SOCIO-ECONOMIC DIMENSIONS AND COMMUNITY BEHAVIOR TOWARDS *Pinus patula* SPREAD IN COMMUNITIES AROUND MULANJE MOUNTAIN FOREST RESERVE AND MISUKU HILLS FOREST RESERVES, MALAWI

MSc THESIS (FORESTRY AND ENVIRONMENTAL MANAGEMENT)

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MZUZU UNIVERSITY

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THESIS SUBMITTED TO THE FACULTY OF ENVIRONMENTAL SCIENCES, DEPARTMENT OF FORESTRY AND ENVIRONMENTAL MANAGEMENT, IN FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF A MASTER OF SCIENCE (MSc) DEGREE IN FORESTRY AND ENVIRONMENTAL MANAGEMENT.

MZUZU UNIVERSITY

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DECLARATION

I hereby declare that this thesis titled "Social-Economical dimensions and community Behaviour towards of *Pinus patula* spread in communities around MMFR and MHFR", has been written by me and is a record of my research work. All citations, references, and borrowed ideas have been duly acknowledged. It is being submitted in fulfilment of the requirements for the award of the degree of Master Forestry and Environmental Management of the Mzuzu University. None of the present work has been submitted previously for any degree or examination in any other University.

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Cosmas Dambo Date

CERTIFICATE OF APPROVAL

I, the undersigned, certify that this thesis is a result of the author's own work, and that to the best of my knowledge, it has not been submitted for any other academic qualification within the Mzuzu University or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on Date.

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Major Supervisor

Professor V. Kasulo Date

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ABSTRACT

Pinus patula is increasingly invading Malawi's montane ecosystems, with Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserve (MHFR) showing notable spread into community lands. While pines were introduced for timber and livelihood support, their rapid expansion now threatens biodiversity, water resources, and arable land. This is creating socio-ecological trade-offs that remain poorly quantified in Malawi. This study addresses the research problem of limited empirical evidence on both the benefits and costs of *P. patula* invasion, and how community knowledge, attitudes, and practices (KAP) shape management responses.

The study aimed to characterize spatial distribution of *P. patula*, assess community KAP toward the species, and analyse socio-economic costs and benefits to local livelihoods. A mixed-methods design was used, including household surveys (n=175), FDG, spatial mapping using QGIS, and opportunity cost–analyses. Non-parametric statistics (Spearman correlations, Mann-Whitney U tests, Kruskal-Wallis tests at 5% significance) were used to analyse variable relationships.

The findings revealed spontaneousness spread in Mulanje, while in Misuku it mostly persists in smallholder woodlots. Community awareness and attitudes were generally high in both sites, but improvement in practices was limited in Misuku, influenced by institutional and livelihood constraints. Economically, *P. patula* contributes income through timber, poles, and fuelwood; however, opportunity cost assessment indicated that diversified crops e.g., maize, coffee yield short term stable returns.

The study concludes that *P. patula* is a classic "conflict-of-interest" invasive species providing socioeconomic benefits while simultaneously degrading ecological integrity and undermining biodiversity-based livelihoods. Therefore, effective management must integrate local social equity and ecological restoration measures. It is recommended that Malawi strengthens participatory invasive species management, promotes alternative livelihood options, and aligns local interventions with the National Invasive Alien Species Strategy and Kunming-Montreal Global Biodiversity Framework commitments.

Keywords: *Pinus patula*; invasive species; socio-economic impacts; biodiversity loss; KAP; cost-benefit analysis; Malawi

DEDICATION

This work is dedicated to those who have walked with me on this journey.

To my **MOTHER** (Alfonsina Luka) and **FATHER** (Vincent Dambo Snr), your sacrifices run deep within.

To my family—your unwavering love, encouragement, and sacrifices have been the foundation of my strength. Thank you for believing in me even when the path was unclear.

To my mentors and teachers, your guidance and wisdom have shaped not only this thesis but also the person I am becoming.

To my friends and colleagues, your support, laughter, and shared moments of perseverance made this process lighter and more meaningful.

And finally, to the communities and environments that inspired this research, may this work contribute, in some small way, to the protection and sustainability of our shared future.

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ACRONYMS

ADB	African Development Bank
ANOVA	Analysis of Variance
BCR	Benefit Cost Ratio
CBD	Convention on Biological Diversity
CI	Confidence Interval
DoF	Department of Forestry
EAD	Environmental Affairs Department
EC	Exceptional Contribution
FRIM	Forestry Research Institute of Malawi
GoM	Government of Malawi
GTZ	Germany Technical Cooperation
IAS	Invasive Alien Species
ISP	Invasion Sensitization Projects
KAP	Knowledge, Attitude & Practices
MMCT	Mulanje Mountain Conservation Trust
NPV	Net Present Value
MMFR	Mulanje Mountain Forest Reserve
NSO	National Statistical Office
OC	Opportunity Cost
UNEP	United Nations Environmental Programme
VIF	Value Inflation Factor
IUCN	International Union for Conservation of Nature

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CHAPTER 1: INTRODUCTION

1.1. BACKGROUND OF THE STUDY OR OVERVIEW OF THE STUDY

Invasive alien plants can be defined as plants that have been introduced into a new geographical location as a result of human activities and are seen to spread beyond that original point of introduction to other areas within the new environment where they have negative impacts (Blackburn *et al.*, 2011; Richardson and Pysek, 2012). Just like Invasive Alien Species (IAS) in general, these have been reported to have both positive and negative impacts on different aspects of biotic and abiotic environments (Sanu & Newport, 2010). Positively they have become crucial for local livelihoods and national economies through provision of goods and services (Shackleton *et al*. 2007; van Wilgen *et al*., 2011), which include provision of fast growing species for pulp, timber and fuel wood (Ravinder *et al*. 2009), livestock folder especially in times, food seasonings, provision of agroforestry tree species, soil erosion control, provide shelter and food resources for native species (Schlaepfer, Sax, & Olden, 2011) and even effectively stabilizing soils in areas where natural forests have been over-exploited . Conversely, negative impacts include shading out and reduction of richness and diversity of native plants communities (van Wilgen *et al*, 2016), reduction of ground water levels (Dzikiti *et al*, 2013), encroachment of agricultural fields resulting in reduced cultivation area and increased cost of production (Shackleton *et al*. 2014), native forest fragmentation which affects richness and assemblage of native birds and mammals (Zurita *et al*., 2017), and restricted movement of people and livestock alongside reduced amount of foliage available to livestock (Shackleton *et al*. 2017).

According to Shackleton (2014) and Weber (2003), some invasive trees are considered “conflict of interest” species because they generate both significant costs and benefits. For instance, Prosopis species may be highly valued when incorporated into agroforestry systems and thus provide pods for livestock feed, while in other contexts they render agricultural land unproductive through their aggressive rate of spread (Weber, 2003). This duality is seen with *Prosopis juliflora* in Kenya and Ethiopia, where locals benefit from fuelwood, charcoal, and fodder, yet experience reduced crop productivity, pasture invasion, and biodiversity loss (Kishoin *et al*., 2024). Other invasive species have been reported to produce both negative and positive effects within the same communities, creating conflicting feedback loops among residents (Shackleton *et al*., 2011; Mwangi & Swallow, 2008). For instance, *Acacia mearnsii* in South Africa where apart from provision of abundant fast growing fuel wood, construction materials and charcoal, it is also a culprit of reduction in surface run off, affect water availability and impact biodiversity (de Weit *et al*, 2001)

Regarding such conflict of interest species and others in a recent appraisal of the impacts of biological invasions on ecosystem services globally, Vila and Hulme (2017a) highlighted that the socio-economic impacts (i.e., both costs and benefits) of such invasive alien trees is context-dependent; arising due to differences in the density and extent of invasions, environmental conditions (soil, climate, ecology), income levels of people and their livelihood diversification in invaded communities, as well as economic priorities of policy makers and planners at a strategic level. Shackleton (2017) further highlighted that the perceptions, attitudes and overall understanding/knowledge levels of communities in how they interact with invasive alien plants is key in defining the actual and perceived socio-economic impacts of conflict-of-interest invasive alien trees.

Good information on the occurrence and distribution is an essential starting point that enables the quantification of these threats and informs the development of appropriate responses (Witt *et al.*, 2018). In situations where information on such aspects of an invasion is missing, implementation of any management intervention is difficult and likely to result in the loss of vital ecosystem services or economic opportunities in the invaded community (Hulme and Vila, 2017b; 2017c). This is the case in most of the sub-Saharan African countries, where no comprehensive lists of invasive alien plants are present (Henderson & Wilson, 2017)

In Malawi, Parita and Mankhambera (2019) revealed the dominance of speculative information and inadequate knowledge on the extent and nature of invasive plant impacts in different communities around protected areas of Malawi, with Mulanje Mountain Forest Reserve as a case in point. This situation is similar for other forest reserves in the country, including Misuku Hills Forest Reserve, where despite a lack of detailed impact studies, there is sufficient evidence of invasive alien tree species in the surrounding communities. These include specifically Himalayan yellow raspberry (*Rubus ellipticus*) and Mexican pine (*Pinus patula*), which have been identified as threats to the reserve's ecological integrity (Makhambera, 2014).

Pines as invasive alien trees have been a cause for substantial concern because of their ecological and socio-economic impacts. Locally, studies in Malawi and the wider region show pine encroachment into montane ecosystems, with early warnings about biodiversity risks and altered ecosystem processes (Makhambera, 2013). Worldwide, pine invasions are now widely recognized as major ecological disruptors. For instance, McConnachie *et al*., (2015) demonstrated that commercial pine plantations often act as an invasion force into surrounding protected areas, imposing significant management costs. Consequently, pines may be classed as conflict-of-interest species because they provide both benefits and costs depending on context (Shackleton *et al*., 2014).

1.2. PROBLEM STATEMENT

The spread of *Pinus patula* in Malawi's montane ecosystems, particularly around Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserve (MHFR), presents a complex socio-ecological dilemma. As a classic "conflict-of-interest" invasive alien species, *P. patula* delivers tangible livelihood and economic benefits while simultaneously imposing significant ecological costs. On one hand, it provides timber, poles, and fuelwood that contribute to rural livelihoods and local markets. On the other hand, its aggressive spread threatens endemic biodiversity, alters hydrological systems, and undermines ecosystem resilience. This dual role complicates ongoing national efforts to develop and implement an invasive alien species (IAS) management program that is both ecologically effective and socially equitable.

Despite growing recognition of these challenges, empirical evidence on the socio-economic tradeoffs of *P. patula* in Malawi remains limited. Earlier studies (Parita & Makhambera, 2019) have noted the absence of systematic evaluations that incorporate local communities' knowledge, attitudes, and practices (KAP) alongside ecological assessments. This gap reflects broader concerns raised by Shackleton (2017) across the Global South, where invasive species management often neglects community perspectives, leading to interventions that lack legitimacy. This generates resistance or fails to account for livelihood dependencies. In Malawi, such an oversight risks undermining the effectiveness of a national IAS management program, thereby potentially resulting in the loss of both critical ecosystem services and unexploited livelihood opportunities associated with *P. patula.*

Against this backdrop, there is a pressing need for a comprehensive appraisal of the costs and benefits of *Pinus patula* invasion in Malawi's montane landscapes. By focusing on MMFR and MHFR as ecologically critical and socially dependent forest reserves, this study aims to generate context-specific evidence to inform balanced, participatory, and livelihood-sensitive invasive species management strategies.

1.3. STUDY OBJECTIVES

To assess the socio-Economic dimensions and community behaviour towards Pinus *patula* spread in communities around Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserve (MHFR) in Malawi

1.3.1. SPECIFIC OBJECTIVES

1. To characterize the spatial distribution of *P. patula* invasion in communities around MMFR and MHFR.
2. To determine the knowledge, attitudes and practices of communities around MMFR and MHFR towards *P. patula* invasion.
3. To assess the cost-benefit impact of *P. patula* invasion to community livelihoods around MMFR and MHFR.

1.3.2. RESEARCH QUESTIONS

1. What is the spatial distribution and abundance of *P. patula* invasion around MMFR and MHFR?

2. What are the prevailing knowledge, attitudes, and practices of communities towards *P. patula* invasion around MMFR and MHFR?
3. What are the social-economic cost and benefits of *P. patula* invasion to community livelihoods around MMFR and MHFR?

1.4. JUSTIFICATION OF THE STUDY

This study is significant in advancing both scientific understanding and policy practice on invasive alien species in sub-Saharan Africa. By systematically evaluating the socio-economic and ecological impacts of *Pinus patula* in communities adjacent to Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserve (MHFR), the research will generate robust empirical evidence on the relative weight of costs and benefits associated with this conflict-of-interest species. Determining whether the livelihood and economic gains outweigh the ecological and social costs or vice versa provides a critical knowledge base for evidence-driven decision-making.

For Malawi, with national IAS strategies already in place, this study provides the field-based evidence needed to put those policies into action. By showing how *Pinus patula* affects livelihoods, biodiversity, and ecosystem services in specific landscapes, the research helps government agencies prioritize interventions, target resources, and adapt management to local realities. In doing so, it strengthens the practical implementation of Malawi's IAS policies and increases the likelihood of effective, socially legitimate management on the ground.

Beyond the national context, this research makes an important contribution to the global discourse on invasive alien species management. While much of the literature on *P. patula* is produced from South Africa, there remains a paucity of community-level cost-benefit analyses that integrate ecological impacts with local perceptions and practices. By filling this gap, the study will add to comparative international knowledge on invasive species management in resource-dependent rural settings, providing a replicable framework for similar assessments across sub-Saharan Africa. In doing so, it will serve as a platform for further scholarly inquiry, stimulate cross-country learning, and ultimately contribute to regional and global strategies for balancing development needs with ecological restoration.

1.5. ETHICAL CONSIDERATION

This study was conducted in strict adherence to established academic and professional research ethics. Prior to the commencement of fieldwork, ethical clearance was obtained from the Mzuzu University Directorate of Research and Postgraduate Studies, ensuring that the research design met institutional standards for the protection of human subjects. Further administrative authorization was sought and granted by the Department of Forestry and the District Councils of Mulanje and Chitipa, under whose jurisdiction the Mulanje Mountain and Misuku Hills Forest Reserves fall.

Before data collection, the researcher provided a comprehensive explanation of the study's purpose, objectives, and scope to all prospective participants. This was done in the local languages of Chichewa for Mulanje and Chitumbuka/Lambya in Chitipa (through a translator). Participants were explicitly informed that their involvement was entirely voluntary and that they retained the right to withdraw from the study at any point without incurring any form of penalty or disadvantage. To uphold the principles of confidentiality and anonymity, no personally identifiable information was recorded on any data collection instruments. All responses were anonymized through coding and securely stored in password-protected digital files accessible only to the researcher. Data were used exclusively for academic purposes and were presented in aggregated form to prevent the identification of individual respondents.

Throughout the research process, the researcher demonstrated cultural sensitivity and respect for local customs, traditional authorities, and community structures. Engagement with local leaders preceded household-level data collection, and their guidance was actively sought to ensure that research activities were culturally appropriate and socially acceptable. At no point during the study were participants subjected to deception, coercion, or undue influence. The research was designed to pose no physical, psychological, or social risks to participants. In instances where discussions involved sensitive topics, particularly those related to livelihoods or environmental concerns, participants were treated with empathy, and their perspectives were handled with discretion and respect.

Finally, all secondary sources, including academic literature, technical reports, and cartographic materials, were properly cited and referenced in accordance with the Harvard referencing style, thereby upholding the principles of academic integrity and avoiding any form of plagiarism.

CHAPTER 2: LITERATURE REVIEW

2.1 THEORETICAL BACKGROUND

Plant species have been moved out of their native ranges into new areas for centuries, for intentions such as agriculture, agroforestry, and ornamental purposes, as well as unintentionally in imported goods and grain shipments (Mack, 2003). Most of these plant species have been observed to conquer and impact the new environments where they are introduced. This has had two faces, dependent on several factors such as the type of plant species and interaction with both biotic and abiotic factors. Therefore, there have been both attributes that provide favorable and unfavorable environmental factors.

According to Shackleton *et al*. 2017 some of these species naturalise, and a smaller proportion become invasive. Naturalised species are those that have established self-sustaining populations but that do not spread, whereas invasive species are those that have spread, often over substantial distances from where they have become naturalised (Blackburn *et al*., 2011), and are causing ecological, health, or economic harm resulting in negative impacts on people and the environment. (Shackleton *et al*., 2017).

Pines (*Pinus* spp.) are among the most widely introduced tree genera globally, planted extensively for timber, pulp, soil stabilization, and other utility purposes (Richardson, 2006; Richardson & Rejmánek, 2004). Their fast growth and adaptability across ecological zones have supported plantation forestry, particularly in the tropics and subtropics. However, these same traits have made them some of the most problematic invasive alien species in non-native environments (Vilà *et al*., 2011; Pyšek *et al.*, 2012). As a result, pines have become model organisms for understanding the dual roles of introduced trees as both providers of socio-economic benefits and drivers of ecological disruption (Nuñez *et al*., 2017).

In the Southern African Development Community (SADC) region, pine species such as *P. patula*, *P. radiata,* and *P. elliottii* were introduced during the colonial period to supply commercial forestry industries and household energy demands (Richardson & van Wilgen, 2012; van Wilgen & Richardson, 2014).

While these plantations remain economically important, they have also been identified as an invasion force, with spillovers into surrounding communities, protected areas, rangelands, and water catchments. In South Africa, the Cape Floristic Region provides some of the clearest evidence. The pine invasion has transformed large tracts of land, reducing streamflow, altering fire regimes, and displacing native biodiversity (van Wilgen, 2015; Le Maitre *et al.*, 2000). These well-documented impacts have placed pines at the centre of debates over invasive species management in the SADC.

By contrast, in Malawi and several other SADC countries, research has been more limited, though available evidence suggests similar concerns. For instance, Makhambera (2014) reported reductions in indigenous plant species richness within Mulanje Mountain Forest Reserve (MMFR) in areas where *P. patula* has expanded. Despite such findings, systematic evaluations of pine invasions remain scarce, particularly with respect to their socio-economic trade-offs. This lack of comprehensive local studies stands in stark contrast to the global literature, which consistently demonstrates both ecological costs and livelihood benefits of pine invasions (Hofstede *et al.*, 2002).

Taken together, the literature underscores a paradox where while pines provide timber, fuelwood, and income to communities, they also degrade biodiversity, water, and soil systems in invaded habitats. The following review, therefore, synthesizes current global, regional, and national evidence on pine invasions, with particular attention to *P. patula* in Malawi. In doing so, it positions the study within broader debates on invasive species as "conflict-of-interest" taxa and highlights the need for more context-specific evidence to guide management in under-researched regions such as Malawi.

2.2. EMPIRICAL EVIDENCE

2.2.1 WHAT ARE INVASIVE ALIEN TREES?

Invasive alien trees (IATs) are non-native, perennial woody species introduced beyond their natural ranges whose introduction and/or spread threatens biodiversity and can cause environmental, economic, or social harm. This often get facilitated through human mediated pathways such as trade, transport, and deliberate plantings (Rejmánek *et al.*, 2005; CBD, 2024). This aligns with the Convention on Biological Diversity's definition of invasive alien species and the recent IPBES global assessment, which identifies invasive species as one of the five major direct drivers of biodiversity loss worldwide (IPBES, 2023).

Their impacts are multifaceted, scaling from genes to ecosystems. Invasive plants, including trees, can depress native species richness and abundance, alter community phylogenetic structure, disrupt trophic interactions, and modify key ecosystem processes (Pyšek *et al*., 2020). Meta-analyses and global syntheses further show that nonnative trees can significantly affect regulation services such as soil fertility, erosion control, carbon storage, and hydrology. Sometimes providing benefits but more often leading to trade-offs, particularly when they dominate local vegetation (Castro-Díez *et al*., 2019; Castro-Díez *et al*., 2021). A consistent pattern across sites is that high local abundance of IATs strongly predicts negative biodiversity impacts (Vilà *et al*., 2011; Vilà *et al*., 2024).

The introduction and establishment of IATs is strongly linked to globalization. Empirical evidence shows no saturation in the accumulation of alien species worldwide, with sharp increases projected through the mid-21st century (Seebens *et al*., 2017; Seebens *et al*., 2018). Human-mediated pathways remain central, with widely adopted classification frameworks emphasizing intentional introductions (e.g., forestry and ornamental escapes), contaminants on traded goods, and unintentional stowaways (Hulme *et al*., 2008; Faulkner *et al.*, 2020). These pathways highlight the role of prevention and pathway management in reducing future invasions.

Many IATs reach abundances sufficient to influence biodiversity and ecosystem services which is consistent with early studies (Vilà *et al*., 2011). Also, more recent policy syntheses underscore the importance of early detection, rapid response, and ecosystem-based management approaches to minimize ecological and socio-economic harm (IPBES, 2023; CBD, 2024).

Invasion is mainly driven by three factors: firstly, the attributes of the invading species such as seed size, growth rate, dispersal traits and mechanisms (Kleunen *et al*., 2010); secondly, it is the environmental characteristics upon which the species land, including soil type, extent (i.e., frequency, intensity and spread) of ecological disturbances in the invaded habitat (Chytry *et al*., 2008a,b) and different aspects of climate change and variability (Lambdon *et al*., 2008; Thuiller *et al*., 2005). Lastly, propagule pressure, which is the period since initial introduction in the new environment (Williamson *et al*., 2009; de Albuquerque *et al*., 2011), the number of individuals introduced, and frequency of introduction events of the species in the habitat (Pysek *et al*., 2009).

2.2.2 IMPACTS OF IATs

These invasive alien plant species have been observed to reduce natural plant species diversity in areas where they conquer. In other areas, they even replace the native plants completely (Brockerhoff *et al*., 2008; Hejda *et al*. 2009; Powell *et al*. 2011), which results in loss of natural habitat and food for wild animals (Lenzi *et al*., 2018). They have also been observed to alter the rate of nutrient recycling (Ehrenfeld 2010), degrade soils, reduce space for agriculture (Pimentel *et al*. 2000), hurt and poison livestock, as well as reduction of river and underground water flow (reducing chances of irrigation and hard for boreholes). However, in other instances, they have been observed to provide fast-growing wood to meet needs for the fast-growing populations, nutritious fodder, erosion checks, and being of high economic value.

In an experiment conducted by Schuster and Duke (2014) on non-additive invasive tree litter shift seasonal nitrogen release, confirmed that invasive alien trees also increase ecosystem productivity by altering the rate of nutrient recycling, which increases their release to more than six times than expected from the single species.

However, studies have revealed that some of these species also create a variety of adverse social, ecological, and economic impacts in the environments they occur, with a double strain on the institutional structures charged with addressing invasions (Vila and Hulme, 2017). For instance, Shackleton *et al*. (2015) revealed that invasions of *Prosopis* species in different environments in South Africa reduced densities of native plant species such as *Acacia erioloba* and *Acacia karroo*, which are very important for local livelihood in terms of income, subsistence, firewood and folders. This is in tandem with what Gaertner *et al.*, (2009), observed with Australian Acacia species which accounted for the most significant declines in native species richness. Native species richness of shrublands, old fields, and dune vegetation showed significant declines, in contrast to insignificant declines for forest habitats. This disruption of natural environment indirectly impacts human wellbeing as they disturb established ecological conditions such as native fauna habitats, vegetation coverage and composition, and water and air quality.

In many instances, the loss of plant diversity affects habitat and food availability for wild animals which results in an imbalance of the food chain, hence a reduction or loss of fauna diversity as well. The loss in pastureland to invasive plants also hinders livestock farming, which in turn distresses the livelihoods of affected communities (Kumari and Choudhary, 2016). For example, Arvin *et al*. (2010) in their study conducted in the Malai Mahadeshwara Hills Wildlife Sanctuary of Southern Kamataka revealed that the Soliga communities reportedly have stopped grazing their cattle in the forest due to spread of *Lantana camara*. Similarly, in Zimbabwe, South Africa, and Australia as noted by Hayson and Murphy (2003), the invasive species of *Acacia farnesiana*, *Mimosa pigra*, *Prosopis glandulosa* and *Prosopis velutina* reduce the amount of grass folder as well as forming very dense thickets through which livestock cannot move. This reduces even the chances of livestock browsing the leaves and pods or fruits of the trees.

Several researchers have observed some cross pollination between alien and native species. This results in hybridisation of the native plant species hence loss of native plant diversity (CBD, 2002). This interspecific hybridisation between abundant alien and rare native plant species can threaten populations of the native species through outbreeding depression or through high rate of gene flow swamping native population (Walter *et al*., 2007) resulting in the loss of genetic purity of native species which is very worrying, especially for the rare and endangered species.

Prosopis species have also been found to be culprits of hybridisation in South Africa (Pasiecznik *et al.*2001), *Leuceana* species in Papua New Guinea, Philippines, and America. This can lead to contamination of natural gene pool.

Increase in ground fuel load by invasive alien species, foster alteration of fire regimes in natural forests. For example, in Wildman reserve in northern Australia, invasion of *Andropon gauanus* increased fuels by up to seven times and fire intensity by up to eight times (Rossiter *et al*. 2003). In Dinosaur national park and Snake River birds of prey national park (USA), *Bromus tectorum* changed the fire frequency from one in 60-100 years to every 3-5 years. This therefore transformed the native shrub lands to an alternative state that is likely to be permanently dominated by alien grasses (Randall, 2011).

2.3 CONFLICT OF INTEREST CREATING INVASIVE ALIEN TREES

IAS may be intentionally or unintentionally introduced into a new environment. The case of weed seeds imported as contaminants of grains is an instance of unintentional introductions (Behailu, 2013). Nevertheless, most of the plants that have been observed to be invasive, were intentionally introduced with positive economic, environmental, and social benefits of the species in mind such as food seasonings, medication (Mack and Emeberg, 2002), ornamental (Arne *et al*, 2018) fast growth forestry, horticulture and agroforestry (Richardson and Rejimaek, 2011). Typical species which have been intentionally introduced for agro forestry include *Pinus*, *Eucalyptus* and Australia *Acacia* species in the forest sector, where they serve as important sources of pulp, timber and fuel wood (Ravinder *et al*., 2009). However, studies have revealed that some of these species also create a variety of adverse social, ecological and economic impacts in the environments they occur, with a double strain on the institutional structures charged with addressing invasions (Vila and Hulme, 2017). For instance, Richardson & Higgins (1998) found that pine invasions altered fire regimes in South Africa by greatly increasing fuel load which increases the frequency and intensity of fires in the fire-prone fynbos and grassland vegetation, leading to erosion as well as decreased native plant species diversity. In the same way, Shackleton *et al*. (2015) revealed that invasions of *Prosopis* species in different environments in South Africa reduced densities of native plant species such as *Acacia erioloba* and *Acacia karroo*, which are very important for local livelihood in terms of income, subsistence, firewood and folders. On the other hand, *Prosopis* also provide them with fast growing fuel, alternative vegetation cover and pods. The same is also observed in India by Pasiecznik *et al*. (2001) where *Prosopis juliflora* was introduced from America. It has conquered pasturelands with its annoying thorns which also hurt livestock and is growing in dense thickets in waste grounds and along roadsides even though the communities enjoy its fuel and pods for animal protein.

2.4 CONTEXT DEPENDENCE OF INVASIVE ALIEN TREES IMPACTS

Invasive alien tree (IAT) impacts are rarely uniform. They emerge from interactions among biophysical settings, disturbance regimes, spatial scale, and socio-institutional contexts. Global assessments now frame invasive species, trees prominent among them, as major direct drivers of biodiversity change, but emphasize that realized impacts hinge on local conditions and management choices (IPBES, 2023). For trees specifically, recent syntheses show heterogeneous effects across ecosystem services (hydrology, soils, carbon, fire) and biodiversity, with direction and magnitude modulated by environment and dominance levels rather than "invasiveness" alone (Castro-Díez *et al*., 2019; Castro-Díez *et al*., 2021; Vilà *et al*., 2011).

Ecological and biophysical setting condition the sign and strength of impacts. In water-limited or fire prone systems such as fynbos, montane grasslands, riparian corridors, IATs can intensify competition for water, elevate fuel loads, and shift disturbance dynamics. These effects may be muted in wetter or less fire adapted ecosystems (Le Maitre *et al*., 2016; Gaertner *et al*., 2017). Classic field work in tropical montane systems illustrates how exotic pine plantations alter soils and moisture, impacts that are seasonally accentuated and site-specific (Hofstede *et al*., 2002). Such findings underline that hydrological and edaphic changes are contingent on geology, elevation, precipitation regimes, and stand age/structure.

Disturbance regimes and feedback further shape outcomes. By modifying fire frequency/intensity and fuel connectivity, some non-native trees create positive feedback that entrench novel states, while in other settings active disturbance management can dampen such feedback (Gaertner *et al*., 2017; IPBES, 2023). The same taxa may thus be classed as high-impact in one biome and lower-impact in another under the IUCN EICAT standard, which explicitly scores impact severity across mechanisms and contexts (IUCN, 2020; Volery *et al*., 2020; Kumschick *et al*., 2024).

Scale of analysis is critical. At local scales, landholders may perceive benefits such as fuelwood, poles, shade and erosion control, producing positive valuations even where landscape scale assessments register habitat homogenization, altered flows, or biodiversity loss. While at regional/global scales, economic syntheses aggregate damage and management costs that can mask local heterogeneity (Vilà *et al.*, 2011; Diagne *et al*., 2021). Consequently, conclusions about "net impact" often invert with the assessment horizon, stakeholders involved, and the bundle of services considered (Castro-Díez *et al*., 2019).

Socio-economic reliance and cultural valuation strongly mediate perceived impact. In regions where smallholders integrate non-native timber species into livelihood strategies, blanket removals without alternatives can trigger welfare losses and provoke resistance even when ecological risks are documented (Shackleton *et al*., 2019). Divergent stakeholder frames of conservation risk vs. livelihood asset, explain why the same tree can be simultaneously "harmful" and "useful," producing contested impact narratives (Kull *et al*., 2011; IPBES, 2023).

Institutions and governance such as policy coherence, funding, and participation determine whether potential impacts become realized or are mitigated. Where forestry and agriculture policies promote the same taxa that conservation policy seeks to control, management stalls and social trust erode. Conversely, coherent strategies with early detection, rapid response and community co-design improve outcomes (van Wilgen & Wilson, 2018; IPBES, 2023). Urban contexts add further complexity where competing values, high propagule pressure, and fragmented jurisdictions demand tailored decision frameworks rather than protected area paradigms (Gaertner *et al*., 2016, 2017).

Finally, temporal dynamics such as intervals, legacy effects, shifting baselines mean that short-term benefits (e.g., rapid biomass, income) can precede long-term ecological costs. Climate and trade globalization continue to expand introduction pressures, so today's low-impact populations may become tomorrow's high-impact invasions as contexts change (Kueffer, 2017; Seebens *et al*., 2017). This underscores why impact appraisal should be iterative, scenario-based, and explicitly contextual.

Invasive Alien Trees' impacts are not intrinsic properties of species; they are contingent outcomes produced by the intersection of environment (water, fire, soil), disturbance, scale, livelihoods, and governance over time. Accordingly, impact evaluation and policy should combine standardized evidence frameworks e.g. Environmental Impact Classification for Alien Taxa (EICAT) with place-based socio-ecological appraisal to avoid both over and underestimation of harm or benefits.

2.5 GROWING CHALLENGES TOWARDS MANAGEMENT OF INVASIVE ALIEN TREES.

Regardless of the acceptable facts of multifaceted impacts associated with IAS (including the socio-economic dimension highlighted by Shackleton *et al*., (2015), there is inadequate data on the impacts of IAS in developing countries (Pratt *et al*. 2017; Nghiem *et al*. 2013), as there has been a bias in studies carried out on invasive species in developed countries (Hulme *et al*., 2013). Reports from the few studies that have been undertaken, and anecdotal evidence report on how IAS have had an important impact in developing countries of sub-Saharan Africa, especially in local communities that totally depend on subsistence farming and natural resources for survival (Pratt *et al*., 2017; Parita and Mankhambera, 2019). Such introductions of fast growing , alien trees which include huge plantations seem to be necessary both to meet demand for wood-based products and to protect remaining natural forests from over-exploitation, and they are usually based on fast-growing, alien trees (Van Wilgen, 2015) For example, introduced trees species in the genera *Pinus, Eucalyptus*, and *Prosopis* in countries such as Tanzania, Malawi, Zimbabwe and Mozambique have been aimed at reducing pressure on the natural forests by providing fast growing alternative sources of timber, fuelwood, and poles for construction (Gladstone & Ledig, 1999) as well as being incorporated in agroforestry technologies for soil fertility enrichment thereby potentially reducing cost on artificial fertilisers (Beedy *et al*. 2013), the case of *Leucaena* and Australian *acacias*. This together with provision of fuelwood and other resources for resource poor communities has a potential of slowing the destruction rate of natural woodland and stabilisation of soils in over exploited natural forests (Haysom and Murphy, 2003) on which local communities depend for nourishment in terms of non-timber forest products such as orchids, mushrooms, honey, bush meat and income by selling such plus curios (Campbell *et al*, 1996; Chidumayo, 1997; Mwambumba *et al*. 1999). However, such species have been observed to replace the native plants which local communities depend on for survival and through their aggressive invasion in arable and grazing land they are reducing the already insufficient farming land.

2.6 PINES AS INVASIVE ALIEN TREES

Pinus patula (Mexican weeping pine) is a coniferous species native to the highlands of Mexico, where it typically grows between 1,500 and 3,100 m above sea level and can reach up to 30 m in height and 1.2 m in diameter (Orwa *et al*., 2009; Farjon, 2013). It has been widely introduced across the tropics and subtropics for timber, pulp, and soil conservation, including into southern Africa in the early 20th century (Richardson & Rejmánek, 2004). Its success as an invader is attributed to rapid maturity, prolific wind dispersed seeds, and strong recruitment following fire disturbance (Richardson & Higgins, 1998; Rejmánek & Richardson, 2013).

2.6.1 SPREAD AND ECOLOGICAL IMPACTS

Once established, *P. patula* readily spreads into adjacent natural habitats, where it alters ecosystem structure and processes. In South Africa's Cape Floristic Region, studies in the late 1990s and 2000s demonstrated that pine invasions significantly increased fuel loads, thereby intensifying fire regimes in fynbos and grasslands. This change promoted soil erosion and reduced native plant diversity (Richardson & Higgins, 1998; van Wilgen & Richardson, 2014). More recent spatial analyses in protected areas confirm that pine invasion is strongly associated with proximity to plantations and fire frequency, highlighting the role of landscape configuration and disturbance in invasion dynamics (McConnachie *et al*., 2015).

2.6.2 HYDROLOGICAL EFFECTS

Hydrological studies consistently show that invasive pines, including *Pinus patula* are high water use trees that depress streamflow and can reduce groundwater recharge with impacts amplified in riparian and high connectivity settings. Stand to catchment syntheses for South Africa estimated national scale river flow reductions of roughly 6–7% attributable to invasive alien trees and demonstrate that riparian invasions impose the greatest penalties on water yield (Le Maitre *et al*., 2015; Le Maitre *et al*., 2016). These findings are reinforced by ecosystem scale measurements in riparian forests showing large streamflow losses where invaders persist, and by classic paired catchment work that recorded streamflow declines following afforestation with *P. patula* (Scott, 1997; Scott-Shaw *et al*., 2017). More broadly, tropical hydrology experiments and global syntheses explain why effects vary with climate, geology, and plantation density where water storage is limited or dry season demand is high, forest (re)planting and invasion disproportionately reduce water yield and recharge (Ilstedt *et al*., 2016; Evaristo *et al*., 2019).

Recent reviews and updates converge on the same mechanism where greater transpiration and evaporation losses from dense stands of alien trees, while highlighting higher sensitivity in dry season catchments and along streams (Le Maitre, 2020; Inbar *et al*., 2022). Given Malawi's montane catchments and pronounced dry seasons, these process-based results are directly policy relevant for sites where *P. patula* has escaped plantations into riparian corridors and upper catchments such as MMFR and MHFR. Although such reductions vary with rainfall, geology, and plantation density, the results are particularly relevant for montane catchments in Malawi, where dry season water scarcity already constrains livelihoods.

2.6.3 BIODIVERSITY AND LIVELIHOOD TRADE-OFFS

The biodiversity effects of *P. patula* are context dependent. For example, in the Colombian Andes, van Wesenbeeck *et al*. (2003) found that *P. patula* plantations at 3,100 m a.s.l. reduced the richness and cover of native subpáramo vegetation, with implications for traditional medicinal plants and wildlife habitat. In southern Africa, pine-dominated stands similarly displace native species, but at the same time provide valued fuelwood, construction poles, and income (Shackleton *et al*., 2019). This duality has led to their classification as "conflict-generating species" (van Wilgen, 2015; Zengeya *et al*., 2017), reflecting their simultaneous economic value and ecological harm.

2.7. GENERAL INTRODUCTIONS OF PINES ACROSS THE WORLD AND SADC

Spread of pines including *P. patula* wis likely to increase in the Southern Africa because their economic value encourages more plantation establishment, increasing the risk of invasion. s (Ferraro *et al*, 2015; Richardson & Van Wilgen, 2012). In their study, Hofstede *et al*. 2002, also discovered that the soils under exotic trees such as *Pinus patula* in Ecuadorian High Andes was drier and less organic than those from the natural forest. This indicated that the presence of the pines resulted in less diverse ground litter and low soil moisture.

Several invasion studies in Southern Africa were conducted over the past years to review species impact on environment and biodiversity (Greenaway *et al*, 2015) as far as their existence in non-native ecosystems is concerned (Pauchard, 2015; Essl *et al*, 2011). For instance, in South Africa in Cape Floristic Region, pines were documented to invade a huge land (Van Wilgen, 2015) and also determined to elicit reduction of soil water relative to natural vegetation they replace (Richardson & Van Wilgen, 2012) while lightly reported in Malawi (Makhambera, 2014) despite reducing indigenous plant species richness in MMFR in the context of biodiversity composition.

2.7.1 PINE INVASION IN MALAWI

In Malawi, along with other tress species for pine and *Eucalyptus*, *Pinus patula* provenance trials were established in the years between 1968 and 1975. Where particularly Mexican pine (*Pinus patula*) seed was collected from Mexico in 1968.This was an effort for autonomy from the extrapolated tree breeding/ improvement results from Zambia, Zimbabwe and South Africa. It was to meet the increased demands of the seed for Viphya pulpwood project and other timber plantations in Malawi (Venkatesh & Kananji, 1985).

Since then, there has been multiple reintroductions of the species in a number of sites such as Mulanje Mountain, Misuku Hills, Viphya plantation, Zomba Mountain. Through the time, many self-sown established colonies have been observed in most of these areas including Nyika national park, Viphya and Mulanje Mountain where it has been observed to spread beyond introduced areas (Nyika Vwaza Trust report, 2017; Kacheche & Mzuza, 2021).

These invasions have been characterised by several impacts over time. For instance, in Nyika National Park, there has been a reduction of river flow and grass cover in sites where it is present. For the communities in Misuku Hills, it has become a great part of their economic uplifting cash crops along with coffee and bananas. Its timber has been favoured by construction industry as compared to indigenous trees which are mostly hard wood.

Makhambera (2014) indicated that the Forestry Department in Mulanje district has also significantly influenced the invasion of Mulanje Mountain Forest Reserve by exotic pine species, through initial introduction and the same factor was attributed for pine invasion in southern hemisphere (Burgess & Wingfield, 2001).

2.7.2 IMPACTS OF *Pinus patula* INVASION IN MALAWI.

The invasion of *Pinus patula* in Malawi has been widely documented across several ecological regions, including within protected areas such as the Mulanje Mountain Forest Reserve (MMFR), Nyika National

Park (NNP), and Zomba Plateau, as well as in the surrounding highlands near Mzuzu. Initially introduced for timber, firewood, and construction purposes, *P. patula* has now escaped cultivation and spread into native grassland, shrubland, and forest-grassland ecotones. Its establishment in these ecosystems poses a considerable threat to indigenous plant communities, biodiversity integrity, and hydrological stability (Nyika Vwaza Trust report, 2017; Kacheche & Mzuza, 2021).

On Mulanje Mountain, *P. patula* invasion is already well advanced, particularly on the northeastern plateaux where natural regeneration has been observed (Verboom, 1992). The species encroach into high-elevation grasslands and afro-montane forest communities, replacing native shrubs, grasses, and forest-margin species. The pine's rapid growth rate and tolerance to nutrient poor soils allow it to outcompete slow growing indigenous species such as the endemic Mulanje cedar (*Widdringtonia whytei*), whose regeneration is thereby suppressed (Verboom, 1992). This dynamic results in reduced native recruitment, homogenization of vegetation structure, and a marked decline in overall species richness.

Similar ecological transformations are evident in Nyika National Park, where *P. patula* was first introduced at Chelinda Camp but has since spread widely across surrounding grasslands and shrublands. Field observations and monitoring by the Nyika-Vwaza (UK) Trust (2013) indicate that pine invasion has altered grassland composition, reduced shrub cover, and displaced native grasses and forbs. These vegetation changes disrupt the habitat mosaic critical for diverse fauna, including insects, birds, and small mammals that rely on open grassland or mixed shrub habitats for foraging and nesting. As the pine canopy closes, light penetration decreases, soil microclimate cools, and moisture dynamics shift, conditions that further inhibit native understorey regeneration and alter the ecological structure of the plateau ecosystem.

In the northern highlands near Mzuzu, *P. patula* has also been recognized among the dominant alien species modifying woodland and grassland ecotones. Surveys conducted by the Mzuzu University Foresty Students' Club (2013) revealed extensive stands of *P. patula* and *Acacia mearnsii* around Chelinda and Lake Kaulene, particularly along drainage lines and forest margins. Subsequent removal trials by the

Nyika-Vwaza Trust confirmed *P. patula* as the most abundant invasive tree regenerating even after clearing efforts, demonstrating its persistence and resilience to control interventions. In line with this, Kacheche and Mzuza (2021) reported that 95 % of respondents in Nyika National Park identified *P. patula* as a major driver of habitat loss, groundwater alteration, and reduction in native vegetation cover, highlighting the species perceived ecological threat at the community level.

Comparable patterns are also found on the Zomba Plateau in southern Malawi. Verboom (1992) noted that *P. patula* had overtaken much of the indigenous upper-plateau vegetation, with native flora largely replaced by pine stands (Chapman & White, cited in Verboom, 1992). This long-term invasion history underscores the species' strong adaptive capacity to Malawi's montane environments. Given that the Zomba Plateau shares similar climatic and edaphic characteristics with the Dedza and Viphya highlands, there is growing concern that pine naturalization could extend across other central and northern highland zones where plantations were historically established.

Although quantitative hydrological studies remain scarce in Malawi, evidence from comparable ecosystems elsewhere in the region suggests that pine invasion could diminish water yields from plateau wetlands (dambos) and headwater streams (Nyika-Vwaza Trust, 2013). Such reductions in catchment discharge would have downstream consequences for agriculture, domestic water supply, and ecological flow maintenance.

The socio-ecological impacts of *P. patula* invasions in Malawi are not uniform but depend on context. In Misuku Hills, smallholders frequently integrate pine woodlots with cash crops like coffee and bananas, deriving economic benefits from timber and fuel access (Kacheche & Mzuza, 2021). In contrast, on Mulanje Mountain, where land pressure is acute and conservation of the endemic Mulanje cedar (*Widdringtonia whytei*) is a priority, the presence of *P. patula* heightens ecological risks which is threatening to biodiversity, altering hydrology, and increasing fire vulnerability. Studies on the demography and restoration of *W. whytei* reinforce the conservation importance of Mulanje and illustrate the trade-offs between livelihood utility and ecological integrity posed by pine invasion (Chanyenga *et al*., 2011).

2.8 CONCEPTUAL FRAMEWORK OF THE STUDY

This section presents the conceptual framework that guided the study. It is illustrating the relationships among the key variables i.e., spatial distribution and management of *Pinus patula*, community Knowledge, Attitudes, and Practices (KAP), ethnobotanical resource use, and socio-economic outcomes. The framework is grounded in a socio-ecological systems perspective, recognizing that human and ecological components interact dynamically. It hypothesizes that demographic and spatial factors such as land tenure, distance from the reserve, and education influence how communities perceive and manage pine, which in turn affects biodiversity, resource availability, and livelihoods. Feedback loops exist whereby livelihood benefits and ecological impacts reshape community attitudes and management decisions. The framework thus provides a structured lens for analysing how *P. patula* invasion simultaneously presents ecological challenges and economic opportunities within rural landscapes.

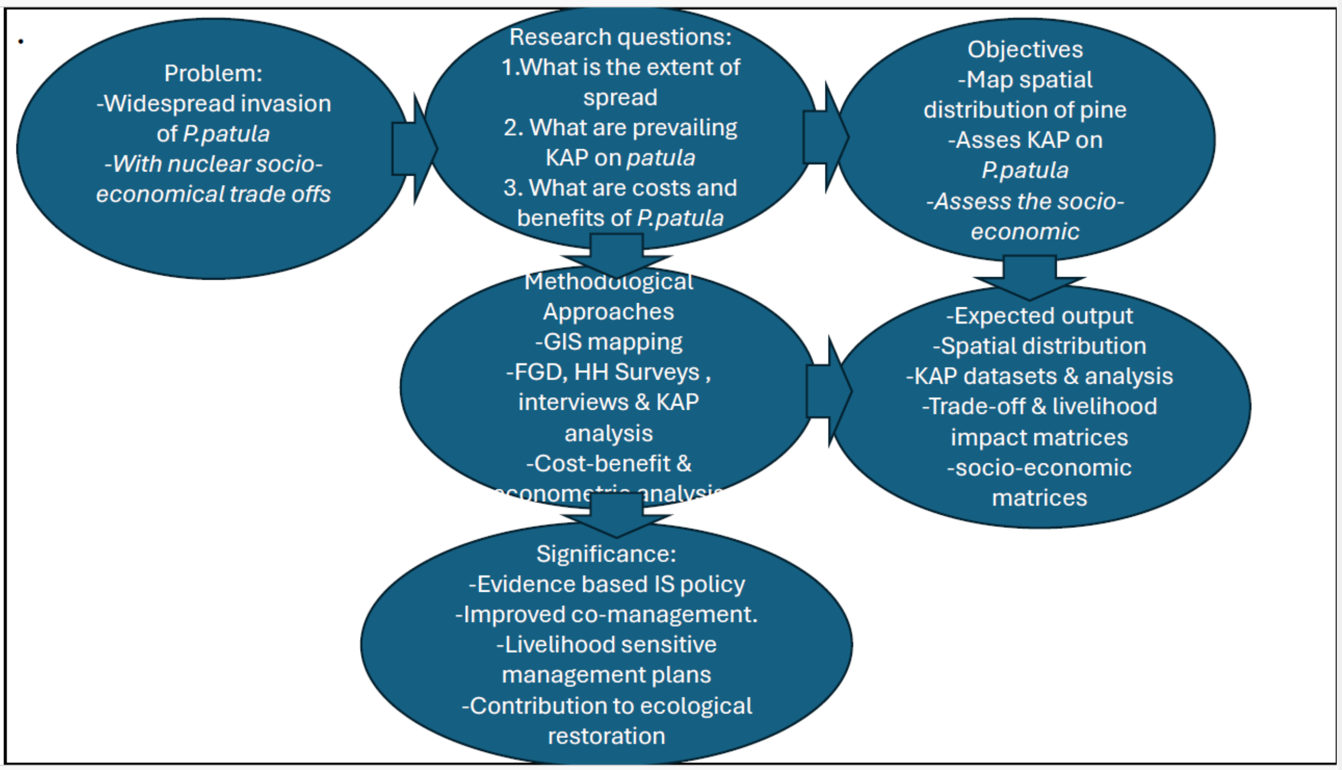

Table 2.1 Conceptual Framework for the study

This framework begins with the recognition of *Pinus patula* invasion as a socio-ecological challenge that threatens both biodiversity and local livelihoods. From this problem, specific research questions are formulated to capture the ecological extent, community knowledge and practices, and economic implications of pine management. These questions are operationalized into objectives, which are addressed through a combination of spatial, quantitative, and qualitative methods. The methodological pathways yield concrete output maps, datasets, trade-off assessments, and cost-benefit analyses that directly inform management. Finally, these outputs feed into the broader significance: evidence-based invasive species policy, strengthened co-management, livelihood-sensitive strategies, and contributions to ecosystem restoration.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. STUDY AREA

The study was conducted in selected communities adjacent to MMFR and MHFR in Malawi. These sites were chosen due to documented established plantation within or adjacent to forest reserves and distribution of *P. patula* among the surrounding communities, ecological significance, and heavy reliance of local populations on forest resources.

3.1.1 MISUKU HILL FOREST RESERVE

The Misuku Hills are situated in the extreme north of Malawi near the Tanzanian border. They rise above a much-dissected plateau to a peak of 2,050 m of Matipa on the Latitude of -9.65037 and Longitude of 33.4322 degrees. They consist of two Forest Reserves located along parallel ridges running north-west–south-east: Mughesse Forest Reserve (1,600–1,880 m & -9.66983 Latt, 33.54447 Long) includes one block of montane rainforest of c.720 ha and is separated from Wilindi–Matipa Forest Reserve (1,700–2,050 m & -968932 Lat, 33.47004) by a few km of lower-altitude cultivated land. Wilindi–Matipa supports some 2,400 ha of forest intersected on the ridge by small clearings of montane grassland. The forests of the Misuku Hills are the most floristically diverse in the country (with over 150 species of trees recorded); the main species are *Aningeria adolfi-friedericii* and *Entandrophragma excelsum*. The district forest office has been able to organise the community into block committees to sustainably manage the natural forests. Mainly, the communities indignantly the Msukwa tribe under Traditional Authority Mwenemisuku do cross border trade between Malawi and Tanzania and most of them depend much on coffee, bananas and pine woodlots for their income.

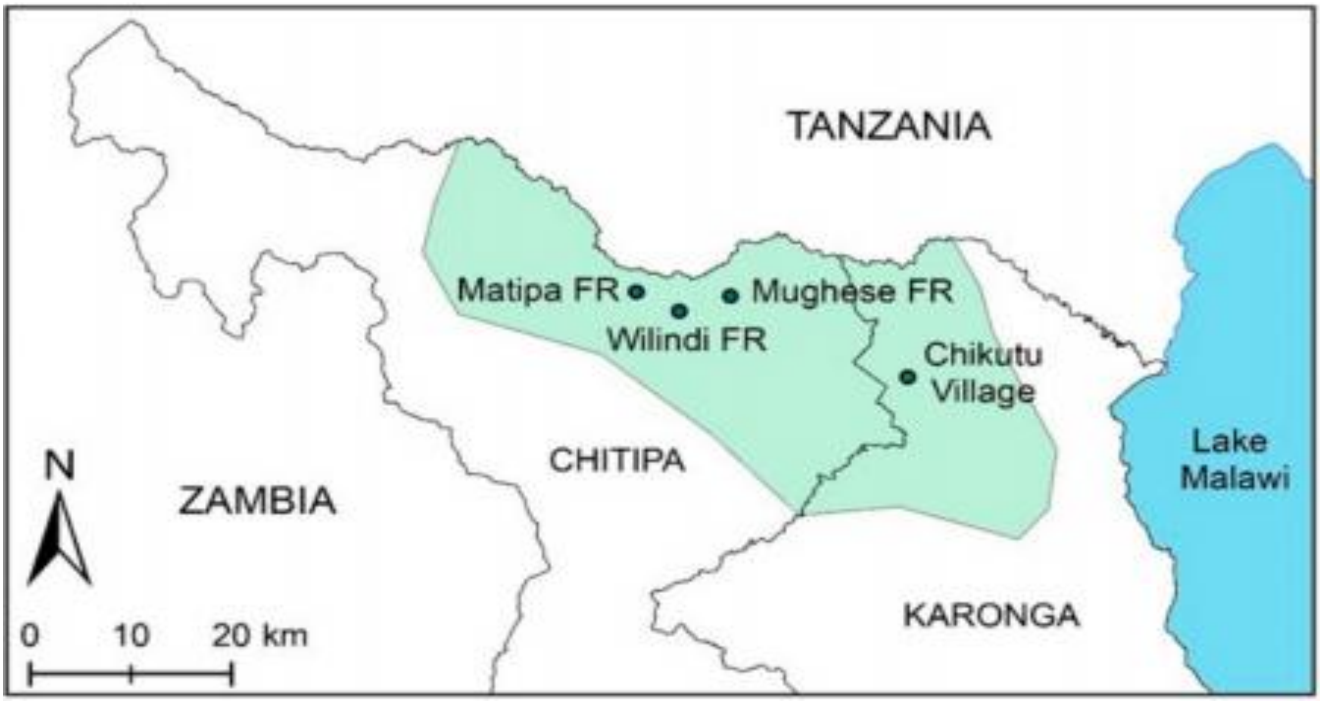

Figure 3.1 Misuku Hills Forest Reserves and sampling area. *Source: Coutts et al.* (2029).

3.1.2 MULANJE MOUNTAIN FOREST RESERVE

Mulanje Mountain Forest Reserve is situated in the far southeast corner of Malawi. It is the largest mountainous massif in the afro-montane archipelago (15075S 35038E) (Figure 3.2). It is itself a huge syenite intrusion of 640km^2 rising steeply and abruptly from the south-central African plains to form a broad plateau of basins and deep river gorges at 1800m and rocky peaks that reach 2800m. Being surrounded by tea estates, most community members earn their income from piece works at the farms, others curve and sell curios to tourists, tour guiding, fuelwood selling, and seasonal forestry operations with both the department of forestry and Mulanje Mountain Conservation Trust. For the most part, subsistence farming of maize and sorghum. The area is home to Lomwe and Mang'anja tribes with the Lomwe in majority (More than 88%) (District profile, 2022). The massif with its stories and the endemic Mulanje cedar commands a lot of tourism.

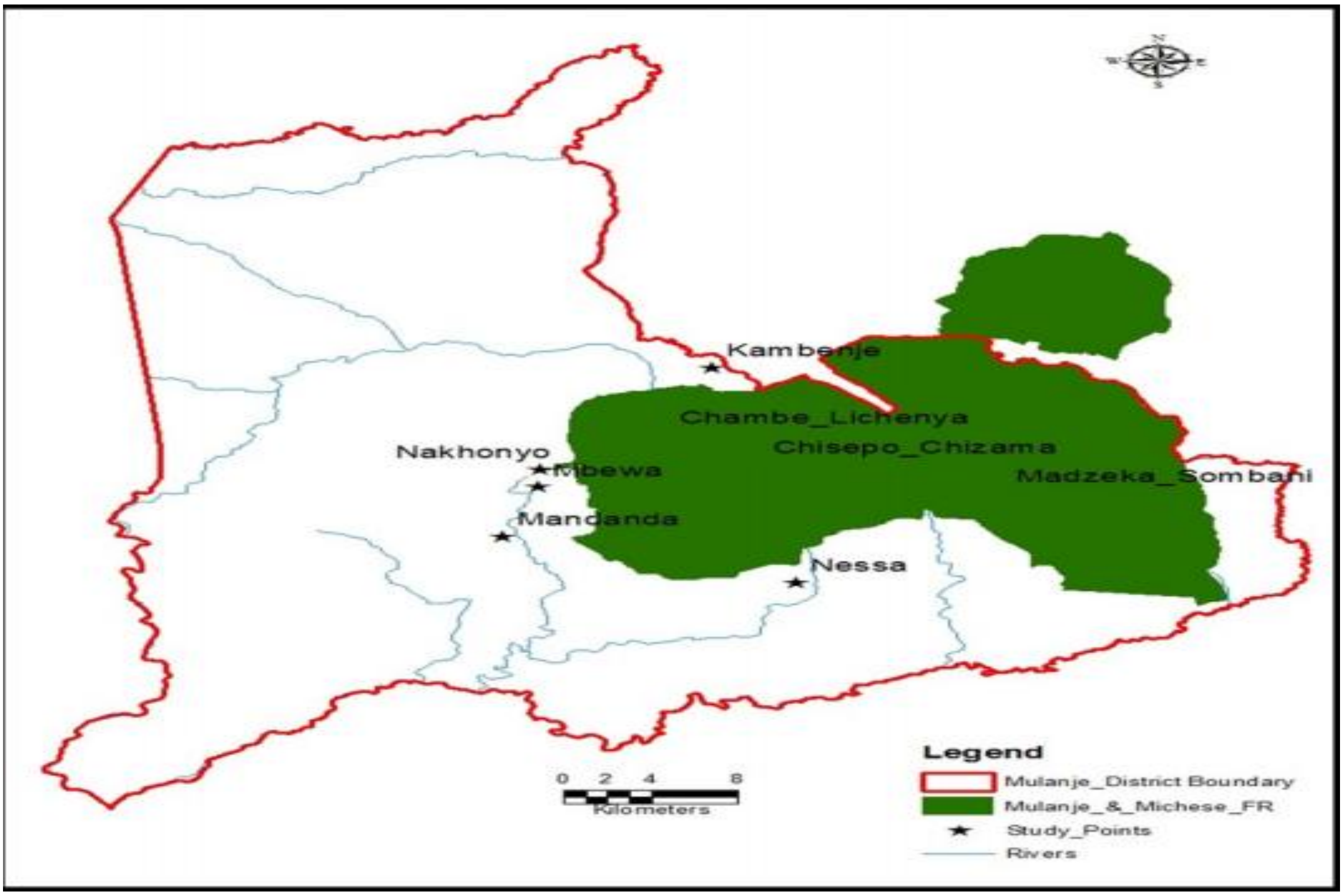

Figure 3. 2. Map of Mulanje Mountain Forest Reserve and sampling area. Source: Mankhambera and Shah (2019).

3.2. RESEARCH DESIGN

This study employed a cross-sectional mixed-methods research design to comprehensively capture both the breadth and depth of community perspectives. This integrated quantitative and qualitative approaches allowed for triangulation of findings, thereby enhancing the validity and richness of the data. Data were collected from 20 villages which were systematically selected and situated around the Misuku Hills Forest Reserves (MHFRs) and the Mulanje Mountain Forest Reserve (MMFR), chosen due to their direct exposure to *Pinus patula* plantations and observed interactions with the surrounding communities. This methodological framework was selected to ensure a multi-dimensional understanding of the socio-ecological dynamics in the study areas.

3.3. SAMPLING FRAMEWORK AND METHODS

3.3.1 SPATIAL DISTRIBUTION OF P. PATULA INVASION

Sampling Procedure: Ten randomized transect walks were conducted in all the villages villages of study to gage the spread of pine in those communities.

Villages Sampled: Selected based on proximity to forest reserves and the known *P. patula* presence.

3.3.2 COMMUNITY KNOWLEDGE, ATTITUDES, AND PRACTICES (KAP)

To assess the knowledge, attitudes and practices of communities towards *P. patula*, 10 of the village communities around both reserves were selected based on location, distance from the reserve, population density. Cochran's formula was used to determine the sample size.

n0 = (Z^2 * p (1 - p)) / e^2

Where:

- n_0= required sample size (for a large/unknown population)
- Z= Z-score for confidence level at 95% confidence (1.96)
- p= estimated proportion in the population (0.5)
- e= desired margin of error (0.05 for ±5%)

Sampled villages in Misuku Hills Forest Reserve: Mwalawila, Mwamalangi, Mwandisi 1 and 2, Yapoma, Tayali, Yolamu Kajere, Muwona, Mwangulukulu.

Sampled villages in Mulanje Mountain Forest Reserve: Kambenje, Cholo, Mukhalepo, Matonya, Manolo, Nakhonyo, Magombo, Chilanga, Kazembe, Nkanda, Mwanyali, Ncheziwa, Mphaya, Msitika and Muhiyo.

The total number of respondents was 174 with 99 from Mulanje and 75 from Misuku.

3.3.4 SOCIOECONOMIC CONTRIBUTION OF *P. patula*

Sampling: Semi-structured interviews were conducted with households engaged in *P. patula* related activities.

3.4. DATA COLLECTION

Spatial Data: GPS coordinates of *P. patula* occurrences were recorded during transect walks. This includes the number of individual trees as for Mulanje while for Misuku it was number of woodlots.

KAP Survey: Semi-structured questionnaires were administered to community members to obtain information on their views regarding *P. patula*. This was complemented by key informant interviews with selected members in respective communities.

Key Informant Interviews: Conducted with 2 NGOs i.e. Mulanje Mountain Conservation Trust, We Forest, 4 CBOs, 10 (5 in Mulanje and 5 in Misuku) local authorities, and 6 Department of Forestry officers (3 for at each site). These were chosen due to their knowledge, experience and interaction with the issue of forestry, natural resources management and late alone pines.

Livelihood Data: Semi-structured interviews were conducted to gather qualitative and quantitative information on household livelihoods. Market valuation was used to capture earnings from *P. patula* related activities such as timber harvesting, pine cultivation and plantation jobs. Respondents also provided data on opportunity costs including non-timber forest products (NTFPs) and agricultural activities.

3.5. DATA ANALYSIS

Spatial Analysis: Data was organized in Microsoft Excel and mapped using Google Earth and QGIS.

KAP Data: Responses were scored on a scale of 1 to 5 which were later converted to percentages for quantitative data analyses. Descriptive statistics, including frequency distributions and cross-tabulations, were generated. Inferential analyses, including Chi-square tests for categorical data and non-parametric correlation tests (Spearman's rank correlation), were conducted to examine associations and patterns of KAP for each site. All inferential tests were run against a 5% confidence level of significance.

Livelihood Analysis: The collected data was analysed in excel using opportunity cost matrices to compare income from *P. patula* related activities with forgone sources of livelihood. Disaggregated income data were examined to account for variations among households. Additionally, opportunity cost valuation techniques and livelihood dependency indices were applied to assess the economic trade-offs and level of reliance on various livelihood sources.

CHAPTER 4: RESULTS

4.1 INTRODUCTION

This chapter presents the research findings from communities surrounding the Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserve (MHFR). Data is organized to address the socio-demographic profiles and the four research objectives: (1) Spatial distribution and management of *P. patula*, (2) community knowledge, attitudes, and practices (KAP), (3) socio-economic contribution of *P. patula* invasion to community livelihoods. The chapter integrates descriptive and inferential results, drawing comparisons between Mulanje and Misuku to analyse socio-ecological and economic trade-offs.

4. 2 RESPONDENTS DEMOGRAPHICS

Respondents were drawn from both Misuku and Mulanje. A total of 175 respondents participated. The summary of gender, marital status, education, family size, age, distance from reserve, and residential period is provided in Table 4.1.

The demographic categories used in this study were selected to balance both universal standards and local relevance. Variables such as gender, marital status, age, and education follow internationally recognized and nationally applied classifications, including those of the Malawi National Statistical Office (NSO, 2018) and the United Nations (UN, 2019), allowing comparability with broader demographic data. These categories capture critical dimensions of household structure, labour availability, and decision-making capacity, all of which influence interactions with forest resources. Family size, distance from the reserve, and residential period were included as context-specific variables to reflect local socio-ecological realities. For example, household size determines labour supply and consumption pressure; distance from the reserve indicates differential access to and dependency on forest resources, while length of residence reflects historical knowledge and generational attachment to the landscape. The inclusion of these variables aligns with previous socio-ecological and livelihood studies that emphasize the importance of household composition, spatial proximity, and tenure duration in shaping natural resource use and perceptions (Shackleton *et al*., 2015; Fisher *et al*., 2024). Together, these categories provide a nuanced understanding of the social conditions influencing community engagement with *Pinus patula* invasion.

Table 4.2 Demographics of Study Participants in MHFR and MMFR

Variable	**Category**	**Overall (%)**	**Misuku (%)**	**Mulanje (%)**
Gender	*Male*	50.7	66.7	26.7
	Female	49.3	33.3	73.3
Marital Status	*Single*	4.7	0	4.0
	Married	75.8	78.6	63.6
	Divorced	11.8	12.9	20.2
	Widowed	7.6	8.6	12.1
Level of Education	*Non-formal*	3.7	0	8
	Primary	68.2	55	64
	Secondary	27	18	28
	Tertiary	0.9	2	0
Family Size (Individuals)				
	≤3	*15.6*	*12.9*	18.2
	4-6	*56.4*	*60*	*27.3*
	7-9	*26.1*	*24.3*	*27. 3*
	≥10	*2.3*	*2.9*	*27.2*
Age (Years)	*≤15 (Minors)*	0	0	0
	16-24 (Youths)	3.8	4	5
	25-64 (Adults)	87	71	87
	≥65 (Old Adults)	9.2	0	8
Distance from the reserve (km)	*≤5*	61.1	19	90
	6-10	33.1	47	10
	11-20	5.7	10	0
	21-30	0	0	0
	≥31	0	0	0
Residential period (Years)	*≤10*	10.9	6.8	11.1
	11-20	22.8	11.4	17.8
	21-30	23.2	18.2	15.6
	≥31	49.2	63.6	55.6

The demographic profile highlights socio-economic patterns influencing community interactions with *Pinus patula*.

4.1.1 GENDER

The study included 175 participants, 100 in Mulanje and 75 in Misuku with overall gender distribution of 50.7% male and 49.3% female. However, site-specific data revealed contrasting patterns with Misuku being male dominated and 66.7% male respondents, while Mulanje had a higher proportion of female respondents at 73.3%. These differences suggest regional variations in gender participation, possibly influenced by cultural roles, availability, or engagement in local activities.

4.1.2 MARITAL STATUS

Marriage is the predominant marital status overall (75.8%), with Misuku exhibiting a higher proportion of married individuals (78.6%) and lower rates of singlehood. In contrast, Mulanje shows a lower marriage rate (63.6%) and significantly higher levels of marital disruption, including divorce (20.2%) and widowhood (12.1%), compared to Misuku (12.9% and 8.6%, respectively). These differences suggest varying household structures and potential patterns of social vulnerability and cohesion between the two regions.

4.1.3 EDUCATION LEVEL

Educational attainment is predominantly at the primary level (68.2% overall). Misuku reports no respondents with non-formal education (0%) but also a lower proportion with secondary education (18%) compared to Mulanje (28%). A small share of tertiary-educated individuals (2%) is observed only in Misuku. In contrast, Mulanje has a higher percentage of respondents with no formal education (8%), indicating greater variability in educational outcomes between the two areas. However, the relatively high primary school education levels indicate a fairly good level of numeracy and literacy in the two study areas.

4.1.4 HOUSEHOLD SIZE

Household sizes are predominantly medium (4–6 members), accounting for 56.4% general. Misuku aligns closely with this pattern, with 60% of households falling within this range. In contrast, Mulanje exhibits a more polarized household structure, with notable proportions of small households (≤3 persons, 18.2%) and very large households (≥10 persons, 27.3%), alongside a significant share in the 7-9 person range (approximately 27.3%). This distribution suggests the presence of more extended or multi-family living arrangements in Mulanje**.** It also shows that labour is readily available in Mulanje compared to Misuku.

4.1.5 AGE

Adults aged 25–64 years constitute the majority in both Mulanje (87%) and Misuku (71%), with the overall share at 87%. Misuku also has a slightly higher proportion of youth (4%). Older adults (65 years and above) are present in Mulanje (8%) and overall (9.2%), but none were recorded in Misuku. This absence may reflect either sampling limitations or genuine demographic differences between the two areas.

4.1.6 PROXIMITY TO THE RESERVE

Most households are in close proximity to the reserve, with 61.1% residing within 5 km and an additional 33.1% within 6–10 km while very few (5.8) live beyond 20 km. However, spatial patterns differ notably between sites. In Mulanje, proximity is high, with 90% of households within 5 km and the remaining 10% within 6–10 km, indicating likely frequent interaction with reserve resources and management. In contrast, Misuku households are more spatially dispersed, with 19% within 5 km, 47% between 6–10 km, and 10% between 11–20 km. This suggests comparatively lower, though still meaningful, day-to-day engagement with the reserve. This may have been an issue of sampling bias as only villages deemed close to the reserves were included in the study.

4.1.7 RESIDENTIAL PERIOD

Residential tenure is notably long in both sites, with 49.2% of respondents reporting residence of 31 years or more, and an additional 23.2% having lived in their communities for 21–30 years, indicating that over 70% are long-term residents. Misuku shows the highest proportion of long-term settlement (63.6% ≥31 years), followed by Mulanje (55.6%). Short-term residence (≤10 years) is relatively rare, accounting for only 10.9% overall. These patterns suggest a high degree of land tenure security, as long-term residence is often associated with stronger claims to land, deeper community integration, and greater investment in local resources and land management practices.

In summary, respondents are primarily adult, married, and primary-educated, with medium-sized households common. Mulanje shows greater household size variation, higher marital disruption, and educational vulnerability, while Misuku reflects more stable demographics and longer residence. Proximity to reserves is highest in Mulanje, suggesting intense resource interaction, whereas Misuku's longer tenure implies strong local knowledge and land claims. These patterns underline to some extent the difference in the interaction with pine between the two where in Misuku people own pine stands unlike in Mulanje.

4.2 LIVELIHOOD ACTIVITIES

This section presents the main livelihood activities of respondents in Misuku Hills and Mulanje, which are largely dependent on land and forest resources. These activities have shaped how communities interact with pine plantations, particularly where pine has contributed to income, employment, or household needs. Understanding these patterns is key to assessing how the presence or absence of pine affects local livelihoods and informs sustainable management strategies. Below are Venn diagrams (Figure 4.1) used to illustrate key livelihood activities by the communities in both sites and general.

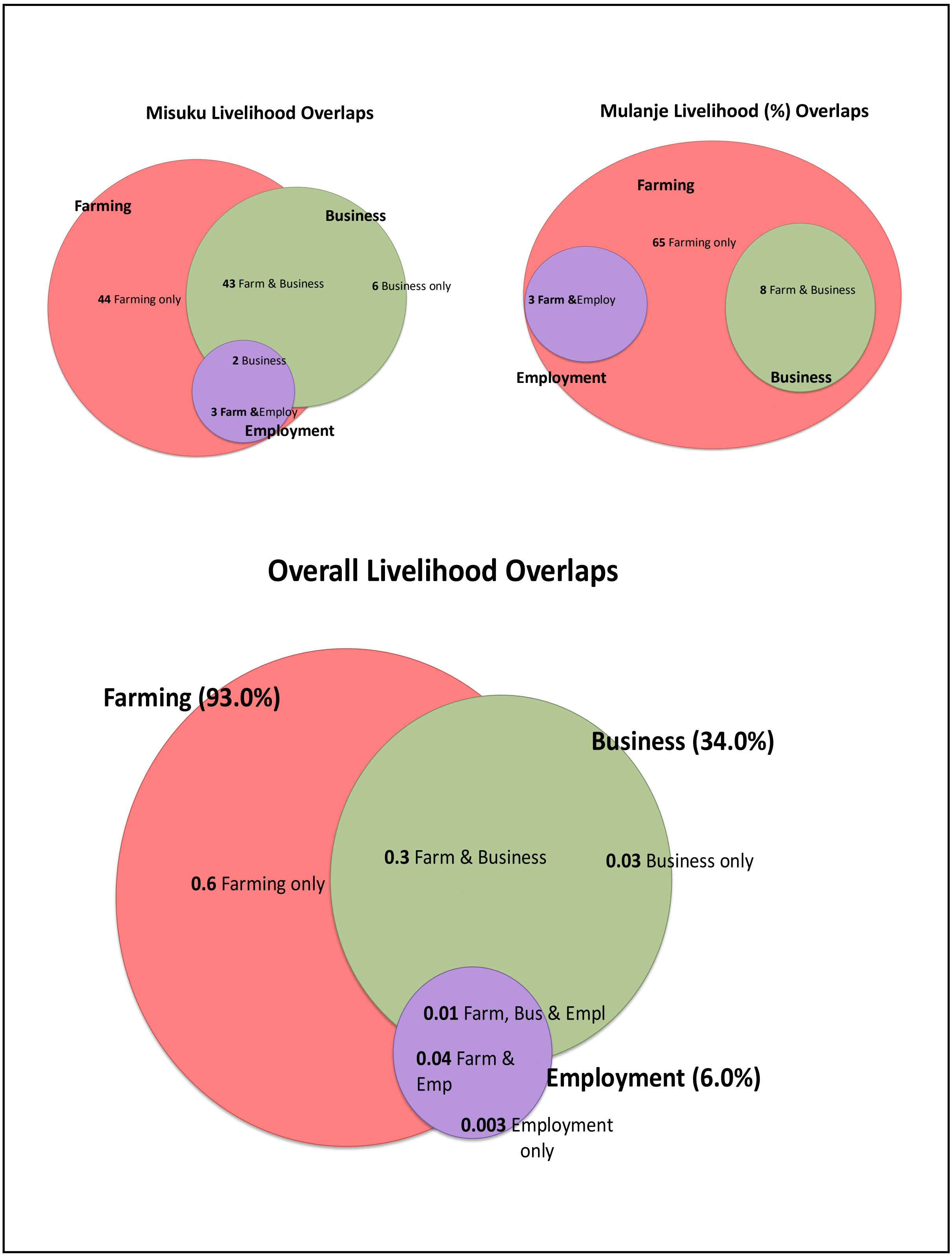

Figure 4.3. Distribution of livelihood activities interaction of respondents in percentages for Misuku, Mulanje and General.

Across sites, livelihoods are centred on agriculture with diversification mainly into small business and only marginal wage employment. In Misuku, farming involvement is near universal (**~92%),** and diversification is comparatively strong. About half run a business (mostly alongside farming), a few combine farming, business with employment, and employment only is rare. In Mulanje, reliance on farming is even more concentrated with roughly two-thirds (≈65%) farm only, limited farm plus business (≈8%) and farm with employment (≈3%) and virtually no stand-alone business or employment. The overall pattern mirrors that about 93% farm, ~60% farm only; ~30% farm plus business; ~3% business only; ~4% farm plus employment; ~0.3% employment only; and ~1% engage in all three.

4.2 SPATIAL DISTRIBUTION AND LOCAL MANAGEMENT OF *P. patula*

4.2.1 MULANJE

In Mulanje, *P. patula* was more abundant and increased southwards, particularly in communities near the Likhubula River. In villages like Gibsan and Magombo, pines were planted intentionally in boundaries and small woodlots, while in areas like Kambenje, the species appeared to be randomly present showing to be self-propagated. Approximately 90% of observed waypoints were single trees and only 10% were small woodlots.

Table 4.3 Pine Distribution Percentages and Spread per each Sampled Village In Mulanje

Village	***Places spotted***	***Distribution Percentage***	***Pin Distribution Patterns***
Nakhonyo	14	27.5	Random,
Chole	6	11.8	Random
Kazembe	4	7.8	Random
Kambenje	2	3.9	Random
Gibisan	8	15.7	Random, Boundaries, on farm
Mbewa	4	7.8	Random,
Mangombo	13	25.5	Random, Boundaries, small cluster like woodlots

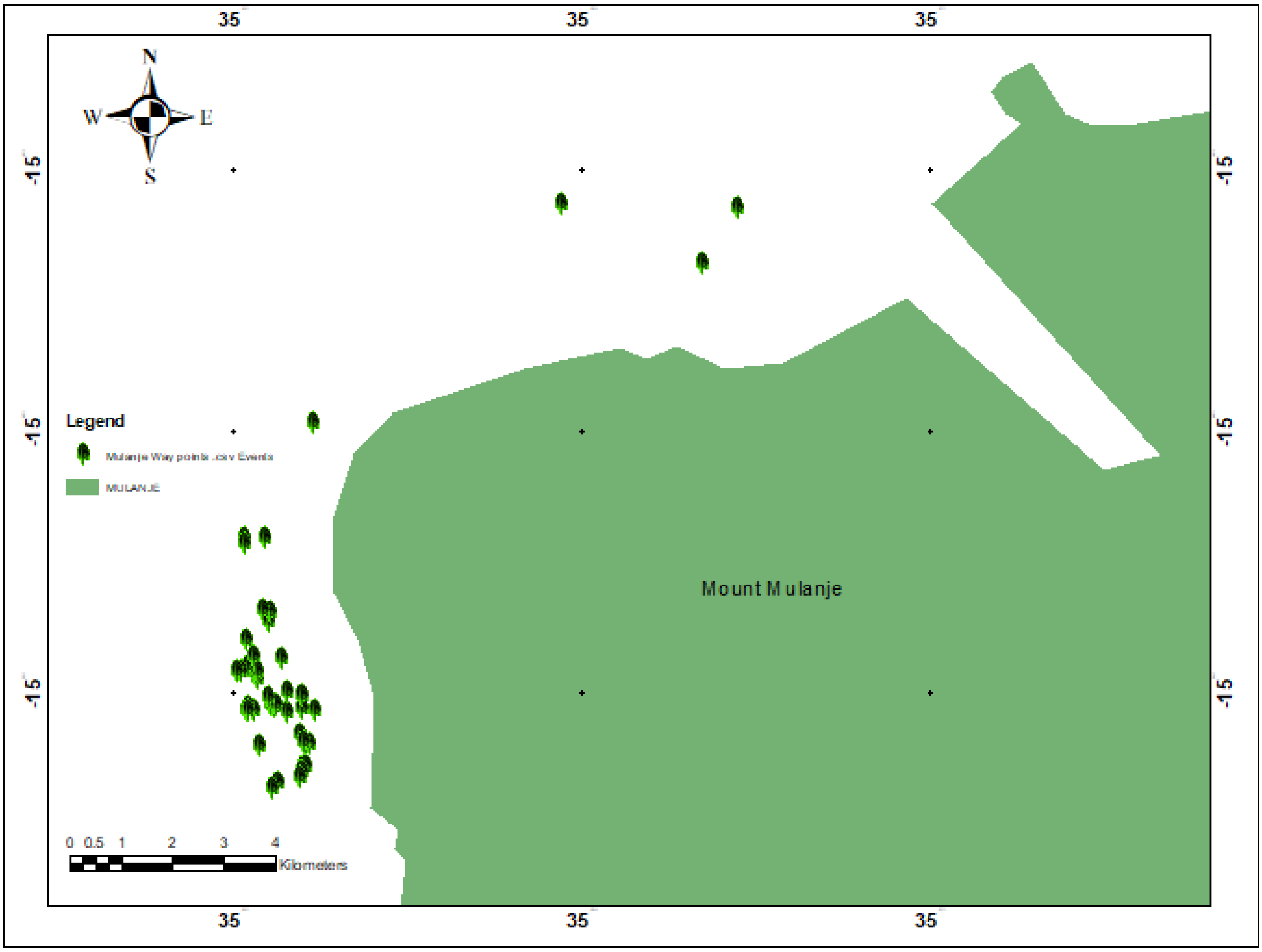

Figure 4.4. Pine distribution in communities around MMFR

There are several sites in the villages that were sampled along MMFR in the Traditional Authorities Nkhanda and Mabuka. In villages such as Gibsan and Magombo, it was evident that the pine trees were purposively introduced for their economic value while in others like Kambenje and Mbewa, it looked to be more sporadic and accidental or self-sown. However, in each of these instances, the *P. patula* trees were being taken care of by someone who planted them or had assumed ownership.

Table 4.4. Pine woodlots Distribution percentages and Patterns per each Sampled Village in Misuku Hills.

Village	***Woodlots spotted***	***Distribution Percentage***	***Pine Distribution Patterns***
Yoram Kanjeri	4	12.5	Woodlots
Mwandisi	9	28.1	Woodlots
Mwamalange	2	6.4	Woodlots
Yatali Kanjeri	3	9.4	Woodlots
Mughese	2	6.4	Woodlots
Yapoma	3	9.4	Woodlots
Mwandisi 2	6	18.8	Woodlots
Mwandisi Kasamba	3	9.4	Woodlots

4.2.2 MISUKU

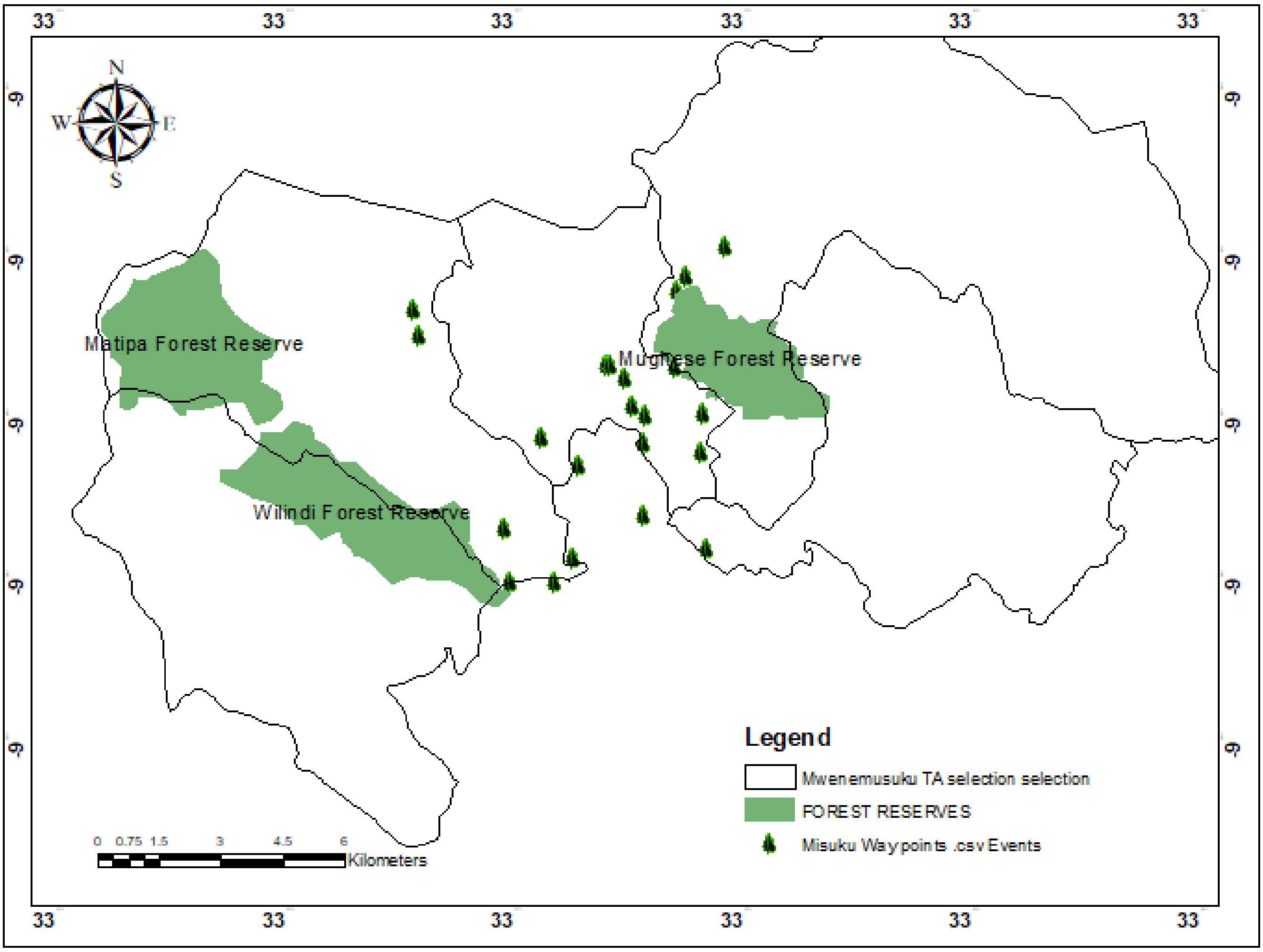

Figure 4.5. Pine stands distribution in communities around MHMFR

With reference to the distribution map in figure 4.3 and table 4.3, pine occurrences are highly uneven across villages. Mwandisi accounts for the largest share of sightings (9 woodlots; 28.1%), followed by Mwandisi 2 (6; 18.8%), indicating two clear focal areas for pine presence and management. The remaining villages each contribute 6–12% of observations (2–4 woodlots), suggesting scattered, lower-density stands. The recurring note of "woodlots, irregular clusters" implies smallholder-scale planting which are a form of investments where all or a number of silviculture operations are applied and opportunistic spread near homesteads/fields rather than continuous plantation blocks.

4.3. COMMUNITY KNOWLEDGE ATTITUDES AND PRACTICE RESULTS

KAP values were tabulated across eight villages surrounding both the reserves. All respondents reported farming as their primary livelihood activity, with variations across crop cultivation, livestock rearing, or a combination of both. This agricultural focus forms the foundation of household economies across the study sites. However, despite their primary reliance on farming, respondents also demonstrated regular engagement with surrounding forest landscapes. These interactions included the extraction of both timber and non-timber forest products, such as firewood, poles, wild fruits, and medicinal plants. This dual dependence on agriculture and forest resources highlights the integrated nature of rural livelihoods and underscores the importance of forest access in supporting household resilience and resource diversification.

The KAP value elements from these 175 respondents were analysed against demographics which produced the results in the following tables.

Table 5.4 Spearman's Correlation Among KAP variables

RESPONDENTS		CORRELATION	SIGNIFICANCE
MULANJE (N=99)	Knowledge & Attitude	0.4317	0.00
	Knowledge & Practice	0.5318	0.00
	Attitude & Practice	0.4247	0.00
MISUKU (N=76)	Knowledge & Attitude	0.0186	0.8733
	Knowledge & Practice	-0.1454	0.2101
	Attitude & Practice	-0.0480	0.6808
ALL (N=175)	Knowledge & Attitude	0.5410	0.00
	Knowledge & Practice	0.6199	0.00
	Attitude & Practice	0.5375	0.00

Spearman's Correlation for Mulanje has revealed that there is moderate positive relationship between knowledge and attitude (0.4317), knowledge and practice (0.5318) and attitude and practice (0.4247). These are relatively weak relationships that demonstrate that as knowledge increases, practice also increases.

For Misuku, Spearman's Corelation has revealed that there is no relationship between knowledge and attitude **(**0.0186), knowledge and practice (-0.1454) and attitude and practice (-0.0480). significant correlations among the KAP variables. These demonstrate that an increase in knowledge does not translate to any change in attitude or practice. These findings may point to contextual factors limiting the translation of knowledge and attitude into practice.

Table 4.6 Comparison of KAP Values Between Misuku and Mulanje

Variable	U-Statistic (Z)	P-Value	Rank Sum	
			Misuku	**Mulanje**
Knowledge	9.391	< 0.001	9481.5	5918.5
Attitude	6.607	< 0.001	8854.5	6545.5
Practice	6.217	< 0.001	87743	6657

The Mann–Whitney U test results demonstrate statistically significant differences in Knowledge, Attitude, and Practice (KAP) scores between respondents from Chitipa and Mulanje districts, with consistently higher scores observed in Chitipa. For Knowledge, the rank sum for Chitipa was 9481.5 compared to the expected 6688, yielding a z-value of 9.391 and a p-value < 0.001 (exact p = 0.0000), indicating a substantial difference. Similarly, Attitude scores showed a significant disparity, with Chitipa's rank sum at 8854.5 (z = 6.607, p < 0.001), while Practice scores followed the same trend, with a rank sum of 8743 for Chitipa (z = 6.217, p < 0.001). These findings provide robust evidence to reject the null hypotheses across all three dimensions and suggest that respondents in Chitipa exhibit significantly higher levels of knowledge, more positive attitudes, and better practices towards pine compared to those in Mulanje.

Table 4.7. Ordered Logical Regression

Category	**Knowledge** **LR $chi^2(8)$ =101.8, P<0.000** **R^2 = 0.2361 (23.6%)**		**Attitude** **LR $chi^2(8)$ =45.93, P<0.000** **R^2 = 0.0608 (6.1%)**		**Practice** **LR $chi^2(8)$ =42.55, P<0.000** **R^2 = 0.0391 (3.9%)**	
	Coefficient	P	Coefficient	P	Coefficient	P
Gender	-1.110	0.000	-0.564	0.089	-0.695	0.035
Age	0.0337	0.025	0.0083	0.555	0.020	0.096
Marital status	-0.1508	0.600	-0.246	0.398	0.397	0.175
Distance from Reserve	3.6498	0.000	1.053	<0.001	1.025	0.000
Livelihood means	0.8077	0.338	1.395	0.065	0.590	0.421
Education	0.9432	0.006	0.107	0.696	0.323	0.215
Residential Period	0.0151	0.117	0.0285	0.008	0.019	0.054
Family Size	0.0005	0.995	-0.110	0.168	-0.119	0.136

Table 4.1 KAP Values distribution along sampled villages

Site	Village	Knowledge%	Attitude%	Practice%
Mulanje	Chole 1 & 2	66.67	-18.18	21.05
	Gibisan	50	27.27	55.26
	Kambenje 1&2	66.67	40.91	5.26
	Kazembe	50	27.27	26.32
	Mangombo 1 &2	100	81.82	84.21
	Mbewa	50	27.27	21.05
	Nakhonyo	100	27.27	63.16
Misuku	Mwakayela	85	18.18	68.42
	Mwalawira	100	72.73	63.16
	Mwamalange	99	64.59	63.16
	Mwamalange Njewete	96	71.13	73.42
	Mwandisi	100	68.87	78.95
	Mwangulukulu	98	72.73	78.75
	Mwanyali	0	18.18	21.05
	Mughona	95	71.04	77.92
	Yatali Kanjeri	100	74.81	73.68
	Yoramu Kanjeri	99.18	65.94	79.25

The final ordered logistic regression models identified several significant predictors of community Knowledge, Attitude, and Practice (KAP) regarding management of pine spread. For knowledge, the four variables were statistically significant at the 5% level. Gender had a significant negative association (β = -1.110, p = 0.000), indicating that male respondents had approximately 67% lower odds (OR = 0.33) of reporting higher knowledge levels compared to females. Age was a positive predictor (β = 0.0337, p = 0.025), where each additional year of age slightly increased the odds of higher knowledge (OR = 1.03). Education level also showed a positive effect (β = 0.9432, p = 0.006), with individuals at higher education levels being approximately 2.57 times more likely (OR = 2.57) to report higher knowledge levels. Distance from the reserve emerged as the strongest predictor (β = 3.6498, $p < 0.001$), with those living farther from the forest reserve having approximately 38.5 times greater odds (OR = 38.45) of higher knowledge compared to those living nearer. Regarding attitudes, distance from the reserve (β = 1.053, $p < 0.001$; OR

= 2.87) and residential period (β = 0.0285, p = 0.008; OR = 1.03) were the only significant predictors, suggesting that respondents residing farther from the reserve and those living longer in the area held more favourable attitudes. For practice, gender (β = -0.695, p = 0.035; OR = 0.50) and distance from the reserve (β = 1.025, p = 0.000; OR = 2.79) were significant, indicating that males and those residing closer to the reserve were less likely to adopt recommended practices. Overall, proximity to the reserve consistently influenced all three KAP outcomes, highlighting spatial factors as critical determinants of community response to pine management interventions.

4.4 COST-BENEFITS AND OPPORTUNITY COST

This section presents assessment of the socio-economic contribution of *P. patula* invasion to community livelihoods around MMFR and MHFR. The study picked on most common economic activities that communities are involved for their livelihood that have a relationship with spread and eradication of pine in their area. This includes agriculture (maize, Bannas, coffee), tree farming and casual labour. The period of analysis is a 5-year span from 2021 to 2025. A 5% social discount rate which reflects the **s**ocial time preference rate (STPR) appropriate for long-term environmental and natural resource evaluations in developing economies was adopted (World Bank, 2016; The African Development Bank,2019**;** Ministry of Forestry and Natural Resources,2021).

4.4.1 MULANJE

Table 4.10 presents the opportunity costs pertaining land use change in the reserve as relating to pine growing and removal. Cost–benefit results show limited gains from *Pinus patula* after plantation eradication. With pine-related income lost, households now depend mainly on maize farming and increasingly harvesting indigenous trees for timber and fuelwood, heightening pressure on the reserve. Average benefits remain modest relative to ecological and socio-economic costs, giving a moderate net return and a BCR of about 2.4.

4.4.1.1 OPPORTUNITY COST

Opportunity cost to the community due to the eradication of pine stands on the mountain was calculated by the formula below adopted from the REDD+ report (2012).

$OC=Bf-Bc$

Where:

- OC = Opportunity Cost
- Bf = Benefit of the foregone option (next best alternative)
- Bc = Benefit of the chosen option

Then

OC (Maize–Pine) =Net (Pine)−Net (Maize)

Table 4.8. Comparative Annual Net Benefits and Opportunity Cost (MWK) for Mulanje

Year	**Pine** Employment **Net Benefit (MWK)**	Maize Net Benefit (MWK)	OC (Maize-Pine)
2021	664,950	950,000	-285,050
2022	1,329,900	950,000	379,900
2023	1,994,850	950,000	1,044,850
2024	2,058,635	950,000	1,108,635
2025	2,124,518	950,000	1,174,518
Total (5 years)	**8,172,853**	**4,750,000**	**3,422853**

OC = Opportunity Cost. Negative values indicate that Maize performs better than pine in that year.

Over a five-year period, net benefits from pine employment increased steadily from MWK 664,950 in 2021 to MWK 2,124,518 in 2025 (Projected), reflecting the maturation of the pine value chain and rising labour demand for pruning, harvesting, and processing. In contrast, maize maintained a constant annual net benefit of MWK 950,000, indicative of its stable short-term returns. Cumulatively, pine generated

MWK 8172853 in net benefits, substantially exceeding maize's MWK 4.75 million. Opportunity cost analysis, calculated as the difference in net benefits (pine minus maize), reveals an initial shortfall in 2021 (-MWK 285,050), but a positive and increasing advantage for pine from 2022 onward, culminating in a cumulative opportunity cost of approximately MWK 3422853 in favour of pine. These results highlight a temporal trade-off: while maize offers immediate and consistent returns, pine provides superior long-term economic gains.

Importantly, the eradication of pine has resulted in the loss of employment opportunities not only within plantations but also across the entire pine value chain. This includes harvesting, transport, processing, and informal trade. This disruption has significant implications for household incomes and local economies, particularly in areas where pine had become a key livelihood source. The findings underscore the need to weigh ecological restoration goals against the socio-economic costs of removing economically valuable species.

4.4.2 MISUKU HILLS

In Misuku Hills Forest Reserve (MHFR), cost–benefit results indicate strong economic dependence on *Pinus patula* through privately owned woodlots and related trades. Most households earn income from pine sales alongside coffee, banana, and maize farming. Despite notable ecological costs such as reduced biodiversity and water use, high returns yield a positive net benefit and a BCR of about 3.6. The tables below compare revenues and opportunity costs (OC) of pine, coffee, and maize per acre over five years and Benefit Cost ratio among the three crops. Maize offers stable, short-term income but lower long-term returns. Pine generates moderate, steadily increasing income over time.

4.4.2.1 OPPORTUNITY COST

OC (Alt crop–Pine) =Net (Pine)−Net (Alt crop)

Table 4.9. Comparative Annual Net Benefits and Opportunity Costs (MWK) for Misuku Hills

Year	Pine Net Benefit (MWK)	Coffee Net Benefit (MWK)	Maize Net Benefit (MWK)	OC (Coffee-Pine)	OC (Maize-Pine)
2021	-1,050,000	-9,870,000	335,000	-8,820,000	1,385,000
2022	-460,000	-320,000	432,000	140,000	892,000
2023	-245,000	50,000	745,000	295,000	
					990,000
2024	250,000	6,680,000	625,000	6,430,000	375,000
2025	12,000,000	10,620,000	980,000	-1,380,000	-11,020,000
Total (5 years)	**104,950,000**	**7,160,000**	**3,117,000**	**-3,335,000**	**-7,378,000**

OC = Opportunity Cost. Negative values indicate that the alternative crop performs better than pine in that year.

The opportunity cost analysis among Maize, coffee and *Pinus patula*, reveals that pine cultivation, though less profitable in the early years, cumulatively outperformed both coffee and maize over the five-year period. From 2021 to 2024, maize and coffee generally yielded higher short-term net benefits, with coffee performing exceptionally well in 2024. However, pine's substantial return in 2025 reversed earlier trends, giving it the highest cumulative net benefit. The overall negative opportunity costs (–3.34 million MWK for coffee-pine and –7.38 million MWK for maize-pine) indicate pine's superior long-term profitability, though its delayed payoff underscores the need for patience and risk tolerance. The negative values show that choosing coffee or maize instead of pine would have resulted in losing 3.34 million MWK and 7.38 million MWK respectively in total net gains. Thus, pine is the most profitable crop overall in this comparison, despite slower early returns. In contrast, maize and coffee offer more stable short-term income but lower long-term gains.

4.4.2.2 BENEFIT COST RATIO

The Benefit–Cost Ratio (BCR) analysis provides an integrated measure of the economic efficiency of each land-use option by comparing total benefits to total costs over the five-year study period. This section presents the computed BCR values for pine, coffee, and maize enterprises to determine which investment yields the highest return per unit of cost incurred. Interpreting the BCR helps to identify the relative profitability and sustainability of each crop under varying economic and ecological conditions around the study sites. A BCR greater than one indicates economic viability, suggesting that the benefits outweigh the costs, whereas values below one reflects losses or unprofitable ventures.

Benefit Cost ratio = Present Value (PV) of Costs /Present Value (PV) of Benefits

BCR = ΣPV(Benefits) / ΣPV(Costs)

Where 5% is the discount rate

*Table 4.110.*Cost-Benefit Analysis of Coffee, Maize, and *Pinus patula* Production at 0% and 5% Discount Rates

Crop	**Total Benefits (MWK)**	**Total Costs (MWK)**	**BCR (0%)**	**PV Benefits (5%)**	**PV Costs (5%)**	**NPV (5%)**	**BCR (5%)**
Coffee	20,470,000	13,310,000	1.5379	17,175,101.94	12,796,976.9	4,378,125	1.3421
Maize	5,250,000	2,133,000	2.4613	4,673,379.919	1,905,067.46	2,768,312	2.4531
Pine	12,250,000	1,755,000	6.9801	10,088,389.1	1,710,317.46	8,378,072	5.8985

The cost–benefit analysis reveals a clear livelihood gradient among the three land-use options, reflecting their varying contributions to household welfare and economic resilience. *Pinus patula* offers the highest long-term profitability, with a discounted Benefit-Cost Ratio (BCR) of 5.9 and a Net Present Value (NPV) of MWK 8.38 million, making it a strong driver of asset accumulation and long-term livelihood support. However, its extended rotation period and ecological trade-offs, such as reduced soil moisture and biodiversity loss, limit its short-term livelihood benefits. Maize, in contrast, demonstrates the greatest short-term impact on food security, income regularity, and nutritional stability, supported by a stable BCR of approximately 2.45 that remains consistent even when discounted. Coffee occupies an intermediate position, providing moderate but diversified returns (BCR = 1.34 at 5% discount) and contributing to household income diversification and employment generation, especially among women and youth engaged in harvesting and processing.

Collectively, these findings indicate that maize sustains immediate livelihood needs, coffee enhances medium-term income stability, and pine underpins long-term economic security. An integrated cropping system that combines these enterprises would therefore optimize economic efficiency, livelihood resilience, and ecological sustainability.

4.7 CONCLUSION

The spatial distribution and management of *Pinus patula* revealed contrasting patterns between Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserve (MHFR). In Mulanje, pines were mostly scattered as self-propagated individuals or small boundary plantings, while in Misuku they appeared in deliberately managed household woodlots, reflecting stronger private ownership and investment. This variation underscores the influence of land availability, tenure security, and economic motivation on pine establishment. The deliberate cultivation of pine in Misuku suggests its integration into local livelihood systems as a long-term economic asset, while in Mulanje, limited land and conservation restrictions have led to more accidental or opportunistic presence. These findings highlight how spatial and socio-economic factors shape community engagement with invasive yet economically valuable species.

Regarding community Knowledge, Attitudes, and Practices (KAP), significant regional differences were observed. Mulanje demonstrated moderate positive correlations among knowledge, attitude, and practice, indicating that increased awareness translates into improved environmental behavior. Conversely, Misuku exhibited weak or no correlation among these variables, suggesting that socio-economic or institutional barriers may hinder the translation of knowledge into sustainable practices. The ordered logistic regression further revealed that gender, education, distance from the reserve, and residential period significantly influenced KAP outcomes. In particular, individuals living farther from the reserves or with higher education levels demonstrated greater awareness and more favorable attitudes. These results emphasize the importance of targeted education, gender-sensitive programming, and spatially differentiated interventions in enhancing community participation in invasive species management.

Ethnobotanical assessments revealed that *P. patula* invasion is altering the diversity and availability of indigenous species critical to local livelihoods. Invaded areas recorded lower mean species richness and Shannon diversity indices compared to non-invaded sites, indicating negative ecological impacts of pine expansion. Communities reported a noticeable decline in medicinal, fruit, and agroforestry species, reflecting the displacement of ecologically and culturally significant flora. However, some respondents acknowledged the short-term benefits of pine, such as increased access to firewood and construction materials. The dominance of indigenous species (64.9%) over exotics (35.1%) highlights the continued reliance on native biodiversity despite pine proliferation. These patterns underscore the ecological trade-offs associated with pine management and the need for restoration strategies that safeguard indigenous species while accommodating local livelihood needs.

The socio-economic analysis demonstrated that *P. patula* provides the highest long-term economic returns among the compared land uses, with a discounted Benefit–Cost Ratio (BCR) of 5.9, surpassing maize (2.5) and coffee (1.3). Although maize ensures steady short-term food and income security, and coffee offers medium-term cash flow, pine functions as a long-term “savings” asset that contributes substantially to household wealth accumulation. The high opportunity costs associated with choosing coffee or maize over pine (–3.34 million MWK and –7.38 million MWK, respectively) further affirm pine’s superior profitability. Nonetheless, its ecological costs such as reduced water availability and biodiversity loss necessitate careful policy balance. Collectively, the results advocate for integrated landscape management that harmonizes ecological restoration with livelihood resilience, combining short-term crops with long-term forestry to optimize economic efficiency and sustainability around Malawi’s montane reserves.

CHAPTER 5: DISCUSSION

5.1 OVERVIEW

This chapter provides an in-depth discussion of the findings of this study on the socio-economic and ecological trade-offs associated with *Pinus patula* invasion in communities surrounding Mulanje Mountain Forest Reserve (MMFR) and Misuku Hills Forest Reserves (MHFR). The analysis is structured thematically based on the study's four main objectives: (1) to characterize the spatial distribution of *P. patula*; (2) to evaluate community knowledge, attitudes, and practices (KAP) toward *P. patula*; (3) to examine the ethnobotanical relationship between communities and tree species. (4) to assess the opportunity costs of growing *Pinus patula* or its removal; and results are discussed within the context of socio-ecological resilience theory, conflict-of-interest invasive species literature, and related African case studies.

5.2 SPATIAL DISTRIBUTION OF *Pinus patula*

The spatial analysis reveals clear differences in the distribution patterns of *Pinus patula* across the two study sites. In Misuku, pine trees are mostly deliberately cultivated by communities as part of household woodlots, particularly for income generation, alongside perennial crops such as coffee and bananas. Such practices align with broader patterns observed in East African montane landscapes, where smallholder managed woodlots often composed of pine and eucalyptus serve both commercial and subsistence functions (Bailey *et al*., 2021; Kimambo and Naughton-Treves, 2019). Empirical evidence from Misuku Hills confirms that forestry activities, including tree planting and management, are deeply embedded within local livelihood strategies. Communities actively engage in forestry for both conservation and production (Coutts *et al*., 2019). This study has unveiled that approximately 85% of respondents in Misuku reported ownership or at least household association with pine stands which reflects the species' integration into household economies and its role in sustaining rural incomes. This cultivation frequently occurs within diversified agroforestry systems, where coffee is intercropped with shade or companion trees such as pine, banana, and indigenous species, a practice also documented among smallholder coffee farmers in Malawi (Wienhold *et al*., 2023). Broader studies on farm tree use further demonstrate that such integration contributes not only to income security but also to improved household food systems and dietary diversity (Vansant *et al*., 2024). The prominence of pine in these livelihood portfolios is underpinned by its established history in Malawi's plantation forestry sector, where it has been valued for its timber and other economic uses (Missanjo and Matsumura, 2016).

In contrast, in Mulanje, *Pinus patula* occurs more sporadically. The distribution is highly uneven, with greater presence in villages close to the district center such as Nakhonyo (27.5%) and Mangombo (25.5%), where government pine stands, tea estate windbreaks, and some household woodlots are concentrated. Due to limited farmland, households rarely establish dedicated pine woodlots; instead, pine occurs along farm and household plot perimeters or as self-sown trees that are selectively protected. This pattern reflects broader findings that land scarcity and competing agricultural demands constrain smallholder tree planting (Meijer *et al*., 2015; Bailey *et al*., 2021). A clear spatial gradient emerges, with pine presence declining from the southwest near the district center to the northeast, where villages like Kambenje (3.9%) report the lowest occurrence. Similar distance-decay effects have been observed elsewhere, where pine spread is greatest near plantations and propagule sources and decreases with remoteness (McConnachie *et al*., 2015; Taylor *et al*., 2016; Wyse *et al*., 2022). This opportunistic integration of pine into farming systems contrasts with regions such as Misuku, or Tanzania's Southern Highlands, where smallholder woodlots have expanded under market demand and more abundant land (Kimambo & Naughton-Treves, 2019; Kimambo *et al*., 2020). The Mulanje case thus underscores how institutional presence, proximity to commercial plantations, and spatial limitations jointly shape pine dynamics, echoing regional studies on both the benefits and ecological risks of non-native conifers (van Wilgen & Richardson, 2012; Brundu *et al*., 2020; Wells *et al*., 2023).

Results reveal that the distribution of *Pinus patula* is highly context dependent. Misuku shows a widespread and deliberate pattern of cultivation through household woodlots and agroforestry systems, while Mulanje exhibits a fragmented and uneven distribution shaped by land scarcity and proximity to institutional plantations. Historical studies confirm that pine spread on Mulanje has long been not uniform and patchy, with seedling dispersal constrained to localized sites (Verboom, 1992), while more recent work highlights the uneven yet significant impacts of these invasions on surrounding farming communities (Makhambera & Shah, 2019). This contrast underscores how ecological conditions, land availability, and institutional presence jointly shape pine distribution patterns across Malawi's montane landscapes.

The observed spatial differences in the distribution of *Pinus patula* between Misuku and Mulanje reveal that the species' spread, and presence are strongly influenced by local socio-economic conditions, land availability, and historical land-use practices. Practically, these findings reflect two very different social and ecological realities. This pattern means that pine does not spread uniformly, it follows people, their land-use decisions, and their opportunities. In Misuku, pine's wide and deliberate distribution shows how communities have actively integrated it into their farming systems as a reliable income and resource source. Households cultivate pine because they have space, cultural familiarity with tree planting, and economic incentives to maintain woodlots. This indicates that pine's spread here is not accidental, it is socially constructed. The landscape itself has been shaped by intentional cultivation, meaning any management must work *with* people, not against them.

In Mulanje, however, pine's distribution is fragmented and opportunistic. It thrives mostly near plantations, tea estates, and settlements where seed sources and disturbed soil are available, but rarely deep in farmlands where land competition is intense. This means pine persists here because of proximity and chance, not much by deliberate human effort. Its limited spread reflects land scarcity and competing agricultural priorities. Practically, this implies that pine control and monitoring should target institutional and plantation zones rather than expecting community level interventions.

Overall, the spatial distribution of *Pinus patula* across the two sites shows that human decisions determine ecological patterns. Where land is abundant and pine has social value as in Misuku, it spreads intentionally. Where land is scarce and agriculture dominates as in Mulanje, it remains patchy and secondary. This realization emphasizes that managing pine distribution in Malawi is not just about ecology but also about understanding people's relationship with their land and tailoring management to those realities.

5.3 KNOWLEDGE, ATTITUDES, AND PRACTICES (KAP) ANALYSIS

The conversation of community knowledge, attitudes, and practices (KAP) toward *Pinus patula* explores the complex interplay between awareness, perception, and behavioural response across contrasting socio-ecological settings in Malawi. While the results reveal high levels of awareness in both Misuku and Mulanje, they also expose a persistent gap between what people know and what they do in managing the species. This section interprets these patterns through social-ecological and behavioural lenses, considering how education, proximity to forest reserves, land availability, and institutional engagement shape community action. It further situates the findings within broader regional scholarship, emphasizing that environmental behaviour is not solely a function of knowledge or attitude, but emerges from the interaction between cognitive, material, and governance factors. In doing so, the discussion underscores that effective management of *P. patula* requires integrated interventions that address both informational and structural barriers to practice.

There is almost universal awareness of *Pinus patula* at both Misuku and Mulanje sites. However, there are weak practice effects, more especially in Misuku where the overall model fit is poor (Adj. R^2 =-0.322). This of course is consistent with broader evidence that knowledge and even favourable attitudes often fail to translate into consistent behaviour (Ardoin *et al*., 2020). Large combinations show that education and knowledge can improve environmental intentions and some behaviours, but effects are typically dependent on enabling conditions and social context rather than determination on their own (Ardoin *et al*., 2020; Ifegbesan *et al*., 2022; Amoah and Addoah, 2021). The insignificant knowledge to practice coefficient in Mulanje (≈0.155%, $p = 0.738$) and similarly weak attitude effects echo African studies finding that, while environmental knowledge is frequently a positive predictor, socio-economic and institutional factors e.g., market access, extension and resource constraints, moderate or overwhelm these effects (Amoah and Addoah, 2021; Sobeng *et al*., 2023).

The logistic regressions identifying education and proximity to forest reserves as positive predictors of knowledge and attitudes align with Fisher *et al*., 2024; Sobeng *et al*., 2023. They unveiled that education is repeatedly associated with greater environmental literacy and action, and proximity to protected areas often increases exposure, information flows, and program contact mechanisms that can lift knowledge and support. By contrast, the absence of robust predictors for practice is also unsurprising. Reviews of invasive species and restoration programs in the region highlight practical bottlenecks such as tenure, land competition, liquidity, and especially seed or seedling supply and quality that limit uptake even when knowledge and attitudes are high (Kindt *et al*., 2023; Bosshard *et al*., 2021; Giacomini *et al*., 2023).

5.3.1 PREDICTORS OF KNOWLEDGE AND ATTITUDES VS. PRACTICE

The logistic regressions identify education and proximity to forest reserves as positive predictors of knowledge and attitudes. This mirrors broader evidence where formal education is repeatedly associated with higher environmental literacy and pro-environmental predispositions, and living near protected areas increases exposure to information flows, programs and social contacts that raise conservation knowledge and support (Fisher *et al.*, 2024; Abukari & Mwalyosi, 2020; Oldekop *et al*., 2016). The absence of robust practice predictors is also not as surprising. Reviews of invasive species management and restoration across Africa highlight practical bottlenecks due to tenure frictions, land competition, liquidity, and especially seedling supply and quality that stall adoption even when knowledge and attitudes are high (Kindt, 2023; Bosshard *et al*., 2021; Giacomini *et al*., 2023).

5.3.2 A RESILIENCE AND GOVERNANCE LENS

Interpreting these patterns through a socio-ecological resilience lens clarifies why practice depends on assets, feedback and governance, not just individual cognition. Resilience scholarship emphasizes enabling diversity, learning, participation, and polycentric governance as levers to shift behaviour at scale (Ostrom, 2010). These maps closely to the finding that education and proximity shape knowledge/attitudes while material and institutional conditions are a gate way to practice (Folke *et al*., 2016; Ostrom, 2010). In practical terms, interventions that pair education with reliable, locally adapted seedling systems, extension support, and inclusive local institutions are more likely to close the knowledge to practice gap than information campaigns alone (Kindt, 2023; Bosshard *et al.*, 2021; Giacomini *et al*., 2023).

5.4 SOCIO-ECONOMIC CONTRIBUTIONS AND TRADE-OFFS OF *Pinus patula*

This section discusses the socio-economic contributions, opportunity costs, and ecological trade-offs associated with *Pinus patula* across the MMFR and MHFR. Drawing from cost–benefit and livelihood analyses conducted between 2021 and 2025, it interprets how the species, though ecologically invasive, has become economically embedded within local livelihood systems. The discussion highlights that while pine and coffee generate higher long-term returns compared to maize, their benefits are delayed and volatile, creating scale–timing trade-offs that shape household economic decisions. In Mulanje, where pine eradication has disrupted income streams and employment opportunities, the findings reveal the species' critical buffering role in sustaining rural economies with few alternatives. Conversely, in Misuku, *P. patula* has been domesticated within smallholder agroforestry systems, functioning as both an investment asset and livelihood safety net. By situating these findings within regional and global debates on invasive species management, this section underscores the need for context-specific strategies that reconcile ecological restoration with livelihood resilience thereby advocating for adaptive management approaches that acknowledge both the socio-economic utility and environmental risks of *Pinus patula* in Malawi's montane landscapes

5.4.1 OPPORTUNITY COST

The opportunity cost analysis conducted in Mulanje reveals that the removal of *Pinus patula* has generated substantial local economic losses, with estimated daily economic effects of MK 1,694 which were well above the national per capita daily income (GoM, 2022/23). This finding underscores the crucial buffering role that *P. patula* has played in the livelihood systems of highland communities, where economic opportunities are otherwise limited. Comparable patterns have been observed elsewhere in sub-Saharan Africa, where invasive alien tree species, once embedded within production, trade, and wage labor niches, become indispensable to rural economies (Shackleton *et al*., 2017; Shackleton *et al*., 2024).

The evidence from Mangombo and Nakhonyo communities, where over 80% of respondents reported involvement in pine-related employment, illustrates the depth of economic integration at the sub-area level. The multimodal pine value chain in Mulanje provided diverse employment pathways. Men predominantly engaged in tree felling, timber sawing, and pit-sawing while mostly women were active in transporting timber and firewood and as community members undertook plantation maintenance tasks. This mirrors gendered labour divisions widely documented in both commercial plantation forestry and community woodlot management across East and Southern Africa (Obiri *et al*., 2019; Cocks *et al*., 2020; Kiptot & Franzel, 2012). Such gender based differentiated tasks facilitated multiple entry points for household income generation, enhancing economic inclusivity and reinforcing pine's role as a "livelihood equalizer" in otherwise resource constrained environments. Studies on household livelihood portfolios consistently emphasize that these multi-nodal forms of engagement help buffer families against market volatility, climate shocks, and agricultural risks (Sovacool *et al*., 2022; Angelsen *et al*., 2014).

The onset of large-scale eradication campaigns led by the Mulanje Mountain Conservation Trust (MMCT) after 2007, with funding support from the Global Environment Facility, precipitated significant socio-economic disruptions. In the absence of viable economic substitutes, some households reported shifting extraction pressure to indigenous species, particularly *Widdringtonia whytei*. This pattern aligns with the "substitution effect" described by Gaertner *et al*. (2014), whereby the removal of economically embedded invasive species triggers compensatory harvesting of native resources. Similar dynamics have been reported in Kenya and Madagascar, where attempts to control or eradicate invasive species led to secondary ecological degradation as rural populations redirected exploitation to indigenous forests

(Mwangi & Swallow, 2008; Kull *et al.*, 2011; Shackleton *et al*., 2022). These outcomes reinforce broader concerns articulated by Pratt *et al*. (2017) and updated by Shackleton *et al*. (2024), that removal strategies devoid of alternative livelihood pathways may produce net socio-ecological losses**,** undermining both conservation and development objectives.

The Mulanje case thus illustrates a critical policy dilemma where while *P. patula* is ecologically problematic as an invasive alien species, it has become economically indispensable for certain forest-adjacent households. Its eradication, without a deliberate strategy to introduce viable livelihood alternatives, whether through market-integrated agroforestry systems or diversified forest product enterprises risks not only economic disenfranchisement but also accelerated ecological degradation through substitution. Balancing restoration imperatives with livelihood security therefore remains central to any sustainable management framework.

On the other hand, in the Misuku Hills, *patula* cultivation has become an integral part of local farming systems, complementing traditional cash crops such as coffee (*Coffea arabica*) and bananas (*Musa spp.*). Household survey data indicate that approximately 85% of respondents either owned pine stands themselves or had close relatives engaged in pine cultivation as a commercial venture. This aligns with broader observations that exotic timber species, particularly *Pinus patula* and *Pinus elliottii*, have been integrated into smallholder agroforestry systems across highland Malawi, where climatic conditions are favourable and market access for timber is relatively strong (Kalaba *et al*., 2021; Lowore, 2018).

Pine stands in Misuku are widely regarded as a form of household capital, frequently traded, inherited, or liquidated in response to immediate cash needs. The informal land timber transaction system allows farmers to sell standing trees at various stages of growth, with buyers assuming responsibility for management until harvesting. Upon harvesting, the land reverts to the original owner, thereby maintaining land tenure security while enabling flexible timber-based income generation. This system resembles the "standing tree markets" described in East Africa, where trees constitute an accessible savings and investment mechanism within smallholder economies (Schure *et al*., 2015; Kubbinga, 2018).

Such practices underscore the socio-economic embeddedness of exotic pines in rural livelihoods**.** While coffee remains the region's dominant income source perennial, pines provide an alternative and relatively stable income stream in contexts where agricultural prices are volatile and climate change poses risks to traditional cropping systems (Kambewa & Utila, 2008; Zulu & Schoneveld, 2019). Indeed, the cultivation and trade of pine woodlots in Misuku illustrate how smallholders diversify livelihood strategies through forest-based assets, creating an informal but dynamic timber economy that interacts with both local and regional markets.

However, increasing reliance on pines as a cash crop also raises important questions about ecological sustainability and land-use trade-offs. Literature on invasive alien species highlights that while pines deliver significant short-term socio-economic benefits, they may simultaneously impose ecological costs through biodiversity loss, water depletion, and displacement of indigenous species (Richardson, 2006; Pratt *et al*., 2017). Thus, any valuation of the "multi-nodal" role of *Pinus patula* in Misuku livelihoods must also incorporate these potential trade-offs, balancing household economic resilience against long-term ecological integrity.

The evidence from Mulanje and Misuku supports a nuanced, site-specific approach to *P. patula* management. In Mulanje, where historical dependence is high and alternatives scarce, blanket eradication risks intensifying both economic hardship and pressure on native forests. Transition strategies could have included phased removal, coupled with targeted livelihood diversification programs, skill training, and facilitated market access for alternative products. In Misuku, management needs to focus on preventing uncontrolled spread while maintaining managed production within household agroforestry systems. These approaches align with recent calls in the invasion management literature for integrated, socially aware strategies that recognise both ecological harm and socio-economic value (Shackleton *et al*., 2024; Gaertner *et al*., 2017).

5.4.2 ECONOMIC EFFICIENCY, TRADE-OFFS, AND LIVELIHOOD IMPLICATIONS OF PINE, COFFEE, AND MAIZE PRODUCTION

The Benefit–Cost Ratio (BCR) analysis provides a comprehensive lens through which to assess the relative economic efficiency, livelihood significance, and ecological implications of *Pinus patula*, coffee (*Coffea arabica*), and maize (*Zea mays*) systems within the Mulanje and Misuku landscapes. By comparing the present value of benefits and costs over the 2021–2025 period, the results reveal a distinct scale timing trade-off, reflecting the coexistence of short-term survival strategies and long-term investment behaviour typical of Malawi's smallholder systems (Shackleton, Shackleton & Kull, 2019; TEEBAgriFood, 2019).

Across the five-year period, *Pinus patula* and coffee deliver the highest total values and Net Present Values (NPVs) but exhibit backloaded and volatile cash flows due to high establishment costs and delayed harvests. In contrast, maize yields smaller yet steadier annual gains, producing the relatively highly discounted BCR (2.45) and thereby the most cost-efficient enterprise under liquidity-constrained smallholder conditions. This efficiency gradient mirrors patterns in rural Malawi, where maize serves as the primary subsistence and income crop, sustaining immediate household needs even amid low average yields and price fluctuations (TEEBAgriFood, 2019). For tree-based systems, the combination of substantial early costs and deferred revenues explains why NPVs remain high while BCRs lag behind maize at a 5% discount rate. This is a dynamic widely documented smallholder investment decisions involving perennial crops (Shackleton, Shackleton & Kull, 2019).

Pinus patula demonstrates the highest long-term profitability, with a discounted BCR of 5.9 and an NPV of MWK 8.38 million, confirming its role as a household capital asset and a "living bank account" that can be liquidated to meet major financial needs (Kalaba *et al*., 2021; Shackleton *et al*., 2024). However, despite that the pine stands in case of Misuku can be sold at any stage since establishment, worthwhile benefits as presented in the results are realized only after several years, meaning the species is most viable for households with sufficient land and the capacity to defer returns. The observed ecological trade-offs associated with pine include reduced streamflow, lower groundwater recharge, and suppression of native plant diversity, mirror broader findings from southern Africa on the hydrological and biodiversity impacts of invasive conifers (Le Maitre, Gush & Dzikiti, 2015; Le Maitre *et al*., 2016; Chamier *et al*., 2012). Therefore, while economically attractive, the species' ecological footprint necessitates mitigation strategies such as buffer zones, mixed-species replanting, and rotational harvesting to balance long-term financial gains with ecosystem health.

Coffee occupies a middle ground between subsistence and investment crops, with a discounted BCR of 1.34 and an NPV of MWK 4.38 million. Despite moderate profitability, coffee plays a crucial role in income diversification and household resilience. Once established, it generates consistent seasonal income and provides employment opportunities, particularly for women and youth involved in picking and processing (Kambewa & Utila, 2008; Wienhold *et al*., 2023). Its integration into agroforestry systems, often under pine, banana, or indigenous shade trees, enhances soil fertility and microclimate regulation, linking economic productivity to ecological restoration. However, high establishment costs, pest sensitivity, and market volatility constrain expansion, emphasizing the importance of cooperative marketing and access to finance to enhance coffee's viability within smallholder systems (Zulu & Schoneveld, 2019).

Maize remains the livelihood economic and nutritional cornerstone of rural livelihoods in Malawi, offering the highest cost efficiency (BCR = 2.45) and the most immediate returns. Its annual production cycle, low capital intensity, and contribution to household food and cash needs make it indispensable, particularly for land-constrained households. While maize generates lower absolute profits than perennial systems, its predictability and liquidity enable farmers to sustain consumption, pay school fees, and reinvest in higher-value crops. Nonetheless, thin margins and vulnerability to input price fluctuations and climatic variability limit its potential as a long-term growth pathway (TEEBAgriFood, 2019; GoM, 2023).

The results continue to highlight two very different livelihood realities between Mulanje and Misuku, shaped by how communities interact with *Pinus patula*, coffee, and maize. This means that the economic logic behind land use decisions is deeply rooted in context, access, and opportunity, rather than purely in profitability.

In Mulanje, maize stands out as the only actively cultivated crop among the three, a reflection of both land scarcity and immediate livelihood needs. Households here depend almost entirely on maize for food and income, valuing their short cycle and predictable returns. The high Benefit–Cost Ratio for maize (≈2.45) confirms its importance as a short-term survival crop that ensures household food security and regular liquidity. The earlier dependence on *Pinus patula* was not through cultivation, but through indirect economic benefits i.e. employment, timber, and fuelwood from government plantations. The 2007 eradication campaigns, therefore, disrupted a significant economic safety net, creating livelihood gaps that maize alone cannot fill. This experience reveals that while maize ensures daily sustenance, the loss of access to pine-based employment left communities vulnerable and more dependent on an already strained subsistence crop.

In Misuku, the picture is very different. Here, smallholders actively cultivate pine, coffee, and maize together, effectively managing their land as a diversified livelihood portfolio. Pine is seen as a long-term investment and form of savings, coffee as a medium-term cash crop, and maize as a short-term food and sometimes income source. The high discounted BCR for pine (5.9) and coffee's moderate profitability (1.34) confirm that farmers here think strategically about time and value. They accept delayed returns from tree crops because they have land, patience, and institutional support (e.g., forestry and coffee cooperatives) to make such systems work. This balance enables households to meet current food needs while also accumulating long-term assets, demonstrating a multi-layered resilience strategy uncommon in more land-constrained areas like Mulanje.

From a management perspective, these contrasts imply that policy and intervention must be spatially differentiated. In Misuku, supporting improved market access, sustainable pine management, and eco-friendly coffee to pine intercropping could enhance both economic and ecological outcomes. In Mulanje, however, recovery strategies must focus on livelihood restoration. Not through pine eradication alone, but through introducing viable alternatives such as community woodlots, expansion of the small-scale irrigation already present, or high-value short-cycle crops that can substitute for lost pine-derived income.

Ultimately, these results underscore that *Pinus patula* is not just an ecological issue, it is a livelihood question. In Misuku, it symbolizes long-term economic hope, while in Mulanje, it represents a lost opportunity and ecological tension. Sustainable management must therefore recognize this dual identity by treating pine not merely as an invasive species, but as part of a complex social–ecological system where people's survival strategies are intimately tied to the landscapes they inhabit.

5.5 CONFLICT OF INTEREST INVASIVE SPECIES

The case of *Pinus patula* in Malawi illustrates the characteristics of a conflict-of-interest invasive species. It causes ecological harm in displacing native species and potentially reducing water flows but also supports rural economies.

Concerns about reduced water flow post-invasion have been substantiated in other contexts. For example, Dzikiti *et al*. (2013) demonstrated that *Pinus patula* significantly reduces streamflow and groundwater recharge in South Africa, supporting local conservationists' concerns. However, whether this dynamic holds true across varying altitudes and hydrological systems, such as in Misuku or Mulanje, warrants further localized research.

The dual role of pine mirrors findings from *Prosopis juliflora* in Kenya and Nepal, where removal has similarly triggered social backlash (Rai & Clements, 2022). Management must therefore acknowledge both ecological and socio-economic dimensions. Blanket eradication may not be appropriate where communities lack viable alternatives.

With respect to ecological trade-offs, evidence from Mulanje indicates competitive interactions between planted or escaped *P. patula* and the endemic *Widdringtonia whytei* (Mulanje cedar), with pine invasion flagged as a threat in technical assessments and academic reports. This is supporting local conservationists' concerns that pine can displace native assemblages while altering fire regimes and recruitment dynamics (Verboom, 2017; CITES CoP documents). Although these are not hydrology experiments per se, they situate pine impacts within broader biodiversity risks that matter for restoration choices. On the social side, recent scholarship documents why "eradicate everywhere" strategies often face backlash where alien trees provide energy, construction wood, or cash income. In East Africa, Prosopis studies offer a close analogue where household level econometric work in Kenya shows that perceived benefits (notably charcoal) increase participation in use and reduce willingness to eradicate. This implies that management framed solely as removal can erode support and produce perverse incentives (Tabe-Ojong, 2023). Large-N syntheses and local surveys in Ethiopia likewise report mixed perceptions and livelihood trade-offs, advocating combinations of targeted control, value-chain diversification, and co-designed governance (Shiferaw *et al*., 2022; Kamiri *et al*., 2024). These lessons generalize to *P. patula* in Malawi where pine substitutes for scarce timber/poles, abrupt removal without viable alternatives can undermine buy-in, whereas zoned control might work and better aligns ecological and livelihood objectives.

The implications for Misuku as well as Mulanje inferences that streamflow reductions documented elsewhere may not translate uniformly across Malawi's uplands is consistent with the recent forest water literature. Given differences in elevation, rainfall, and land-use mosaics i.e. smallholder woodlots in Misuku and spontaneous individual tree, legacy plantation and institutional landscapes around Mulanje, a robust approach would pair local sap-flow/eddy-covariance measurements in representative pine stands with paired sub-catchment flow records or Budyko-type water-balance modelling stratified by P/PET and stand position. That design would test whether Mulanje's riparian interfaces exhibit the larger pine driven flow penalties seen in other riparian contexts, while quantifying whether Misuku's dispersed woodlots exert weaker, more diffuse hydrologic effects.

5.6 METHODOLOGICAL LIMITATIONS AND FUTURE RESEARCH

This study employed a cross-sectional design, limiting the ability to capture long-term changes in livelihoods or ecological recovery. Recalling bias may have affected self-reported income or land use. Future research should use longitudinal mixed methods, spatial invasion modelling, and experimental livelihood trials to track outcomes post-eradication.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The study shows that the spread and management of *Pinus patula* in Malawi's montane landscapes are shaped by intertwined socio-economic realities, community behaviours, and institutional histories. Misuku's greater land availability has enabled households to integrate pine into agroforestry systems as a long-term livelihood asset, though the potential for future spillover into the forest reserve remains a notable ecological risk. In Mulanje, community interaction with pine has been driven largely by plantation-based wage labour, resulting in socio-economic disruptions when plantations were removed without alternatives. Across both landscapes, the gap between knowledge, attitudes, and practice reflects broader constraints with limited land tenure security, financial resource, and inconsistent policy direction. Economic analysis further highlights that while pine and coffee offer long-term returns, maize continues to support immediate household needs, shaping livelihood decisions.

Overall, the findings confirm that *P. patula* management is a context-specific socio-ecological challenge. Effective and sustainable responses will require adaptive, local evidence-based strategies that align conservation goals with community livelihood realities and anticipate long-term ecological risks.

6.2 RECOMMENDATIONS

Sustainable management of *Pinus patula* around MMFR and MHFR requires strengthening community-based control measures, including proper awareness of *patula's* behaviour and local monitoring more especially in Misuku where future spillover risk remains. Diversified livelihood options such as beekeeping, fruit trees, and small-scale irrigation should be promoted in Mulanje to caution the eliminated plantation wage labour. Improving land tenure security and expanding forestry and agricultural extension support will enable households to adopt more sustainable practices. Stronger coordination between the Department of Forestry, District Councils, and communities is needed to ensure coherent management approaches, with future plantation removals incorporating clear livelihood transition plans. Finally, long-term ecological monitoring and further research on livelihood trade-offs should guide adaptive and evidence-based decision-making

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APPENDICES

Appendix 1: Research Questionnaire

MZUZU UNIVERSITY

My name is Cosmas Dambo, a final year Forestry and Environmental Management student at Mzuzu University. I am conducting academic research to assess "Social-Ecological Dimensions of Pinus patula Invasion: Evidence from Mulanje Mountain and Misuku Hills, Malawi". To meet the objectives of the study, several strategies are being used including conducting discussions with local households in Misuku Hills, Chitipa District and Mulanje Mountain in Mulanje district. The information obtained from this questionnaire will be used sorely for the purposes of this study and shall be confidential. Time taken will be not more than 30 minutes. Thank you in advance for willing to spare your time on this useful discussion.

HOUSEHOLD QUESTIONNAIRE

A. **Official Detail**	B. **Location**
Name of Interviewer:	Village:
Name of Respondent:	T/A:
Date of Interview:	District:
Interviewers' Comment:	
Geographical coordinates:	

C. Demography

Please tick against the chosen option (where necessary)

1) Sex: 1. Male ☐ 2. Female ☐

2) Age: 1. 15 below ☐ 2. 16 to 24 ☐ 3. 25 to 64 ☐

4. 65 and above ☐

3) Marital status.

1. Single ☐ 2. Married ☐ 3. Divorce ☐ 4. Widower ☐

5. Widow ☐

4) Education: 1. None ☐ 2. Primary ☐ 3. Secondary ☐ 4. Tertiary ☐

5. Vocational ☐

5) How far are you from the reserve? (MMFR/MHFR)

1. $\geq$ 5 Km ☐ 2. 6 Km to 10 Km ☐ 3. 11 Km to 15 Km ☐

4. 16 Km to 20 Km ☐ 5. $\leq$ 21 Km ☐

6) Occupation: 1. Subsistence Farmer ☐ 2. Business ☐ 3. Student ☐

4. Livestock keeping ☐ 6. Firewood collection ☐ 7. Lumbering ☐

9. Other: ____

7) How many are you in your immediate family?

1. 1 to 3 ☐ 2. 4 to 6 ☐ 3. 7 to 9 ☐ 4. 10 and above ☐

8) How long have you lived in this community?

1. 5-10 years ☐ 2. 11 – 20 years ☐ 3. 21-30 ☐ 4. $\geq$ 31 ☐

D. Knowledge, attitude and practices towards pines

please circle the appropriate response.

1) Do you know pines?

   1. Yes. ☐ 2. No. ☐

2) Are pines exotic (originally from outside Malawi) or native (Naturally growing In Malawi)?

   1. Native ☐ 2, Exotic ☐ 3. No idea ☐

3) Who introduced pines in your areas

   1. Government ☐ 2. NGOs ☐ 3. Business people ☐

   2. 4. Some community individuals ☐ 5. Local NRCs ☐ 6. No one ☐
   7. They have always been here ☐ 8. Just appeared on their own ☐ 9. No idea ☐

4) Do you think it was a good Idea to introduce pines?
   1. Yes. 2. No

5) Do you utilize pines? 1. Yes. 2. No

6) If no, Why?

   ____

7) If Yes, what do you utilize pines for?

   1. Medicine ☐ 2. Fuel-wood ☐ 3. Timber ☐ 4. Poles ☐

   5. Sale ☐ 6.Other: ____

8) Which parts of the pine trees are used?
   1. Root ☐ 2. Stem ☐ 3. Bark ☐ 4. Branch ☐

   5. Leaves ☐ 6. Cones ☐ 7. Seeds ☐

9) Where do you harvest pine products from?

   1. Wild growing 2. Plantations 3. Your own Planting 4. Other ……….

10) If you do grow pines;
(a) Where do you plant pines

1. Within compounds ☐ 2. Along fence ☐ 3. Farming area ☐

4. Woodlots ☐ 5. Others: ______________________________

(b) Are they tended?

1. Yes. ☐ 2. No. ☐

(c) If yes, how?

1. Thinning and pruning 2. Only weeded 3. Fire control 4. All silvicultural operations

(d) Is there organized harvesting?

1. Yes. ☐ 2. No ☐

(e) If yes, how is it done?

____

__

____

(f) Are they grown separately or intercropped?

1. Separately. ☐ 2. Intercropped. ☐

11) If no (you don't plant pines), Why?

1. Difficult to raise 2. Not interested 3. Not good

4. Easily attacked by pests and diseases 5. Take long to grow 6. Lack of land

7. Other: ____

12) . Do you collect natural resources in areas where pines are abundant?

1. Yes. ☐ 2. No. ☐

13) What do you collect from areas where pines are abundant *(e.g., plantations or where they have spread to on their own)*?

1. Firewood ☐ 2. Seeds ☐ 3. Herbs ☐ 4. Hunting ☐

5. Medicinal Plants ☐ 6. Pine cones ☐ 7. Other ☐

14) How often?

a) 1. Daily 2. Weekly 3. Twice a Month 4. Monthly

5. Other: ____

b) Does pine benefit you financially? 1. Yes. ☐ 2. No. ☐

15) If yes, how have you come to know that they are problematic?
1. Formal education 2. Civic education 3. Observation 4. Told

5. Other (Specify)

____

16) What other plants grow in pine plantations?

1……………………………………………………

2……………………………………………………

17) Do you find more useful species in areas where there are many pines or in areas outside of pine plantations?
1. Areas with many pines ☐ 2. Areas without pines ☐

18) Which plant species cannot be found in pine plantations?

1……………………………………………………

2……………………………………………………

3……………………………………………………

19) Do pines spread on their own in your area?

1. Yes. ☐ 2. No. ☐

20) If yes, is it good that they spread on their own?

1. Yes. ☐ 2. No. ☐

21) (i) In your opinion, do you think Government of Malawi through Department of Forestry in the district and Private sector will be able to control the issue of pine invasion in the reserve?
1. Yes ☐ 2. No ☐

(ii) Give a reason for your answer in 9 (i)

____

22) Do pines impact negatively on the following?

No.	**Component**	**Yes/No**	**Type of problems (Alteration of nutrient cycle , Alter fire regimes, shading , Host plant pests and diseases , Displacement Alteration of nutrient cycle, Hosting plant pests and disease)**	**What do you do about it**	**What you think should be done**
1	People				
2	Livestock				
3	Wildlife				
4	Water				
5	Soil				
6	Other plants				
7	Air				
8	Other (Specify)				

Thank you

Appendix 2: Pinus patula Location Coordinates Data Collection Form

PINE OBSERVATION DATA COLLECTION SHEET				
Point No	**Coordinates**		**Number of Pines** **(size of woodlot)**	**Village Name**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Appendix 3: Ethical considerations

MZUZU UNIVERSITY

DIRECTORATE OF RESEARCH

Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2
MALAWI
TEL: 01 320 722
FAX: 01 320 648

MZUZU UNIVERSITY RESEARCH ETHICS COMMITTEE (MZUNIREC)

Ref No: MZUNIREC/DOR/25/130 **15/12/2025**

Cosmas Dambo, Mzuzu
University, P/Bag 201,
Luwinga,

Mzuzu . Email:

Dear Cosmas,

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL REF NO. MZUNIREC/DOR/25/130: SOCIOECONOMIC DIMENSIONS AND COMMUNITY BEHAVIOUR TOWARDS PINUS PATULA SPREAD IN COMMUNITIES AROUND MULANJE MOUNTAIN FOREST RESERVE AND MISUKU HILLS FOREST RESERVES, MALAWI

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the Mzuzu University Research Ethics Committee (MZUNIREC) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee with a final report of the study.

The Committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Wishing you a successful implementation of your study Yours

Sincerely,

MZUZU UNIVERSITY
RESEARCH ETHICS COMMITTEE
1[illegible] DEC 2025
PRIVATE BAG 201, LUWINGA
MZUZU 2

Faith Mwangonde
Research Ethics Administrator.

FOR : MZUNIREC CHAIRPERSON

Mzuzu University Research Ethics Committee Directorate of

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