.225**	0	0.017	0.081	0	**0.098**	0	0	0	0	**0**	**0.824**
Wrightia natalensis	0	0	0.368	0	**0.368**	0	0	0.005	0	**0.005**	0	0	0	0	**0**	0	0	0.014	0	**0.014**	**0.389**
Clematis brachiata	0	0	0.060	0.015	**0.075**	0	0.005	0.451	0	**0.457**	0.005	0	0.098	0	**0.104**	0	0	0.083	0	**0.083**	**0.721**
Erythrina lysistemon	0	0	0.010	0.232	**0.242**	0	0	0	0.022	**0.022**	0	0.034	0.040	0	**0.075**	0	0	0.017	0	**0.017**	**0.358**
Melia azedarach	0	0	0	0.126	**0.126**	0	0	0.028	0.265	**0.293**	0	0	0.011	0.186	**0.197**	0	0.029	0.011	0.044	**0.086**	**0.704**
Totals	**2.939**	**2.398**	**1.929**	**1.924**	**9.191**	**3.169**	**3.220**	**2.621**	**2.197**	**11.056**	**2.674**	**2.837**	**1.552**	**1.168**	**8.232**	**2.486**	**1.602**	**0.985**	**0.498**	**5.573**	**34.054**

Appendix 3: SIMPER analysis of tree species abundance similarity

Immediate distance (Av.sim=19.70)				**Intermediate distance (Av.sim=15.04)**				**Far distance (Av.sim=25.5)**			
Species	**Av. Abund**	**Av. Sim**	**C. %**	**Species**	**Av. Abund**	**Av. Sim**	**C. %**	**Species**	**Av. Abund**	**Av. Sim**	**C.%**
Mangifera indica	0.67	11.18	56.77	*Pteleopsis myrtifolia*	0.47	3.02	20.06	*Pteleopsis myrtifolia*	0.82	9.17	35.88
Persea americana	0.4	3.6	18.28	*Tabernaemontana elegans*	0.37	1.98	13.17	*Albizia adianthifolia*	0.5	3.32	13.01
				Bridelia micrantha	0.35	1.86	12.38	*Englerophytum magalismontanum*	0.37	1.79	6.99
				Pseudolachnostylis maprouneifolia	0.27	1.04	6.89	*Parinari curatellifolia*	0.37	1.71	6.7
				Combretum molle	0.27	0.91	6.03	*Tabernaemontana elegans*	0.37	1.67	6.52
				Albizia adianthifolia	0.22	0.64	4.27	*Combretum molle*	0.35	1.41	5.52
				Acacia ataxacantha	0.18	0.52	3.43				
				Afzelia quanzensis	0.18	0.42	2.82				
				Parinari curatellifolia	0.17	0.41	2.73				

Av. A= Average abundance. Av.sim= Average similarity. C= Contribution. Imm= Immediate distance. Int= Intermediate distance. Far= Far distance

Appendix 4: SIMPER analysis of tree species abundance dissimilarity

Average dissimilarity (Imm & Int) =94.8%					Average dissimilarity (Int & Far) =82.9%					Average dissimilarity (Imm & Far) =94.5%				
	Imm	Int				Int	Far				Imm	Far		
Species	Av. A	Av. A	Av. D	C.%	Species	Av. A	Av. A	Av. D	C.%	Species	Av. A	Av. A	Av. D	C.%
Mangifera indica	0.67	0	6.72	7.08	*Pteleopsis myrtifolia*	0.47	0.82	4.07	4.91	*Pteleopsis myrtifolia*	0.13	0.82	6.64	7.02
Pteleopsis myrtifolia	0.13	0.47	4.52	4.76	*Albizia adianthifolia*	0.22	0.5	3.74	4.51	*Mangifera indica*	0.67	0	5.97	6.31
Persea americana	0.4	0	3.88	4.09	*Tabernaemontana elegans*	0.37	0.37	3.43	4.13	*Albizia adianthifolia*	0.07	0.5	4.49	4.75
Tabernaemontana elegans	0.08	0.37	3.81	4.02	*Combretum molle*	0.27	0.35	3.06	3.69	*Persea americana*	0.4	0	3.46	3.66
Bridelia micrantha	0.05	0.35	3.62	3.82	*Parinari curatellifolia*	0.17	0.37	3.03	3.66	*Englerophytum magalismontanum*	0.07	0.37	3.44	3.64
Sclerocarya birrea	0.23	0.15	3.06	3.23	*Bridelia micrantha*	0.35	0.22	3.03	3.66	*Tabernaemontana elegans*	0.08	0.37	3.37	3.56
Pseudolachnostylis maprouneifolia	0.07	0.27	2.97	3.13	*Englerophytum magalismontanum*	0.12	0.37	2.94	3.54	*Parinari curatellifolia*	0.03	0.37	3.3	3.49
Combretum molle	0.03	0.27	2.58	2.72	*Pseudolachnostylis maprouneifolia*	0.27	0.18	2.57	3.11	*Combretum molle*	0.03	0.35	2.99	3.17
Albizia adianthifolia	0.07	0.22	2.34	2.47	*Xylopia parviflora*	0.17	0.22	2.16	2.61	*Sclerocarya birrea*	0.23	0.03	2.21	2.34
Acacia ataxacantha	0.05	0.18	2.19	2.31	*Artabotrys brachypetalus*	0.17	0.2	2.13	2.57	*Hyperacanthus amoenus*	0.02	0.23	2.11	2.24
Parinari curatellifolia	0.03	0.17	1.95	2.06	*Dalbergia nitidula*	0.1	0.22	2.02	2.44	*Artabotrys brachypetalus*	0.07	0.2	2.1	2.22
Artabotrys brachypetalus	0.07	0.17	1.82	1.92	*Hyperacanthus amoenus*	0.08	0.23	2.01	2.42	*Dalbergia nitidula*	0.02	0.22	2.06	2.18
Afzelia quanzensis	0.02	0.18	1.77	1.87	*Acacia ataxacantha*	0.18	0.13	1.96	2.37	*Bridelia micrantha*	0.05	0.22	2.03	2.14

Psidium guajava	0.13	0.05	1.68	1.77	*Strychnos madagascariensis*	0.12	0.2	1.88	2.27	*Pseudolachnostylis maprouneifolia*	0.07	0.18	2	2.12
Trichilia emetica	0.15	0.03	1.64	1.73	*Syzygium cordatum*	0.1	0.17	1.69	2.04	*Xylopia parviflora*	0.02	0.22	1.9	2
Citrus sinensis	0.18	0	1.61	1.7	*Vangueria infausta*	0.13	0.13	1.63	1.96	*Strychnos madagascariensis*	0.02	0.2	1.77	1.87
Xylopia parviflora	0.02	0.17	1.49	1.57	*Peltophorum africanum*	0.13	0.1	1.5	1.81	*Syzygium cordatum*	0.05	0.17	1.71	1.81
Peltophorum africanum	0.02	0.13	1.46	1.54	*Brachylaena huillensis*	0.08	0.15	1.46	1.76	*Citrus sinensis*	0.18	0	1.46	1.54
Syzygium cordatum	0.05	0.1	1.43	1.51	*Afzelia quanzensis*	0.18	0.03	1.44	1.73	*Acacia ataxacantha*	0.05	0.13	1.43	1.51
Albizia versicolor	0.05	0.12	1.41	1.49	*Ficus sur*	0.08	0.12	1.34	1.62	*Ficus sur*	0.03	0.12	1.38	1.46
Englerophytum magalismontanum	0.07	0.12	1.41	1.48	*Hexalobus monopetalus*	0.15	0.05	1.29	1.55	*Scolopia Mundii*	0	0.15	1.34	1.42
Vitex ferruginea	0	0.17	1.4	1.47	*Brachylaena discolour*	0.12	0.08	1.29	1.55	*Trichilia emetica*	0.15	0	1.28	1.35
Hexalobus monopetalus	0	0.15	1.37	1.45	*Sclerocarya birrea*	0.15	0.03	1.2	1.45	*Brachylaena huillensis*	0	0.15	1.26	1.33
Dichrostachys cinerea	0.02	0.12	1.36	1.44	*Scolopia Mundii*	0.02	0.15	1.19	1.44	*Vangueria infausta*	0.02	0.13	1.24	1.32
Brachylaena discolor	0.03	0.12	1.32	1.39	*Grewia microthyrsa*	0.08	0.1	1.14	1.38	*Psidium guajava*	0.13	0.02	1.24	1.31
Vangueria infausta	0.02	0.13	1.27	1.34	*Vitex ferruginea*	0.17	0	1.09	1.31	*Pavetta lanceolata*	0	0.12	1.19	1.26
Erythrina lysistemon	0.12	0.02	1.22	1.29	*Dichrostachys cinerea*	0.12	0.03	1.06	1.28	*Brachylaena discolor*	0.03	0.08	1.01	1.07
Annona senegalensis	0.05	0.1	1.22	1.28	*Pavetta lanceolata*	0.02	0.12	1.06	1.28	*Terminalia sericea*	0.05	0.08	1	1.05
Diospyros mespiliformis	0.03	0.08	1.1	1.16	*Zanthoxylum davyi*	0.08	0.07	1.01	1.21	*Croton sylvaticus*	0.02	0.1	0.99	1.05
Musa acuminita	0.12	0	1.06	1.11	*Antidesma venosum*	0.1	0.07	0.98	1.18					
Ficus sur	0.03	0.08	1.04	1.09										

Strychnos madagascariensis	0.02	0.12	1.03	1.09

Av. A= Average abundance. Av. D= Average dissimilarity. C= Contribution. Imm= Immediate distance. Int= Intermediate distance. Far= Far distance

Appendix 5: SIMPER analysis of endemic and exotic tree species abundance similarity

Immediate distance (Av.sim=26.25)				Intermediate distance (Av.sim=3.34)				Far distance (Av.sim=7.16)			
Species	**Av. Abu**	**Av. Sim**	**C.%**	**Species**	**Av. Ab**	**Av. Sim**	**C.%**	**Species**	**Av. Ab**	**Av. Sim**	**C.%**
Mangifera indica [a]	0.67	18.10	68.97	*Brachylaena discolour* [b]	0.12	1.22	36.40	*Hyperacanthus amoenus* [b]	0.23	3.97	55.40
Persea americana [a]	0.40	5.48	89.83	*Grewia microthyrsa* [b]	0.08	0.45	65.25	*Scolopia Mundii* [b]	0.15	1.27	73.15
				Hyperacanthus amoenus [b]	0.08	0.52	51.87				
				Zanthoxylum davyi [b]	0.08	0.41	77.50				

[an] Exotic species, [b] Endemic species, Av.Abu= Average abundance, Av.sim= Average similarity, C= Contribution

Appendix 6: SIMPER analysis of endemic and exotic tree species abundance dissimilarity

Average dissimilarity (imm& int) = 99.09					Average dissimilarity (imm&far) = 99.48					Average dissimilarity (int&far) = 96.30				
	Imm	Int				Imm	Far				Int	Far		
Species	**Av. A**	**Av. A**	**Av. D**	**C.%**	**Species**	**Av. A**	**Av. A**	**Av. D**	**C.%**	**Species**	**Av. A**	**Av. Ab**	**Av. D**	**C.%**
Mangifera indica [a]	0.67	0	26.41	26.65	*Mangifera indica* [a]	0.67	0	24.05	24.17	*Hyperacanthus amoenus* [b]	0.08	0.23	19.08	19.81
Persea americana [a]	0.40	0	13.43	40.20	*Persea americana* [a]	0.40	0	12.36	36.59	*Brachylaena discolor* [b]	0.12	0.08	11.85	32.11
Psidium quajava [a]	0.13	0.05	7.41	47.68	*Hypercanthus amoenus* [b]	0.02	0.23	8.93	45.57	*Grewia microthyrsa* [b]	0.08	0.10	9.16	41.62
Brachylaena discolor [b]	0.03	0.12	6.13	53.71	*Psidium guajava* [a]	0.13	0.02	5.57	51.17	*Scolopia Mundii* [b]	0.02	0.15	8.75	50.70
Citrus sinensis [a]	0.03	0	4.80	58.71	*Scolopia mundii* [b]	0	0.15	4.87	56.06	*Pavetta lanceolate* [b]	0.02	0.12	8.01	59.02
Hyperacanthus amoenus [b]	0.02	0.08	3.76	62.51	*Citrus sinensis* [a]	0.18	0	4.48	60.56	*Zanthoxylum davyi* [b]	0.08	0.07	7.08	66.37
Grewia microthyrsa [b]	0.02	0.08	3.48	66.02	*Pavetta lanceolate* [b]	0	0.12	4.26	64.84	*Psidium guajava* [a]	0.05	0.02	4.23	70.76
Ficus tettensis [b]	0.03	0.05	3.20	69.24	*Brachylaena discolor* [b]	0.03	0.08	3.87	68.73					
Musa acuminita [a]	0.12	0	3.12	72.39	*Grewia microthyrsa* [b]	0.02	0.10	3.36	72.10					

[an] Exotic species, [b] Endemic species, Av. A= Average abundance, Av. D= Average dissimilarity, C= Contribution, Imm= Immediate distance, Int= Intermediate distance, Far= Far distance

Appendix 7: Tree species contributing 5% of IVI in traditional agroforestry.

Distance level	Tree species	RF (%)	RDo (%)	RDe (%)	IVI (%)
Immediate	*Erythrina lysistemon*	2.85	3.39	2.85	9.1
	Persea americana	9.96	7.18	9.96	27.1
	Mangifera indica	33.98	18.87	33.98	86.8
	Psidium guajava	2.14	0.24	2.14	4.5
	Citrus sinensis	3.38	1.24	3.38	8.0
	Musa acuminata	10.67	1.52	10.67	22.9
	Trichilia emetica	2.85	7.65	2.85	13.3
	Sclerocarya birrea	3.20	9.26	3.20	15.7
	Ficus sur	0.89	12.32	0.89	14.1
	Pteleopsis myrtifolia	1.25	3.49	1.25	6.0
	Diospyros mespiliformis	0.53	3.53	0.53	4.6
Intermediate	*Acacia ataxacantha*	2.81	0.35	2.82	6.0
	Afzelia quanzensis	3.45	9.35	3.45	16.3
	Albizia adianthifolia	3.45	7.94	3.45	14.8
	Brachylaena discolor	2.30	0.61	2.31	5.2
	Bridelia micrantha	6.52	8.19	6.53	21.2
	Combretum molle	2.68	1.28	2.68	6.7
	Commiphora marlothii	2.05	2.16	2.05	6.3
	Dichrostachys cinerea	2.55	0.37	2.56	5.5
	Diospyros mespiliformis	1.27	2.01	1.28	4.6
	Ficus tettensis	0.76	3.48	0.76	5.0
	Hexalobus monopetalus	2.17	1.44	2.17	5.8
	Parinari curatellifolia	2.43	2.03	2.43	6.9
	Pseudolachnostylis maprouneifolia	3.45	4.01	3.45	10.9
	Pteleopsis myrtifolia	9.07	11.64	9.09	29.8
	Sclerocarya birrea	1.92	6.72	1.92	10.6
	Syzygium cordatum	1.41	8.35	1.41	11.2
	Tabernaemontana elegans	9.46	3.20	9.47	22.1
	Vitex ferruginea	2.43	1.09	2.43	6.0
	Ximenia caffra	2.17	0.36	2.17	4.7
	Xylopia odoratissima	1.92	0.68	1.92	4.5
Far	*Acacia ataxacantha*	1.74	1.09	1.71	4.5
	Afzelia quanzensis	1.37	2.12	1.35	4.8
	Albizia adianthifolia	5.57	10.54	5.49	21.6
	Brachylaena huillensis	1.55	2.35	1.53	5.4
	Bridelia micrantha	3.66	5.48	3.60	12.7
	Combretum molle	3.29	2.94	3.24	9.5

Dalbergia nitidula	4.21	1.89	4.14	10.2
Diplorhynchus condylocarpon	1.28	2.27	1.26	4.8
Englerophytum magalismontanum	4.94	1.86	4.87	11.7
Ficus sur	1.18	4.36	1.17	6.7
Hyperacanthus amoenus	2.74	0.59	2.70	6.0
Parinari curatellifolia	5.85	9.04	5.77	20.7
Peltophorum africanum	1.28	2.67	1.26	5.2
Pseudolachnostylis maprouneifolia	1.55	2.64	1.53	5.7
Pteleopsis myrtifolia	21.48	24.46	21.17	67.1
Scolopia Mundii	2.19	1.32	2.16	5.7
Strychnos madagascariensis	2.83	3.23	2.79	8.9
Syzygium cordatum	1.83	2.94	1.80	6.6
Tabernaemontana elegans	4.85	1.66	4.77	11.3
Xylopia odoratissima	2.01	1.49	1.98	5.5

Appendix 8: List of tree species uses per community.

DAMANI COMMUNITY				
Vernacular	**Common name**	**Scientific name**	**S.A No.***	**Uses***
Luanakha	Mauritius-thorn	*Caesalpinia decapetala* (Roth) Alston	NA*	B
Muafukhada	Avocado	*Persea americana* Mill.	NA	A, B
Mudedede	Lavender-tree	*Heteropyxis natalensis* Harv.	455	A, B
Muelela	Flatcrown	*Albizia adianthifolia* (Schumach.) W. Wight var. adianthifolia	148	A, B, C, D, E
Muembe	Wild custard-apple	*Annona senegalensis* Pers. subsp. Senegalensis	105	A, B, C, D, E
Muenene	Forest bigleaf	*Anthocleista grandiflora* Gilg	632	B
Mufhata	Lowveld silver-oak	*Brachylaena discolor* DC.	724	A, B, D, E
Mufula	Marula	*Sclerocarya birrea* (A. Rich.) Hochst. subsp. caffra (Sond.) Kokwaro	360	A, B, C, D, E
Mugwavha	Guava	*Psidium guajava* L.	778	A, B, C
Mugwiti	Velvet bushwillow	*Combretum molle* R.Br. ex G.Don	537	A, B, E
Muhataha	Round-leaved bloodwood	*Pterocarpus rotundifolius* (Sond.) Druce subsp. rotundifolius	236.5	B, E
Muhatu	Toad-tree	*Tabernaemontana elegans* Stapf	644	B, C
Muhuhuma	Shakama-plum	*Hexalobus monopetalus* (A.Rich.) Engl. & Diels	106	A, B, C, E
Muhuyungala	Broom-cluster	*Ficus sur* Forssk.	50	A, B, C, E
Mukavhavhe	Lemon	*Citrus limon* (L.) Osbeck	NA	B, C
Mukolokote	Camels-foot	*Piliostigma thonningii* (Schumach.) Milne-Redh.	209	B, C
Mukurukuru	Pigeon wood	*Trema orientalis* (L.) Blume	42	B, C
Mukwakwa	Black monkey-orange	Strychnos madagascariensis Poir.	626	A, B, C
Mukwalikwali	Tassel berry	*Antidesma venosum* E. Mey. ex Tul.	318	A, B, C
Mulitshi	Litchi	*Litchi chinenesis* Sonn	NA	C
Mululudza	Eared vernonia	*Gymnanthemum myrianthum* (Hook.f.) H. Rob.	723	B
Muluwa	Flame thorn	*Acacia ataxacantha (*DC.) Kyal. & Boatwr.	160	A, B, E
Mumvumvu	White stinkwood	*Celtis africana* Burm.f.	39	B, C, E
Munembenembe	Sjambok pod	*Cassia abbreviata* Oliv. subsp. beareana (Holmes) Brenan	212	B
Munerengisi	Mandarin orange	*Citrus reticulata* Blanco	NA	C

Munnamutswu	Red hookberry	*Artabotrys monteiroae* Oliv.	105.1	B
Munngo	Mango	*Mangifera indica* L.	NA	A, B, C
Munombelo	Milk plum	*Englerophytum magalismontanum* (Sond.) T.D.Penn.	581	A, B, C, E
Mumungu	Forest knobwood	*Zanthoxylum davyi* (I. Verd.) P.G. Waterman	255	B
Munzere	Mitzeerie	*Bridelia micrantha* (Hochst.) Baill.	324	A, B, C, E
Mupfuka	Sand raisin	*Grewia microthyrsa* K. Schum. ex Burret	461.1	A, B, C, E
Mupfumbupfumbu	Plum fingerleaf	*Vitex ferruginea* Schumach. & Thonn.	659	C
Muramba	Spiny monkey-orange	*Strychnos spinosa* Lam. subsp. spinose	629	A, B, C, E
Murathamapfene	Wild gardenia	*Rothmannia capensis* Thunb.	693	A, B, E
Murenzhe	Sickle bush	*Dichrostachys cinerea* (L.) Wight & Arn. subsp. africana Brenan & Brummitt	190	A, B, D, E
Murombe	Spiny gardenia	*Hyperacanthus amoenus* (Sims) Bridson	690	A, B, C
Musese	African wattle	*Peltophorum africanum* Sond.	215	A, B, E
Musimbiri	Lebombo-ironwood	*Androstachys johnsonii* Prain	327	A, B, E
Musinde	Purplewood flat bean	*Dalbergia nitidula* Baker	530	E
Mususu	Silver cluster-leaf	*Terminalia sericea* Burch. ex-DC.	551	B, E
Muswiri	Orange	*Citrus sinensis* (L.) Osbeck	NA	C
Mutamba-na-mme	Bead-bean tree	*Maerua angolensis* DC. subsp. Angolensis	132	B
Mutambapfunda	Large-leaved albizia	*Albizia versicolor* Welw. ex Oliv.	158	B, E
Mutango	Willow beechwood	*Faurea saligna* Harv.	75	A, B, E
Mutondo	Transvaal teak	*Pterocarpus angolensis* DC.	236	B, E
Mutondowa	Kudu-berry	*Pseudolachnostylis maprouneifolia* Pax	308	B
Mutswiriri	Pride-of-De Kaap	*Bauhinia galpinii* N.E.Br.	208.3	B, E
Mutu	Water berry	*Syzygium cordatum* Hochst. ex C. Krauss subsp. Cordatum	555	A, B, C, E
Mutungu	Rubber-hedge euphorbia	*Euphorbia tirucalli* L.	355	B
Muvhula	Mobola-plum	*Parinari curatellifolia* Planch. ex Benth.	146	A, B, C, E
Muvhulavhusiku	Kalahari bitterwood	*Xylopia odoratissima* Welw. ex Oliv.	109	A, B
Muvuvha	Bicoloured bushwillow	*Combretum collinum* Fresen. subsp. gazense (Swynn. & Baker f.) Okafor	541	A, E
Muzwilu	Velvet wild-medlar	*Vangueria infausta* Burch. subsp. Infausta	702	A, B, C, E
Nwanda	Stink-bushwillow	*Pteleopsis myrtifolia* (M.A. Lawson) Engl. & Diels	547	A, E
Phetane	Lowveld bitter tea	*Gymnanthemum coloratum* (Willd.) H. Rob. & B. Kahn sens.lat.	723	B

Unknown	Climbing raisin	*Grewia caffra* Meisn.	459	A, B, C, E

THENZHENI COMMUNITY

Vernacular name	Common name	Scientific name	S.A No.	Uses
Muafukhada	Avocado	*Persea americana* Mill.	NA	A, B
Muberegisi	Peach	*Prunus persica* (L.) Batsch var. persica	NA	B, C
Muelela	Flatcrown	Albizia adianthifolia (Schumach.) W. Wight var. adianthifolia	148	A, B, C, D, E
Muembe	Wild custard-apple	*Annona senegalensis* Pers. subsp. Senegalensis	105	A, B, C, D, E
Mufhanza	Jackal-coffee	*Tricalysia lanceolata* (Sond.) Burtt Davy	698	A
Mufhata	Lowveld silver-oak	*Brachylaena discolor* DC.	724	A, B, D, E
Mufula	Marula	*Sclerocarya birrea* (A. Rich.) Hochst. subsp. caffra (Sond.) Kokwaro	360	A, B, C, D, E
Mugugunu	Kooboo-berry	*Mystroxylon aethiopicum* (Thunb.) Loes. subsp. aethiopicum	410.1	A, B, C, E
Mugwavha	Guava	*Psidium guajava* L.	NA	A, B, C
Mugwiti	Velvet bushwillow	*Combretum molle* R.Br. ex G.Don	537	A, B, E
Muhashaphande	Wild mulberry	*Trimeria grandifolia* (Hochst.) Warb. subsp. Grandifolia	503	A, B, E
Muhatu	Toad-tree	*Tabernaemontana elegans* Stapf	644	B, C
Muhuhuma	Shakama-plum	*Hexalobus monopetalus* (A. Rich.) Engl. & Diels	106	A, B, C, E
Muhuyungala	Broom-cluster	*Ficus sur* Forssk.	50	A, B, C, E
Mukho	False cabbage-tree	*Schefflera umbellifera* (Sond.) Baill.	556	B, E
Mukwalikwali	Tassel berry	*Antidesma venosum* E. Mey. ex Tul.	318	A, B, C
Mukwakwa	Black monkey-orange	*Strychnos madagascariensis* Poir.	626	A, B, C
Mukwatule	Cape-blackwood	*Maytenus peduncularis* (Sond.) Loes.	401	B, E
Mukavhavhe	Lemon	*Citrus limon* (L.) Osbeck	NA	B, C
Mula-notshi	Wild elder	*Nuxia floribunda* Benth.	319	A, B, E
Mula-thoho	Forest fever-berry	*Croton sylvaticus* Hochst.	330	B
Mululudza	Eared vernonia	*Gymnanthemum myrianthum* (Hook.f.) H.Rob.	723.2	B
Muluwa	Flame thorn	*Acacia ataxacantha* (DC.) Kyal. & Boatwr.	160	A, B, E
Mumvumvu	White stinkwood	*Celtis africana* Burm.f.	39	A, B, C
Munadzi	Quinine-tree	*Rauvolfia caffra* Sond.	647	B
Munembenembe	Sjambok pod	*Cassia abbreviata* Oliv. subsp. beareana (Holmes) Brenan	212	B
Munerengisi	Mandarin orange	*Citrus reticulata* Blanco	NA	C

Munnamutswu	Red hookberry	*Artabotrys monteiroae* Oliv.	105.1	B
Munngo	Mango	*Mangifera indica* L.	NA	A, B, C
Munombelo	Milk plum	*Englerophytum magalismontanum* (Sond.) T.D.Penn.	581	A, B, C, E
Munukatshilongwe	Smooth tinderwood	*Volkameria glabra* (E. Mey.) Mabb. & Y.W. Yuan	667	B, E
Munzere	Mitzeerie	*Bridelia micrantha* (Hochst.) Baill.	324	A, B, C, E
Muombva	Banana	*Musa acuminata* Colla	NA	B, C
Mupapawe	Pawpaw	*Carica papaya* L.	NA	B, C
Mupfure	Castor-oil tree	*Ricinus communis* L. var. communis	NA	B
Murenzhe	Sickle bush	*Dichrostachys cinerea* (L.) Wight & Arn. subsp. africana Brenan & Brummitt	190	A, B, D, E
Muringa	Horse-radish tree	*Moringa oleifera* Lam.	NA	B
Murombe	Spiny gardenia	*Hyperacanthus amoenus* (Sims) Bridson	690	A, B, C
Musenzhe	Cabbage-tree	*Cussonia spicata* Thunb.	464	B
Musese	African wattle	*Peltophorum africanum* Sond.	215	A, B, E
Musinde	Purplewood flat bean	*Dalbergia nitidula* Baker	530	E
Musuma	Jackal-berry	*Diospyros mespiliformis* Hochst. ex A.DC.	606	A, B, C, E
Muswiri	Orange	*Citrus sinensis* (L.) Osbeck	NA	C
Mutambapfunda	Large-leaved albizia	*Albizia versicolor* Welw. ex Oliv.	158	B, E
Mutangauma	Whiteberry-bush	*Flueggea virosa* (Roxb. Ex Willd.) Voigt subsp. Virosa	309	A, B, C
Mutango	Willow beechwood	*Faurea saligna* Harv.	75	A, B, E
Mutebeila	Mulberry	*Morus alba* L. var. alba	NA	C
Muthanzwa	Large sourplum	*Ximenia caffra* Sond. var. caffra	103	B, C
Muthasiri	Red currant	*Searsia chirindensis* (Schönland) Moffett	380	A, C
Mutibamela	False assegai	*Maesa lanceolata* Forssk.	37	B, C
Mutobvuma	Cape-ash	*Ekebergia capensis* Sparrm.	298	B, E
Mutomboti	Rock-alder	*Afrocanthium mundianum* (Cham. & Schltdl.) Lantz	710	A, B, C, E
Mutondowa	Kudu-berry	*Pseudolachnostylis maprouneifolia* Pax	308	B
Mutshetshete	Buffalo thorn	*Ziziphus mucronata* Willd. subsp. Mucronata	447	A, B, C, E
Mutshikili	Natal-mahogany	*Trichilia emetica* Vahl subsp. emetic	301	B, C
Mutswiriri	Pride-of-De Kaap	*Bauhinia galpinii* N.E.Br.	208.3	B, E
Mutu	Water berry	*Syzygium cordatum* Hochst. ex C. Krauss subsp. Cordatum	555	A, B, C, E
Mutumbula	Cassava	*Manihot esculenta* Crantz	NA	B, C

Muumo	Common wild fig	*Ficus burkei* (Miq.) Miq.	48	B, C
Muunga	Sweet thorn	*Acacia karroo* (Hayne) Banfi & Gallaso	NA	A, B, D
Muvhazwi	Mountain nettle	*Obetia tenax* (N.E.Br.) Friis	70	C
Muvhale	Sacred coral-tree	*Erythrina lysistemon* Hutch.	245	B
Muvhula	Mobola-plum	*Parinari curatellifolia* Planch. ex Benth.	146	A, B, C, E
Muvhulavhusiku	Kalahari bitterwood	*Xylopia odoratissima* Welw. ex Oliv.	109	A, B
Muvhuyu	Baobab	*Adansonia digitata* L.	467	B, C
Muzwilu	Velvet wild-medlar	*Vangueria infausta* Burch. subsp. Infausta	702	A, B, C, E
Nwanda	Stink-bushwillow	*Pteleopsis myrtifolia* (M.A. Lawson) Engl. & Diels	547	A, E
Pathane	Unknown	*Gymnanthemum amygdalinum* (Delile) Sch.Bip. ex Walp.	723.4	B
Tshituku	Weeping brides-bush	*Pavetta lanceolata* Eckl.	718.1	B

TSHIOAKO COMMUNITY

Vernacular name	Common name	Scientific name	S.A No.	Uses
Muafukhada	Avocado	*Persea americana* Mill.	NA	A, B
Mudzidzi	Large hook-berry	*Artabotrys brachypetalus* Benth.	105.2	B, C, E
Muelela	Flatcrown	*Albizia adianthifolia* (Schumach.) W. Wight var. adianthifolia	148	A, B, C, D, E
Muembe	Wild custard-apple	*Annona senegalensis* Pers. subsp. Senegalensis	105	A, B, C, D, E
Mufhafha	Paperbark corkwood	*Commiphora marlothii* Engl.	278	B, C
Mufhata	Lowveld silver-oak	*Brachylaena discolor* DC.	724	A, B, D, E
Mufhulu	Wild seringa	*Burkea africana* Hook.	197	A, B, E
Mufula	Marula	*Sclerocarya birrea* (A.Rich.) Hochst. subsp. caffra (Sond.) Kokwaro	360	A, B, C, D, E
Mugwavha	Guava	*Psidium guajava* L.	778	A, B, C
Mugwiti	Velvet bushwillow	*Combretum molle* R.Br. ex G.Don	537	A, B, E
Muhashaphande	Wild mulberry	*Trimeria grandifolia* (Hochst.) Warb. subsp. Grandifolia	503	A, B, E
Muhataha	Round-leaved bloodwood	*Pterocarpus rotundifolius* (Sond.) Druce subsp. rotundifolius	236.5	B, E
Muhatu	Toad-tree	*Tabernaemontana elegans* Stapf	644	B, C
Muhuhuma	Shakama-plum	*Hexalobus monopetalus* (A. Rich.) Engl. & Diels	106	A, B, E
Muhuyungala	Broom-cluster	*Ficus sur* Forssk.	50	A, B, C, E
Mukavhavhe	Lemon	*Citrus limon* (L.) Osbeck	NA	B, C
Mukudakhombe	Sourberry	*Dovyalis rhamnoides* (Burch. ex-DC.) Burch. & Harv.	509	B

Mukwalikwali	Tassel berry	*Antidesma venosum* E. Mey. ex Tul.	318	A, B, C
Mukwatule	Cape-blackwood	*Maytenus peduncularis* (Sond.) Loes.	401	B, E
Mulanotshi	Wild elder	*Nuxia floribunda* Benth.	319	A, B, E
Mulathoho	Forest fever-berry	*Croton sylvaticus* Hochst.	330	B
Mulingwi	Wing-leaved wooden-pear	*Schrebera alata* (Hochst.) Welw.	612	B
Mulumanamana	Bushveld saffron	*Elaeodendron transvaalense* (Burtt Davy) R.H.Archer	416	B
Muluwa	Flame thorn	*Acacia ataxacantha* (DC.) Kyal. & Boatwr.	160	A, B, E
Mundodzi	Pigeon pea	*Cajanus cajan* (L.) Millsp.	NA	C
Munerengisi	Mandarin orange	*Citrus reticulata* Blanco	NA	C
Munngo	Mango	*Mangifera indica* L.	NA	A, B, C
Munombelo	Milk plum	*Englerophytum magalismontanum* (Sond.) T.D.Penn.	581	A, B, C, E
Munzere	Mitzeerie	*Bridelia micrantha* (Hochst.) Baill.	324	A, B, C, E
Muombva	Banana	*Musa acuminata* Colla	NA	B, C
Mupapawe	Pawpaw	*Carica papaya* L.	NA	B, C
Mupfuka	Sand raisin	*Grewia microthyrsa* K. Schum. ex Burret	461.1	B, C, E
Mupfumbupfumbu	Plum fingerleaf	*Vitex ferruginea* Schumach. & Thonn.	659	C
Muputamazhana	Narrow-leaved violet-bush	*Rinorea angustifolia* (Thouars) Baill. subsp. natalensis (Engl.) Grey-Wilson	489	B
Murathamapfene	Wild gardenia	*Rothmannia capensis* Thunb.	693	A, B
Murenzhe	Sickle bush	*Dichrostachys cinerea* (L.) Wight & Arn. subsp. africana Brenan & Brummitt	190	A, B, D, E
Murombe	Spiny gardenia	*Hyperacanthus amoenus* (Sims) Bridson	690	A, B, C
Musanana	Mountain gonna	*Passerina montana* Thoday	NA	E
Musenzhe	Cabbage-tree	*Cussonia spicata* Thunb.	464	B
Musese	African wattle	*Peltophorum africanum* Sond.	215	A, B, E
Musinde	Purplewood flat bean	*Dalbergia nitidula* Baker	530	E
Musuma	Jackal-berry	*Diospyros mespiliformis* Hochst. ex A.DC.	606	A, B, C, E
Mususu	Silver cluster-leaf	*Terminalia sericea* Burch. ex-DC.	551	B
Mutambapfunda	Large-leaved albizia	*Albizia versicolor* Welw. ex Oliv.	158	B, E
Mutangule	Magic guarri	*Euclea divinorum* Hiern	595	B, C
Muthasiri	Red currant	*Searsia chirindensis* (Schönland) Moffett	380	A, C
Muthowa	Horn-pod tree	*Diplorhynchus condylocarpon* (Müll.Arg.) Pichon	643	B

Mutobvuma	Cape-ash	*Ekebergia capensis* Sparrm.	298	B, E
Mutokota	Pod-mahogany	*Afzelia quanzensis* Oliv.	207	A, B
Mutomboti	Rock-alder	*Afrocanthium mundia* Schltdl.) Lantz	710	A, B, C, E
Mutondo	Transvaal teak	*Pterocarpus angolensis* DC.	263	B, E
Mutondowa	Kudu-berry	*Pseudolachnostylis maprouneifolia* Pax	308	B
Mutswiriri	Pride-of-De Kaap	*Bauhinia galpinii* N.E.Br.	208.3	B, E
Mutu	Water berry	*Syzygium cordatum* Hochst. ex C. Krauss subsp. Cordatum	555	A, B, C, E
Mutulume	Matumi	*Breonadia salicina* (Vahl) Hepper & J.R.I.Wood	684	A, B, E
Mutwari	Purple-pod cluster-leaf	*Terminalia prunioides* M.A. Lawson	550	A, E
Muumo	Common wild fig	*Ficus burkei* (Miq.) Miq.	48	B
Muvhale	Sacred coral-tree	*Erythrina lysistemon* Hutch.	245	B
Muvhazwi	Mountain nettle	*Obetia tenax* (N.E.Br.) Friis	70	C
Muvhula	Mobola-plum	*Parinari curatellifolia* Planch. ex Benth.	146	A, B, C, E
Muvhulavusiku	Kalahari bitterwood	*Xylopia odoratissima* Welw. ex Oliv.	109	A, B
Muvhungo	Rubber vine	*Landolphia kirkii* Dyer ex Hook.f.	NA	A, B, C, E
Muvhuyu	Baobab	*Adansonia digitata* L.	467	B, C
Muvuvha	Bicoloured bushwillow	*Combretum collinum* Fresen. subsp. gazense (Swynn. & Baker f.) Okafor	541	A, E
Muzwilu	Velvet wild-medlar	*Vangueria infausta* Burch. subsp. Infausta	702	A, B, C, E
Nwanda	Stink-bushwillow	*Pteleopsis myrtifolia* (M.A. Lawson) Engl. & Diels	547	A, E
Sando	Forest bersama	*Bersama tysoniana* Oliv.	443	B

TSHIOMBO COMMUNITY

Vernacular name	Common name	Scientific name	S.A No.	Uses
Muafukhada	Avocado	*Persea americana* Mill.	NA	A, B
Muberekisi	Peach	*Prunus persica* (L.) Batsch var. persica	NA	B, C
Mububulu	Red milkwood	*Mimusops zeyheri* Sond.	585	A, B, C
Muelela	Flatcrown	*Albizia adianthifolia* (Schumach.) W. Wight var. adianthifolia	148	A, B, C, D, E
Mufhafha	Paperbark corkwood	*Commiphora marlothii* Engl.	278	B, C
Mufhanda	Apple-leaf	*Philenoptera violacea* (Klotzsch) Schrire	238	B, E
Mufhata	Lowveld silver-oak	*Brachylaena discolor* DC.	724	A, B, D, E

Mufhulu	Wild seringa	*Burkea africana* Hook.	197	A, B, E
Mufula	Marula	*Sclerocarya birrea* (A.Rich.) Hochst. subsp. caffra (Sond.) Kokwaro	360	A, B, C, D, E
Mugwavha	Guava	*Psidium guajava* L.	778	A, B, C
Mugwiti	Velvet bushwillow	*Combretum molle* R.Br. ex G.Don	537	A, B, E
Muhashaphande	Wild mulberry	*Trimeria grandifolia* (Hochst.) Warb. subsp. Grandifolia	503	A, B
Muhataha	Round-leaved bloodwood	*Pterocarpus rotundifolius* (Sond.) Druce subsp. rotundifolius	236.5	B, E
Muhatu	Toad-tree	*Tabernaemontana elegans* Stapf	644	B
Muhuhuma	Shakama-plum	*Hexalobus monopetalus* (A. Rich.) Engl. & Diels	106	A, B, C, E
Mukavhavhe	Lemon	*Citrus limon* (L.) Osbeck	NA	B, C
Mukonde	Lebombo euphorbia	*Euphorbia confinalis* R.A.Dyer	345	B
Mukundandou	Cork-bush	*Mundulea sericea* (Willd.) A. Chev. subsp. Sericea	226	B
Mukwakwa	Black monkey-orange	*Strychnos madagascariensis* Poir.	626	A, B, C
Mulitshisi	Litchi	*Litchi chinenesis* Sonn	NA	C
Mumvumvu	White stinkwood	*Celtis africana* Burm.f.	39	A, B, C
Munarengisi	Mandarin orange	*Citrus reticulata* Blanco	NA	C
Munnamutswu	Red hookberry	*Artabotrys monteiroae* Oliv.	105.1	B
Munngo	Mango	*Mangifera indica* L.	NA	A, B, C
Munombelo	Milk plum	*Englerophytum magalismontanum* (Sond.) T.D.Penn.	581	A, B, C, E
Munungu	Forest knobwood	*Zanthoxylum davyi* (I. Verd.) P.G. Waterman	255	B
Muombva	Banana	*Musa acuminata* Colla	NA	B, C
Mupapawe	Pawpaw	*Carica papaya* L.	NA	B, C
Mupfuka	Sand raisin	*Grewia microthyrsa* K. Schum. ex Burret	461.1	B, C, E
Mupfumbupfumbu	Plum fingerleaf	*Vitex ferruginea* Schumach. & Thonn.	659	C
Mupfure	Castor-oil tree	*Ricinus communis* L. var. communis	NA	B
Mupimbi	Lowveld mangosteen	*Garcinia livingstonei* T. Anderson	486	B, C, E
Murenzhe	Sickle bush	*Dichrostachys cinerea* (L.) Wight & Arn. subsp. africana Brenan & Brummitt	190	A, B, D, E
Muringa	Horse-radish tree	*Moringa oleifera* Lam.	NA	B
Murombe	Spiny gardenia	*Hyperacanthus amoenus* (Sims) Bridson	690	A, B, C
Murombe	Spiny gardenia	*Hyperacanthus amoenus* (Sims) Bridson	690	A, B, C
Muserenga	Syringa	*Melia azedarach* L.	604	B, D, E
Musese	African wattle	*Peltophorum africanum* Sond.	215	A, B, E

Mushakaladza	Karee	*Searsia lancea* (L.f.) F.A. Barkley	386	A, B, C, E
Musinde	Purplewood flat bean	*Dalbergia nitidula* Baker	530	E
Musiri	Small Ironwood	*Olea capensis* L. subsp. Capensis	618	A, B
Musuma	Jackal-berry	*Diospyros mespiliformis* Hochst. ex A.DC.	606	A, B, C, E
Muswiri	Orange	*Citrus sinensis* (L.) Osbeck	NA	C
Mutambapfunda	Large-leaved albizia	*Albizia versicolor* Welw. ex Oliv.	158	B, E
Mutamvu	Knobbly fig.	*Ficus sansibarica* Warb. subsp. Sansibarica	47	B, C
Mutebeila	Mulberry	*Morus alba* L. var. alba	NA	C
Mutobvuma	Cape-ash	*Ekebergia capensis* Sparrm.	298	B, E
Mutokota	Pod-mahogany	*Afzelia quanzensis* Oliv.	207	A, B
Mutondowa	Kudu-berry	*Pseudolachnostylis maprouneifolia* Pax	308	B
Mutshikili	Natal-mahogany	*Trichilia emetica* Vahl subsp. emetic	301	B, C
Mutshimba	Apricot sourberry	*Dovyalis zeyheri* (Sond.) Warb.	511	B
Mutswiriri	Pride-of-De Kaap	*Bauhinia galpinii* N.E.Br.	208.3	B, E
Mutu	Water berry	*Syzygium cordatum* Hochst. ex C. Krauss subsp. Cordatum	555	A, B, C, E
Mutumadi	Bushveld waterberry	*Syzygium guineense* (Willd.) DC. subsp. Guineense	557	A, B, C
Muungakova	Umbrella thorn	*Acacia tortilis* (Forssk.) Gallaso & Banfi subsp. heteracantha (Burch.) Kyal. & Boatwr.	188	A, B, D, E
Muvhale	Sacred coral-tree	*Erythrina lysistemon* Hutch.	245	B
Muvhibvelashadani	Turkey berry	*Canthium inerme* (L.f.) Kuntze	708	A, C
Muvhola	Common false thorn	*Albizia harveyi* E. Fourn.	155	B
Muvhula	Mobola-plum	*Parinari curatellifolia* Planch. ex Benth.	146	A, B, C, E
Muvhulavhusiku	Kalahari bitterwood	*Xylopia odoratissima* Welw. ex Oliv.	109	A, B
Muvhungo	Rubber vine	*Landolphia kirkii* Dyer ex Hook.f.	NA	A, B, C, E
Muvhuyungala	Broom-cluster	*Ficus sur* Forssk.	50	B, C
Muvuvha	Bicoloured bushwillow	*Combretum collinum* Fresen. subsp. gazense (Swynn. & Baker f.) Okafor	541	A, E
Muzwilu	Velvet wild-medlar	*Vangueria infausta* Burch. subsp. Infausta	702	A, B, C, E
Nwanda	Stink-bushwillow	*Pteleopsis myrtifolia* (M.A. Lawson) Engl. & Diels	547	A, E
Sando	Common white ash	*Bersama tysoniana* Oliv.	443	B
Tshikululu	African-rock fig	*Ficus glumosa* Delile	64	B, C
Tshiphophamadi	White pear	*Apodytes dimidiata* E. Mey. ex Arn. subsp. dimidiates	422	B

Tshituku	Weeping brides-bush	*Pavetta lanceolata* Eckl.	718.1	B

*S. A No. = South Africa's national number
NA= Not registered in South Africa
Uses= Uses in Vhembe District
A= Fuelwood, B= Traditional medicine, C= Wild fruits, D= Fodder, E= Constructions

Appendix 9: Questionnaire English version

General information.

1. Questionnaire no: ………………
2. Date: ....../....../ 2020
3. Name of the Village: ……………………
4. How long have you been staying here? ....

A. Respondent and household background.

1. Age

Age category	18-25	26-35	36-60	61-Above
Tick	1	2	3	4

2. Gender

Gender	Male	Female
Tick	0	1

3. Household source of income.

Source of income	No Income	Employed	Self-employed	Pensioner	Social grant
Tick	1	2	3	4	5

4. Level of Education.

Highest education	No education	Primary	Secondary	Tertiary
Tick	1	2	3	4

5. How many are you in the household? ………………………………………..
6. Are you born in this community? Yes ☐ No ☐
7. Was farming part of your childhood or family history? Yes ☐ No ☐

B. Provisioning ecosystem services in traditional agroforestry landscape

1. Food and Fruits

1.1 From which landscape do you harvest food (e.g. Fruits, etc.)?

Source of food and fruits	Occurrence			
	Often all the time	Occasionally	Little	Not at all
Immediate distance	1	2	3	4
Intermediate distance	1	2	3	4
Far distance	1	2	3	4

1.2 Provide the most important trees species for food and fruits?
A ………………………………B ……………………………………
C ………………………………D………………………………………
E ………………………………………

2. Fuel wood

2.1 From which landscape do you harvest/collect the fuel wood?

Source of food	Occurrence			
	Often all the time	Occasionally	Little	Not at all
Immediate distance	1	2	3	4
Intermediate distance	1	2	3	4
Far distance	1	2	3	4

2.2 Provide the most important trees species for fuel wood?

A ……………………………….. B …………………………………

C ……………………………….D………………………………….

E ………………………………………

2.3 Which source of energy is important to your household?

Source of food	Very important	Important	Least important	Not important
Fuel wood	1	2	3	4
Electricity	1	2	3	4
Gas	1	2	3	4
Solar	1	2	3	4
Charcoal	1	2	3	4

2.4 How much fuel wood do you collect/harvest from your landscape?

Source	A lot	Some	A little
Immediate distance	1	2	3
Intermediate distance	1	2	3
Far distance	1	2	3

3. Traditional medicine

3.1 From which landscape do you harvest/collect traditional medicine?

Source of traditional medicine	Occurrence			
	Often all the time	Occasionally	Little	Not at all
Immediate distance	1	2	3	4
Intermediate distance	1	2	3	4
Far distance	1	2	3	4

3.2 Provide the most important trees species for harvest/collect traditional medicine?

A ……….……………. B ……………………….

C ……………………D………………………….

E ………………………………

3.3 Which plant parts do you collect most?

Plant parts	Often	Sometimes	Rarely	Not at all
Leaves	1	2	3	4
Bark	1	2	3	4
Roots	1	2	3	4
Whole tree (Shrubs)	1	2	3	4

4. Livestock grazing

4.1 Do you own livestock? Yes [1] No [2]

4.2 If Yes, Q 4.1, from which landscape does your livestock graze?

Livestock	Immediate distance	Intermediate distance	Far distance
Goats	1	1	1
Sheep	2	2	2
Cattle	3	3	3
Donkey	4	4	4

4.3 Provide the most tree species livestock's feed on?

A …………………………. B ………………………………..

C ……………………………D……………………………….

E …………………………………

5. Do these factors influence your harvesting/collection of provisioning ecosystem services?

Factors	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
Poverty	1	2	3	4	5
Culture/Tradition	1	2	3	4	5
Value/Usefulness	1	2	3	4	5
Elevation	1	2	3	4	5
Accessibility	1	2	3	4	5
Availability	1	2	3	4	5
Other (Specify)……	1	2	3	4	5

C. Biodiversity

1. Do you think your community deliberately conserve tree species diversity?

Yes	No	I do not know
1	2	3

2. What are the major benefits of biodiversity in traditional agroforestry landscape?

Benefits	A benefit	Somewhat a benefit	Not a benefit
Food production	1	2	3
Traditional medicine production	1	2	3
Cultural value	1	2	3
Fresh water and air	1	2	3
Firewood production	1	2	3
Timber production	1	2	3
Environmental benefit	1	2	3
Livestock feeds production	1	2	3
Other…………………………	1	2	3

3. What is the purpose of collecting provisioning ecosystem services?

Provision ecosystem services	Purpose		
	Consumption	Trade	Both
Fuel wood	1	2	3
Food/Fruits	1	2	3
Timber/Poles	1	2	3
Medicine	1	2	3
Livestock fodder	1	2	3
Other (Specify)…………………………	1	2	3

4. What are the tree species availability status over the last 20 years??

Landscape	Increased	No change	Decreased	Disappeared
Immediate distance	1	2	3	4
Intermediate distance	1	2	3	4
Far distance	1	2	3	4

5. Do you manage your landscape as a community? Yes ☐ No ☐
6. If Yes, in Q5, What are the management activities are done by community for tree species protection and conservation in your landscape?

Activities	Immediate distance	Intermediate distance	Far distance
Sustainable harvesting of resources	1	2	3
Reporting illegal harvesting	1	2	3
Planting more indigenous trees	1	2	3
Conserving indigenous trees	1	2	3

Planting exotic trees	1	2	3
Other	1	2	3

7. Who is responsible for community landscape management?

Landscape	Institutions/Stakeholders				
	Government	Community	NGO	Tribal	Household
Immediate distance	1	1	1	1	1
Intermediate distance	2	2	2	2	2
Far distance	3	3	3	3	3

8. Rate the effectiveness of these institutions/stakeholders on tree species and biodiversity protection?

Institutions/Stakeholders	Not effective	Effective	Very effective
Government	1	2	3
Community	1	2	3
NGO	1	2	3
Tribal	1	2	3
Household	1	2	3

9. Would you support community initiative in forest and biodiversity conservation/protection in your landscape?

Degree of willingness	Strongly willing	Willing	Undecided	Not at all
Tick	1	2	3	4

D. Comments and questions

………………………………………………………………………………………………

Appendix 10: Questionnaire Tshivenda version

General information.

5. Questionnaire no: ………………
6. Date: ____/____/ 2020
7. Name of the village: ……………………
8. Ndi tshikhala tshingafhani vhatshi dzula afha? ....

E. Zwidodombedzwa zwa mufhinduli.

8. Minwaha

Khethekanyo ya minwaha	18-25	26-35	36-60	61-Uya ntha
Tick	1	2	3	4

9. Mbeu

Mbeu	Munna	Mufumakadzi
Tick	0	1

10. Zwididombedzwa zwa masheleni mutani.

Ndila ine vha unda muta	Ahuna	Ushuma	Udishuma	Phesheni	Mundende
Tick	1	2	3	4	5

11. Zwidodobedza zwa Pfunzo.

Murole wa ntha	Usadzhena tshikolo	Phuraimari	Sekondari	Yunivesithi
Tick	1	2	3	4

12. Vha dzula vha vhangana afha mutani? …………………………………………..
13. Vho bebwa kha kusi uku? Ee ☐ Hai ☐
14. Vho vhuya vhadi dzhenisa kha zwavhulimi afha mutani? Ee ☐ Hai ☐

F. Zwibveledzwa zwa mupo

6. Zwiliwa na mitshelo ya daka

6.1 Vha wana gai zwiliwa na mitshelo ya daka afha mutani?

Vha wana gai?	Kuwanele kwa zwiliwa na mitshelo			
	Tshifhinga tshothe	Nga zwifhinga	Zwituku	Usa itea tshifhinga tshothe
Hanefha kusini	1	2	3	4
Nnda ha kusi (tsini)	1	2	3	4
Nnda ha kusi (kule)	1	2	3	4

6.2 Ndi i fhio mirhi ya ndemesa yo no shumisiwa sa zwiliwa na mitshelo?
A ………………... B ………………….
C …………………D………………….
E ………………………

7. Khuni dzau vhasa

7.1 Vha wana gai khuni dzau vhasa afha mutani?

Vha wana gai?	Kuwanele kwa khuni

	Tshifhinga tshothe	Nga zwifhinga	Zwituku	Usa itea tshifhinga tshothe
Hanefha kusini	1	2	3	4
Nnda ha kusi (tsini)	1	2	3	4
Nnda ha kusi (kule)	1	2	3	4

7.2 Ndi i fhio mirhi ya ndemesa yau shumisiwa sa khuni dzau vhasa?
A …………………... B ……………….
C ……………………D………………….
E ……………………
7.3 Ndi zwifhio zwishumiswa zwau vhasa zwa ndemesa kha muta wavho?

Zwishumiswa zwau vhasa	Zwa ndemesa	Zwa ndeme	Zwa ndeme zwituku	Asi zwa ndeme
Khuni dzau vhasa	1	2	3	4
Gese	1	2	3	4
Mudagasi	1	2	3	4
Malasha	1	2	3	4
Solar	1	2	3	4
Zwinwevho………	1	2	3	4

7.4 Khuni dza u vhasa vha wana nngafhani kha kusi kwavho?

Vha wana gai	Nnzhisa	Nzhi	Thuku
Hanefha kusini	1	2	3
Nnda ha kusi (tsini)	1	2	3
Nnda ha kusi (kule)	1	2	3

8. Mushonga

8.1 Vha wana gai mishonga ya mirhi ya daka?

Vha wana gai?	Kuwanele kwa mushonga			
	Tshifhinga tshothe	Nga zwifhinga	Zwituku	Usa itea tshifhinga tshothe
Hanefha kusini	1	2	3	4
Nnda ha kusi (tsini)	1	2	3	4
Nnda ha kusi (kule)	1	2	3	4

8.2 Ndi I fhio mirhi ya ndeme yau shumisiwa sa mushonga?
A ………………..…. B ………………….
C ……………………D………………….
E ……………………
8.3 Vha shumisesa zwipida zwifhio zwa muri?

Zwipida zwa tshimela	Tshifhinga tshothe	Nga zwifhinga	U konda	Usa itea tshifhinga tshothe

Matari	1	2	3	4
Makwati	1	2	3	4
Midzi	1	2	3	4
Muri wothe	1	2	3	4

9. Zwifuo

9.1 Vhana zwifuwo? Ee 1 Hai 2

9.2 Arali phindulo hu Ee, Q 4.1, Vhana zwifuwo zwifhio? Zwi fula gai?

Zwifuwo	Hanefha kusini	Nnda ha kusi (tsini)	Nnda ha kusi (kule)
Mbudzi	1	1	1
Nngu	2	2	2
Kholomo	3	3	3
Mbongola	4	4	4
Zwinwevho………….	5	5	5

9.3 Ndi if fhio mirhi yau fula nga zwifuwo?
A ……………………..……. B ……………………………….
C ……………………………D……………………………….
E ……………………………

10. Zwiitisi zwitevhelaho zwina masiandaitwa kushumisele kwavho kwa zwibveledzwa zwa mupo?

Zwiitisi	Utenda vhukuma	U tenda	Vhukati	Uhana	Uhana vhukuma
Vhusiwana	1	2	3	4	5
Sialala	1	2	3	4	5
Vhundeme	1	2	3	4	5
U sa dura	1	2	3	4	5
Zwivhanga/Mathakheni	1	2	3	4	5
U swikelelea	1	2	3	4	5
U wanalea	1	2	3	4	5
Zwinwevho……	1	2	3	4	5

G. Fhamba-fhambano ya mirhi

1. Vha vhona u nga vhathu vha vhuponi havho vhaa tsireledza tshaka dza miri na zwi zwi no tshila kha vhupo?

Ee	Hai	A thi divhi
1	2	3

2. Ndi dzi fhio mbuyelo dza fhamba-fhambano ya miri kha kusi kwavho?

Mbuyelo	Zwia vhuyedza	Uvhuyedza sa zwezwo	Usa vhuyedza
Ubveledza zwiliwa	1	2	3
Ubveledza mishonga	1	2	3

Vhundeme ha sialala	1	2	3
Madi na muya zwo kunaho	1	2	3
Ufhungudza muya mufhe	1	2	3
Ubveledza khuni dzau vhasa	1	2	3
Ubveledza matanda	1	2	3
Ulanga gomelelo na midalo	1	2	3
Ubveledza zwiliwa zwa zwifuwo	1	2	3
Zwinwevho…………………….	1	2	3

3. Tshipikwa tshau koleka mikovhe ya mupo?

Tshumelo I wanalaho kha mupo	Tshipikwa		
	Ula	Urengisa	Zwothe
Khuni dzau fhasa	1	2	3
Zwiliwa/Mitshelo	1	2	3
Matanda	1	2	3
Mushonga	1	2	3
Pfulo	1	2	3
Zwinwevho…………………………	1	2	3

4. Tshiimo tsha kuwanelo ka mirhi kha minwahani ya 20 yo fhiraho

Fethu	Uengedzea	Usa shanduka	U fhungudzea	Usa wanala
Hanefha kusini	1	2	3	4
Nnda ha kusi (tsini)	1	2	3	4
Nnda ha kusi (kule)	1	2	3	4

5. Vhaya thogomela mupo/madaka a shango lavho sa kusi? Ee ☐ Hai ☐
6. Arali phindulo hu Ee, Q5, Ndi zwifhio zwine sa kusi vha zwi ita u tshireledza mupo?

Maga	Hanefha kusini	Nnda ha kusi (tsini)	Nnda ha kusi (kule)
U rema nga ndila vhulungeyaho	1	2	3
Uvhiga u rema zwisiho mulayoni	1	2	3
Utavha miri fhano nga tshivhalo	1	2	3

U tsireledza nau vhulunga miri ya fhano	1	2	3
Utavha miri isi ya fhano nga tshivhalo	1	2	3
Zwinwevho……………….................	1	2	3

7. Ndi nnyi ari na vhudi fhinduleli kha u thogomela mupo?

Fhethu	Zwiimiswa				
	Muvhuso	Shango	NGO	Musunda	Muta
Hanefha kusini	1	1	1	1	1
Nnda ha kusi (tsini)	2	2	2	2	2
Nnda ha kusi (kule)	3	3	3	3	3

8. Ku shumele kwa zwiimiswa khau tsireledza tshaka dza miri na zwi no tshila kha vhupo

Zwiimiswa	Usa shuma	U shuma	U shuma nga maanda
Muvhuso	1	2	3
Shango	1	2	3
NGO	1	2	3
Musanda	1	2	3
Muta	1	2	3

9. Naa vhanga tikedza u tsireledziwa ha mupo na madaka vhuponi havho?

Tshiimo tshau tenda	U tenda vhukuma	U tenda	Vhukati	Usa tenda
Tick	1	2	3	4

H. Mbudziso na u dadzisa

……………………………………………………………………………………

Appendix 11: Inventory form

Village: ………………....... Transect no. ………Plot no.………….

Date of assessment: …. /……/ 2020 Assessed by: …………………

Distance level	**Tick**
Immediate distance	
Intermediate distance	
Far distance	

A. General description of the landscape

Latitude: …………………		**Longitude:** ……………...		**Altitude (m):** ………………	
Aspect	Level	Gentle	Steep	Very steep		**Stand height**	…….(m)
Tick	1	2	3	4		**Canopy cover**	…….(%)

Forest stand structure (*tick*)

Open	1	Stand initiation	2	Stand exclusion	3
Old growth	4	Other	5		

Understory type (*tick*)

Grass	1	Herbs	2	Shrubs	3
Other	4				

B. Disturbance

Scientific name	**Local name**	**DBH (cm)**	**Height (m)**	**Tree condition**		
				Live	**Dead**	**Damaged**
1.						
2.						
3.						
4.						
5.						

1. Forest fire extent

Heavy	1	Moderate	2	Light	3	No fire	4

2. Fire type

Underground	1	Surface	2	Crown	3	Not sure	4
Not applicable	5						

3. Grazing evidence	Yes	1	No	2	

4. Grazing incidence

Slightly	1	Moderate	2	Severe	3	None	4

5. Timber and fuel wood extraction

Clear cutting	1	Selective felling	2	Group felling	3	No felling	4
Other …………	5						

6. Mining

Surface collect	1	Quarry	2	No	3

C. Stand composition.

1. Trees and shrubs form

2. Sapling

Scientific name	**Local name**	**No. of individuals**	**Height (m)**
1.			
2.			
3.			
4.			
5.			

3. Seedlings

Scientific name	**Local name**	**No. of individuals**
1.		
2.		
3.		
4.		
5.		

4. Remarks

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………