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How 'local' is local knowledge?

the role of local knowledge in implementing locally appropriate land restoration interventions

Kuria, Anne

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Anne Wanja Kuria

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Anne Wanja Kuria

Student ID Number: 500399578

May, 2019

The College of Environmental Sciences and Engineering

School of Natural Sciences (SNS)

Bangor University, Gwynedd, LL57 2DG, United Kingdom

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Doctoral Advisory Committee Members:

Fergus Sinclair, PhD – Doctoral Supervisor

Timothy Pagella, PhD – Doctoral Supervisor

Sophie Wyne-Jones, PhD – Internal Examiner

Morag McDonald, PhD- Chair

Co-supervisors at ICRAF:

Catherine Muthuri, PhD - Subject-specific supervisor and Trees for Food Security Project Manager

Leigh Winowiecki, PhD - Subject-specific supervisor and Land Restoration Project Manager

Edmundo Barrios, PhD - Subject-specific supervisor

This is a full-time PhD research programme conducted through the place of employment at the World Agroforestry Centre, ICRAF. Headquarters, Nairobi, Kenya

SUMMARY

Globally, there is an emerging interest in scaling the adoption of land restoration interventions as a sustainable approach to improving food security. Past attempts to scale restoration interventions have tended to promote a few generic options that are often poorly tailored to their context. This has resulted in restoration interventions that are not locally adapted, acceptable or cost-effective. I explored the potential for utilising local knowledge to better inform land restoration options across scale. Local knowledge was elicited through a systematic knowledge-based systems approach involving smallholder farmers (n=482) using 'paired-landscape experimental design' for degrading and recovering systems in both Rwanda and Ethiopia. My findings demonstrate that in landscapes affected by degradation, livelihood systems operate across broad landscape scales beyond the farm boundary and have wide spatial livelihood system boundaries and as a result the thesis was able to capture locally informed scaling dimensions. This included identifying use of indicators, such as *Dichogaster itoliensis* (an earthworm new to science) whose burrowing behaviour is a local indicator of soil quality. Local knowledge can also be used to inform understanding about ecosystem service scaling processes (both spatial and temporal) but also for identifying critical knowledge gaps in farmer understanding about degradation processes. This local knowledge informs how farmers adapt and modify their land restoration interventions to better suit their needs and context; hence the acquisition and analysis of local knowledge provides an effective mechanism to track iterative development of adaptation measures and to evaluate both positive and negative consequences resulting from these actions. These findings support the 'options by context' approach to 'research in development' for adapting restoration technologies (with a focus here on agroforestry systems) to better suit the needs of smallholder farmers trying to recover their soils and points towards the need for further integration of local knowledge in the development of restoration activity.

Key words: local knowledge, land degradation, land restoration, agroforestry, scale

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LIST OF ACRONYMS

ACIAR - Australian Centre for International Agricultural Research

AKT - the Agro-ecological Knowledge Toolkit

BOARD - Bureau of Agriculture and Rural Development

CGIAR - Consultative Group of International Agricultural Research

CIP - Crop Intensification Programme

CoP – Communities of Practice

CSI - Coping Strategies Index

DPSIR – Drivers-Pressures-State-Impacts-Response

DryDev - Drylands Development

EPRDF - the Ethiopian People's Revolutionary Democratic Front

EU – European Union

FAO - the Food and Agriculture Organization

FCS - Food Consumption Score

FGD - Focus Group Discussions

FIES - Food Insecurity Experience Scale

FMNR - Farmer Managed Natural Regeneration

FTA - Forests, Trees and Agroforestry

FWLG - F-Fungus growers, W-Wood, L-Litter, G- Grass feeders

GDP – GROSS Domestic Product

GIS - Geographic Information System

HDDS - Household Dietary Diversity Scale

HFIAS - Household Food Insecurity and Access Scale

ICRAF- World Agroforestry Centre

IFAD - International Fund for Agricultural Development

InPAC-S - Participatory Knowledge Integration on Indicators of Soil Quality

LDN – Land Degradation Neutrality

LDSF - Land Degradation Surveillance Framework

PRA – Participatory Rural Appraisals

RAB - Rwanda Agricultural Board

rCSI - Reduced Coping Strategies Index

REMA - Rwanda Environment Management Authority

REST - Relief Society of Tigray

SDG - Sustainable Development Goals

SES – Socio-Ecological Systems Approach

SOC – Soil Organic Carbon

SSA- Sub-Saharan Africa

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AUTHORSHIP INFORMATION

I have personally compiled and prepared all three data chapters for peer review publications. Chapter two has been published by Geoderma Regional Journal. Chapter three and four are complete and undergoing final revisions and will be submitted to the respective journals in the coming months. I am the lead author for all three chapters, with support, mentorship and close guidance from Fergus Sinclair and Timothy Pagella, who are my University supervisors. There are also other co-authors from ICRAF Nairobi (Catherine Muthuri, Leigh Winowiecki, Edmundo Barrios); ICRAF Rwanda (Athanase Mukuralinda) and Mekelle University- Ethiopia (Mitiku Haile) who have contributed immensely towards this research through offering subject-specific expertise. Other people who are not necessarily co-authors but who were helpful in various areas such as guiding me on translation, research design, data analysis, macrofauna have been acknowledged accordingly.

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I conceptualized and designed the research survey with guidance from EB, TP, CM and FS. I personally undertook data collection and statistical analysis using R software. AM provided technical guidance on soil aspects, including local taxonomy of soils, macrofauna and indicator plants. EB guided me on refining the questionnaires and further advise on the analysis methodology and providing intensive day to day revisions on the manuscript as ideas progressed. TP, CM and AM provided comments on the draft manuscript while FS provided revisions on the final manuscript before submission to the journal.

Chapter 4: Anne W. Kuria, Timothy Pagella, Leigh Winowiecki, Mitiku Haile, Fergus L. Sinclair. Restoration for whom? incorporating local knowledge promotes adaptive land restoration technologies that deliver multiple ecosystem services across scale. Manuscript prepared to be submitted to the Restoration Ecology Journal.

I conceptualized and designed the research survey with guidance from LW, TP and FS. I personally collected the local knowledge data and analysed it. MH assisted me to refine my research questions and focus while the ground in Tigray, Ethiopia, provided background information from his previous complementary studies. TP provided the day to day intensive refining of ideas throughout the article. LW, MH and FS reviewed the draft manuscript.

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I conceptualized and designed the survey with the research focus guided by TP, CM and FS. I personally undertook data collection and data analysis. TP provided the day to day intensive refining of ideas throughout the article. CM and FS advised and commented on the final draft manuscript.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

In this chapter, I begin with a general discussion of my subject area on land degradation being a challenge, then I discuss the relevance of land restoration and highlight the challenges current restoration efforts are facing currently. I then highlight the different options to land restoration including agroforestry. I then narrow down to the role of local knowledge in contributing to ‘options by context’ framework to restoration and further highlight knowledge gaps that exist which may limit achievement of land restoration at scales beyond the farm level.

1.1.1 Global challenge of land degradation

In the 21st century, land degradation has been associated with an increasing set of challenges faced by the global population. Land degradation results in a decline in ecosystem functions. This loss of function manifests in various forms, with the major ones being loss of biological diversity, loss of soil and water (Borrelli et al., 2016; Lal, 2017). Thus, land degradation presents a major barrier to the achievement of many of the Sustainable Development Goals (SDGs). Land degradation is defined as “the long-term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover unaided” (Bai et al., 2008). A third of all global agricultural land is currently classified as being moderately to highly degraded (FAO and ITPS, 2015). According to Nkonya and Mirzabaev (2016), sub-Saharan Africa has experienced the most serious land degradation in the world. The livelihoods of the more than 950 million people who depend heavily on natural resources especially agriculture is thus threatened (OECD and FAO, 2016).

In sub-Sahara African countries as in most countries globally, land degradation has been largely associated with human-induced drivers largely associated with agricultural expansion or intensification (Jayne et al., 2014). The primary driver of land degradation is deforestation (Bai et al., 2013; Birhanu, 2014; Bizoza and Havugimana, 2013). The pressing demand for agricultural land by smallholder farmers has led to increasing tree cover loss (Cerretelli et al., 2018; Jew et al., 2017). Tree cover loss is driven by a range of factors which are often context specific. For example, in Ethiopia, poor agronomic practices, overgrazing, insecurity of tenure and overexploitation of trees for products largely drives deforestation (Tesfa and Mekuriaw, 2014) whereas in Rwanda, continuous cultivation due to limited available farming land (a factor which also pushes farmers on to cultivation of steep slopes) and over extraction of products are the main drivers (Safari, 2010). The challenge of dealing with land degradation is worsened by other emerging threats primarily driven by climate change (Webb et al., 2017).

One of the major challenges facing smallholder farmers in the wake of land degradation is the need to increase and sustain food production on decreasing average household land sizes while protecting the ecological health of the farming systems. Understanding the complex nature of drivers and effects of land degradation as they manifest in specific socio-ecological contexts is important when designing land restoration interventions (Coe et al., 2014).

1.1.2 Can land restoration enable resilience in smallholder livelihood systems?

Land restoration is the process of restoring ecological functions in degraded ecosystems. In many cases, this involves activities that are aimed at re-developing ecosystem structure and functions and the provision of goods and services. This is through intervening to repair soil productive functions, limit water loss and increase ecological complexity. Initially, restoration was a primarily ecologically driven process (i.e. the recovery of ecosystems driven by conservation objectives) but increasingly the term is now used within a development context to mean the process land is brought back to a point where sustainable production is possible (Crossman, 2017). In this context, the aim of restoration moves beyond meeting ecological criteria to include livelihood and economic components. For land restoration to be successful and sustainable, it should not be passive but should include tangible benefits, and should add value to the land and livelihoods of resource users (Meli et al., 2017).

In Ethiopia, various land restoration interventions have been deployed since the Derg regime (between 1974 and 1991). The government, international institutions and local communities embarked on substantial land management, soil and water conservation interventions. These included activities such as terracing, construction of stone and soil bunds, contour planting and the creation of exclosures on previously degraded grazing lands (Yirdaw et al., 2017). There were also larger scale approaches, for example, a regreening initiative that promoted the planting of *Eucalyptus sp.* trees across landscapes, which was the Ethiopia government's response to acute shortage of fuelwood and timber. This, sadly, resulted in a range of unforeseen consequences such as water bodies drying up (Lemenih and Kassa, 2014). Likewise, in Rwanda, following the genocide that occurred in 1994/5, the government implemented soil and water conservation programmes. These included the establishment of bench terraces and tree planting (Bizoza, 2014). This too had unforeseen consequences as many interventions involved tree monocrops with low diversity.

Land restoration implementation is a challenging process. It requires an understanding of how ecosystem services are generated (often across scales). In theory this requires an understanding of the flow pathways of ecosystem services and often involves taking interventions to scale to address processes that manifest at these scales (Pagella and Sinclair, 2014). However, the majority of implementing bodies have had limited success in addressing scaling dynamics. There are many potential reasons for this. Addressing scale requires a interdisciplinary approaches from bio-physical and socio-economic disciplines to reconcile economic, social and environmental aspects (Aradóttir and Hagen, 2013). Ecosystem services should be managed concurrently to meet the needs of the multiple resource users, which requires a systems approach to management. It requires active participation by stakeholders, from local actors such as smallholder farmers, who are the main beneficiaries, through to policy stakeholders (Derak et al., 2017). Taking land restoration to scale thus involves more than implementation of generic field scale physical interventions but requires a level of analysis which includes identification of context specific knowledge gaps (Menz et al., 2013). In reality, different stakeholders often have different interests and priorities that inform their adoption behaviours towards specific interventions (see Chirwa et al., 2015; Ocampo-Melgar et al., 2015). It is imperative to understand and manage these varying interests to allow restoration to be successful.

More recently there have been calls to address Land Degradation Neutrality (LDN) (see Kust et al., 2017; Webb et al., 2017). At the heart of this concept is the idea that restoration of land once it is degraded is costlier than preventing further degradation of less degraded land. This advocates for the importance of integrating preventive measures, such as agroforestry, to protect landscapes from further degradation. When taking into account climate change, preventive measures such as these are more likely to ameliorate the effects of such threats, and the suggestion is that these are cost-effective interventions (Copeland et al., 2018; Stanturf et al., 2018). Despite this, barriers to widescale adoption of these technologies persist.

1.1.3 The contribution of agroforestry in land restoration and promoting food security

Agroforestry is defined by the World Agroforestry Centre as "a collective name for land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be either in spatial mixture or temporal sequence, and there are normally both ecological and economic interactions between the woody and non-woody components in agroforestry". Well-designed agroforestry systems can provide a wide range of ecosystem services, which support food production, improve nutrition, contribute to poverty alleviation, and enhances human and ecological well-being (Carsan et al., 2014).

With respect to restoration processes, agroforestry has the potential to contribute to soil formation; and the presence of trees in most cases will result in regulating benefits such as soil erosion control, carbon sequestration, biological pest control, pollination, nutrient cycling and water regulation (Verchot et al. 2007; Swift, Izac & van Noordwijk 2004). Agroforestry systems also support soil biota such as earthworms that play a critical role in regulating soil-based ecosystem services such as carbon and nutrient cycling and modifying the soil structure (Barrios, 2007) which maintains agricultural ecosystems. As such, agroforestry is seen as an important tool for restoring degraded landscapes.

Recent studies have shown that the combination of the right trees with crops in the right densities and niches, accompanied by appropriate tree management practices maximize on possible positive interactions and promote diverse functions and benefits of trees (Muthuri et al., 2009; Ong et al. 2007). However, as illustrated in the Ethiopian example above, the wrong tree (or the wrong design of agroforestry systems) can contribute to problems. Mbow et al., (2014a) showed that tree monocrop systems were less resilient and highly susceptible to various environmental threats such as climate variability, pests and diseases. Increasing tree diversity and density leads to increased ecological and livelihood benefits (Iiyama et al., 2017). This is due to the fact that various trees play unique and multi-purpose roles in the system, and these benefits are realized at different times of the year (especially from products) hence meeting varying needs. Dumont et al., (2017) found that through structured stakeholder engagement in Eastern Democratic Republic of Congo, more than 70 tree species were identified as important in restoration activity, signifying the highly diverse and multiple purpose roles that different tree species play. This reinforces the need for detailed knowledge to underpin the selection of appropriate tree combinations (or agroforestry systems) that suit their context. This is highly challenging.

Effective and sustainable adoption and scaling of agroforestry best practices on farm is inhibited by various factors such as lack of local participation in problem identification and tree selection, limited knowledge and skills in tree propagation and management, limited land, insecurity of land tenure, lack of tangible benefits of trees and poor markets for tree products (Endale et al., 2017; Kabwe et al., 2009; Nyaga et al., 2015). Most often, this is due to agroforestry options being inappropriately matched with the local biophysical context and farmer circumstances (Coe et al., 2014).

To address these issues, both specifically for agroforestry and more generally in development, there has been increasing interest in developing research where options are matched to sites and circumstances (Coe et al., 2014). This recognises the need to understand the intra and inter-system fine-grain variations in context found in agroecosystems to come up with customized management options and interventions that match those contexts. Past development approaches have however promoted and focused on one or a few options across different contexts, which has led to failure of the projects (Coe et al, 2014). There is great need to improve the success and performance of development activities through employing research methodologies and tools that capture these fine-grain variations in local context. One such approach is the acquisition and use of local knowledge.

1.1.4 The role of local knowledge in implementing locally appropriate land restoration options

Local knowledge is dynamic and is a combination of traditional knowledge (passed down over time from one generation to another), indigenous knowledge (knowledge embedded within a community's cultural values), locally derived and contemporary knowledge acquired through observation or external sources (ICRAF, 2014). Local knowledge has been utilized extensively in triangulation of scientific information derived from landscape scale methodologies especially spatially explicit GIS methodologies (Jackson et al., 2013; Pagella et al., 2012). Integration of local knowledge has also led to better coping mechanisms for emerging threats such as climate change, diseases and pests (Jacobi et al., 2017). Barrios et al., (2012a) further notes that local knowledge is the language that allows communication between farmers, scientists, extension workers and development agents.

Local knowledge has the potential to play a major role in complementing scientific knowledge in natural resource management (Berkes and Turner, 2006). More studies have shown that local knowledge plays a critical role in characterizing socio-ecological systems as well as developing customized interventions required to sustainably manage such systems (Carmona, Varela-Ortega & Bromley 2013; Ginger 2014). For example, Dumont et al., (2017) found that through structured stakeholder engagement, more than 70 tree species were identified, signifying the highly diverse and multiple purpose roles that different tree species play in the system for various stakeholder needs. They highlighted the importance of local participation of stakeholders in tree selection as it led to the adoption of diverse and inclusive tree species suited to local needs and context (Dumont et al., 2017).

Other studies have demonstrated the role local knowledge plays in providing in-depth understanding of the role of specific tree attributes such as leaf texture and size and crown shape and density in improving the provision of ecosystem services (Cerdán et al., 2012). Local knowledge has also been applied in tree attribute ranking which promotes selection of more diverse and context-appropriate tree species in coffee systems (Lamond et al., 2016; Smith Dumont et al., 2018). A study in Brazil further showed that men had deeper knowledge of landscapes further from their residence whilst women had more detailed knowledge of their immediate landscape (Nunes et al., 2018).

One of the critical stages in assessing the effectiveness and impacts of land restoration options is monitoring the gradual changes occurring on the biotic and abiotic indicators (Dudley et al., 2018; Warren et al., 2017). Flores-Díaz et al., (2018) notes that local communities are a key stakeholder in monitoring these changes due to their immediate and regular contact with the local landscapes. Understanding how local stakeholders cope with the changes is critical in adapting interventions to system dynamics and shifts (Martins et al., 2018).

1.1.5 Potential limitations surrounding the use of local knowledge across scale

Despite the benefits associated with local knowledge integration, most projects do not embed local knowledge to inform their activities. For example, policy initiatives often consist of blanket assessments, and land restoration interventions are designed at the coarse – mostly landscape scales (Cerretelli et al., 2018). This ignores fine-scale contextual variations (Firn et al., 2018). This mismatch between scales and action can contribute to lack of social-ecological resilience (Cumming et al., 2006). To address this, activities to restore ecosystems should be aware of and develop around ecological boundaries as opposed to the more commonly used socio-political boundaries (Pisano, 2012; Reed et al., 2013). This should lead to the design of more appropriate and successful interventions because it will be more likely to capture the changes in the flows of ecosystem services at appropriate scales.

While policy makers make decision at the coarse-scale, most smallholders make decisions at the farm scale, mainly informed by observation of their immediate environment. Most local knowledge studies have not looked closely at the effective range of local knowledge. There is limited evidence to suggest that the range is limited. Anecdotally, smallholder farmers who are working towards controlling soil erosion will appear to make decisions about which restoration intervention to adopt at their farm or field, perhaps without considering if their choice will have any effect on surface run-off on the adjacent farms. Similarly, farmers may decide to take no action on their degrading land, which can render the adjacent farm efforts unsuccessful, especially where land is steep. The extent to which this is a real knowledge gap is critical to establish while designing restoration interventions.

Understanding the multiple-nested scales of ecosystem service generation and manifestation, and the diverse needs of different users is a pre-requisite for designing effective and appropriate land restoration interventions. A central theme of this research is that effective land restoration will benefit from rigorous assessment of the extent to which farmers and other actors have knowledge of ecosystem service generation and manifestation across scales, that may inform restoration activities. Acquisition of this knowledge should enable better identification of appropriate intervention points that are customized to suit local needs. The aim of this research was to explore the potential for utilising local knowledge to inform land restoration options at the appropriate scales to deliver livelihood benefits.

1.2 CONCEPTUAL LINKAGE

In this section, I discuss the conceptual linkage of the thesis which has four sub-sections namely:

1. A review of academic discourse about land degradation
2. Adopting a socio-ecological approach to land restoration
3. Barriers to operationalizing a socio-ecological systems approach
4. Conceptualization of local knowledge and its role in informing socio-ecological systems approach

1.2.1 A Review of academic discourse about land degradation

The genesis of serious land degradation globally can be traced back to the Green Revolution period in the 1950s and 1960s, especially implemented in Asia and other regions (Djurfeldt et al., 2005; Pingali and Rosegrant, 1994; Singh, 2000). In this period, technologies such as plant breeding and increased specialization in a few crops (mainly maize, rice and wheat) (Pingali, 2012), irrigation and mechanization and heavy use of inorganic fertilizers and other external inputs were employed intensively to improve agricultural productivity aimed at reducing food insecurity (Davari et al., 2010; Dawson et al., 2016). These agricultural technologies came at a great cost because they were blamed as a major cause of global environmental degradation (Bezner-Kerr, 2012; Ramankutty et al., 2018) as it led to decreased land productivity, pollution and over-exploitation of land resource that led to diminishing socio-ecological resilience of agricultural systems (Evenson and Gollin, 2003; Pingali, 2012). This is because the natural processes that support and regulate agro-ecosystems across scale such as nutrient cycling, erosion control, water regulation, climate regulation among others were completely ignored (Garnett and Godfray, 2012; Toenniessen et al., 2008).

In sub-Saharan Africa, implementation of the Green Revolution had far reaching negative impacts on land. Over-intensification of land led to rapid soil degradation in an area where the majority of smallholder farmers had limited land and were wholly dependent on it (Lal, 2009). The resulting food insufficiency contributed to a vicious cycle of land degradation as farmers attempted to further intensify on the already unproductive land resource to produce more food (Otsuka and Kalirajan, 2005). This further accelerated the loss of soil nutrients and soil organic carbon (SOC) leading to land degradation.

Land degradation has also been blamed for the loss of arable land as it becomes marginal and chunks of land are carried away by water erosion or landslides thus reducing potentially available cropland (Lambin et al., 2013). This not only leads to a decrease in crop production acreage and productivity, but also leads to more pressure being exerted on the remaining arable land. This, coupled with other drivers such as increasing pressure on land due to increasing global population, deforestation, unstainable agricultural practices and overgrazing further makes land degradation a complex issue (Meshesha et al., 2012; Schmidt and Pearson, 2016). The challenge of land degradation is made worse by emerging threats of climate change and desertification (Ramón Vallejo et al., 2012).

A review of existing literature indicates that there are numerous approaches that have been used to assess land degradation. These include: expert opinion, field measurements, field observations, land users opinions, remote sensing, modelling, land productivity monitoring among others (Taimi, 2008). Furthermore, there have been ongoing debates regarding how best to address the challenge of land degradation. This includes suggestions of having a political, socio-economic and a biophysical approach (Andersson et al., 2011).

Despite numerous attempts to reduce land degradation, it has remained a persistent and serious threat over the decades. One of the reasons for land degradation challenge is the fact that it is contextual and heterogeneous spatially, temporally, culturally, economically and environmentally (Warren, 2002). Therefore, addressing the challenge would involve first understanding the context. Secondly, land degradation involves numerous and complex interactions between people and their environment; and includes processes and often involves human behaviours and decision making (Rounsevell and Robinson, 2012). Land degradation is thus multifaceted in nature in terms of its complex bio-physical, anthropogenic, socio-economic, and political triggers that occur at varying temporal and spatial scales (Lambin and Geist, 2008).

Despite land degradation drivers being mostly anthropological and contextual (Warren, 2002), majority of policy makers implementing large-scale land management approaches that have the potential to drive large-scale restoration of degraded landscapes have often excluded people (i.e. resource users and degradation drivers themselves) from being part of problem identification

(Mekuria et al., 2011; Nyssen et al., 2010). This translates to further exclusion of people from providing solutions to the challenges which they created in the first place, which is a major contributing factor to the persistent land degradation challenge.

In sub-Sahara Africa, approaches that have been adopted by many governments are largely top-down and non-participatory in nature. For example, in Ethiopia the government and development partners have implemented ‘blanket’ or ‘one-size-fits-all’ interventions across the entire country. The interventions include soil-water conservation measures such as terracing, stone bunds, contour planting; and the establishment of exclosures to restore communal grazing lands, (Descheemaeker et al., 2009; Gebremichael et al., 2005). This has led to many interventions being unsuccessful as they were locally inappropriate and, in many cases, not cost-effective. Similarly in Rwanda, the top-down approach to land restoration is evident as the government directly controls and prescribes which soil and water management interventions can be implemented and the types of priority high-value crops to be grown across vast regions (Cioffo et al., 2016). This approach has not only been ineffective but has also contributed to the marginalization of women, who mainly control ‘low-value’ crops (Rwibasira E., 2016). It has also led to loss of crop diversity contributing to further loss of ecological resilience (Seburanga, 2013).

One of the major consequences of top-down approaches to land restoration is the design and implementation of blanket and generalized interventions across heterogeneous agricultural systems without taking into account local people’s views and ideas (Vanlauwe et al., 2014). This results in land restoration interventions that are locally inappropriate, not adapted, and not acceptable to the beneficiaries, which leads to low success, impact and sustainability of such interventions.

1.2.2 Adopting a socio-ecological systems approach to land restoration

One mechanism to address the issues raised in the above section is through adoption of an integrated systems approach. According to Lal et al., (2002), an integrated systems approach aims to integrate several disciplines and involve different stakeholders operating in their own subsystems across different spatial and temporal scales. These approaches focus on identifying management strategies for sustaining natural resource stocks and flows of goods and services as well as their underlying ecological processes and drivers. Berkes and Ross, (2013) further notes that from an integrated systems point of view, achieving resilience of a system involves dealing with adaptive relationships and learning in social–ecological systems across nested levels, with attention to feedbacks, scale, renewal cycles, drivers, disturbance events and system memory.

One way to encourage greater involvement of farmers in land restoration is through the evaluation of their human-nature relationships. This is where integrated, participatory and interdisciplinary approaches (which integrate natural and social sciences) are used to develop context appropriate approaches for addressing land degradation (Bethel et al., 2014; Hewitt et al., 2014).

One of the approaches to achieving system resilience is through implementing land restoration interventions on degraded landscapes. Land restoration is the process of restoring ecological functions in degraded ecosystems (Menz et al., 2013). One of the benefits of land restoration is that besides increasing livelihood resilience, it also increases the ecological resilience of agro-ecological systems through supporting processes that enhance continued productivity (Chasek et al., 2015). However, in practice, land restoration is seldom successful and mostly result in winners and losers. Hence the need for taking a socio-ecological systems approach, which incorporates the 'people' element to land restoration.

To achieve both livelihood and ecological resilience requires linking both social and ecological systems (Janssen, 2006). This can potentially be delivered through adoption of a socio-ecological systems approach. According to Berkes and Folke, (1998), "social-ecological systems are linked systems of people and nature, hence humans must be seen as a part of, not apart from, nature". Socio-ecological resilience is thus achieved through integrating agro-ecological knowledge systems, including social and human capital, to manage systems and enhance the natural capital, including prevention of further natural resource degradation (Borron, 2006; Folke, 2006a).

Adopting a socio-ecological systems approach to address land degradation has many advantages. One of the principal advantages of adopting the approach is that it leads to the simultaneous engagement of different actors to assess and make decisions on socio-ecological resilience indicators of their system that are important to them (Rounsevell and Robinson, 2012) . This has been shown to lead to greater empowerment of resource users to collectively conceptualize land restoration and realise potential benefits (Folke, 2006b). Through this, it creates local understanding, acceptability and successful adoption of land restoration technologies (Cote and Nightingale, 2012).

Lebel et al., (2019) further observe that when incorporating socio-ecological dimensions in designing land restoration interventions that build resilience, it is critical to consider three key questions namely: 1). "Who decides what should be made resilient to what? 2). For whom is resilience to be managed? and 3). For what purpose?". Participatory research with local stakeholders is essential for answering these questions.

The primary aim of taking a socio-ecological systems' approach is to secure the future supply of ecosystem services (Reyers et al., 2009).In order to achieve this, there is need for people to be involved in from the initial stage of identification of the existing gaps and threats to supply of ecosystem services. For example, when addressing land degradation, people's involvement is critical in identifying: drivers–pressures–impacts–states–responses (DPSIR) to ecosystem service management (Burkhard and Müller, 2009). This approach makes resource users the centre of designing solutions.

One of the key ingredients that is likely to make socio-ecological systems more robust is ensuring that local resource users are well linked with the right institutions and infrastructure. Anderies et al., (2004) propose the need to organize and offer institutional support to resource users who have a common interest. This calls for the need for enabling governance functions that encourage local participation to build resource users trust (Janssen, 2006), that acknowledges understanding of local needs and that enhances the adaptive capacity of vulnerable resources users (Lebel et al., 2019). This is a critical step in creating collective adaptation and resilience (Osbahr et al., 2010), and also enhances resource user's ability to sustain themselves after external support has been withdrawn (Kitamura et al., 2018). One of my research focus was to assess the level to which farmers were working with governments and policy makers to address land degradation challenges and to adapt technologies to local context hence contributing to their success and sustainability.

1.2.3 Barriers to operationalizing a socio-ecological systems approach

In practice, one of the major barriers to operationalizing the socio-ecological systems approach to identifying needs, gaps and opportunities as entry points for addressing challenges that affect natural resources is the difficulty of adopting truly interdisciplinary and integrated approaches (Cote and Nightingale, 2012; Mcconnell et al., 2009). This is because various disciplines addressing the same natural resource, use different concepts and approaches and take fragmented and often linear to address complex and interrelated socio-ecological systems (Ostrom, 2009). At the policy level, the lack of interdisciplinary approaches to restoration often inhibits collective understanding and action (McNae et al., 2016). For example, failure of policy makers (who are addressing the drivers of land degradation) to consult local land users and instead only relying only on natural scientists' findings would more likely result in them missing out the critical underlying anthropological factors (Reed et al., 2013). This leads to often fragmented and isolated knowledge systems that are disconnected, hence leading to isolated and piece-meal interventions which results into ineffective and inappropriate interventions.

One of the key entry points is assessing new approaches and methodologies that enhance interdisciplinary collective action from how it has been done in the past (Stojanovic et al., 2016). For example, policy makers could begin engaging local resource users not only as mere observers and adopters but also adapters of technologies to suit their context. Such approaches have been rarely reported in literature, hence this gap formed one of the aims of my PhD research.

Further, in East Africa as it is in many sub-Sahara African countries, lack of local participation is especially serious among women. Despite women being heavily involved in agricultural activities, their participation in finding solutions to challenges facing their farming systems such as land degradation is often limited as men dominate (Kiptot and Franzel, 2012). Women are also disadvantaged due to unfavourable factors such as lower resource endowment, lack of land ownership, control and decision making rights, and lower land productivity due to lack of inputs and knowledge (Peterman et al., 2014).

Despite women exclusion, research has shown that gender differences exist between men and women which influences their needs, priorities, knowledge, experiences, actions and decision-making processes (Dah-gbeto and Villamor, 2016; Villamor et al., 2014b). Research shows that women hold a special category of unique knowledge and capabilities due to the unique roles they play in society and in farming systems (Hitomi and Loring, 2018). Such include being able to form self-sustaining collective action (Westermann et al., 2005). Lack of women's inclusion has been blamed to the implementation of interventions that are skewed towards men thus resulting to their marginalization from using, controlling or benefiting from resources thus rendering them powerless and vulnerable (Raha et al., 2013).

In countries such as Rwanda and Ethiopia, low participation by women leads to them benefitting less, and renders interventions unsuccessful because of their exclusion yet they are the main actors in the farm (Shiferaw et al., 2014). There is therefore a great need to better integrate gender into social-ecological systems approach to deliver resilience. In my research, elicitation of gendered-local knowledge was thus key in all my three study objectives.

Panpakdee and Limnirankul, (2018) further notes that there are diverse resilience indicators, which differ from place to place and from actor to actor. However, there is currently lack of understanding of the context-relevant indicators and a general lack of adaptive learning principles that are able to respond to local context and needs (Dressel et al., 2018). One of the objectives of the present study was therefore to elicit farmers' local knowledge of indicators that signify their soil quality, and whether it varies with land degradation status. I was also assessing whether this knowledge further influences their land management practices, and whether there are gender differences in local indicators of soil quality or soil management practices. Local knowledge acquisition is one of the key approaches to integrating socio-ecological systems approach to natural resource management.

1.2.4 Conceptualization of local knowledge and its role in informing socio-ecological systems approach

One approach for embedding local knowledge within ongoing development efforts is through conceptualizing how the various categories of local knowledge shape resource users' behaviours, perceptions, interests, beliefs, objectives, decision-making processes, and access to information and resources that affect their livelihoods (Ottinger, 2013; Sinclair and Walker, 1999). This influences the adoption, acceptance and sustainability of various development initiatives. There are many categories of local knowledge, that contribute towards promotion of socio-ecological systems approach. These are described below.

Local knowledge refers to the knowledge of a defined group of people in a given community have developed over time and continue to develop. Local knowledge is usually a mixture of indigenous, traditional, locally-derived knowledge; and knowledge acquired from external sources and contemporary learning (ICRAF, 2014). It includes knowledge that is based on experience, embedded within community practices, relations and institutions, adapted to local environment and culture, and may be knowledge held by individuals or group of people. It is often knowledge that has been tested over a long period of time and is dynamic and evolves over time (Berkes and Turner, 2006). It includes a collection of facts and relates to the entire system of concepts, beliefs and perceptions that people hold about the environment around them.

One category of local knowledge is indigenous knowledge, which refers to knowledge that is culturally embedded and is intimately bound up with cultural values and cannot be meaningfully separated from the cultural context within which it sits (Sillitoe, 1998). Often this relates to higher level explanations for phenomena. For example, mapping community livelihood behaviours and practices helps identify resources within and without their areas, and also understand patterns in natural resource availability and natural environment status (Aswani and Lauer, 2006).

This is achieved by for example learning about pastoralists, farmers or fishermen livelihood behaviours and strategies and adaptation practices and coping strategies at different times of the year or changes over time due to the aforementioned factors (Eddy et al., 2017; Thomas et al., 2007). This form of knowledge is useful in forecasting and designing preparedness interventions such as for disasters that affect natural resources and livelihoods (Materer et al., 2001). This knowledge helps shed light on underlying system dynamics, including regulating ecosystem services that have a wider spatial flow scale. In the current study, this form of local knowledge was utilized in assessing and monitoring changes in ecosystem service flows across scales because of the threat of land degradation such as regulating soil, water food, tree products and other provisioning and cultural ecosystem services. This was to provide reliable indicators that can be used by scientists to identify and monitor system changes and threats and identify system gaps and entry points for interventions such as land restoration.

Traditional knowledge is another category of local knowledge and refers to that knowledge which is passed down through generations. It includes agricultural, environmental, medicinal knowledge, knowledge that is associated with genetic resources and other forms of biological diversity (Kenya, 2016). It is knowledge acquired by people native to, or long-term inhabitants of, specific places, over long periods of time; which can originate from an individual, local or traditional community. Examples of traditional knowledge include the uses of trees and foods in various communities (Nunes et al., 2012); and knowledge that is held with regards to protection of genetic resources, preservation of biodiversity (Muriithi and Kenyon, 2002).

For example, the Kaya forest which despite being a non-gazetted forest in Kenya, through local taboos and beliefs that term it as a sacred forest, has led to the preservation of threatened species of both flora (121 species) and fauna (46 species) representative of Kenya's coastal forest (Metcalfe et al., 2009). Utilization of this category of knowledge is enhanced through involving different age groups/ sets of farmers as this ensures a wide range of traditional knowledge is captured. This is because for example, older farmers possess more knowledge acquired over decades while younger farmers may possess less long-term knowledge but have current in-depth knowledge of their surrounding environment and livelihoods (Birmingham, 2003). In the current study, traditional knowledge was utilized throughout as the sample of farmers interviewed cut across all ages. For example, I utilized it to identify lost and threatened native tree species that played critical roles in the livelihoods of farmers in Ethiopia, which have been lost through land degradation. The re-introduction of such tree species will play a key role towards meeting restoration goals.

Locally derived knowledge is another category local knowledge and it entails that part of local knowledge that is based on local interpretation of locally made observations, often involving deliberate experimentation (Joshi et al., 2004b). One of the strengths of locally derived knowledge is that it is not static and is dynamic and continues to develop based on contemporary learning. This includes the way people observe their surroundings, how they solve problems and validate new information. This category of knowledge is especially useful while implementing biophysical interventions such as land management and restoration (Zhang et al., 2013). This is because, through observation and testing of what interventions work in a given context, local resource users implementing the interventions can closely monitor and adapt the technologies and inform on appropriate interventions based on what is working in which context.

Locally derived knowledge is critical for the success and adaptation of interventions to suit local context, especially in the wake of threats such as land degradation and climate change (Galicia et al., 2015). However, there is limited documentation and evidence of the application of this category of knowledge especially in adapting interventions to context. Hence one of the objectives of my study was to assess whether farmers local knowledge of observation and experimentation was present and if it played a role in improving the suitability and success of land restoration interventions in Ethiopia.

Another category of local knowledge is knowledge that is derived from external sources such as education, media, dialogue with other communities and contemporary learning is another category of local knowledge (Jacobi et al., 2017). This knowledge category is on-going and supports all other categories of knowledge named above. For example, farmers who have received sensitization on regulating ecosystem services may have added understanding on the way landscape scale restoration interventions work compared to non-sensitized farmers (Mercer et al., 2012). In the current study, I was interested in assessing what sort of knowledge farmers have acquired aspects such as soil and land management practices, land restoration and food security interventions that have been introduced by the Ethiopian and Rwandan governments and extension, Non-governmental Organizations and other external sources; and how it interacts with other categories of knowledge. For example, do farmers go beyond what they have been taught to modify or alter interventions or implement additional management practices outside the acquired knowledge.

One of the strengths of local knowledge is that it involves social learning, which can be a key opportunity for scaling the adoption of various interventions. This form of social learning is supported by the Social-cognitive theory (Bandura, 1999), which promotes that part of an individual’s local knowledge acquisition can be directly attributed to observing others within the context of their social interactions and experiences and also external (outside media) influences. The theory further explains that through observation, people tend to remember actions including the sequence of actions that have a specific outcome. Singh et al., (2018) further notes that individual and collective memories and perceptions of extreme past events shape their future expectations and livelihood decisions.

Thus, in terms of scaling the adoption of land restoration interventions, having local resource users such as farmers being involved in all stages of intervention development and encouraging co-learning initiatives such as model farmer approach, demonstration trials, farmer exchange visits and Communities of Practice approaches (Ardichvili et al., 2006; Groote et al., 2010) can lead to wider and faster adoption and scaling of land restoration interventions that are appropriate and successful locally as evidence from initial technology adopters. Further, because local knowledge is contextual, it can thus promote understanding of diversity, which leads to the design of and scaling of diverse and context-appropriate interventions that meet the needs of multiple resource users.

Research shows that resource users are faced with making everyday livelihood decisions, which depend on and are shaped by various factors. For instance, it not only depends on the resources they have access to and control over, but also by their perceptions of their capabilities in addressing various challenges. These are all shaped by the local knowledge they possess. For example, farmers classify soils based on location, their perceived potential of the soil and interactions with the wider ecological framework (Osbahr and Allan, 2003). Some farmers plant and match crops that require varying soil quality and nutrient requirements (Barbero-Sierra et al., 2018). Further, resource users' perceptions also influence their risk-taking behaviours. It has been reported that farmers will invest in enterprises and interventions that have low perceived risk of failure (Kiptot et al., 2007). Kelly et al., (2015) sums it up by stating that communities that fully embrace global trends and technologies without imbedding them within the framework of their local knowledge and practices were found to be less resilient.

Despite the critical role that local knowledge plays in shaping livelihoods as exemplified above, often, the local knowledge possessed by the rural communities, in particular women, is overlooked and ignored. One of the limitations facing local knowledge is whereby it is conceptualized as being too ‘local’ and different from scientific knowledge by scientists and policy makers (Taylor and de Loë, 2012). Also, some researchers have reported that farmers local knowledge diminishes as they move away from their farms into the landscape scale and especially knowledge of ecological services (Warren-Kretzschmar and Haaren, 2014; Winowiecki et al., 2014b). This skewed perception often leads to local knowledge not being adequately incorporated into research and development agendas. However, research shows that local knowledge helps in creating a local understanding and interpretation of scientific theories and observations. In this study, I was thus interested in assessing how local knowledge can result into more appropriate interventions through bringing out fine-scale variations in local context such as through local adaptation and local understanding of the genesis of challenges such as land degradation.

The PhD was built around three key hypotheses outlined below:

1. Smallholder farmers in East Africa have detailed and explanatory knowledge about scaling processes of ecosystem services that their livelihoods depend on.
2. The extent of local knowledge that smallholder farmers along a land degradation gradient have about ecosystem services varies with the scale at which they manifest
3. The relationship between local knowledge and scale is important in determining how local knowledge can be used to adapt land restoration options to context

1.3 OBJECTIVES OF THE RESEARCH

1. To elicit local indicators of soil quality, determine farmers’ management practices and assess whether they vary with land degradation status and gender.
2. Assess the role of incorporating local knowledge to promote adaptive land restoration technologies that deliver multiple ecosystem services across scale
3. To explore local knowledge on the influence of crop diversity and food insecurity and assess whether it varies with land degradation status

CHAPTER 2: OVERALL RESEARCH DESIGN, METHODS, ANALYTICAL APPROACHES AND CONTEXT.

This section provides the overall research design (overall structure of the research) I applied for my PhD study, methodological and analytical approaches and study area context in which I carried out my study. It consists of three sections as highlighted below:

Section 1: Overarching research design

1. Where? At which location or situation did I conduct your investigation?
2. When? At what point in time or in what period did the research take place?
3. Who or what? Which individuals, groups or events did I examine (as my sample)?
4. How? What methodological frameworks, tools and approaches did I use to collect data?
5. How? What methods did I use to analyse data?

Section 2.2: Contextual information about case study countries

1. What are the implications if this contextual information for research design?
2. What agro-ecological systems exist within the two case study locations?
3. How are approaches to land degradation different between the two case studies?
4. Who were important stakeholders?
5. What specific projects engaged with the study in-country, as these formed the basis of the research study?
6. How are livelihoods shaped (including drives of crop selection and the role of gender)?

2.1: OVERARCHING RESEARCH DESIGN

This section presents and explains the overarching research design, which presents an overview of the means I used to undertake my research, and it describes where and when I conducted my research, the sample I used, and the approach and methods I employed. The section also provides clarity about the choice of case studies I selected for my research, phasing of the research activities through the full period of study and how these activities relate to the research objectives and sampling approach, including at village level.

2.1.1 Where? At which location or situation did I conduct my investigation?

This section highlights the study locations I selected for my research and provides clarity and justification for the choice of those sites. Overall, I hypothesized that local knowledge helps in informing the design of appropriate and context-relevant land restoration interventions. This is a pre-requisite to successful and sustainable adoption and scaling of land restoration interventions across smallholder farms, which are heterogeneous ecologically, social-economically, biophysically, historically and politically (Vanlauwe et al., 2014). I hypothesized that capturing farmers' knowledge from varying context and different scales is critical in guiding the development of diverse scaling strategies as different context present unique challenges and opportunities for the design of restoration interventions, which is the focus of this study.

However, there are limited studies that explicitly capture these heterogeneities across diverse scales and little is documented on how local knowledge of farmers in these heterogeneous contexts can inform the design of appropriate and scalable land restoration interventions (Odendo et al., 2010; Paudyal et al., 2015; Toomey, 2016). Considering these limitations in the literature and my positionality, I designed my study to capture farmers' local knowledge of land degradation and restoration across different context and scales. I achieved this through selecting study locations using a stratified sampling technique (Mugenda and Mugenda, 1999) using a Four -Tier stratification criteria. This included: 1). Countries, 2). Agro-ecological zones, 3). Landscapes of varying degradation/ restoration degrees, 4). Villages and farms in different slope locations.

For the first stratification level, I selected two countries namely Ethiopia and Rwanda, whose heterogeneities included having different political, socio-economic triggers to land degradation, and their landscapes are undergoing different land degradation trajectories (Birhanu, 2014; Bizoza and Havugimana, 2013). They also had different restoration approaches and implementation timelines (Bizoza, 2014; Yirdaw et al., 2017). Both countries also differ in other areas including having different land tenure systems, and livestock management systems (Nabahungu and Visser, 2011; Tesfa and Mekuriaw, 2014). The selection criteria for the two countries is discussed in detail in Section 2.2.

The second stratification level involved selecting landscapes from varying agro-ecological zones in each of the two countries (Antle et al., 2004) namely the Sub-humid area in Rwanda and Semi-arid agro-ecological zone in Ethiopia (See Figure 2.1). I included the two agro-ecological zones to capture biophysical heterogeneities that I hypothesized would influence farmers' knowledge of different drivers or effects to land degradation. For example, I hypothesized that in the sub-humid agro-ecological site, high rainfall, slope inclination and soils would be key drivers of land degradation through soil erosion, while in the semi-arid site, water shortage would be a key effect of land degradation. Agro-ecological heterogeneities thus present different sets of biophysical challenges (Nkheloane et al., 2012), that would inform the design of more inclusive and diverse land restoration interventions, especially in the tropics including dub-Sahara African countries, where majority of countries have both sub-humid and semi-arid agroecological zones.

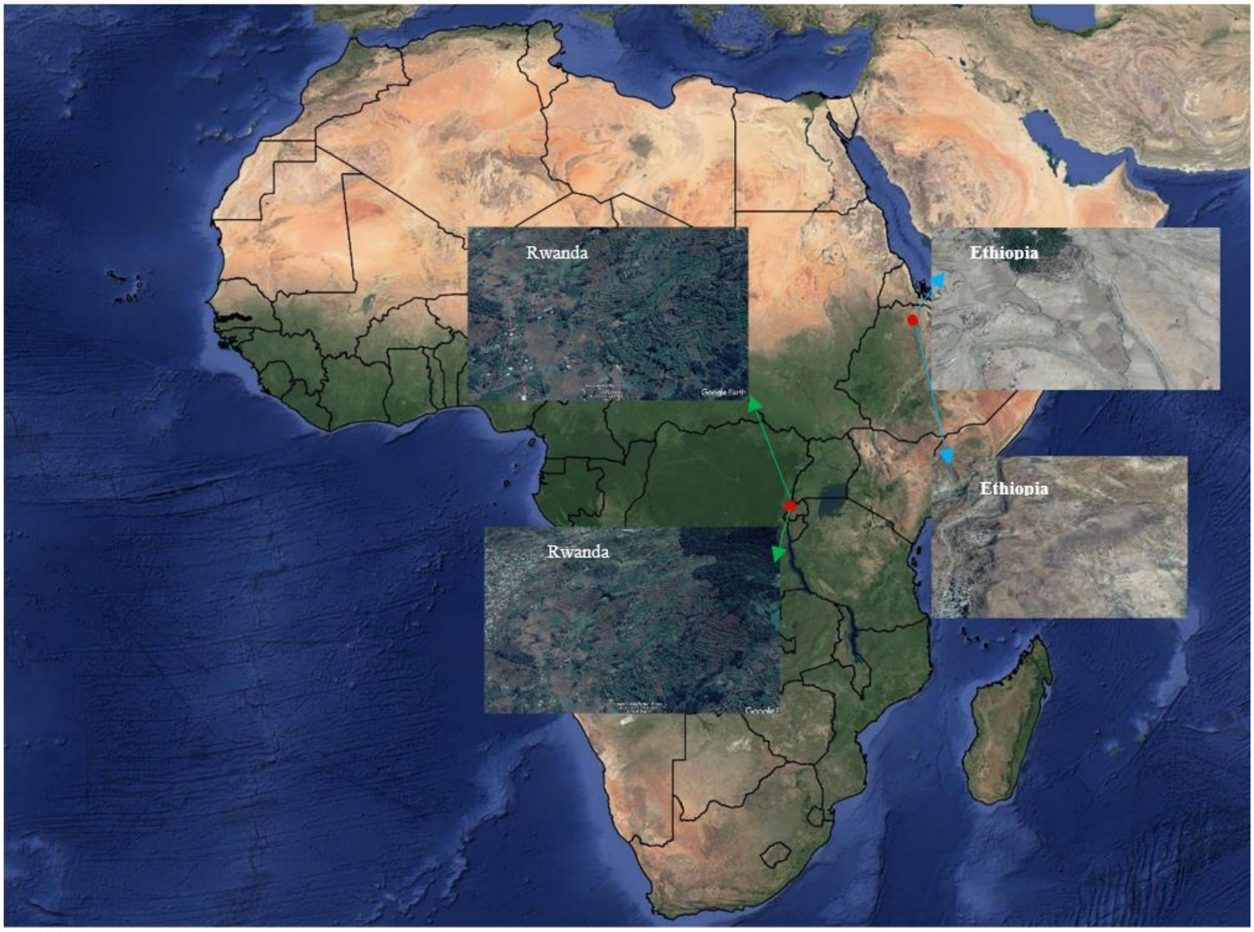

Figure 2.1 Map showing research study sites in two contrasting agro-ecologies, sub-humid AEZ of Western Rwanda and semi-arid AEZ of Northern Ethiopia.

The third stratification level involved selecting landscapes of varying degree of land degradation or restoration in each agro-ecological zone. In order to test whether farmers along a land degradation or restoration gradient held different local knowledge, I decided to test landscapes that were at different levels of degradation or restoration. This study adopted a Paired- Catchment experimental design (Brown et al., 2005; Lloyd and Wong, 2008) to capture this heterogeneity, whereby three study sites were selected from each agro-ecological zone. This involved the selection of catchments and villages (Aynekulu et al., 2014; Kuria et al., 2014) which met the desired criteria of degradation or restoration status.

In Rwanda, I compared 3 landscapes: degraded (no intervention), recovering (exposed to recent restoration interventions- 2012) and restored (exposed to older and established restoration interventions hence soil loss is controlled -2007). I selected to focus on catchments cutting across three out of nine villages in Kadahenda cell, Karago sector and three out of five villages from Gikombe cell, Nyakiliba sector.

In Ethiopia, the ultimate study objective was to assess farmers' perceptions and indicators of land restoration, only sites that have some form of land restoration, but of varying degree were selected. I selected recovering landscapes with older restoration interventions (2012) and newer interventions (2016) since my main goal to purposively sample (Tongco, 2007) and interview farmers already implementing land restoration interventions. I selected catchments occupying three out of 19 villages.

The fourth level stratification involved selection of farmers from different slope locations due to the steep slope inclination that characterize all study landscapes. This criteria was especially critical because land degradation and restoration involves material flows and ecological services that are generated or manifested at scale such as soil and water (Richard et al., 2015). Further, within each slope location, Stratified Random Sampling was used to select farmers based on gender, resource endowment, and age (Hitomi and Loring, 2018). This is because I hypothesized that these factors influence local knowledge, perceptions and decision-making processes regarding natural resource use and management.

2.1.2 When? At what point in time or in what period did the research take place?

This section presents the phasing of my research activities through the full period of my PhD study. The research interest and topic for my thesis was first inspired by my observation of farmers' keen interest on finding sustainable solutions to their poor soils and food insecurity. I am a researcher employed by the World Agroforestry Centre (ICRAF) for the past nine years and I have been engaged in undertaking intensive fieldwork under various projects across Eastern Africa countries. My overall research interest was born during one such fieldwork where I conducted a local knowledge research study in 2013 in the sub-humid Gishwati area of Rwanda under the Trees for Food Security project. As I was eliciting farmers' local knowledge on the impacts of trees and associated management on food security (Kuria et al, 2013), I noticed during the interviews, that the majority of farmers tended to deviate the discussion to their soils, with their keen interest being on how they can make their soils more productive to increase crop yields and achieve food security.

This observation, coupled with a Land Degradation Surveillance Framework (LDSF) study (Betemariam et al, 2013) carried that out in the area which showed declining nitrogen and carbon levels especially in areas with no soil and water conservation interventions led to my keen interest of soils and finding out the genesis and drivers of decreasing soil quality. I thus became interested in assessing farmers' knowledge of soil quality and the current soil management practices and assess whether this could help shed light and enrich scientific knowledge already available on restoring and improving the general land health. Hence the first research objective was born that aimed at assessing farmers knowledge of indicators of soil quality and its influence on soil management practices; and whether farmers were employing the appropriate restoration interventions. This study was conducted between August and November 2015.

When I began data analysis for this first objective, preliminary results showed some inconsistencies in the classification of earthworms as being indicators of both high quality and low-quality soils. This is against research that supports that earthworms are only an indicator of high quality soils (Fonte et al., 2010; Lal and Stewart, 2010). I decided to go back to my research study area and triangulate this new information from farmers, including collecting specimen of earthworms and other soil macrofauna for taxonomic identification using INPAC-S methodology that focuses on integration of local and scientific knowledge. I undertook the macrofauna specimen collection exercise was undertaken during the rainy season of March 2017 as it us during the wet season that soil macrofauna are found near the soil surface (Pelosi et al., 2009). The analysed results played a key role in guiding in the interpretation of my data.

Secondly, I had noted that farmers in Rwanda were primarily associating the decreasing soil quality and health to food insecurity in the area, which was their greatest concern food insecurity threatened their livelihoods. This led to my second objective of assessing the drivers and indicators of food insecurity in the area and whether it was solely due to decreasing soil quality. I carried out data collection in the Rwanda sites from August to November 2015.

Thirdly, I was interested in contributing to the wider body of knowledge regarding scaling strategies for land restoration interventions. This required an understanding of a wider context, in this case a different country and agro-ecological zone to capture unique challenges and unique opportunities for scaling. I also interested in finding out whether the situation was the same in the semi-arid areas and whether farmers were also going through similar challenges with regards to soils and land degradation, and whether the ongoing land restoration were appropriate, hence the third objective was conceptualized. This is because contextual variations are likely to influence the success and effectiveness of restoration interventions (Coe et al., 2014b). This led to me carrying out data collection in Samre, Ethiopia from September to November, 2016.

2.1.3 Who or what? Which individuals, groups or events I examined as my sample?

This study examined smallholder farmers in Rwanda and Ethiopia, with the unit of analysis being the individual farmers while the unit of observation was the farms, landscapes and ecosystem services therein that are influenced by land degradation and restoration. In order to develop a more representative sample whose findings could be generalized to a wider population, I selected the farmers to belong to various categories including: different gender (men and women), different age groups, farmers with small land, medium and large land sizes; upstream, midstream and downstream farmer farmers, land owners and landless (in Ethiopia) among others (Bewket and Stroosnijder, 2003; Getahun Desta and Wahelo, 2017). The table below presents study sample information.

Table 2.1 Overview of Thesis Chapters showing objectives, methodology used, sample and context

Chapter	Research Objectives	Methodology	Country, Location, Agroecology
Chapter 3	To elicit local indicators of soil quality determine farmers' management practices and assess whether they vary with land degradation status and gender	Use of knowledge-based systems approaches for acquisition of local knowledge (AKT5 and INPAC-S methodologies). Informants consisted of 150 farmers (83 men and 67 women). Soil macrofauna samples and indicator plants were collected	Location: Gishwati, Western Rwanda Sub-humid agro-ecological zone Recovering and Restored Landscapes *were in* Nyabihu District, Karago Sector, Kadahenda Cell. Villages: Karandaryi, Gakoma, Nkomane *Degraded landscape was in* Rubavu District, Nyakiliba Sector, Gikombe Cell, Villages: Rushubi, Nyakibade, Nyabibuye
Chapter 4	To assess the extent to which incorporating local knowledge promotes adaptive land restoration technologies that deliver multiple ecosystem services across scale	A total of 95 farmers were interviewed though Focus Group Discussion (55 farmers) and individual interviews (30 farmers). The study was undertaken upto stage three (compilation) of AKT5 methodology	Location: Samre woreda (District), Tigray Region, Northern Ethiopia Semi-arid Agroecological zone Bara sub-catchment in Maytekli Village, Endagiorgis and Endamariam sub-catchments, Waza village
Chapter 5	To explore local drivers of crop diversity and food insecurity and assess whether it varies with land degradation status	Six focus group discussions were held 69 farmers from the three landscapes. In stage four of local knowledge acquisition using AKT5 tool, a structured survey was administered on 150 farmers (83 men and 67 women).	Location: Gishwati, Western Rwanda Sub-humid agro-ecological zone Recovering and Restored Landscapes *were in* Nyabihu District, Karago Sector, Kadahenda Cell. Villages: Karandaryi, Gakoma, Nkomane *Degraded landscape was in* Rubavu District, Nyakiliba Sector, Gikombe Cell, Villages: Rushubi, Nyakibade, Nyabibuye

To understand the above units of observation, during the scoping stage of AKT methodology application, I also held Key Informant Interviews with extension personnel from the agriculture, water, natural resource management and livestock sectors in both countries; and the respective local administration of the villages or catchments that I studied. These groups represent key stakeholders in the local smallholder farming systems as they interact with farmers on a more regular and deeper level through undertaking farmers' needs assessments, implementation of government policies and programmes, through advice, trainings and capacity building and also communicating farmers' needs back to higher levels of policy makers (Luloff, 1999). As such, they were able to provide not only vital information about farmers' livelihoods and the current status of ecosystem services, underlying issues with regards to land degradation and restoration but also what interventions are being employed to address land degradation (Mehring et al., 2017). Their insights provided useful ideas that informed the formulation of discussion points with farmers. They are thus a target group for recommendations that will bring change to the farmers.

2.1.4 How? Which methodological frameworks, tools and analytical approaches did I use to collect data?

This section discusses the methodological frameworks I used in my research and why it was I chose the specific methods. It also highlights potential limitations of the methods and how I addressed or navigated around the limitation. The section begins from the broader methods and narrows down to specific methods used.

In this PhD, I employed the following methodological frameworks:

1. Participatory Research Appraisals
2. The Agroecological Knowledge Toolkit (AKT5)
3. InPaC-S participatory knowledge integration and sharing methodology

These are described and discussed below

2.3.1 Participatory Rural Appraisals

2.3.1.1 Description of the approach

First, informed by Socio-ecological Systems approach to research in development (F Berkes and Folke, 1998), the present research adopted a Participatory Rural Appraisal (PRA) approach (Campbell, 2010) and was enriched through combining different participatory methodologies.

Participatory Rural Appraisal approaches emerged in the 1970's in response to the concern that 'top-down' development was being pursued in the absence of adequate knowledge and involvement of local communities. In this case, local community's feedback was required because the research aimed at eliciting their knowledge about resources which they are custodians of and which affected their livelihoods (Virapongse et al., 2016).

The approaches ensure that the opinions, views and knowledge of rural resource users are incorporated into the planning, management and monitoring of development projects, thereby making them successful and sustainable. PRA utilizes participatory techniques to facilitate local peoples' analytic abilities and empower them to plan and undertake sustainable action, thus leading to elicitation of relevant and timely information.

2.3.1.2 Why the approach was used

There are a number of PRA approaches that exist and are widely used to collect local knowledge data. These include: focus group discussions, key informant interviews, survey interviews, case studies, resource mapping, wealth ranking, perception mapping, Venn diagram of institutions, resource cards, seasonal calendars, income and expenditure matrix, and daily activity clocks (Uddin and Anjuman, 2017). In my research, the approaches I used are; focus group discussions, key informant interviews, survey interviews, land degradation hotspot mapping and seasonal calendars (to capture crop / food availability). This is because they were the approaches that adequately answered my research questions at different stages of AKT5 methodology application.

2.3.1.3 Potential limitations of the approach (and how these were overcome)

One of the limitations normally experienced is whereby researchers undertake the above exercises using already pre-determined questions (Couper, 2005). This leads to researchers not collecting data that adequately and appropriately answers their research questions because having a pre-defined set of questions is biased and does not represent the situation on the ground including contextual needs for adjustment of questions. This is especially critical where collecting contextual information, which calls for the customizing and adapting the questions to suit the heterogeneous local context. This was addressed through the application of local knowledge acquisition through

AKT5 methodology that begins with discussion of context-relevant issues using semi-structured questions before embarking on the formulation of structured questions.

Secondly, due to the fact that I was applying multiple approaches that addressed multiple study objectives, it would be challenging to decide the sequence of the approaches, including which one fed into the other. This challenge was addressed using application of these PRA approaches within the framework of the AKT5 methodology that has step by step that guides the for the application of the various approaches at every step.

2.3.2. Agroecological Knowledge Toolkit (AKT5)

2.3.2.1 Description of the approach

In this study, the research was primarily undertaken through the application of the Agroecological Knowledge Toolkit (AKT5) and methodological framework (Sinclair and Walker, 1998; Walker and Sinclair, 1998). The AKT5 software was developed by Bangor University in conjunction with the Department of Artificial Intelligence at Edinburgh University. The aim of the toolkit is to elicit local ecological knowledge in a rigorous and systematic way in order for it to be robust enough to be useful for informing development projects. It was designed to provide an environment for knowledge acquisition in order to create knowledge bases from a range of sources. It allows representation of knowledge elicited from farmers and scientists or knowledge abstracted from written material. The use of formal knowledge representation procedures offers researchers the ability to evaluate and utilise the often complex, qualitative information relevant stakeholders have on agro-ecological practices and the knowledge underlying these practices. The methodology associated with knowledge elicitation for the AKT5 system allows for formalized flexible knowledge bases to be created.

The research approaches I incorporated into the AKT5 methodology to collect data were primarily dependent on the nature of questions I had formulated for each of the three study objectives. Questionnaires in Appendixes 1, 2 and 3 of the thesis, which represent the respective three study objectives were formulated following iterative exercises which led to the identification of context-relevant questions. The process of formulating the overall sub-objectives for each of the three research objectives involved two processes namely first undertaking Theory Building then Theory Testing (David A. de Vaus, 2001). Theory building involved making observations and deriving theories from the observations through inductive reasoning. Theory building was undertaken during the initial three stages of the Agroecological Knowledge Toolkit (AKT5) and methodological framework process (Sinclair and Walker, 1998; Walker and Sinclair, 1998) namely scoping, definition and compilation stages as follows (Figure 2.2).

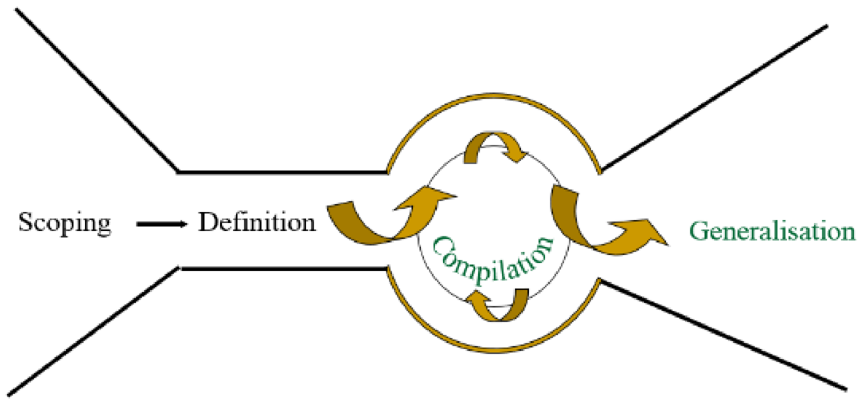

Figure 2.2 AKT5 methodological framework process

I combined various knowledge-based methods namely semi-structured interviews, focus group discussions, transect walks, seasonal calendar (food crops), causal diagrams, historical timelines, matrix tables, photography, participatory degradation hotspot mapping and resource mapping. I knowledge was then recorded and represented the knowledge derived from smallholder farmers using the AKT5 software (Dixon et al., 2001). This combination of approaches is especially critical in addressing various system dynamics and components as each method has specific roles.

At the initial (scoping) stage, I carried out research activities that helped me to make observations about the landscapes and livelihoods namely: participatory transect walks to understand the landscape setting, topography, degradation hotspots, soil types, field typologies, crops grown and the location of different resources. This also helped to inform stratification criteria. Further, key informant interviews were held with the crop, livestock, and natural resource extension officers and the area administration to elicit expert knowledge on the research subject. Focus group discussions were conducted on farmers drawn from the study landscapes using a set of semi-structured questions and a participatory process that aimed to identify, categorize and prioritize farmers priority needs and challenges that they were experiencing with regards to land degradation/ restoration which formed the focus of this study. Transect walks were also undertaken along and across the slopes to familiarize myself with the landscape and resources and to triangulate the information provided by farmers.

The definition stage highlighted knowledge boundaries and stratification parameters. Farmers in each of the sites and locations (e.g. three slope positions – upslope, midslope and downslope, on each study site were selected at random for in-depth interviews on each of the three research objectives. The compilation stage involved an iterative process whereby knowledge elicited from individual farmers using semi-structured questions was recorded systematically using the AKT5 software (Dixon et al., 2001) were evaluated for consistency and then further explored through repeated visits to the same farmers in order to probe further to get additional information or clarifications where apparent contractions or gaps were revealed. This process was repeated (at least two visits per farmer) until no new information was obtained from further discussion with the respondent. This led to the identification of locally-relevant theories and questions, which constitute the questionnaires used in this research, which can be found in the Appendix 1 to 3.

I then used the theories and key research questions formulated in the first three stages of AKT5 methodology to design a formal and structured questionnaire based on issues deemed pertinent. I then tested and triangulated this in the 4th (generalization) stage of AKT5 acquisition through deductive reasoning (David A. de Vaus, 2001). This is where I tested whether each of the observations made were unique or could be generalized to a larger population. The aim of this stage was to test the external validity, which refers to how generalizable are the results beyond a particular population (Campbell, 2010). I then pre-tested the questionnaire (Lancaster et al., 2004) with several farmers from each of the landscapes and then administered it to a larger number of farmers sampled from the study sites.

Below was the focus for each of the three objectives.

In objective 1, the focus was ‘What are the local indicators of soil quality along a land degradation gradient? Here, I was also interested in understanding the ‘Why’ question, which was answered by assessing why are the indicators important and how do they assist us to understand the context including land degradation? Other important aspects of focus for my study were: What are the predominant soil management practices applied by farmers along the land degradation gradient, Why do farmers employ those specific practices, that is, which soil management goals are they aiming to achieve? Who (gender) knowledge of indicators of soil quality and who employs which soil management practices- and why?

In Objective 2, the main focus was 'What is land degradation? What are the local drivers and effects of land degradation? What is land restoration? Explanatory questions included: How and Why does land degradation occur? Who benefits from land restoration and How does restoration manifest? What contextual factors influence the suitability of land restoration interventions and How or by how much do they influence? In objective 3, the focus was on: What crops are currently being grown? What are the indicators of food insecurity? What are the local drivers of food insecurity? What coping mechanisms do farmers employ to cope with food insecurity? Explanatory questions included: Why those crops, that is, what are the drivers influencing crop diversity? How has crop diversity changed between 1995 and 2015? Why the changes? How similar or different are these trends across landscapes of different degradation status? Why those specific indicators of food insecurity and Why the local drivers of food insecurity? Who possesses knowledge of indicators and drivers of food insecurity?

2.3.2.2 Why the approach was used

I used the AKT approach because it provides these key benefits over the other PRA approaches. One of the strengths of acquiring local knowledge through AKT5 methodology is that unlike majority of other PRAs that utilize a short period in data collection (usually one visit per farmer), local knowledge acquisition takes a more anthropological approach (Mosse 1995) and involves repeated interviews with the same farmers over a long period of time until no more new information is derived. In my case it involved spending about several months interacting with a small sample of farmers; and the process involves observing farmers, listen closely, and probing further. The prolonged stay with farmers also cultivated familiarity, confidence with farmers and trust with farmers. This was advantageous as it enabled me to make continuous local observations which aids in understanding the complex socio-ecological relations and processes; and derive more in-depth and trusted information especially with regards to household food security issues, which farmers are sensitive sharing.

In addition, I was able to learn the local language and terminologies especially pertaining to components of farming systems, which ensured I interacted with farmers better and was able to follow discussions as the translators were translating, hence I did not miss out on key information. Also, I am very familiar with the AKT5 methodology having used it to collect data for over six years. Hence, since I personally administered all the research instruments with the help of a translator, this enhanced clarity of the questions and precision of the information received and provided for follow-up questions and triangulation of information. This ensured that the right and adequate information was captured.

2.3.2.3 Potential limitations of the approach (and how these were overcome)

AKT and the associated methodology have a number of limitations. I found that when studying soil quality indicators that involved biological indicators such as soil macrofauna and indicator plants using AKT5 methodology, the methodology was limited in that I could not fully capture meaningful knowledge of such indicators from only farmers' word of mouth. In addition to farmers' oral knowledge, it also required a collection and taxonomic identification of specimen that farmers were referring to in their local language. While analysing preliminary results on biological indicators of soil quality, I noticed some discrepancies and conflicting results regarding earthworms that farmers had named as being an indicator of both fertile and infertile soil. This led to me undertaking a second farmer visit using the InPaC-S participatory knowledge integration and sharing methodology, which is discussed below INPAC-S methodology (discussed below) in order to collect specimens for taxonomic identification. This step was critical in order to establish their globally known identity. The innovative combination of the AKT5 and INPAC-S methodology led to a noble discovery, that contributed new knowledge to global research as discussed in the respective Chapter.

2.3.3 InPaC-S participatory knowledge integration and sharing methodology

2.3.3.1 Description of the approach

The InPaC-S participatory knowledge integration and sharing methodology The methodological guide aims at fostering the integration of local knowledge into coil quality monitoring systems and to support decision-making processes aiming at sustainable management of natural resources in agricultural systems and landscapes (Barrios et al., 2012a). To monitor systems, there are indicators highlighted in the guide that allow for early diagnosis of soil degradation processes and monitoring of changes in soil quality. This leads to identification of indicators that can be addressed in the short, medium and long-term to prevent soils from degrading. The methodology provides scientific interpretation of indicators that local farmers are likely to use.

2.3.3.2 Why the approach was used

In objective 2 which focused on assessing the local indicators of soil quality, AKT5 was combined with InPaC-S participatory knowledge integration and sharing methodology (Barrios et al., 2012a). Following the identification of native indicator plants as an important biological indicator of soil quality, farmers were requested to help locating specimens of these plants for botanical classification. Indicator plants were collected, dried and stored in a press and mounted following standard botanical sample collection methodology (Eymann et al., 2010). Information collected for each specimen included: photos, plant number, date, Kinyarwanda name, topography, elevation, latitude, longitude, habitat, abundance, and collector's name. Further, farmers were asked to identify if an indicator plant had another Kinyarwanda name/s, which were noted down to avoid registering one species known by more than one name as a separate species. The specimens were then transferred to the National Museums of Kenya for botanical identification.

Following the identification of soil macrofauna (earthworms, milli-pedes, termites, ants and beetles) as important biological indicators of soil quality, and with conflicting results regarding earthworms being named as an indicator of both fertile and infertile soil, a second farmer visit was conducted in order to collect specimens, accompanied with more in-depth farmer interviews. Sampling of macrofauna was under-taken during the rainy season in March 2017; a time when macrofauna are expected to be most active in the top-layer of the soil and thus easily captured. The macrofauna were collected by farmers through hand-picking or excavation where necessary (Pelosi et al., 2009; Smith et al., 2008). The samples were then identified by an entomologist. Combining both AKT5 and INPAC-S methodologies made it easier to compare between local and scientific indicators of soil quality, hence resulting into more precision of interpretation of results.

2.1.5 How? What methods did I use to analyse data?

In the first three stages of AKT5 acquisition (scoping, definition and compilation) stages, farmers' knowledge elicited was qualitative and was analysed and interpreted qualitatively using the AKT5 tool (Sinclair and Walker, 1998; Walker and Sinclair, 1998). This involved breaking down knowledge into unitary statements and then representing it using formal grammar and taxonomies where applicable. This is what formed a basis for formulating the questionnaire for collecting quantitative data. As indicated in the above section, data expected was qualitative and included: unitary statements from the AKT5 software to represent farmer's knowledge recorded from structured interviews and focus group discussions, seasonal calendar on food crops growing and availability periods, causal diagrams on drivers and effects of land degradation, historical timelines on drivers of land degradation and timing for land restoration interventions, Options by Context matrix tables on farmers' knowledge of suitability of land restoration interventions, photographs, and maps. In the generalization stage of AKT5 methodology, data expected was quantitative and mainly descriptive and involved eliciting 'presence or absence of knowledge of a particular aspect, hence nominal data (presence/ absence) was expected.

Farmers' responses to formal questions were recorded in Microsoft Excel as whether specific knowledge items were or were not articulated by the farmer. The data was then exported to R statistical software (R Development Core Team, 2013) for further statistical analysis. Frequency statistics (including percentages) were run to show the number of farmers that held knowledge about a specific parameter. Data was also represented through bar plots generated using the 'ggplot' function. Due to the categorical nature of the variables, where a stratum had a sample size of at least five, a Chi-square Test of Independence was applied for analysis (Gingrich, 2004; Mchugh, 2013). The test was undertaken to determine whether the sample data was consistent with the distribution that had been hypothesized, that is, that there were significant differences in farmers' knowledge about indicators of soil quality along the different levels of degradation, different field locations along a slope and gender. Where sample sizes per strata were less than five, Fisher's Exact Test was applied to give exact accurate and unbiased p-value for small sample sizes (Raymond and Rousset, 1995).

2.2: CONTEXTUAL INFORMATION ABOUT CASE STUDY COUNTRIES

2.2.1 What are the implications of this contextual information for research design?

The main function of research design is to ensure that the evidence obtained helps to effectively address the research problem under study, and thus helps to identify which information is required to address the research problem (David A. de Vaus, 2001). Contextual information about the study countries and sites captured in this section helped this research in different ways. First, my positionality is that it helped in the interpretation of my results as it ensures that the data I obtain will help me to answer my research questions adequately and appropriately. Further, as highlighted earlier, different context present different challenges and hence provide varying opportunities for designing targeted interventions. Also, I hypothesized that with limited financial resources available globally, through testing under which context we require different interventions would lead to the design of the most appropriate and cost-effective interventions.

When undertaking local knowledge studies, context is especially critical in that it helps to compare local perceptions from reality, hence provide some form of validation of findings over wider scales. This is critical in identifying whether farmers and other resource users, who are custodians of the resources have local understanding of globally accepted practices and concepts and the capacity to manage and sustain their resources. Studying context would also shed light on which circumstances would lead to local acceptance and adoption of interventions.

The sub-sections below shed light on the context under which I undertook my studies.

2.2.2 What agro-ecological systems exist within the two case study locations?

This study was undertaken in two agro-ecological zones namely the Sub-humid area in Rwanda and Semi-arid agro-ecological zone in Ethiopia. The inclusion of the two agro-ecological zones was critical in capturing biophysical and other forms of heterogeneities that helps address different sets of challenges (Nkheloane et al., 2012). These present different opportunities for scaling of land restoration interventions across significant portions of each country. Table 2.2 below highlights the different characteristics of the two agro-ecologies.

Table 2.2: Characterization of study sites

	Rwanda (Sub-humid Agro-climatic zone)			**Ethiopia (Semi-arid Agro-climatic zone)**		
	Degraded	**Recovering**	**Restored**	Recovering	Recovering	**Semi-restored**
Villages or catchments	Rushubi, Nyakibade, Nyabibuye	Karandaryi, Gakoma, Nkomane	Gihira	Bara	Endagiorgis	Endamariam
Elevation (m.a.s.l)	1890-2180	2350-2540	2380-2570	1833 to 2024	2095-2631	2200 to 2600
Rainfall (mm)	900-1500	1200-1500	1200-1500	350-700	350-700	350-700
Soils	Andosols	Alisols	Alisols	Cambisols, Luvisols, Vertisols	Luvisols, Leptosols	Cambisols, vertisols
Ave. household land size (ha.)	0.15	0.44	0.31	0.44ha	0.75ha	0.5ha
Dominant Crops	Maize, sweet potatoes, beans, irish potatoes	Irish potatoes, maize, beans, carrots	Irish potatoes, maize, beans, carrots	Wheat, barley, teff, sorghum	Teff, wheat, barley, beans	Wheat, barley, teff, lentils
Restoration interventions	None	Progressive terraces, trees	Bench terraces, trees	bench terraces, stone bunds, deep trenches, percolation channels, percolation ponds, large half- moon basins, eye-brow basins, micro-basins, and gabion check-dams	bench terraces, stone bunds, deep trenches, percolation channels, percolation ponds, large half- moon basins, eye-brow basins, micro-basins, and gabion check-dams	bench terraces, stone bunds, deep trenches, percolation channels, percolation ponds, large half- moon basins, eye-brow basins, micro-basins, and gabion check-dams
Age of restoration interventions	No intervention	2012	2007	2016	2016	2012

2.2.3 How were approaches to land degradation different between the two case studies?

Both study sites have undergone varying land degradation and restoration trajectories. In the Rwanda sites, land degradation was blamed on the socio-political factors and is largely blamed on 1995 and is associated with the aftermath of the Rwandan genocide (Safari, 2010). In Ethiopia, land degradation was perceived as gradual and occurred over a long period of time and blamed on multiple drivers including war between Ethiopia and Eritrea which occurred between 1988 and 2000, 1991 war due to change of government regime, introduction of communal land policy and land redistribution policies (Lanckriet et al., 2015).

In both cases, land restoration interventions are majorly top-down and government-led, with the respective governments having taken varying approaches to land restoration. Land restoration efforts also occurred at different time frames in the two study sites (Table 2.2). They also differed in the nature and mode of implementation. In Rwanda, the approaches are mostly implemented at the individual farm level and consisted of mainly bench and progressive terraces. On the contrary, in Ethiopia due to the communal approach to land (Tesfaye et al., 2011) and the presence of communal grazing land and exclosures, most interventions were undertaken at the landscape scale and involved a combination of multiple interventions. Because land restoration involves managing material flows across landscapes, it is imperative to address the issue from a landscape scale.

Another difference in the approach to restoration is that in Rwanda, interventions were implemented administratively at the village level and at different periods of time. On the contrary in Ethiopia, interventions had been implemented using ecological boundaries at the catchment level, which cuts across various villages. However, interventions that involves restoration of land should be done using ecological boundaries as this involves material flows and ecological processes across administrative boundaries (Cumming et al., 2006; Strayer et al., 2003).

I hypothesized that through studying the contextual differed in approaches to addressing land degradation would lead to different outcomes and would present farmers with different experiences, challenges and opportunities to addressing land degradation. This is especially with regards to the suitability and sustainability of restoration interventions as farmers in each of the sites are likely to have varying knowledge.

2.2.4 What specific projects were engaged with the study sites?

Though I was involved in various activities and projects, through purposive sampling (Etikan et al., 2016), I assessed which study areas were relevant candidate sites that would help me to answer my research questions and objectives, based on level of degradation and restoration. This study adopted an ecological as opposed to administrative boundaries approach (Strayer et al., 2003). This is because land degradation and restoration processes involve material flows within the landscapes and interactions of multiple stakeholders with ecosystem services beyond the administrative boundaries across the landscapes.

I selected Rwanda and Ethiopia sites in the Trees for Food Security Project and Degraded land restoration project respectively. This is because some of the project sites fell within a land degradation gradient, which was my main criteria for stratification. The study sites I selected consisted of both project-sites and non-project sites that I found to be suitable candidates for answering my research questions on land degradation and restoration. Although I have was working on many projects spread across the greater Eastern Africa region, I chose to undertake my PhD research under two of those projects because they had sites or adjacent non-project sites that were best suited to answer my research question and objectives. Since I was interested in capturing the real effects of land degradation, sites outside the project areas were also selected as control sites comprising of severely degraded landscapes in Rwanda where no intervention had been implemented.

The two projects of focus were: the Australian Centre for International Agricultural Research (ACIAR) funded Trees for Food Security Project (2012-2017), is implemented in three countries namely Uganda, Ethiopia and Rwanda and aims at sustainably improving productivity of farming landscapes, and to recover food and nutritional security through the promotion of suitable agroforestry interventions. The second project is the IFAD/EU funded Restoration of Degraded Lands project (2015-2018) works in three countries namely Kenya, Ethiopia and Niger and aims at reducing food insecurity and improve livelihoods of poor people living in African drylands by restoring degraded land, and returning it to effective and sustainable tree, crop and livestock production, thereby increasing land profitability and landscape and livelihood resilience.

In Rwanda, the project site that represents recovering landscape (2012) was included in the study, while a non-project degraded site (with no intervention) was included and a non-project site that is restored owing to older and effective restoration interventions (2007) was also included. Likewise, in Ethiopia, I chose candidate sites that met restoration gradient criteria namely sites that had recently begun restoration (Endagiorgis and Bara were established in 2016) and a site that had established restoration (Endamariam were established in 2012).

2.2.5 Who are the important stakeholders and how are livelihoods shaped

This section focused on the key stakeholders studied in this research and explores aspects of farmers' livelihoods that were likely to influence research design, including crop selection and the role of gender. This study focused on smallholder farmers in Rwanda and Ethiopia as the key stakeholders. In both countries, agriculture is the main source of livelihood, with farming accounting for over 80% of the population (FAO et al., 2017). One of the differences between the two study sites is that in Rwanda, farmers lease and control land individually unlike in Ethiopia where there are communal and individual land control, though land belongs to the government (Tesfahunegn et al., 2011). Another key stakeholder are the policy makers. I hypothesized that findings from this research were also targeting policy makers through identifying policy recommendations aimed at enhancing the performance, suitability and sustainability of on-going land restoration and food security interventions.

In Ethiopia, farmers mostly utilize ox-ploughs and thus there is no fencing of crop-fields amongst different households. This is likely to expose livestock to farms, which would jeopardise both vegetative and structural restoration interventions (Tesfaye et al., 2011). In Rwanda, crop fields are fenced and land is cultivated mostly using hand hoes. Further, in Ethiopia, free-grazing of livestock is the common mode of livestock management- with farmers accessing fodder from communal grazing land and periodically from exclosures (here cut and carry is practiced) (Mekuria et al., 2011). This is likely to also jeopardise interventions through encouraging browsing of vegetative interventions by livestock. In Rwanda, farmers practice 'cut and carry' system of livestock management. In Ethiopia, land ownership is communal, which presents a challenge of insecurity of tenure (Tesfa and Mekuriaw, 2014) unlike in Rwanda where there has been Land Tenure Regularization Programme and where the government has also introduced land-use consolidation where farmers plant similar crops, usually high-value crops across their individual land (Muhinda and Dusengemungu, 2011a).

In both countries, land resources are mainly controlled by men while farming systems are male-dominated including men dominating sale of high-value crops, while women are alienated from actively participating in the processes (Rwibasira E., 2016; Shiferaw et al., 2014). This is despite the fact that it is women who are mainly involved in production activities on the farms such as ploughing; and they are also a key target for land restoration interventions.

In Rwanda, drivers of crop selection by farmers can be attributed to not only on decreasing soil quality due to land degradation but also on other contextual factors that cut across biophysical and socio-economic (Nabahungu and Visser, 2011). Such include the Crop Intensification Programme and land-use consolidation government policy that has promoted a few high-value crops at the expense of low-value diverse crops. Further, market demand has driven crop selection, with farmers resulting to crops that fetch high returns in the market (which are mostly controlled by men) while ignoring those that have low economic value. Hence, I focused on eliciting gender-disaggregated knowledge as an important output for my study.

In Ethiopia, one of the key drivers influencing crop selection is the resulting climate change effects, that have seen farmers move from traditional crops to growing crops that are resistant and adaptable to drought conditions (Abebe et al., 2010). Such include a move from crops such as maize to sorghum and millet. Also, due to decreasing household land size, and coupled with the need to intensify on land, farmers have shifted to growing 'quick crops' that grow and mature faster such as vegetables while abandoning crops that take long time to grow (Holden and Yohannes, 2002a). Hence household land size was one of the stratification criteria for my study; especially where I was focusing on on-farm crop diversity and its relationship to resilience of farms.

CHAPTER 3: FARMERS' KNOWLEDGE OF SOIL QUALITY INDICATORS ALONG A LAND DEGRADATION GRADIENT IN RWANDA

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ABSTRACT

The growing need to intensify smallholder farming systems to enhance food security for a rapidly growing population in sub-Saharan Africa constitutes a major sustainability challenge. Intensification of agriculture has often resulted in degraded, highly vulnerable, exhausted and unproductive soils. Even though smallholder farming systems are heterogeneous and dynamic, conventional approaches to improving soil management have focused on promoting one or two technologies, informed by coarse-resolution assessments, rather than tailoring technologies to context. This has resulted in technologies that have been promoted not being locally adapted. The research reported here explores the extent to which farmers' indicators of soil quality vary with land degradation status and gender and can be used in selecting locally appropriate land restoration practices. Knowledge was elicited from 150 smallholder farmers across a land degradation gradient in Rwanda through combined use of a systematic knowledge-based systems approach (AKT5), and a participatory knowledge sharing method for indicators of soil quality (InPaC-S). Data were analysed using R software through frequency statistics, 'ggplot'-generated bar plots and Chi-square tests of independence. Farmers described 12 indicators of soil quality with a mean of five per farmer. The four most frequently mentioned were: soil colour (96%), indicator plants (90%), crop vigour (71%) and soil texture (67%). Farmers' knowledge about 10 out of 12 indicators varied with land degradation status (p b .05), and there were other variations according to location of fields along slopes, and gender. Farmers had knowledge of 51 indicator plants and 22 soil macrofaunal species and mentioned seven soil management practices, including: compost manure (83% of farmers), livestock manure (64%) and tree biomass incorporation (54%). There were variations in the practices by degradation status, slope location and gender. These variations revealed the importance of matching management options to ecological context and farmer circumstances to foster adoption. There were relationships between farmers' knowledge of indicators of soil quality and their soil management practices. This research has shown that acquiring farmers' knowledge about soils can help to identify fine-scale contextual differences useful for informing the design of soil management options and it is recommended that this is done in future so that appropriate options can be offered to different farmers making them more likely to be adopted.

3.1. INTRODUCTION

Land degradation is a major threat to food security, particularly in the context of a rapidly growing global population living on finite land resources. Approaching 15% of the seven billion people alive today are classified as food insecure (FAO et al., 2017; FSIN, 2018). With the global population projected to hit nine billion by 2050 (Montpellier, 2013), the food insecurity challenge can be expected to become more severe, especially for sub-Sahara Africa, where an estimated quarter of the people are already hungry (Bremner, 2012). Current attempts to meet food and livelihood needs of sub-Saharan smallholder farms have often led to severe soil degradation.

Land degradation has been blamed on various factors including un-sustainable agricultural practices that emphasize use of external inputs while ignoring the natural processes that support soil formation and build agroecosystem resilience. These include nutrient cycling, soil erosion control, carbon sequestration and water regulation (Swift et al., 2004; Verchot et al., 2007). Other drivers include deforestation and land-cover loss (Bewket and Stroosnijder, 2003; Eshetu et al., 2004; Tsegaye et al., 2010), unfavourable government policies, insecurity of tenure, overstocking and free grazing, slash and burn, and lack of adequate soil and water conservation interventions (Eswaran et al., 1997; Sanchez et al., 2003; Tesfahunegn et al., 2011).

In Rwanda, following the 1994/1995 genocide, extensive deforestation took place as a result of population pressure and its associated effects, such as high demand for land for cultivation, settlements, energy, tree products and grazing that collectively led to severe land degradation (Bizoza and Havugimana, 2013; Safari, 2010). Soil quality degradation also occurred due to loss of soil nutrients resulting from continuous cultivation with few or no inputs, and short or no fallow periods because of decreasing size of household land holdings (Byiringiro and Reardon, 1996a; Drechsel et al., 2001). Other drivers include cultivation of unsuitable areas such as steep slopes and wetlands (Bizoza and Havugimana, 2013; Nabahungu and Visser, 2016). Coupled with the effects of climate change, such as prolonged drought and flash floods (Westoff, 2013), there has been severe soil loss through erosion and landslides. There is, therefore, an urgent imperative to employ sustain-able intensification strategies to not only increase food productivity and profitability, but also to ensure the ecological resilience of the agroecosystems from which it is produced (Folke et al., 2010; Pretty and Bharucha, 2014). Such an approach can contribute to reconciling achievement of two of the United Nations Sustainable Development Goals (SDGs) to end hunger (SDG 2.3) while protecting the environment (SDG 15.3) (United Nations, 2015).

A key challenge limiting sustainable intensification of agriculture is that smallholder farming systems are heterogeneous and dynamic, not only in their biophysical context (including soils) but also in terms of famer circumstances, production objectives and socio-technical conditions (Kmoch et al., 2018; Tittonell et al., 2005; Vanlauwe et al., 2014). Despite this heterogeneity in smallholder farming systems, conventional soil management and land restoration approaches in Rwanda have prescribed a narrow set of soil management options, often informed by coarse-resolution assessments. This has led to variable performance and adoption of these options because they are not tailored to variable farmer context (Habarurema and Steiner, 1997; Verdoodt and Van Ranst, 2006). Acquisition of local knowledge is a potential means to capture contextual heterogeneity but there has been only limited effort to collect or collate knowledge about land degradation and restoration processes in Rwanda (Rushemuka et al., 2014a).

Research elsewhere indicates that acquiring farmers' knowledge can provide detailed understanding of fine-scale farm and farmer context (Barrios and Trejo, 2003; Cerdán et al., 2012; Dumont et al., 2014). This often complements global scientific knowledge about managing ecosystem service provision, and can be used in the design of more sustainable and locally adapted agricultural technologies (Jacobi et al., 2017; Tengö et al., 2014). This knowledge is dynamic and evolves with changing circumstances, through observation and experience of farmers and knowledge exchange, representing a practical and direct feedback mechanism useful when responding to system changes (Joshi et al., 2004a).

Soil scientists categorize indicators of soil quality as either biological, chemical or physical. Chemical indicators refer to nutrient cycling, water relations and buffering and include: measurements of Ph, salinity, soil organic carbon, total nitrogen (Nael et al., 2004). Biological indicators of soil quality include plant and animal species that play a key role in supporting critical soil functions and hence ecosystem services and include: soil macro and micro fauna and indicator plants (Barrios, 2007). Physical indicators are related to the arrangement of solid particles and pores involved in soil hydraulic flows and include aggregate stability, soil structure, available water capacity, bulk density, infiltration, porosity, slaking, texture and compaction (Schloter et al., 2003). Previous farmers' knowledge studies on soil quality indicators have revealed that they have knowledge of mostly physical or biological indicators. Physical indicators reported by farmers include soil colour, texture, soil tilth, moisture retention; while biological indicators include crop performance, crop yield, indicator plants, soil macrofaunal and the main chemical indicator reported by farmers is soil organic matter (Barbero-Sierra et al., 2018; Ericksen and Ardón, 2003; Mairura et al., 2007).

The majority of scientific studies that have assessed landscape function have failed to incorporate resource users knowledge (Merrill et al., 2013). This leads to the exclusion of farmers, who are the main managers of soils and whose observations might be useful to enrich and inform the use of scientific knowledge. Other studies have focused on only a few pre-selected soil types or only one of the three categories of soil quality indicators (Tesfahunegn, 2016; Veum et al., 2014) or have only focused on the fertility aspect of soil quality (Kambiré et al., 2015; Mowo et al., 2006). Most local knowledge studies have focused single landscapes (Carter, 2002; Tesfahunegn et al., 2016), so that comparative analysis of different landscapes at various levels of land degradation are not available. Studies in Rwanda have mostly focused on the influence of soil quality indicators on decisions about which crops to grow where and have often been confined to single landscapes (Nabahungu and Visser, 2016; Rushemuka et al., 2014b). This has contributed to the promulgation of universal soil restoration interventions across soils, despite the very different constraints they are subject to.

Even within a single landscape, previous studies have not assessed indicators of soil quality along slopes despite their importance in land degradation. Research on gender and farmers' knowledge has mostly focused on the soil fertility component of soil quality (Christie et al., 2016) and has not assessed whether understanding of soil quality by gender influences soil management practices.

The objective of the present research was to elicit farmers' knowledge about indicators of soil quality and assess whether they varied along a land degradation gradient and in relation to gender. There were two interrelated central hypotheses: 1) that farmers' indicators of soil quality vary with land degradation status and gender, and 2) that farmers knowledge of indicators of soil quality and their gender influence soil management practices.

3.2. MATERIALS AND METHODS

3.2.1. Study area

This research was carried out in two districts, Nyabihu and Rubavu, which form part of Gishwati forest, a protected reserve in Western Rwanda, that falls within the sub-humid agro-climatic zone. The area comprises fragmented forest remnants resulting from decades of land degradation and deforestation, with the greatest impact occurring after the 1994/95 genocide due to resettlement of returnees and refugees who had high dependence on forest resources (Ordway, 2015). Three landscapes with contrasting levels of land degradation were selected for the research along a degradation gradient. Recovering and re-stored landscapes were located in Kadahenda cell, Karago sector of Nyabihu district, located at 1°37′38.28“S and 29°30’48.24”E within the Eastern Congo-Nile Highland Subsistence Farming Zone, with a mean annual rainfall ranging from 1200 to 1500 mm (REMA, 2010) across an elevation range from 1460 to 3000 m above sea level.

Plate 3.1: Recovering (left) and Restored (right) Landscapes in Gishwati

The degraded landscape was located in Gikombe cell, Nyakiliba sector of Rubavu dis-trict, located at −1°40′16.68“S and 29°21’37.44”E, with an elevation of 2109 m within the North-Western Volcanic Irish Potato Zone (*ibid*) that receives a mean annual rainfall ranging from

900 to 1500 mm. The soil map of Rwanda taken at a scale of 1:50,000 classifies soils in Nyabihu district as Alisols while those in Rubavu district as Andosols using the World Reference Base (Verdoodt and Van Ranst, 2006). The topography of all sites is mountainous and steep sloped with some areas having a slope inclination of over 50%, hence the landscape is susceptible to severe soil erosion (Byiringiro and Reardon, 1996b; D M Kagabo et al., 2013; Roose and Ndayizigiye, 1997).

Plate 3.2: Degraded landscape in Gishwati

3.2.2. Site selection

Using a Paired-Catchment Experimental design, three study sites that we labelled as: degraded, recovering and restored; were selected along a land degradation gradient identified in previous studies (Aynekulu et al., 2014; Bigagaza et al., 2002; Hintjens, 2006; Kuria et al., 2014). Historical timelines show that all three study sites underwent simultaneous tree cover loss during their conversion to agriculture and settlements following the post-genocide period in 1995 but then followed different restoration and recovery trajectories.

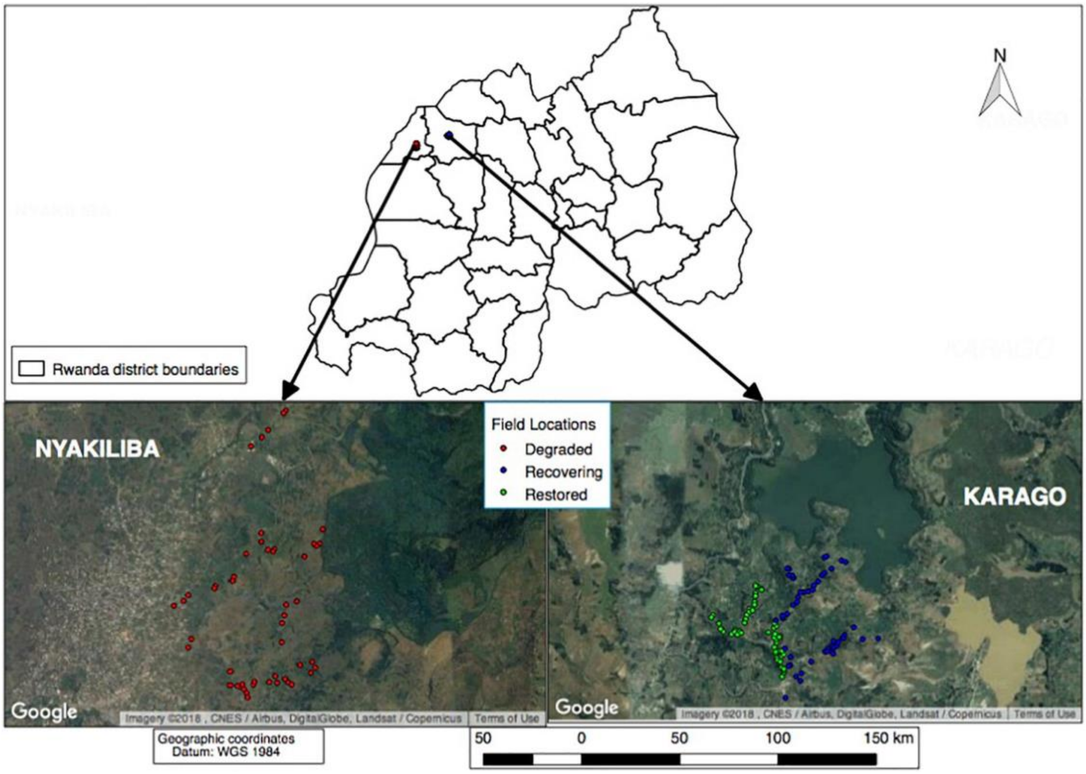

Fig. 3.1: Map of Rwanda showing location of fields sampled in Nyabihu and Rubavu Districts (n = 150).

The upper part of the degraded landscape is an area adjacent to Gishwati protected forest while the lower part borders Mahoko town. It is characterized by severe soil loss as a result of soil erosion, landslides and siltation as well as frequent flooding in the flat areas found downslope (Fig. 3.1). The area has not received any soil and water conservation interventions following the post genocide deforestation in 1995. After the government of Rwanda evicted farmers who had encroached Gishwati forest in 2010, soil and water conservation efforts have involved reforestation of the protected forest, but not the adjacent farming landscapes. The study villages included: Rushubi, Nyabibuye and Nyakibande, Nyakiliba sector in Rubavu district.

The recovering landscape is adjacent to Karago Lake and still experiences significant soil loss through surface run-off and erosion. This area is receiving soil and water conservation interventions led by ICRAF through the Australian Centre for International Agricultural Research (ACIAR) Trees for Food Security Project. The project aims at sustainably improving productivity of farming landscapes, and to recover food and nutritional security through the promotion of suitable agroforestry interventions. The study villages included: Karandaryi, Gakoma and Nkomane in Kadahenda cell, Karago sector of Nyabihu district.

In the restored landscape, which is adjacent to Lake Karago and the recovering landscape, soil loss has been controlled as a result of soil and water conservation interventions that were implemented over a decade ago. In 2005/2006, the government of Rwanda through the 'umuganda' community service embarked on soil erosion control as part of the national soil and water conservation programme; whereby bench and progressive terraces were established on steep slopes (Bizoza, 2014) and stabilized through planting of *Alnus acuminata* and *Setaria sphacelata*. The interventions were also intended to protect Lake Karago and Busoro river from siltation including provision to set aside a 50 m strip of adjacent land all around water bodies for planting trees. The study village was Gihira village, Kadahenda cell, Karago sector of Nyabihu district.

3.2.3. Data collection

This study, which was conducted between August and November 2015, used the Agroecological Knowledge Toolkit (AKT5) and methodological framework (Sinclair and Walker, 1998; Walker and Sinclair, 1998), in combination with the InPaC-S participatory knowledge integration and sharing methodology to study indicators of soil quality (Barrios et al., 2012a). Agroecological (local) knowledge on indicators of soil quality was elicited by use of knowledge-based methods and semi-structured interviews with a stratified sample of willing and knowledgeable informants. The knowledge was then recorded and represented using the AKT5 software (Dixon et al., 2001).

The AKT5 methodology comprises four stages (Walker and Sinclair, 1998). At the scoping stage, research activities carried out included: participatory transect walks to understand the landscape setting, topography, degradation hotspots, soil types, field typologies and the location of different resources. This also helped to inform stratification criteria. Further, key informant interviews were held with the crop, livestock, and natural resource extension officers and the area administration to elicit expert knowledge on the research subject. Six focus group discussions were held with a total of 69 farmers drawn from the three study landscapes. These were conducted using a set of semi-structured questions and a participatory process that aimed to identify, categorize and prioritize farmers' indicators of soil quality associated with high and low quality soils using the InPaC-S methodological guide (Barrios et al., 2012a). This was followed by participatory soil mapping of the three study landscapes. In addition, photography was used to visually capture differences between soil types along the slope and across the slope. Transect walks were also undertaken along and across the slopes to identify the different soil types and to triangulate the information provided by farmers.

Plate 3.3: Female farmers discussing degradation hotspots during an FGD

The definition stage highlighted knowledge boundaries and stratification parameters. Two farmers in each of the nine locations (e.g. three slope positions - upslope, midslope and downslope, on the three study landscapes - degraded, recovering and restored) were selected at random for in-depth interviews, which aimed at understanding the status and characteristics of soils, as related to indicators of soil quality and soil management practices. The compilation stage involved an iterative pro-cess whereby knowledge elicited from individual farmers guided by the InPaC-S methodological guide (*ibid*) and recorded systematically using the AKT5 software, were evaluated for consistency and then further explored through repeated visits to the same farmers in order to probe further to get additional information or clarifications where apparent contractions or gaps were revealed. This process was repeated (at least two visits per farmer) until no new information was obtained from further discussion with the respondent.

In the generalization stage key research questions were formulated as a formal questionnaire based on issues deemed pertinent from analysis of the in-depth knowledge obtained during the previous three stages. Pre-testing of the questionnaire was then conducted with 12 farmers (four from each of the three landscapes) and the questionnaire then administered to 150 farmers (50 farmers from each of the three landscapes). To ensure degradation-related heterogeneities were represented in the sample, 50 farmers were drawn from each of the three study landscapes namely degraded, recovering, restored, in a stratified random sample. Within each landscape, stratified random sampling was further applied to select farmers from various slope locations (up-slope, midslope, downslope) based on transects walks along and across the slopes. The sample comprised 67 women and 83 men. Results presented here were generated at the generalization stage.

Following the identification of native indicator plants as an important biological indicator of soil quality, farmers were requested to help locating specimens of these plants for botanical classification. Indicator plants were collected, dried and stored in a press and mounted following standard botanical sample collection methodology (Eymann et al., 2010). Information collected for each specimen included: photos, plant number, date, Kinyarwanda name, topography, elevation, latitude, longitude, habitat, abundance, and collector's name. Further, farmers were asked to identify if an indicator plant had another Kinyarwanda name/s, which were noted down to avoid registering one species known by more than one name as a separate species. The specimens were then transferred to the National Museums of Kenya for botanical identification.

Plate 3.4 A farmer in Kadahenda explaining how she uses indicator plants to differentiate poor and fertile soil

Following the identification of soil macrofauna (earthworms, millipedes, termites, ants and beetles) as important biological indicators of soil quality, and with conflicting results regarding earthworms being named as an indicators of both fertile and infertile soil, a second farmer visit was conducted in order to collect specimens, accompanied with more in-depth farmer interviews. Sampling of macrofauna was under-taken during the rainy season in March 2017; a time when macrofauna are expected to be most active in the top-layer of the soil and thus easily captured. The macrofauna were collected by farmers through hand-picking or excavation where necessary (Pelosi et al., 2009; Smith et al., 2008). Earthworms collected were first placed in 70% ethanol and then preserved in 4% formaldehyde; while the millipedes, termites, ants and beetles were preserved in 70% Ethanol prior to identification by an entomologist.

Plate 3.5 Earthworm sample collection (left) and an earthworm specimen (right)

3.2.4. Data analysis

Data and knowledge elicited through the first three stages of the AKT process were analysed and interpreted qualitatively using the AKT5 tool (Sinclair and Walker, 1998; Walker and Sinclair, 1998). This involved breaking down knowledge into unitary statements and then representing it using formal grammar and taxonomies where applicable. This is what formed a basis for formulating the questionnaire for collecting quantitative data.

Farmers' responses to formal questions were recorded in Microsoft Excel as whether specific knowledge items were or were not articulated by the farmer. These results was then exported to R statistical software (R Development Core Team, 2013) for further statistical analysis. Frequency statistics (including percentages) were run to show the number of farmers that held knowledge about a specific indicator of soil quality or soil management practice. Data was also represented through bar plots generated using the ‘ggplot’ function. Due to the categorical nature of the variables, where a stratum had a sample size of at least five, a Chi-square Test of Independence was applied for analysis (Gingrich, 2004; Mchugh, 2013). The test was undertaken to determine whether the sample data was consistent with the distribution that had been hypothesized, that is, that there were significant differences in farmers' knowledge about indicators of soil quality along the different levels of degradation, different field locations along a slope and gender. Where sample sizes per strata were less than five, Fisher's Exact Test was applied as it gives an exact accurate and unbiased p-value for small sample sizes (Raymond and Rousset, 1995)

3.3. RESULTS

3.3.1. Farmers' soil classification and perceptions about land degradation status

Farmers in all three study landscapes in Gishwati named and described nine soil types, with Kinyarwanda names being assigned and differentiated according to several dominant characteristics: texture, colour, level of compactness, easiness to plough and productivity potential. Table 3.1 illustrates the characteristics for each of the nine soil types encountered in Gishwati fields. ‘inombe’ in Kinyarwanda translates as ‘to stick together or smash’, while ‘urucucu’ means that soil can be transported easily by wind because it contains a lot of dust; while ‘igitakaza’ means a mixture of very fine particles from various sources, while ‘urubuye’ means soil that contains gravel and stone and destroys the hoe; ‘gahuhuma’ means shallow, degraded soil which the hoe or roots do not go through easily, ‘ibeja’ means shallow soil with nutrient deficiency. ‘urusenyi’ means deep and soft soil with fine sandy particles, while ‘uruchanga’ means large sandy particles. ‘ubuseseka’ means loose and soft soil where the hoe enters easily.

Farmers described land degradation as gradual loss of fertile soil and clay content to water erosion. All study landscapes had some dominant soils in common, though their location along a slope could differ in some cases (Table 3.1). Fields in the recovering and restored landscapes shared dominant soil types ‘inombe and urucucu’ on the up-slope and midslope locations, but there was additional sand deposition (‘uruchanga’) downslope in the recovering landscape. On the contrary, the degraded landscape had three dominant soil types of differing texture, with de-creasing clay content from upslope downwards from upslope to midlopes, with the fertile top soil being deposited downslope. The upslope, which is adjacent to Gishwati protected forest mainly had ‘inombe’ or ‘igitakaza’ soils; while the midslopes were characterized by ‘urubuye’ or ‘urucucu’ soils of coarse and sandy texture suggesting that soil loss processes were taking place. The downslopes constituted soils with high clay and silt content (‘inombe’ or ‘igitakaza’), probably as a result of deposition of eroded top soil.

Consequently, the type of crops grown by farmers along the land degradation gradient varied and was also influenced by the prevailing soil type including its fertility level. Farmers in the restored and recovering landscapes had a choice of planting a wide variety of major crops on any field location along a slope, including Irish potatoes, maize, beans and carrots due to generally healthy soils. In contrast, farmers in the degraded landscape were limited to fewer crops, mainly beans, sweet potatoes or Eucalyptus spp. plantations commonly found on midslopes while Irish potatoes and maize were mostly planted downslope taking advantage of deposition of fertile sediments.

Table 3.1: Farmers local classification of soils

Local Soil Taxonomy/ Name	Local parameters for classification of soil types								Slope location where mostly found		
	Texture	Colour	Plough easiness	Water Infiltration capacity	Moisture content when dry	Water-holding capacity	Fertility	Erodibility	*Degraded*	*Recovering*	*Restored*
'Inombe'	Very fine and loose	Dark-reddish-brown	Sticky	Very low	High	High	High	High	Up/Down	All	All
'Urucucu'	Moderately fine, dusty when dry	Brown-reddish	Moderate	Moderate	High	Moderate	Moderate	High	Dominant	Dominant	Dominant
'Igitakaza'	fine, loose, light particles	dark-brown	Moderate	Low	High	High	High	High	Up/Down	All	All
'Urubuye'	Stones and gravel	Blackish	Easy	High	Low	Low	Low	Low	Mid/Down	-	-
'Gahuhuma'	mixture of sand and gravel	Brownish - yellow	Difficult	Moderate	Low	Low	Very Low	Low	Down	-	-
'Ibeja'	Sandy-loam	Reddish-brown	Moderate	Moderate	Moderate	Moderate	Low	Very High	Up/Down	-	Mid
'Urusenyi'	Sand and gravel	Blackish	Easy	High	Low	Very Low	Low	Low	Mid	-	-
'Uruchanga'	Sandy	Whitish	Easy	Very high	Low	Very Low	Very Low	Low	Mid	Down	-
'Ubuseseka'	Tiny soft and loose particles	Whitish-yellow	Easy	Moderate	Moderate	Moderate	Low	High	Small	Up/Mid/Down	Up/Mid/Down

3.3.2. Farmer knowledge on indicators of soil quality

Farmers had detailed explanatory knowledge of 12 indicators of soil quality, with each farmer having knowledge of an average of five indicators (mean = 5.1 +/− 0.11). Table 3.2 illustrates indicators described by farmers to characterize the fertility status of soils on their farms. The indicators were classified as physical (7), biological (4) or chemical (1). Further, the 12 indicators comprised two landscape scale indicators: field location along a slope and slope gradient, while the remaining 10 indicators were manifest at field level.

Farmers' assessment of soil quality was qualitative and based on physical examination. Methods used by farmers to categorize soil as either being of high or low quality included: visual observation (all indicators), and touch involving passing soil through fingers, especially during ploughing, to assess the texture, soil organic matter, moisture content and easiness to plough. In addition, farmers also used indirect methods to assess biological indicators such as crop vigour and the amount of post-harvest crop residue. Indicator plants and soil macrofauna were viewed both in terms of species presence or absence, and frequency of occurrence (abundance).

Table 3.2: Local diagnostic criteria for describing indicators of soil quality

Local (Kinyarwanda) Name	Scientific Equivalent	Soil Fertility Status		Spatial Scale		Scientific soil properties involved		
		Fertile	Infertile	Field	Landscape	Physical	Biological	Chemical
1. *Ibara ry'ubutaka*	Soil colour	Dark, dark brown, black	Light/ whitish/ yellowish	+	-	+	-	-
2. *Ibyatsi biranga ubutaka*	Indicator plants	Species type and abundance	Species type and abundance	+	-	-	+	-
3. *Imikurire y'ibihingwa*	Crop vigour	Dark green, fast growth, large/tall stem, strong	Yellow & stunted growth, light green, short, weak	+	-	-	+	-
4. *Ubwoko bw'ubutaka*	Soil texture	Fine particles, clay-loam	Coarse, stony, sandy	+	-	+	-	-
5. *Imborera yo' mubutaka*	Soil organic matter	High	Low	+	-	-	-	+
6. *Ibishingwe by' avuye mu myaka*	Amount of post-harvest crop residue	Large, dense biomass	Small, low biomass	+	-	-	+	-
7. *Udusimba two mubutaka*	Soil macrofauna	Species type and abundance	Species type and abundance	+	-	-	+	-
8. *Ubuhaname bw' umusozi*	Slope gradient of a field	Flat/ gentle sloped	Steep sloped	-	+	+	-	-
9. *Aho umuhizi atuye kumusozi*	Location of a field along a slope	Downslope	Upslope/ Midslope	-	+	+	-	-
10. *Ubushobozi by'ubutaka bwo gutambutsa amazi*	Water infiltration rate of soil	High infiltration, no water logging	Low infiltration, water-logging	+	-	+	-	-
11. *Guhingisha isuka byoroshe*	Easiness to plough	Non-sticky	Sticky	+	-	+	-	-
12. *Ubuhehere b'ubutaka*	Moisture content of soil during dry season	Retains moisture in dry season	Dry and retains no moisture during the dry season	+	-	+	-	-

The four indicators of soil quality most commonly used by farmers to characterize soils on their fields were soil colour, soil indicator plants, crop vigour, and soil texture (Fig. 3.2).

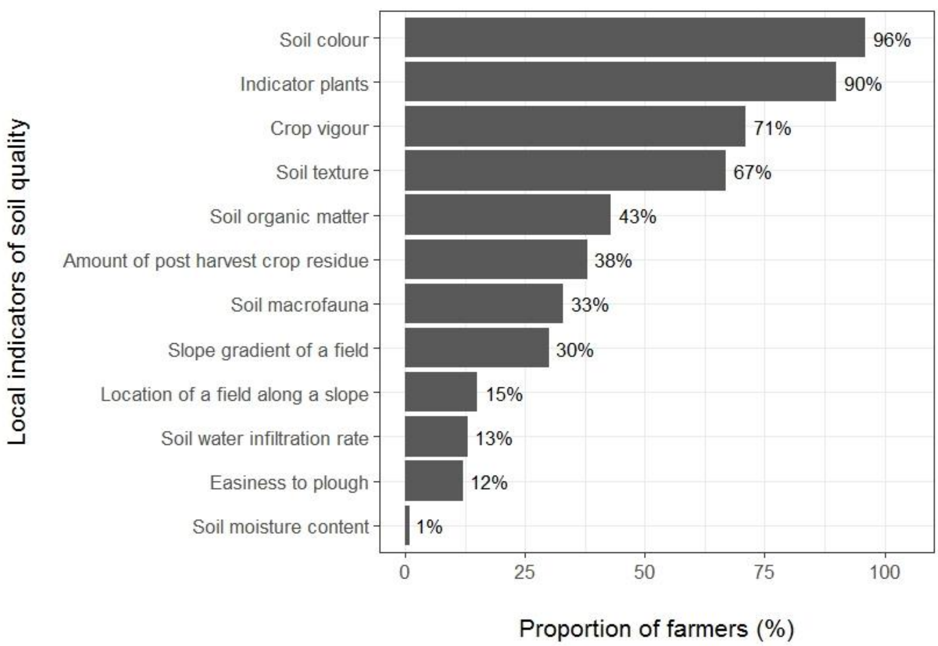

Figure 3.2: Proportion of farmers mentioning local indicators of soil quality (n=150)

Some indicators of soil quality were consistently used across all landscapes while others were more frequently mentioned in some landscapes than others. Farmers consistently used soil colour and indicator plants as the first and second most frequently mentioned indicator across all landscapes (Fig. 3.3). Crop vigour, on the other hand, was more frequently mentioned in the restored and recovering compared to the degraded landscape, while soil texture was more prevalent in the degraded and recovering landscapes (p b .05). Soil organic matter and location along the slope were not mentioned by farmers in the de-graded and restored landscapes respectively while the amount of post-harvest residues and soil macrofauna were more frequently mentioned in the recovering and degraded landscapes than the restored landscape (p b .05). Only farmers in the degraded landscape mentioned field location along a slope (downslope, midslope or upslope) as an indicator of soil quality but more farmers in the restored and recovering landscapes mentioned slope gradient than those in the degraded landscape (p b .05). On the contrary, more farmers in the degraded landscape mentioned easiness to plough, significantly different from other landscapes (p b .05). Water infiltration rate was important in the degraded landscape and significantly different from other landscapes (p b .001).

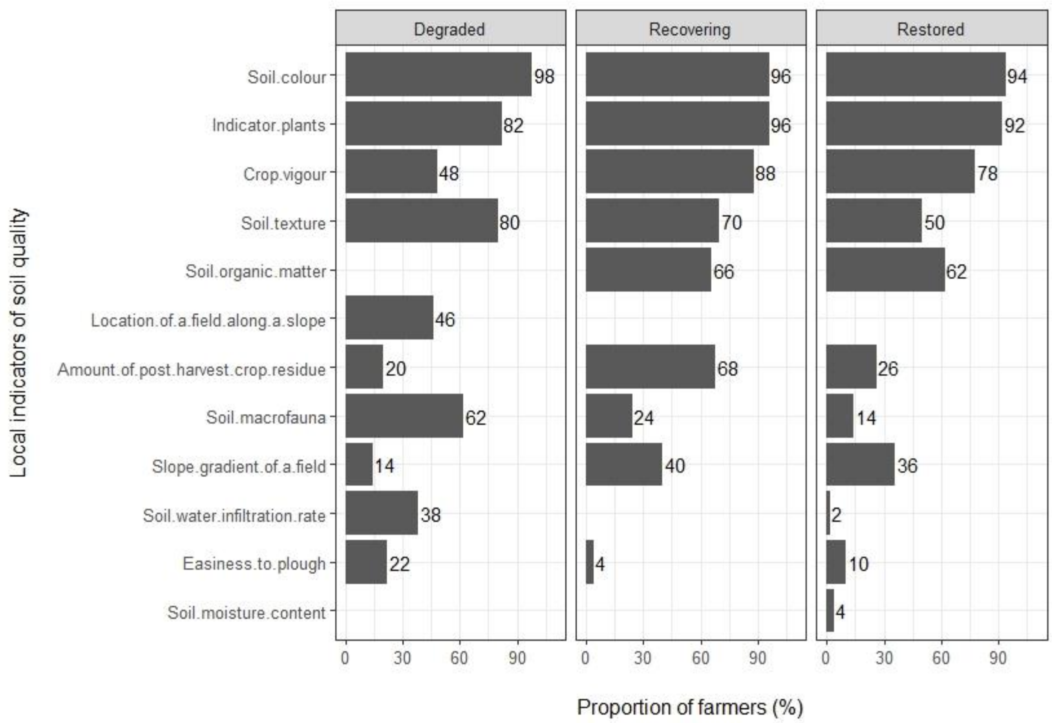

Fig. 3.3. Proportion of farmers mentioning indicators of soil quality along a land degradation gradient (n = 150; n = 50 per strata).

Farmers had knowledge of 28 and 23 indicator plants for high and low-quality soils respectively. Indicator plant species from the Asteraceae family were the most commonly mentioned (seven plant species). Table 3.3 shows the most important indicator plants as identified and prioritized by farmers. *Crassocephalum montuosum* was the most commonly mentioned indicator plant found in fertile soils in the recovering and restored landscapes. On the other hand, *Galinsoga quadriradiata* and *Commelina benghalensis* were the most commonly mentioned indicators of fertile soils in the degraded landscape. *Bromus unioloides* was the most frequently mentioned indicator of low soil quality across all three landscapes, with the highest number of farmers mentioning it in the degraded landscape. In addition, 'absence of native plants' effectively, bare soil, was recognized mainly by farmers in the degraded landscape as indicating extremely poor and infertile soil.

Table 3.3: The most important indicator plants for high and low-quality soils named by farmers along the land degradation gradient.

Local name	Scientific name	Botanical Family	Percentage of farmers (%)			
	Local Indicator Plants for Fertile Soil		***Degraded***	***Recovering***	***Restored***	**Average**
Igifuraninda	*Crassocephalum montuosum* (S. Moore) Milne- Redh.	Asteraceae	22	66	60	49
Ibaraza	*Galinsoga quadriradiata* Ruiz & Pav.	Asteraceae	62	34	42	46
Uruteja/ Inteja	*Commelina benghalensis* L.	Commelinaceae	46	18	20	28
Igihwarara/ Ikigembegembe	*Carduus Benedictus* Linn.	Asteraceae	10	14	34	19
Urukarara	*Galium spurium* L. subsp. africanum Verdc.	Rubiaceae	0	8	8	5
Igisura	*Urtica dioica*	Urticaceae	0	4	10	5
Ifurwe	*Dichrocephala integrifolia* (L.f) O.Kuntze	Asteraceae	0	8	2	3
Maguru ingware	*Polygonum nepalense* Meisn.	Polygonaceae	0	4	4	3
Nyiramuko	*Rumex steudelii* A. Rich.	Polygonaceae	2	4	2	3
	Local Indicator Plants for Infertile Soil		***Degraded***	***Recovering***	***Restored***	**Average**
Urwiri	*Bromus unioloides* H.B.K	Poaceae	62	38	48	49
Umubobi ntaraza	*Spergula arvensis*	Aizoacea	0	34	36	23
Umucaca	*Cynodon dactylon* L. Pers	Graminae	16	8	10	11
Umuturanyoni	*Conyza bonariensis* (l.) Cronq.	Asteraceae	0	10	4	5
Igihehe	*Botriocline longipes*	Asteraceae	0	8	4	4
Ibirongorero	Unidentified*	*	0	4	6	3
Inyabarasanyi	*Bidens pilosa* L. var. minor (Blume)	Asteraceae	2	6	0	3
Umunigi	Unidentified*	*	0	4	4	3
Absence of native plants	n/a	n/a	18	2	0	7

The table contains the most important indicator plants (those commonly mentioned by farmers)

Farmers had knowledge of 12 and 10 soil macrofauna taxa found in fertile and infertile soils, respectively. Earthworms were the most commonly mentioned macrofauna by farmers, who differentiated them based on colour, size, food type and mobility behaviour. Eight taxa of earthworms from three families were mentioned, with the predominant trophic group being epigeic (7 species) and one endogeic. All earthworm species listed in Table 3.4 were viewed as an indicator of fertile soil resulting from high soil organic matter content. However, the species *Dichogaster itoliensis* was also recognized as an indicator of infertile soils. Farmers described the visible high mobility of *D. itoliensis* when in infertile soil presumably due to lack of soil organic matter to feed on. Conversely, the same earthworm species is not conspicuously mobile and mostly found burrowed in fertile soil with high organic cover, mainly from compost manure and litter. Other macrofauna for fertile soil mentioned were: millipedes, termites, beetles and moth larvae, with their main habitat being soils with either compost or dung added. Ants were mentioned as being an indicator of low quality and in-fertile soils. The absence of soil macrofauna was also recognized as an important indicator of low quality and infertile soils in the degraded landscape.

Table 3.4: Soil macrofauna identified by farmers along the land degradation gradient

Local taxonomy	Taxonomic Group					Presence in Landscape		
	Order/Group	Family/ Subfamily	Genera/Species	Functional Group	Soil Found	*Degraded*	*Recovering*	*Restored*
Iminyorogoto	Oligochaeta (Earthworms)	Acanthodrilidae	*Dichogaster (Dt.) itoliensis*	Epigeic	Fertile/Infertile	+	+	-
			Dichogaster (Dt.) saliens	Epigeic	Fertile	+	+	+
			Dichogaster (Dt.) affinis	Epigeic	Fertile	+	+	-
			Dichogaster (Dt.) bolaui	Epigeic	Fertile	+	+	-
			Dichogaster (Dt.) modiglianii	Epigeic	Fertile	+	+	-
		Eudrilidae	*Stuhlamannia spec nov*	Epigeic	Fertile	-	-	+
			Hyperiodrilus africanus	Epigeic	Fertile	-	+	-
		Ocnerodrilidae	*Nematogenia lacuum*	Endogeic	Fertile	+	+	+
Inyongoro	Diplopoda (Millipedes)	Pachybolidae	*Epibolus pulchripes*	Humivore	Fertile	+	-	-
			Trigoniulus sp	Humivore	Fertile	-	-	+
Imiswa	Isoptera (Termites)	Termitinae/Macrotermitinae	*Odontotermes sp*	G II (FWLG)	Fertile	-	-	+
Ikinyomo	Hymenoptera (Ants)	Formicidae/Dorylinae	*Anoma sp*	Humivore	Infertile	+	-	-
Urutozi	Hymenoptera (Ants)	Formicidae/ Ponerinae	*Euponera sp*	Humivore	Infertile	-	-	+
Inanda	Lepidoptera(Moths)	Noctuidae (turnip moth)	*Agrotis segetum*	Humivore	Fertile	-	-	+
Ibihombogoro	Coleoptera (Beetles)	Scarabaeidae	*Phyllophaga sp*	Humivore	Fertile	-	+	+
Ikivumvuri	Coleoptera (Beetles)	Scarabidae/Aphodiinae	*Aphodius ividus ol*	Scavenger/humivore	Fertile	-	-	+

Key: Functional Group for Earthworms based on classification by (Swift and Bignell, 2001); Food type: F-Fungus growers, W-Wood, L-Litter, G- Grass feeders; Functional Group for Ter-mites and Ants based on classification by (Eggleton et al., 2002), Moths and beetles based on classification by (Lavelle et al., 1992).
Key: '+' symbolizes presence; '-' symbolizes absence.

Further, within each landscape, some indicators were consistent across all three slope locations (downslope, midslope, upslope) while others were more frequently mentioned in some slope locations (Fig. 3.4). In the restored landscape, knowledge of indicator plants and soil colour was consistent across all slope locations, but more midslope farmers mentioned soil texture, crop vigour (p b .001) and amount of post-harvest crop residue (p b .05), than those in other slope locations. On the contrary, a larger proportion of downslope and upslope farmers had knowledge about soil organic matter than midslope farmers (p b .05).

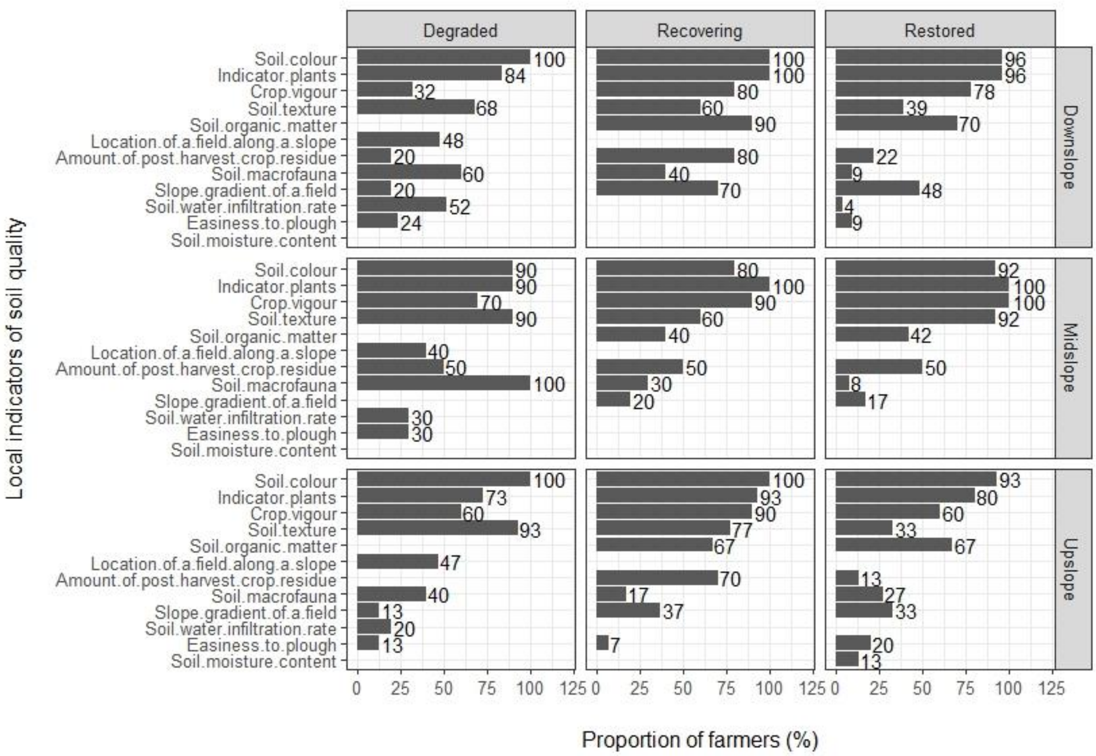

Fig. 3.4. Indicators of soil quality disaggregated by field location along a slope (n = 150).

In the recovering landscape, 10 indicators were consistent across slope, with only soil organic matter and slope gradient of a field being mentioned more frequently by a majority of downslope farmers, than those from other slope locations (p b .001). In the degraded landscape, 10 indicators were consistently mentioned by all farmers along the slope, with the exception of soil macrofauna and crop vigour, which were mentioned by more midslope farmers, but fewer downslope farmers than upslope farmers (p b .05). More male farmers mentioned crop vigour and soil organic matter than female farmers (p b .05) but there were no other significant differences in knowledge of indicators of soil quality according to gender (Fig. 3.5).

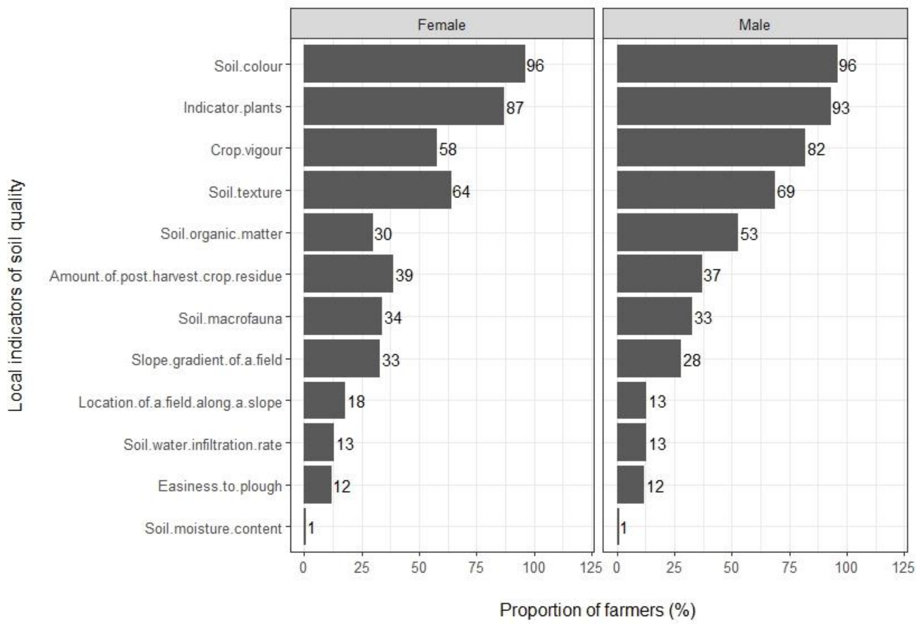

Fig. 3.5. Indicators of soil quality disaggregated gender (n = 150).

3.3.3. Predominant soil management practices

The most commonly used soil management practices were: composted manure and livestock manure additions, and tree biomass incorporation mainly from *Alnus acuminata*. Farmers explained that these soil management practices had four main goals namely to increase: soil nutrient availability, soil organic matter, and water retention and to decrease soil erodibility rate. Other practices included soil erosion control structures including physical structures namely bench terraces, progressive terraces; and vegetative interventions namely planting of trees and grass strips along contours, often associated with the physical structures.

Plate 3.6: *Alnus acuminata* tree biomass incorporation in the Restored landscape (Gihira, Kadahenda), Rwanda

All seven generic types of soil management practice were employed at the field level, with two (erosion control structures and trees in crop land) also manifesting at landscape scale (Table 3.5). Indicators of soil quality most influenced by soil management practices were soil colour, soil texture, crop vigour and subsequent yields, size of post-harvest crop residue, soil organic matter and moisture content of soil. Farmers explained that other indicators such as the presence and abundance of indicator plants and soil macrofauna were also influenced through increased nutrients and organic matter content in the soil.

Table 3.5: Linkages between indicators of soil quality, soil management practices, scale and soil management goals.

Soil Management Practice	Spatial Scale		Soil Management Goal				Local Soil Quality Indicator
	Field level	Landscape scale	Increase soil nutrient availability	Increase soil organic matter	Increase soil structural stability	Increase soil water retention	
Compost manure	✓		✓	✓		✓	1,2,3,5,6,7,12
Livestock manure	✓		✓	✓		✓	1,2,3,5,6,7,12
Tree biomass accumulation	✓		✓	✓		✓	1,2,3,4,5,6,7,12
Soil erosion control structures	✓	✓	✓		✓	✓	1,2,3,4,5,6,10,7,11,12
Chemical Fertilizer	✓		✓				2,3,6,7
Crop residue	✓		✓	✓		✓	1,2,3,5,6,7,12
Trees scattered in cropland	✓	✓	✓	✓	✓	✓	2,5,6,7,12

KEY: 1-Soil colour, 2- Indicator plants, 3- Crop vigour, 4-Soil texture, 5-Soil organic matter, 6- Size of post-harvest crop residue, 7- Soil macrofauna, 8- Slope gradient of land, 9-Field location along a slope, 10-Soil drainage capacity, 11- Easiness to plough the soil, 12-Moisture content of soil

Significantly more female farmers used crop residues than male farmers (p b .001) but significantly more male than female farmers a) incorporated tree biomass, mainly *Alnus acuminata* green manure, retained scattered trees on their farms (an agroforestry practice involving planted and/or regenerated trees retained within landscapes for multiple functions including soil erosion control), c) used livestock manure and d) chemical fertilizers (p b .05) (Fig. 3.6).

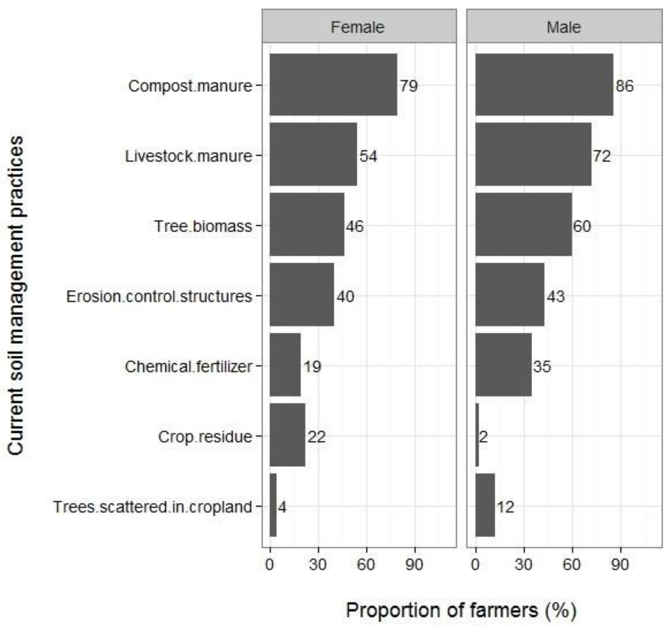

Fig. 3.6. Priority soil management practices disaggregated by gender.

Despite variations in the level of degradation of the three landscapes, there were no significant differences in the number of farmers that used compost manure, livestock manure and chemical fertilizer among the three landscapes (Fig. 3.7). Tree biomass was only used by farmers in the recovering and restored landscapes, but not reported in the de-graded landscape. Similarly, soil erosion control structures were more often used by farmers in the recovering and restored landscapes than in the degraded landscape (p b .001).

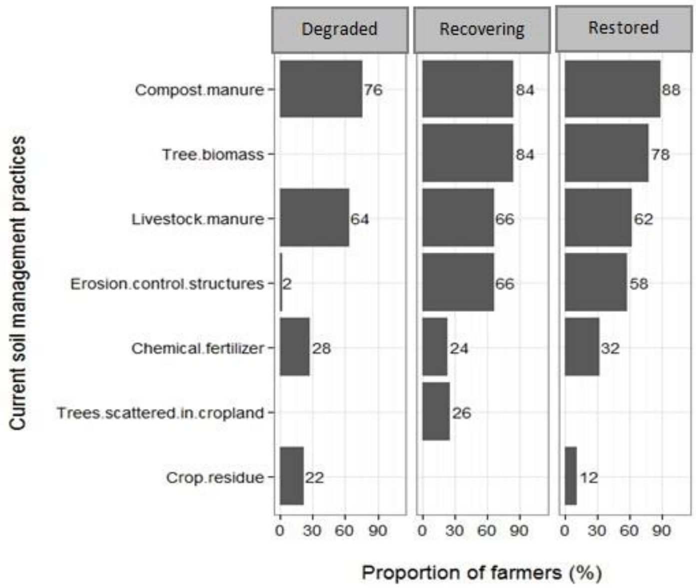

Fig. 3.7. Priority soil management practices along a land degradation gradient.

In the degraded and recovering landscapes, all seven soil management practices were used across all slope locations but only four of the practices: compost manure, tree biomass, soil erosion control structures and crop residues were used across all slope locations in the re-stored landscape (Fig. 3.8). In the restored landscape, livestock manure was mostly used by midslope and downslope farmers than upslope farmers (p b .001).

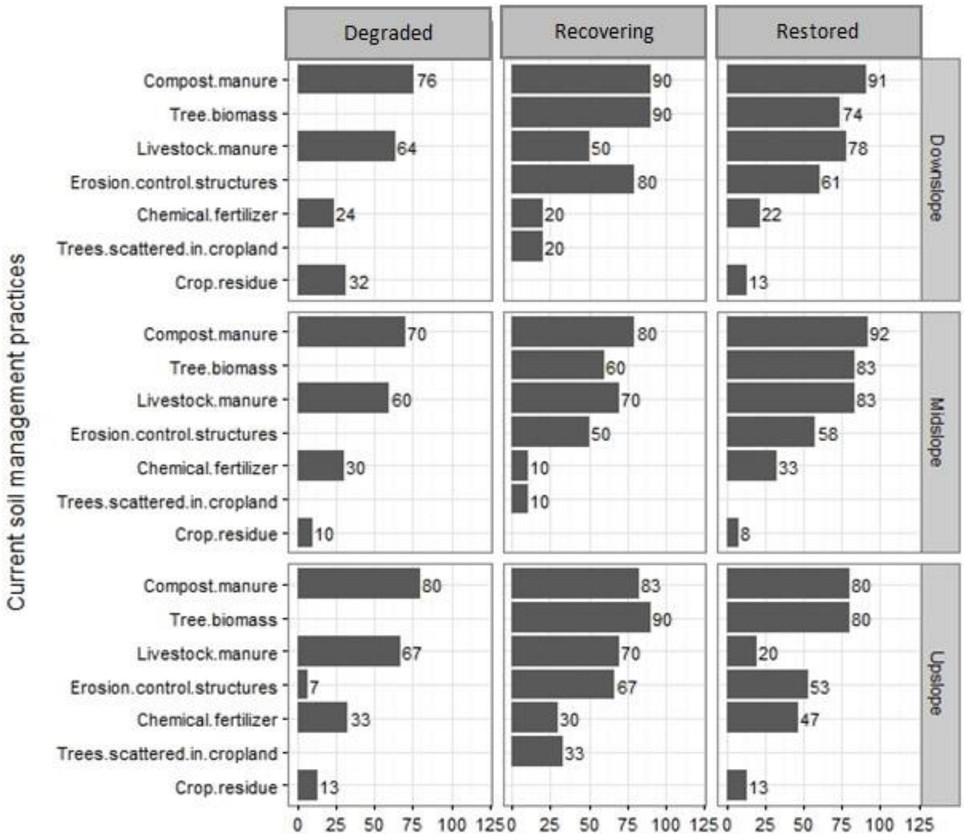

Fig. 3.8. Priority soil management practices by field location along a slope.

3.4. DISCUSSION

3.4.1. Contextual variations in land degradation status

Results from this study demonstrate that soil loss is envisaged by farmers as the most important soil degradation process, and farmers understood that this led to nutrient loss, including the loss of fertile top soil through surface run-off. Farmers from the degraded landscape reported that their soils were mostly rocky and sandy on the midslopes and had high clay deposition downslope, suggesting loss of clay component of the soil, which is also reported by (Dlamini et al., 2014). This knowledge is comparable with other studies (Bryan, 2000; Igwe, 2005) that refer to degradation as the dispersion and loss of clay component of soil and eventual soil aggregate instability over time, mainly from water erosion.

Boix-Fayos et al., (2001) further note that loss of the aggregate inorganic and organic cementing agents leads to the destabilisation of soil aggregates leading to soil loss. On the contrary, farmers in the recovering and restored landscapes reported stable soils with minimal soil loss or deposition, suggesting a more stable soil structure.

Farmers' description of soil quality and classification of high and low-quality soils was mainly in relation to physical, biological, chemical and topographic indicators. This knowledge is in line with technical soil classifications (Barbero-Sierra et al., 2016; Gray and Morant, 2003). Of the 12 indicators that farmers identified, those with the highest consistent frequency of mention across the three landscapes namely soil colour, texture, crop vigour, soil macrofauna and indicator plants are robust indicators which have been consistently reported by multiple authors (Barrios et al., 2006; Mairura et al., 2007; Winowiecki et al., 2014b). Furthermore, it is worth noting that farmers did not view indicators of soil quality independent of each other. For example, soil organic matter is recognized as influencing other indicators such as soil colour, presence and abundance of soil macrofauna and indicator plants as reported by (Porazinska et al., 2003).

While some indicators were consistent across all landscapes and slope locations within each landscape, others such as soil organic matter and location of a field along a slope were more important in some landscapes than in others. For example, although Andosols are normally characterized by high humus content (Matsuyama et al., 2012), farmers in the degraded landscape where these soils were found, reported that they were of low quality. This can be attributed to various factors such as farmers not incorporating organic matter such as green biomass or controlling soil and humus loss through surface run-off. This suggests specific soil characteristics brought about by different levels of land degradation and may in fact provide more accurate representation of the current biophysical and socioeconomic context. This is consistent with farmers' knowledge being informed by their context as noted in other research (Dawoe et al., 2012; Engel-Di Mauro, 2003; Pauli et al., 2016).

Local knowledge is dynamic and evolves in response to changing context, through observation and experience, providing a feedback from system changes to knowledge and practice (Joshi et al., 2004a). As seen in the present research this may include observation of changes in soil at landscape scales over long time horizons (Habarurema and Steiner, 1997; Pulido and Bocco, 2003). Bocco and Winklerprins, (2016) argue that people in a similar con-text are dealing with both common and unique pressures resulting in understanding of historical changes in soils and land quality (Ryder, 2003) and complex interconnected concepts about soil processes (Niemeijer and Mazzucato, 2003; Warren et al., 2003). These findings underpin the need to incorporate farmers knowledge (Barrera-Bassols and Zinck, 2003; Barrios and Trejo, 2003) which often complements scientific knowledge, in helping to understand the heterogeneity in soil conditions of an intervention area before designing and prescribing soil management interventions (Coe et al., 2014a; Nyssen et al., 2009).

3.4.2. Bio-indicators for the degree of soil degradation

Farmers' knowledge of biological indicators of soil quality namely soil macrofauna, indicator plants, crop vigour and amount of post-harvest crop residue suggest an immediate feedback with regards to the prevailing soil fertility and productivity level of land. Studies have reported that macrofauna are a reliable approach to detecting agroecological changes associated with human activities, including extreme habitat disturbance (Andersen et al., 2002; Luke et al., 2014). The absence of indicator plants and macrofauna (in the degraded landscape) signified extremely infertile soils, as mentioned by other authors (Grime et al., 2014). This suggests that biological indicators are a reliable indicator of the extent and degree of land degradation because bare soils signify the absence of essential soil nutrients that support growth.

Farmers had an in-depth and detailed knowledge about how earth-worm types, abundance and behaviour (burrowing and mobility) assisted them in differentiating between fertile and infertile soils. The unusual mobility of *D. itoliensis* on extremely infertile soils noted by farmers has not been reported in any literature and suggests a direct soil quality feedback. Given that *D. itoliensis* is an epigeic earthworm species with horizontal mobility that inhabits the soil litter layer, their conspicuous mobility can be interpreted as particular sensitivity of this species to low organic matter content typical of infertile soils, which encourages their mobility on the soil surface in search of food. This new finding derived from farmers' knowledge, should be further explored to explore how the mobility of some earthworms might be used as a sensitive indicator in soil quality monitoring systems (Barrios et al., 2012b).

3.4.3. Knowledge of soil quality influences crop diversity

Farmers' knowledge of soil taxonomy and understanding of indicators of soil quality and attributes influenced their perceptions and consequent decision-making processes regarding which crops were suitable to be planted on a piece of land. These findings are similar to those reported by other authors (Rushemuka et al., 2014a; Saito et al., 2006; L. Winowiecki et al., 2014b). This can be explained by agricultural productivity being the farmers' primary interest in soils (Ericksen and Ardón, 2003).

However, this scenario also suggests a farmer practice that may potentially become a key impediment to current efforts to increase food production and restore soils whereby over time, some farmers are adapting to perceptions of decreasing soil fertility and gradual soil loss by matching and allocating crops based on the soil nutrient requirement through assessing the status of soil fertility based on the indicators (Gray and Morant, 2003; Osbahr and Allan, 2003), instead of investing in building long-term ecological resilience of the soils, such as through agroforestry and soil and water conservation and restoration interventions. This, in turn, will lead to decreased crop and nutritional diversity because fewer crops are being cultivated as land becomes degraded.

Other studies have reported negative adaptation practices such as full abandonment of marginal land once degradation sets in, thus leading to less food production and food insecurity (Benayas et al., 2007; Geta et al., 2013).

3.4.4. Linkages between local knowledge and practice

The results suggest that farmers' knowledge of soil quality influenced some of their soil management practices. For example, farmers in the restored and recovering landscapes had in depth understanding of the transformation of leaf litter into soil organic matter (Grossman, 2003); while on the contrary, there were no farmers in the degraded landscape that mentioned soil organic matter and consequently none of them incorporated tree biomass into the soil. Also, farmers in the re-covering and restored landscapes had knowledge of the high erodibility rate of Alisols which they noted was made worse by the steep slopes and high rainfall intensity, hence they understood the value of implementing soil erosion control measures such as through bench and progressive terraces, which were promoted by the Government of Rwanda as from 2007. This is consistent with other studies that have reported land management practices being determined by knowledge and perceptions of the soil while other research has shown that farmers may be constrained by social and economic factors in how they apply their knowledge in practice (Barrios and Trejo, 2003; Gobin et al., 2000). Clearly, local knowledge acts on many other actors that determine what soil management practices farmers adopt, including situations were practices such as terracing may be imposed. Structured stakeholder engagement to ascertain what agricultural practices suit different farmers and contexts often identify overarching enabling conditions in respect of markets and policies that are important in determining what can be adopted by farmers (Dumont et al., 2017).

Farmers soil management practices varied along the land degradation gradient. Similar observations have been made elsewhere of different knowledge held by farmers in heterogeneous land conditions and agroecologies (Kumwenda et al., 1996). Furthermore, studies in Rwanda indicate that soil management practices depend on farmer's perception of site-specific land characteristics such as: plot position along the slope and land potential based on other inherent constraints such as soil fertility status, soil texture, water availability and crop diseases (Habarurema and Steiner, 1997; Nabahungu and Visser, 2013).

Tittonell et al., (2005) further observed that planting of crops in fields perceived as having low soil quality took place later on during the cropping season and with sparser crop spacing and less intense soil management compared to fields perceived to be of high fertility level. Moreover, in Rwanda, for severely degraded soil, farmers plant Eucalyptus sp. woodlots on highly degraded and unproductive land for wood products and income (Ndayambaje and Mohren, 2011). Other authors highlight the complexity of other factors such as age and cultural interests (Birmingham, 2003) and land shortage and land fragmentation (Corbeels et al., 2000) as influencing farmers' choice of soil management practices, which eventually leads to farmers abandoning soil fertility management practices such as fallowing, manuring, terracing, and using crop residues. This indicates that soil management interventions are more likely to be adopted where they embrace the holistic nature of farmers management objectives (Adhikari and Hartemink, 2016; Sinclair, 2017) and take account of farmers' knowledge and understanding of soils, which will influence their soil management practices.

3.4.5. Gendered soil knowledge and management

Gender had a significant influence on two out of 12 indicators of soil quality (crop vigour and soil organic matter) and five out of seven soil management practices employed by farmers in Gishwati. These differences are consistent with gender division of labour, since distinctive roles and tasks that men and women play in the society during the cropping cycle (Dah-gbeto and Villamor, 2016; Oudwater and Martin, 2003) and are likely to expose them to different periods of the cropping cycle where some indicators are more evident or important than others. Crossland et al., (2018) reported different spatial assessment of where degradation was occurring in landscapes among men and women in Ethiopia attributed largely to their access and control over different land areas. Other factors that may influence knowledge and management practice are gender- differentiated land-use decisions, land use strategies, preferences and motivations (Christie et al., 2016; Grace B. Villamor et al., 2014a). Other literature (Villamor et al., 2014b) further indicates that men and women's risk taking and access to innovation for land-use decision making may be different. These findings underpin the need for soil management and land restoration options to take gender into consideration when designing soil management interventions.

3.5. CONCLUSIONS

Results from this research show that some locally defined indicators of soil quality are used consistently across landscapes regardless of their degradation status, while others were more important in the more de-graded contexts, highlighting specific soil constraints brought about by different levels of land degradation. Farmers' knowledge of indicators of soil quality influenced their soil management practices, indicating the importance of their utility, alongside other enabling factors, in tailoring soil management and land restoration interventions to contexts. Gender had a significant influence on farmers' knowledge of some indicators of soil quality and soil management practices suggesting that soil and land restoration interventions that recognize gender-sensitive entry points are likely to be more effective than gender-blind approaches. Overall the research shows how combining local and scientific knowledge about soils can help to identify fine-scale contextual differences that could be used to inform the design of soil management options so that they are more appropriate and diverse and hence more likely to be adopted.

CHAPTER 4: INCORPORATING LOCAL KNOWLEDGE PROMOTES ADAPTIVE LAND RESTORATION TECHNOLOGIES THAT DELIVER MULTIPLE ECOSYSTEM SERVICES ACROSS SCALE

ABSTRACT

The increasing global demand to produce more food to support a rapidly growing human population has resulted in adverse ecological effects including land degradation, which threatens the future of smallholder farmers. Although smallholder farming systems are heterogeneous and dynamic, conventional land restoration technologies have focused on promoting few blanket restoration technologies informed by coarse-resolution assessments, rather than customizing technologies to local context. This has resulted in technologies not being locally adapted and effective. We explored the role local knowledge can play in adapting land restoration options to local context and farmer circumstances. Local knowledge was elicited through systematic knowledge-based systems approach (AKT5), on 95 smallholder farmers. Three catchments at different status of restoration were selected through paired catchment design in Samre, Northern Ethiopia. Farmers had an in-depth understanding of land degradation drivers, processes and effects across four scales namely regional, national, landscape and farm level. Farmers viewed land restoration as rehabilitation of already degraded land, and not prevention of degradation of non-degraded land. Farmers reported that some restoration approaches involved conversion of one land-use category to another, which calls for adaptive management approaches. Farmers' knowledge about land degradation and restoration varied with catchment, land-use categories and stakeholder categories. Farmers identified 12 contextual factors that influence the suitability of land restoration options to local context. Biophysical factors were soil erosion type, soil type, soil depth, slope of the field, field location along a slope and field size. Socio-economic factors were: livestock management system, land tenure system, labour, gender, technology and skills. This study also demonstrated that through their own experimentation and observations, farmers utilized their local knowledge to adapt and modify land restoration interventions to suit their needs and context. Hence the acquisition and analysis of local knowledge provides an effective mechanism to track iterative development of adaptation measures and to evaluate both positive and negative consequences resulting from these actions. Combining local and scientific knowledge can help to design, implement and monitor the performance of land restoration technologies to ensure they are locally adaptive, appropriate and effective in delivering multiple ecosystem services for diverse stakeholders at scale.

Key words: local knowledge, land degradation, land restoration, ecosystem services, scale

4.1 INTRODUCTION

The increasing global demand to produce more food to support the rapidly growing human population has resulted in to adverse ecological effects, including land degradation. In sub-Sahara Africa, although drivers of food insecurity are multi-faceted, land degradation has been reported as one of the major causes of food insecurity (Bossio et al., 2010; Capone et al., 2014; Edame et al., 2011). More than 95 million hectares (75%) of arable sub-Sahara African land is considered degraded; and farms lose eight million tons of soil nutrients each year; estimated to be worth $4 billion (Toenniessen et al., 2008).

In Ethiopia, a country where agriculture is the primary occupation for 85% of the population, low agricultural productivity due to land degradation has been reported as the main cause of food insecurity and other effects including poverty and conflicts (Gomiero, 2016; Meshesha et al., 2012; Ramakrishna and Demeke, 2014). This is mainly driven by the loss of ground cover caused by deforestation and uncontrolled free grazing which results in soil loss through soil erosion (Birhanu, 2014; Emiru, 2014; Zeleke and Hurni, 2001). The situation is made worse by prolonged drought resulting from erratic and unreliable rainfall (Haile, 2013; Schmidhuber and Tubiello, 2007). Other drivers of land degradation include continuous and intensive cultivation leading to loss of soil nutrients; and insecurity of land tenure which acts as a disincentive to land management and a catalyst for uncontrolled use of land (Tesfa and Mekuriaw, 2014; Tesfaye et al., 2011).

Since the Derg regime period (1974 and 1991), the government of Ethiopia and other partners have been at the forefront in implementing soil and water conservation interventions across the country (Lemenih et al., 2005; Yirdaw et al., 2017). Soil-water conservation measures such as terracing, stone bunds, contour planting, the establishment of exclosures to restore communal grazing lands, sustainable agricultural practices, among others have been extensively implemented by NGOs, government and local communities (Descheemaeker et al., 2009; Gebremichael et al., 2005). However, despite these numerous initiatives for land restoration and catchment management, land degradation continues to persist (Mekuria et al., 2011; Nyssen et al., 2010).

One of the main reasons for the inappropriate, and unsustainable interventions is the failure to tailor them to variable historical, biophysical, socio-economic and cultural context of smallholder agricultural systems (Beyene et al., 2006; Minang et al., 2014). Vanlauwe et al., (2014) notes that agricultural systems are complex, hence managing the different interactions, actors, land-use types and livelihood needs requires a prior understanding of the intra and inter-system fine-grain heterogeneities. Other studies have found that majority of interventions are designed at coarse resolution and often guided by administrative or watershed boundaries, without considering ecosystem service flow dynamics at scale or taking into account the demand-supply dynamics of the various stakeholders (Pagella and Sinclair, 2014). This leads to inappropriate interventions.

Incorporating local knowledge to has been proven to contribute towards the move from 'top-down' blanket 'best bet' restoration prescriptions to context-specific recommendations that are locally adapted at fine-scale and acceptable (Sinclair and Walker, 1999; Walker and Sinclair, 1998). The recent global call for research to be embedded within development practice has led to the emergence of the 'options by context' approach to research, whereby options are matched to sites and circumstances (Coe et al., 2014a). Recently, local knowledge is receiving global recognition as playing a key role in policy-oriented decision making in both development and conservation initiatives because leads to the design of interventions that are locally adapted (Barrios and Trejo, 2003; Carmona et al., 2013; Ginger, 2014).

The present study was undertaken within the framework of Sustainable Development Goals (SDGs) 15, 2 and 1 (http://www.un.org/sustainabledevelopment/). Specific objectives of the study were threefold namely: 1). To elicit farmers' knowledge on drivers and effects of land degradation, 2). to assess whether land degradation and restoration is defined differently by different stakeholders based on catchment, landuse categories and gender, and 3). to evaluate contextual factors that influence the suitability of land restoration interventions. I had two central hypotheses namely: 1). that local knowledge of land degradation influences understanding of land restoration options, and 2). that the biophysical and socioeconomic context influences the suitability of land restoration options.

4.2. METHODS

4.2.1 Description of Study Sites

This study was carried out in Seharti Samre, one of the four rural woredas in the South-Eastern Zone of Tigray region of Ethiopia. Tigray Region is the Northern-most of Ethiopia; and is bordered by Eritrea to the north, Sudan to the west, the Afar Region to the east, and the Amhara

Region to the south and south-west (Admasu et al., 2011). Samre occupies approximately 1716.74km^2, and falls at 13°11′N and 39°12′E. According to the Central Statistical Agency of Ethiopia census, the woreda has 136767 (125676 in rural & 11091 in urban) population in 2010. The average temperatures fall between 21ºC to 27ºC, while the average annual rainfall ranges between 350mm and 700 mm. The woreda falls within three climatic zones, with 50% of the area falling under the Midland (Weyna-dega), 47% under lowland (Kola) and only 3% is under highland (Dega) and agriculture is the main economic activity.

Table 4.1 below provides characterization of the three study catchments (Relief Society of Tigray (REST), 2015). Endamariam has over 50% of its land classified as gently sloping or sloping while the other catchments have smaller percentage of land under steep slope. Crop fields cover slightly above 50% of total land in Bara and Endamariam, slightly higher than Endagiorgis. Due to the high level of land degradation in Endagiorgis, 44% of its total land area has been put under exclosures; compared to only 18% and 17% of land area in Bara and Endamariam respectively. Bara falls on a lower elevation and has the smallest average household land size (0.44ha) compared to Endamariam (0.5ha while Endagiorgis is 0.75 ha (Plate 3.1).

Table 4.1: Land Characterization for three catchments in Samre, Tigray

	Bara	**%**	**Endagiorgis**	**%**	**Endamariam**	**%**
Slope and Relief						
Flat or Almost Flat (0-3^0)	256	**26**	396	**36**	275	**31**
Gently/ moderately sloped (4-30^0)	202	**21**	200	**18**	193	**22**
Steep slopes (>31^0)	65.5	**6.5**	57	**5**	22	**2.5**
Land Use Category (Total Area (Ha.)						
Crop fields	569	**57**	523	**47**	482	**53**
Exclosures	178	**18**	491	**44**	157	**17**
Forest and bush land	209	**28**	64	**6**	178	**20**
Grazing land	7	**8**	7	**1**	64	**7**
Settlement	44	**4**	25	**2**	33	**4**
Household Characteristics						
Elevation (m.a.s.l)	1833 to 2024		2095-2631		2200 to 2600	
Average land size/HH	0.44ha		0.75ha		0.5ha	
Population	MHH-429, FHH-138		MHH-378, FHH-108		MHH-322, FHH-80	
Population Total	2727		2380		1876	
Major staple crops	Wheat, barley, teff, sorghum		Teff, wheat, barley, beans		Wheat, barley, teff, lentils	

Key: MHH- Male Headed Households, FHH- Female Headed Households
Source: Relief Society of Tigray (REST), Samre (2016)

Plate 4.1: Degraded exclosure in Bara (left) and Restored exclosure in Endamariam (right)

4.2.2. Sampling Strategy

This study adopted a Paired- Catchment experimental design (Brown et al., 2005; Lloyd and Wong, 2008) to capture heterogeneity of three catchments which are undergoing different land restoration trajectories namely Endamariam, Bara and Endagiorgis (Relief Society of Tigray (REST), 2015). Samre is an action site for the ICRAF-led Restoration of degraded land for food security and poverty reduction in East Africa and the Sahel Project, which aims at learning from on-going land restoration interventions that were established by the Drylands Development (DryDev) project; and taking the successes to scale. The DryDev project has implemented land restoration technologies in both crop field and exclosure land-use categories. Restoration activities in Endamariam were established in 2012 while in Endagiorgis and Bara were established in 2016.

Various land restoration technologies were implemented by the DryDev project in Samre. In the exclosures, structural restoration technologies were bench terraces, stone bunds, deep trenches, percolation channels, percolation ponds, large half- moon basins, eye-brow basins, micro-basins, and gabion check-dams. Biological interventions included: gully bank restoration through planting of vegetation cover, tree planting and apiculture. In the cropland, structural technologies were: deep trenches, stone bunds, soil bunds, bench terraces, and moisture retention micro-basins. Biological technologies were: Farmer Managed Natural Regeneration (FMNR), tree planting, gully bank restoration through planting of vegetation cover.

Within each catchment, stratified random sampling technique (Mugenda and Mugenda, 1999) was applied to select informants based mainly on location of crop-fields along a slope and gender. A total of 95 farmers were interviewed though Focus Group Discussion (55 farmers) and individual interviews (30 farmers) (Table 4.2). Figure 4.1 shows study sites and dots show crop fields sampled during individual interviews.

Table 4.2: Sample size of farmers interviewed

	FGD		Individual Farmer Interviews	
Catchment	Male	Female	Male	Female
Bara sub-catchment (Maytekli)	15	10	6	4
Endagiorgis sub-catchment (Waza)	13	5	5	5
Endamariam sub-catchment (Waza)	7	5	6	4
Total	**35**	**20**	**17**	**13**

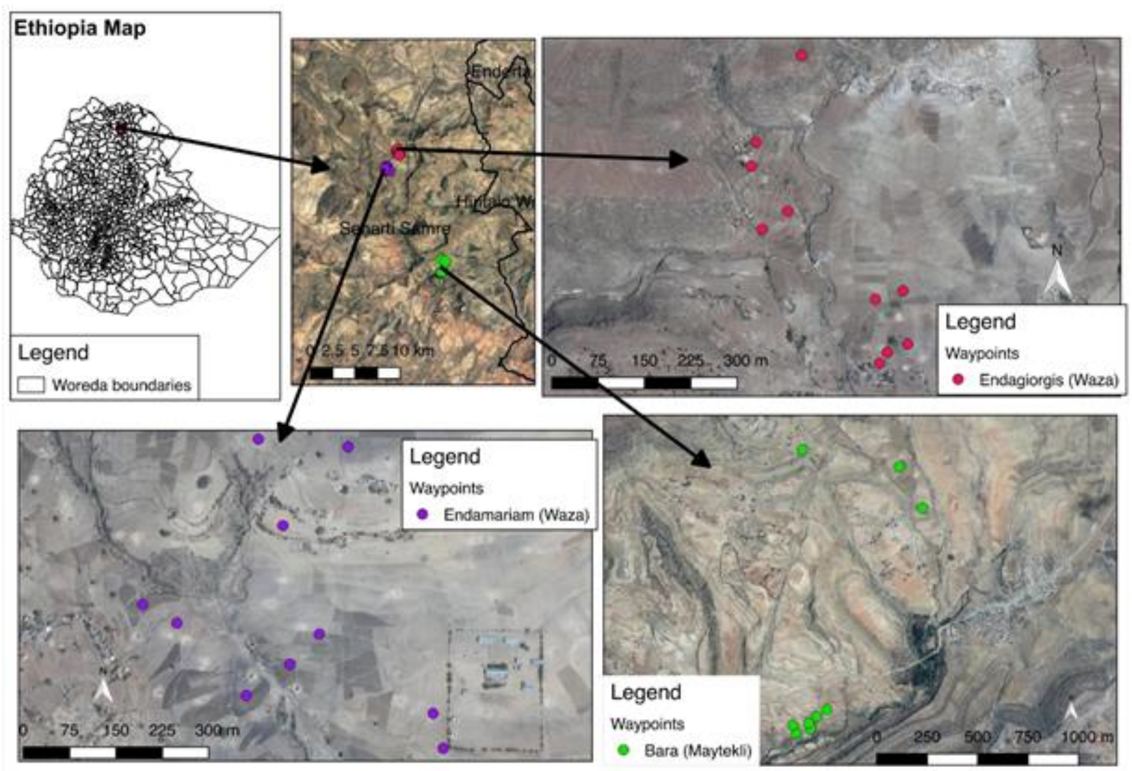

Figure 4.1: Map of Samre study catchment sites, Tigray, Northern Ethiopia

4.2.3 Data Collection and Analysis Methodology

Local knowledge was elicited by using knowledge-based methodology, the Agro-ecological Knowledge Toolkit (AKT5) and methodological framework (Sinclair and Walker, 1998; Walker and Sinclair, 1998). The knowledge collected was represented using the AKT5 software (Dixon et al., 2001). The process entailed three stages namely: scoping, definition and compilation. The scoping stage activities included participatory transect walks to understand the local biophysical and socio-economic context. This exercise informed the stratification criteria. Key Informant Interviews were held with local partners namely natural resource management, crop, livestock and water development agents from Relief Society of Tigray (REST), and Bureau of Agriculture and Rural Development (BOARD), and the local administration. Six Focus Group Discussions were then held with farmers from the 3 catchments (Plate 4.2). This was guided by a set of semi-structured questions aimed to elicit in-depth knowledge about the study area.

The definition stage involved defining knowledge boundaries, and stratification parameters. This involved selection of 10 farmers from each of the three catchments, who are implementing the various land restoration interventions on their farms, stratified mainly according to slope location and gender.

Plate 4.2: Male farmers identifying soil erosion hotspot during an FGD in Bara, Samre, Northern Ethiopia

The compilation stage involved an iterative process whereby knowledge elicited from individual farmers on land degradation and restoration was recorded systematically using the AKT5 software (Plate 4.3). The knowledge was assessed for consistency and where apparent gaps were revealed, repeated visits were made to the same farmers to probe further. This process was repeated until no new information was obtained from further discussion with respondents. Once the study was complete, feed-back sessions were held with the farmers in groups, whose aim was to share with farmers the findings of the research and capture any misunderstood or omitted knowledge.

Plate 4.3: Individual household interviews

At the end of the study, feedback sessions (Plate 4.4) were held with farmers with the aim of thanking them for their valuable time and knowledge shared, sharing with them the findings in order to assess whether the knowledge was captured correctly, and whether there was additional information that had been left out.

Plate 4.4: Feedback sessions with farmers in Endagiorgis sub-watershed, Samre

4.3 RESULTS

4.3.1: Local drivers and effects of land degradation

Farmers demonstrated having an in-depth understanding of land degradation drivers, processes and effects across four scales namely regional, national, landscape and farm level (Figure 4.2). Farmers identified both external drivers (those emanating from outside their catchment namely at regional and national levels) and internal drivers (those directly generated from inside their catchment). Two regional drivers (war between Eritrea and Ethiopia and Orthodox religion) and three national drivers (national war, communal land tenure policy and land redistribution policy) were identified, with farmers linking them to eight internal drivers. For example, war was identified at both the regional and national levels, and besides both wars resulting into three common effects namely social unrest, uncontrolled deforestation uncontrolled grazing), internal war resulted into the disruption of extension services hence poor enforcement and knowledge of soil and water conservation technologies, which was a key driver to land degradation.

According to farmers, some internal drivers had more widespread implications than others. For example, deforestation was highlighted as a major internal driver of land degradation, which according to farmers, was caused by three external and two internal drivers (Figure 4.2). Deforestation in return has led to the loss of numerous ecosystem services at the landscape scale and farm level, which researchers classified as six ecological functions namely climate regulation, erosion regulation, natural hazard regulation, nutrient regulation, water quality regulation and water quantity regulation and two cultural ecosystem services namely loss of aesthetic value and intrinsic cultural value. Plate 3.5 shows gully erosion. Soil loss through erosion was mentioned as an important direct cause of land degradation and was associated with lack of appropriate soil and water conservation interventions, continuous and intensive cultivation and deforestation. At the farm level, farmers mentioned loss of provisioning ecosystem services namely decrease in: crop yields, honey production, tree products and water, which led to decreased livelihood benefits.

Plate 4.5: Gully erosion in Endagiorgis

Farmers also observed that land degradation had resulted in indirect adverse system feedbacks that occurred as a result of disruptions on system functionality. For example, farmers observed that because of decreased availability of fuelwood, they used livestock dung for fuel, thereby decreasing its availability as manure for soil improvement (Figure 4.2). Due to scarcity of products such as fodder, firewood and water locally, farmers travelled long distances to neighboring areas in search for them. This took away their time from engaging in productive livelihood activities such as farming and soil and water conservation. Due to decreased crop yields, there was increased rate of outmigration of the Samre youth population to neighboring towns such as Mekelle in search of jobs to meet their household basic and food needs.

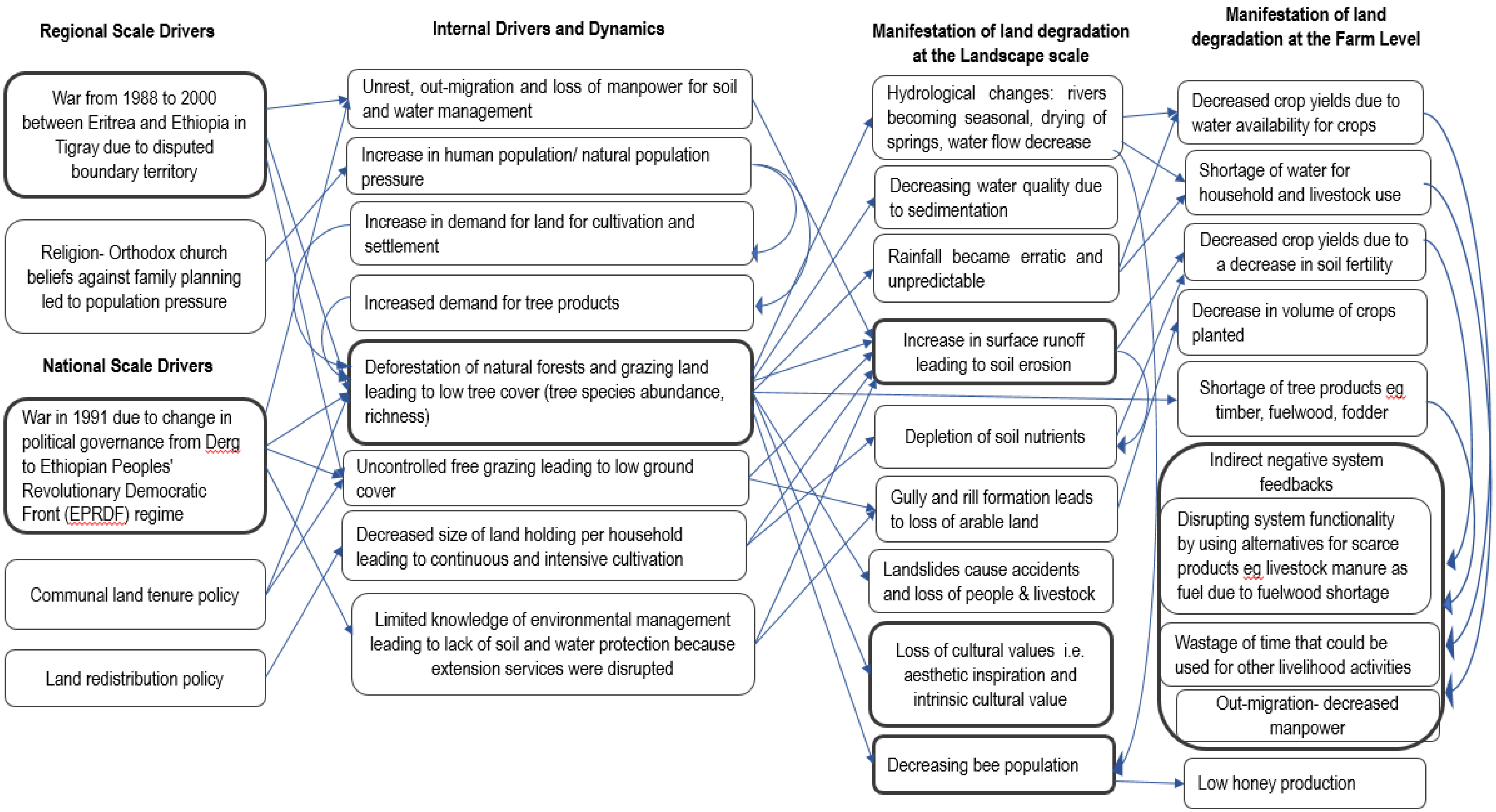

Figure 4.2: Local knowledge on drivers and effects of land degradation
Key: Bold nodes represent significant observations

4.3.2 Stakeholders' perceptions of land degradation and restoration

This study also sought to understand how the various stakeholders, classified into three categories namely: farmers from the different catchments, farmers benefiting from restoration of the various land-use categories, and gender (men, women, landless), view land degradation and restoration. Results indicate that there was common and unique knowledge amongst stakeholders in each category. The following three sub-sections presents results for each of the categories.

Common knowledge across all catchments included: farmers described land degradation based on its primary effects namely: decreasing crop productivity, water availability, vegetation cover and shortage of products (Table 4.3). Secondly, farmers in all catchments viewed land degradation at the landscape scale, noting that land degradation began in the upslope landscapes, which mostly comprised of land previously utilized for grazing. This was blamed on low or absent ground cover upslope as a result of uncontrolled overgrazing of livestock, resulting in high rate of surface run-off downstream that led to significant soil loss. Farmers noted that the rate of surface runoff was severe because of the steep slope inclination in their landscapes. Most land in all catchments is sloped, with 75%, 70% and 64% of land in Bara, Endamariam and Endagiorgis respectively being classified as gently sloped (4^0 – 30^0) to steep sloped (>31^0). A more detailed classification by Relief Society of Tigray is presented in Table 4.1 of Methods Chapter.

Table 4.3: Farmers description of land degradation disaggregated by catchments

	Local description of land degradation	Catchment		
		Bara	Endagiorgis	Endamariam
1.	Decreasing crop productivity due to loss of fertile top soil through water erosion	x	x	x
2.	Water scarcity due to lack of water harvesting for supply all year round	x	x	x
3.	Loss of vegetation cover eg trees and grasses, both in diversity and abundance	x	x	x
4.	Land degradation begins upslope due to surface runoff on bare soils	x	x	x
5.	Landscapes with gullies and landslides are a hazard to livestock and children through accidents and mobility	x	x	
6.	Crops being washed away by rain water leads to reduced yields	x	x	
7.	Loss of arable land through gullies leads to lower volume of crops planted		x	x
8.	Land with no soil organisms is degraded	x		
9.	Poor water quality due to siltation	x		
10.	Decreasing productivity due to loss of fertile top soil through wind erosion		x	
11.	Land degradation is “seasonal” and more pronounced in the dry or wet periods because it is when extreme effects of drought and rain respectively are experienced		x	
12.	Bare land with no grass signifies degraded land		x	
13.	Landscape without bees is degraded as it signifies lack of food and water to feed the bees		x	
14.	Soil that is hard, compact and retains low moisture during dry season is degraded		x	
15.	The local landscape is not homogeneous- you cannot define an entire landscape as degraded- the degree and nature of degradation differs eg gully, sheet erosion,			x

Some local knowledge was unique to specific catchments. For example, in Endagiorgis and Bara catchments where restoration interventions are most recent (2016) compared to Endamariam (2012), farmers highlighted indicators that were indicative that the landscapes have not fully recovered from land degradation processes. These included: wind erosion due to bare ground, and absence of biodiversity such as bees and soil macrofauna, which was blamed on the absence of vegetation cover and bare infertile soils respectively. Farmers in the two landscapes where the dominant soil type is luvisols (*Mekeyih* in Tigrinya language) also noted that it is highly erodible, hence their landscapes were still experiencing soil loss through erosion due to absence of ground cover. This was not reported in Endamariam landscape whose dominant soil type is cambisols (*Baekel* in Tigrinya language).

Knowledge unique to only one catchment included: in Bara, farmers further observed that due to heavy siltation, river water has become polluted and its quality lowered especially for domestic consumption. Farmers in Endagiorgis observed that land degradation was seasonal due to extreme effects they experienced during the rainy and dry seasons and not in other times. Farmers mentioned that during the rainy season, extremely heavy rains result in severe surface run off and other damages including crops being swept away and formation of deep gullies. During the dry season, farmers experience extreme conditions such as drought and scarcity of products eg fodder, water and food. However, during periods between these seasons, some farmers did not perceive their landscape as being degraded because they did not observe the extreme negative effects. In Endamariam, a landscape with relatively older land restoration interventions (2012), farmers referred to the heterogeneous nature of land degradation, observing that for example there are some areas especially in exclosures where vegetation has regenerated fully and thus they were already receiving benefits such as fodder, native tree regeneration and ground water recharge compared to other areas of the landscape such as those that had gullies that were still under rehabilitation, farmers felt such areas were not fully restored.

This study also sought to understand farmers' local understanding of the dynamics involved in land restoration activities (examples shown in Plate 4.6 and Plate 4.7), under different land uses categories that the DryDev project was implementing across all landscapes. This research focuses on two landuse categories namely crop fields and exclosures, where the DryDev project implemented similar land restoration interventions across the three catchments.

Plate 4.6: Deep trenches and *Sesbania sesban* in Bara

Plate 4.7 Recovering exclosures with stone bunds

The size of the various land use categories varies in each catchment as presented in the Methods Chapter (Table 4.1). For example, Endagiorgis had the highest percentage of total land (44%) converted to exclosures and only 47% of its land was under crop fields compared to the other catchments. Through the DryDev project, farmers were sensitized on the different forms of land restoration approaches. Farmers highlighted three restoration processes that involved the conversion of some land-use categories whose value has been diminished through land degradation to other beneficial uses. This is mainly through employing different restoration and management activities to derive currently valued and relevant ecosystem service benefits. Farmers observed that some forms of conversion involved either gaining or losing some landscape or functions. Table 4.4 presents farmers' understanding of the conversion activities taking place.

Table 4.4: Local knowledge of dynamics associated with conversion of land-use categories as an approach to land restoration

A. Conversion of degraded Grazing land into Exclosures

1. Exclosures are severely degraded grazing areas that are set aside with the aim of rehabilitating the landscape to achieve 3 goals namely: controlling soil loss through surface runoff control and trapping sediments, ground water recharge and increasing regeneration of vegetation such as grasses and trees.
2. This also involves changing grazing system from free grazing to cut and carry system of fodder
3. Grazing lands are mostly located upslope on steep slope inclinations while their crop-fields are mostly located at the lower lying flat downslope areas. Hence according to farmers, restoration activities should begin upslope in exclosures then proceed to low-lying areas to reduce the amount and speed of surface runoff into downslope cropland
4. Electing and building the capacity of local catchment committees to oversee everyday maintenance of the exclosures is an important step to ensuring ownership and sustainability of the restoration interventions
5. Regular participatory monitoring of the performance of exclosures is paramount. Farmers in Endamariam, where restoration activities began in 2012 observed that participatory monitoring of the technologies leads to learning from what is working in which context and adapting or modifying less effective interventions to suit context
6. Benefits such as fodder are shared equally amongst all farmers, including the landless farmers
7. In addition, landless farmers engage in apiculture for income generation, which is shared equally

B. Conversion of rehabilitated exclosures to cropland

1. It involved conversion of previously restored exclosures in steep slopes into arable land through construction of bench terraces to create a flat surface area for growing of crops
2. Beneficiaries of the converted landuse category was landless farmers and youths and crops grown are mainly income oriented, hence the activities and type of crops to grow is determined by the village committee eg growing of fruits and vegetables and not the farmers
3. Collective action is utilized to construct the bench terraces
4. Farmers are required to maintain the existing structures and undertake farming collectively
5. Activities in this landuse category eg fruit and vegetable production were supported by water harvested in check dams

C. Gully rehabilitation and conversion into check dams

1. This involves the rehabilitation of gullies occurring in cropfields and grazing lands and constructing downstream check dams for water harvesting
2. Electing and building capacity of catchment committee and all farmers to oversee everyday maintenance of the gully rehabilitation including watering of vegetation along gully banks ensured success of the intervention
3. Building capacity of all farmers to participate in the daily maintenance of gully rehabilitation and check-dam promoted a feeling of ownership of the intervention by all farmers in the area
4. Harvested water was shared equitably amongst downslope and upslope farmers
5. Farmers in Bara and Endagiorgis noted that lack of adequate water harvesting structures led to water unavailability throughout the year

For example, restoration of degraded grazing-lands involved converting them into exclosures and changing various aspects such as: the primary function of the exclosures changed from grazing land to excluded areas of natural vegetation regeneration for ground water recharge, provision of fodder and control of soil erosion. Livestock management changed from farmers having uncontrolled free-grazing to controlled ‘cut and carry’ system, which reduced fodder availability while the management changed from communal all-access to management by catchment committee only. Secondly, once the exclosures are fully restored and soil erosion controlled, the second form of transformation involved converting some of the exclosures into cropland, which landless farmers utilize to grow crops, mostly fruits and vegetables. This conversion occurs in areas that already have significant soil level build up which makes shaping of bench terraces possible. Thirdly, rehabilitation of gullies results into not only soil erosion control of erosion but also water harvesting at various points downstream along the gully.

There was common and unique values and indicators attached to a restored landscape between male and female farmers and landless farmers. All farmers, men, women and landless valued food security (Plate 4.8), improved ecological resilience and social cohesion including increased awareness amongst all farmers to ensure effective and sustainable implementation of the restoration interventions. However, in different locations, farmers had different preferences and values as highlighted in Table 4.5.

Plate 4.8.: Woman farmer in Endagiorgis harvesting vegetables grown through irrigation

Table 4.5: Gender-specific preferences, values and indicators for successful restoration interventions

Indicator or value of restoration	Gender		
	Men	Women	Landless
1. Land restoration means rehabilitating degraded land to be able to sustain household food security needs through increased crop yields	x	x	x
2. Having equitable, adequate, continuous supply of communal resources eg water, fodder and ensuring equitable benefit sharing	x	x	x
3. Controlled soil loss through having appropriate erosion control technologies at the right location and context	x	x	
4. Holistic community sensitization of both 'project' and 'non-project' farmers and collective action to ensure restoration efforts are done with a 'landscape' approach e.g. upslope farmers to control soil erosion	x	x	
5. Increased crop yields generate income from sale of crops and vegetables, hence not looking for supplementary livelihood strategies including out-migration, selling livestock, tree products	x		
6. Rehabilitated gullies ensure safety to livestock from accidents	x		
7. Ground water recharge for irrigation of crops	x		
8. Increase in the number of bees for honey for household use and income	x		
9. Cultural benefits- aesthetic value of landscape	x		
10. Natural vegetation regeneration in exclosures for provisioning services especially grass for livestock fodder	x		
11. Rehabilitated gullies ensure safe mobility to school-going children and community members		x	
12. Availability of firewood hence less use of cow-dung 'kubet' as fuel for cooking)		x	
13. Availability of water for domestic use to avoid walking for long distances in search of water and firewood		x	
14. Improved nutrition for children hence decreased disease prevalence for children		x	
15. Improved performance of children in school and reduced incidents of school abandonment- children missing school to look after livestock over long distances		x	
16. Increased income as a result of improved food production in rented fields, and increased availability of paid labour opportunities leading to food security and outmigration to towns			x

Values and preferences unique to men were mostly income-oriented namely increased yields to guarantee sale of surplus food crops, vegetables and fruits for income, access to water for irrigation of crops for income and sale of honey. Other benefits involved livestock (access to fodder and prevention of livestock accidents due to gullies) while cultural values were aesthetic value and cultural values, especially derived from exclosures. On the other hand, women mostly talked about and valued a wide range of and indirect family well-being benefits from land restoration including enhanced health, safety, education, and knock-on effects eg saving of time and using the right resources for the right purpose. Landless farmers viewed land restoration in terms of benefitting from communal areas and vied land restoration as resulting into increased labour demand, a critical service which they relied on for their livelihoods.

4.3.3 Local knowledge on contextual factors influencing suitability of restoration options

This research also sought to understand contextual factors that influence the suitability of the various land restoration technologies that farmers in Samre are implementing. Results for this study focuses on six technologies which were implemented in both crop fields and exclosures across the three catchments. Majority of the interventions were introduced by the DryDev project and the project also sensitized farmers on their purpose and functions. However, stone bunds had been introduced by the government of Ethiopia in the 1990s, while tree planting has been an ongoing practice, but mostly comprising of promotion of fruit and timber trees in the home compound landuse category.

Farmers identified 11 contextual factors, that is six biophysical and six socio-economic factors that influenced the suitability and success of land restoration options, illustrated in the Options by Context Matrices presented in Table 4.6 and 4.7. Results presented in Table 4.6 illustrate biophysical factors that farmers mentioned namely soil erosion type and extent of land degradation, soil type, soil depth, slope gradient of field, location of field along a slope and field size. Farmers demonstrated an understanding of the functions and purpose of the various land restoration interventions. For example, the role of deep trenches was to control soil erosion through intercepting soil and retaining water, while that of stone bunds is to control surface runoff and trap sediments and convert steep slopes into flat arable land

Table 4.6: Options by Context Matrix on Biophysical contextual factors that influence suitability of land restoration options

Land Restoration Option	Degradation/Erosion type	Soil (Type/ Depth)	Slope (gradient, location)	Field Size
Deep Trenches Trap and retain water and intercept soil and sediments	Suitable for areas experiencing surface sun-off and sheet erosion	Suited for well-drained and deep soils but unsuitable for clay soils If on clay soils, farmers modify them through digging drainage channels	Suitable for flat or gentle slopes in order to retain water and works effectively at the base of the slope because this location is where soil carried downslope is intercepted	Are not preferred by farmers with small farm sizes eg <0.5ha because it occupies a lot of space. Interested farmers with small farm modify them by digging narrower and smaller trenches, <(2x0.5x0.5)m
Stone bunds Control surface runoff and trap sediments and convert steep slopes into flat arable land	Suitable for sheet and rill erosion as they require a relatively flat surface area but unsuited for gullies	Suitable for shallow soils, rocky soils or areas with no top soil because it uses stones and gravel placed across the land, where intercepted soil builds up on top of the stone bunds.	Farmers observed that it should be constructed across steep slopes and especially suited to upslope and midslope positions to reduce the speed of runoff downslope and trap soil	Preferred for all farm sizes as stones are arranged vertically hence minimal arable space is lost, and farmers regain more land for cultivation especially on steep slopes
Soil bunds Control speed of surface runoff and trap sediments	Suitable for sheet and rill erosion because they require a relatively flat surface area but unsuited for gullies	Suitable for deep and moderately deep soils because they are made of raised soil excavated from the lower and upper side of the contour. Farmers modify by planting grass or trees to stabilize the soil bunds and intercept more soil	Farmers observed that it should be constructed across steep slopes and especially suited to upslope and midslope positions to reduce the speed of runoff downslope and trap soil	Mostly preferred by farmers with large farm sizes because they take up space. However, farmers with small farms who adopt them plant fodder, trees and even crops on top of the bunds to maximumly utilize their land
Moisture Retention Micro basins Intercept and retain water and soil moisture	Suitable for sheet and rill erosion because they require a relatively flat surface area	Suitable for deep soils for the excavated basins to retain moisture. Are suited for all except clay soils due to water-logging. On clay soils, farmers modify by digging drainage channels	Suitable for all slope locations because it depends on the targeted location of crops or trees being planted	Suitable for all field sizes as trees or crops are planted inside the basin hence no wastage of space
Gully Rehabilitation with gabion checkdams Reduce surface run-off, enhance sediment deposition	Suitable for areas with gully erosion but unsuitable for rill and sheet erosion	Suitable for all soil types. However, for more effective gully bank stabilization, it requires vegetative treatment eg through planting grasses, bamboo	The location of the intervention depends on the position of the gully. Gabion check-dams should be built at various locations across the gully to harvest water, reduce run-off and trap soil sediments	Gully rehabilitation area depends on the size of the gully, and most gullies cut across the landscape, across multiple farms

Tree planting Multiple products and ecological benefits including soil erosion control	Suitable for all erosion types because they help to control soil erosion	Suitable for moderately deep and well-drained soils to allow for root establishment and support of the tree.	Suitable for slope locations and gradients because the planting location and alignment depends on the purpose of the tree	Farmers with small field sizes preferred trees that occupy less space eg *Sesbania sesban*, while others did not plant trees due to their permanent nature as they prefer rotational crops on small farms

Through own observations and experimentation, farmers reported using their own local knowledge to modify and adapt some of the interventions to suit the local biophysical context. Technologies modified were mainly deep trenches, soil bunds and moisture retention micro-basins, which farmers modified to suit soil types and farm sizes, while in some context, farmers added vegetative cover to support structural technologies. For example, where a farmers' field had clay soils, but they were interested in controlling soil erosion, they implemented deep trenches but modified the trenches through constructing channels to drain the excess water that would accumulate outside the trenches and destroy adjacent crops due to water logging. Farmers who had small farm sizes (less than 0.5ha) but chose to implement deep trenches would modify the recommended size by the DryDev project of 2m by 0.5m by 0.5m into a smaller size depending on their preference.

Table 4.7 illustrates farmers' local knowledge of six socio-economic factors that influenced the suitability of restoration interventions namely: livestock management system, land tenure system, labour and gender, technology and skills. For example, lack of knowledge and skills limited the adoption of some technologies, especially for those that required intensive technical knowledge such as deep trenches and moisture retention basins. Farmers reported lacking skills in tree propagation and management and had limited knowledge of ecological uses of tree species especially soil fertility improvement. Older farmers (>60 years) were not interested in planting trees because they perceived that trees took long time to mature. Free-grazing was also named as a serious problem in all three catchments (Plate 4.9), with farmers noting its incompatibility with most technologies, both structural/ physical and vegetative. The situation was made worse because individual crop fields were not fenced, hence free grazing was a persistent landscape constraint.

Plate 4.9: Free grazing of livestock, which leads to browsing of tree seedlings by livestock

Landless farmers reported that insecurity of tenure limited their uptake of technologies that were viewed as permanent such as stone bunds, trees and soil bunds on the land they rented for growing crops. Conversely, the prevailing communal land tenure and communal labour in Ethiopia was an enabling factor in the implementation of interventions that required collective action and whose implementation design cut across many farms within the landscape such as gully rehabilitation. All technologies had different labour requirements at different stages of their implementation, with some for example deep trenches not being widely adopted by female farmers because their initial construction was viewed as being labour intensive.

Farmers mentioned that lack of inputs such as farm equipment and tools for implementing physical structures such as deep trenches, moisture retention micro-basins, gully rehabilitation and soil bunds, and the lack of water storage tanks was an impediment to successful adoption of technologies as they relied on the implementing projects to supply such inputs. Further, there was widespread lack of quality tree germplasm, while inadequate water harvesting, and storage structures led to water shortage during the dry season, which discouraged scaling the adoption of tree planting amongst farmers.

Table 4.7: Options by Context Matrix on socio-economic contextual factors that influence suitability of land restoration options

Restoration Option	Livestock Management System	Land Tenure	Labour/ Gender	Inputs/ Technology	Enabling environment/skills
Deep Trenches	Unsuitable for areas where free-grazing is rampant due to potential livestock accidents	Suitable for all farmers including those who own or rent land because they are temporary	Initial excavation of the trenches is labour intensive hence not preferred by women	Lack of tools/ equipment especially for poor households.	Unsuited for farmers with no technical skills on its construction especially non-project farmers who received no training
Stone bunds	Suitable to all including free grazing because they are structural in nature	Unsuitable for farmers who rent land because the bunds are permanent and alter the landscape	It is labour intensive especially during initial establishment, but the activity is preferred across all gender because family/ children labour is utilized	Suitable for areas where stones and gravel are locally available because the main raw material is stones and gravel.	Easy to observe and replicate hence majority of farmers are able to implement it even without prior training
Soil bunds	Unsuitable for free grazing during establishment due to livestock trampling	Unsuitable for farmers who rent land because the bunds are permanent and alter the landscape gradually through gradual soil build up	Initial establishment is moderately labour intensive but easy to implement even by women. Labour requirement for management is minimal	Soil excavation equipment are locally available and utilized in other farming activities	Easy to observe and replicate because it involves excavation of soil from upper and lower sides of the slope which is easily achieved.
Moisture Retention Micro Basins	All including free grazing because they are not too deep to cause livestock accidents	Semi-permanent- suitable for private and rented land	Initial establishment is labour intensive especially for women. Easy to manage.	Easy to excavate with the normal hoe and basic equipment	Requires skills on depth and diameter and where to locate trees/ crops and other management practices
Gully Rehabilitation	Unsuitable for free-grazing areas because livestock trample on and destroy gully banks and browse on regenerating vegetation	Gullies cuts across fields and depends on the extent of gully. Communal land ownership in Ethiopia makes implementation easy	In Ethiopia, communities utilize communal labour, hence this is easily implemented, especially in the context of the 'food-for-work' incentive programme.	Requires highly specialized equipment. Type of check-dam depends on available materials eg stones	Requires intensive training and understanding of for gully stabilization and check-dam construction
Tree planting	Unsuitable for free-grazing areas due to browsing of trees by livestock. Tree protection at initial stages of establishment enhances survival	Unsuitable for farmers who have rested or borrowed land due to the permanent nature of trees, and conflicts in tree ownership rights	Tree establishment and management is relatively less labour intensive. However, farmers who own more than one piece of field accord less attention to trees in fields away from their homestead	Lack of quality germplasm and water discourages hinder farmers from tree planting	Lack of skills on tree propagation, management and some benefits of trees in the cropland especially ecological benefits eg soil fertility improvement discourages farmers from planting

4.4. DISCUSSION

4.4.1: The role of local knowledge in understanding land degradation at scale

Farmers' definition and description of land degradation reported in Figure 2 of results is consistent with globally accepted definitions, which define it as a long-term decline in ecosystem functions and productivity (Zhanguo G Bai et al., 2008; Shepherd et al., 2015). Farmers' knowledge of physical factors that influence land degradation such as slope inclination and soil texture have also been reported (Bednář and Šarapatka, 2018; Cerretelli et al., 2018). Results in Figure 1 further show that local knowledge not only provided a description of land degradation processes at the farm and landscape scales but also highlighted the complex interactions between different drivers at the regional and national scales (Ravi et al., 2010; Suding et al., 2004). Majority of single studies do not systematically and adequately capture land degradation dynamics (drivers, processes, effects) across all possible scales (Reed et al., 2011; Vogt et al., 2011).

Other authors have looked at land degradation from a single perspective such as the biophysical perspective usually at the coarse global or landscape scale through approaches such as modeling, without linking it to historical, socio-economic and political context (Veldkamp and Lambin, 2001). This leads to fragmented and piece-meal understanding of local context which translates to inappropriate and disconnected interventions (Basupi et al., 2017; Ramirez-Gomez et al., 2015). Therefore, understanding the complex system interactions of drivers across scales from the local perspective of resource users is critical in identifying holistic land locally appropriate entry points for land restoration (Lambin et al., 2003; Pagella and Sinclair, 2014).

This research also unearthed the indirect adverse system feedbacks that occurred as a result of the disruption of system functionality due to land degradation, such as farmers resulting to using livestock dung as fuel instead of using it for soil fertility replenishment or using time that could have been put towards more productive activities such as crop production to look for scarce resources such as fodder and water. These effects are rarely captured, as researchers mostly focus on the direct provisioning or ecological effects of land degradation (Tarrasón et al., 2016). Therefore, local knowledge provides complementary knowledge to scientific understanding of the wider 'systems' context of land degradation on farming landscapes.

Some knowledge gaps were identified from interactions with farmers. Throughout the study, it was apparent that farmers viewed land restoration as rehabilitation of already degraded land, and not prevention of degradation of non-degraded land. If Land Degradation Neutrality (LDN) is to be achieved, there is need to sensitize farmers on the need to protect non-degraded areas, and not wait until land is degraded in order to begin adopting restoration technologies (Akhtar-Schuster et al., 2017; Kust et al., 2017). Similar to Winowiecki et al., (2014) farmers had limited knowledge of the effects of land restoration on some critical ecological ecosystem services such as whereby farmers linked the loss of bees to only honey production and not pollination, which is a critical regulating ecosystem service in agricultural food production systems (Bommarco et al., 2013).

As shown in Table 4.3, some farmers viewed land degradation as being seasonal, showing a gap in knowledge because they assumed the landscape was restored when extreme dry or rainy season effects were not experienced. Table 4.4, 4.6 and 4.7 further highlights lessons that development organizations can learn on the need for sensitization of not only to 'project farmers' but non-project farmers within the landscape in order to equip them with skills and knowledge required to successfully adopt, sustain and scale the various land restoration interventions on their farms and landscapes (Coe et al, 2014). This is supported by other authors (Amare et al., 2016; Dougill et al., 2017) who noted that addressing knowledge gaps and sensitizing farmers should be inclusive and should occur at all stages of project implementation.

3.4.2: Need for adaptive land restoration options for dynamic agro-ecological systems

Results in Table 4.4 demonstrated farmers' knowledge that land restoration in some cases involved converting the utility or functions of one land-use category to another based on restoration goals and generation of preferred ecosystem services. For example, the conversion of degraded grazing lands where livestock had uncontrolled free-grazing access to exclosures where livestock are excluded and management is through catchment committees in order to control erosion, enhance ground water recharge and ground cover regeneration (Nyssen et al., 2008). Other conversions included: conversion of restored exclosures to cropfields, gully rehabilitation and conversion into check dams for water harvesting. This approach to land restoration is supported by authors who argue that restoration should aim at promoting adaptive resilience through transforming the generation of lost ecosystem functions into fundamentally new or more desirable ecosystem service potentials based on their use-value (Farag et al., 2017; Spangenberg et al., 2014).

Transformative restoration is especially necessary where due to mostly anthropogenic factors, ecosystems have undergone changes in processes and context including climate, property rights, population, soil fertility status, and land-use practices (Schmidt and Pearson, 2016; Wilcox, 2010). Farmers also observed that these processes involved losses or gains to land or uses of land. For example, loss of free-grazing access to grazing lands as a result of conversion into exclosures with controlled use meant that more pressure was put on the cropland. This is because farmers had to produce most of the livestock fodder on-farm, with minimal supplement from grass that is harvested through from exclosures through the 'cut and carry' system. These losses or gains require adaptive restoration and management approaches that aim at reducing trade-offs and enhancing synergies associated with the 'lost' and 'gained' landscape uses (Ocampo-Melgar et al., 2015). The changing context calls for transformative restoration to adapt the system to accommodate new and emerging needs and threats (Farag et al., 2017; Stanturf et al., 2018).

Results presented in Table 4.6 and 4.7 showed that farmers highlighted various biophysical and socio-economic factors that influence the adoption and suitability of various land restoration options. This an indication that land restoration technologies should be adapted and transformed to suit the dynamic local context (Knowler and Bradshaw, 2007; Larney et al., 2016). Inversely, some local socio-economic contextual factors should be adapted to suit the land restoration interventions if successful adoption and scaling is to be achieved (Sietz and Van Dijk, 2015). For example, free-grazing was not compatible with majority of the land restoration options. This is supported by various authors (Asfaw and Neka, 2017; Mango et al., 2017), who noted the importance of adapting socio-economic enabling factors eg access to extension, knowledge and training, labour requirements to enhance the successful uptake and sustainability of various interventions.

Results in Table 4.6 demonstrate that farmers' local knowledge was critical in adapting and sustaining land restoration technologies on their landscapes. Farmers' employed their own local modification of the interventions to generate the desired results through experimentation and observations, for example through constructing drainage channels where deep trenches are implemented on clay soils to reduce waterlogging. Similar observations have been reported by other authors (Kelly et al., 2015; Tarrasón et al., 2016). Incorporating local knowledge on modification into on-going interventions ensures better adaptability of options to context and provides a reliable source of feedback and co-learning on what option works where (Derak et al., 2016; Tiwari et al., 2004). Implementing organizations should thus work closely with farmers to co-learn as this form of bottom-up participation and knowledge exchange has been reported as an effective approach to adapting technologies to local context (Bautista et al., 2017; Sinclair, 2017).

3.4.3 Generation of multiple ecosystem service for varying stakeholders needs

Results in Table 4.3, 4.4 and 4.5 demonstrated that local knowledge of the landscapes was heterogeneous as represented by the different stakeholders namely farmers from the three catchments and gender (men, women, landless). Heterogeneity of agricultural landscapes has also been reported (Alvarez et al., 2018; Vanlauwe et al., 2014). For example, farmers from Bara and Endagiorgis catchments which had more recent restoration interventions (2016) and had luvisols which are highly erodible, possessed knowledge that suggests recent ecological recovery processes. This is in contrast with Endamariam which had older interventions (2012) and had cambisols, where farmers referred to the heterogenous nature of land degradation in some part of the landscape and not the other, suggesting some form of land restoration has been achieved in some areas of the landscape. The results demonstrate that local knowledge provides an accurate interpretation of the status of ongoing ecological processes (Aynekulu et al., 2006).

Results on gender presented in Table 4 showed that although the primary indicator of a restored landscape for all farmers namely men, women and landless farmers was improved household food security and equitable access of communal resources, it also showed that in different locations, farmers had different preferences, including gender-unique perceptions and expectations. Studies have shown that different stakeholders possess different knowledge and hold different perceptions of ecosystem services being generated from land restoration processes (García-Nieto et al., 2015; Tengo et al., 2017). For example, men valued income-oriented benefits, ecosystem services affecting livestock and cultural benefits. Women valued indirect well-being benefits including health, safety, education and trade-offs of not having required ecosystem services in terms of time spent, use of alternative resources. This may influence the uptake of land restoration technologies (Meijer et al., 2015). Some authors have observed that gender differences in preferences and perceptions many be due to the productive and reproductive roles that men and women play respectively including decision making (Peterman et al., 2011; Grace B. Villamor et al., 2014c).

The existence of diverse stakeholders requires understanding of changes in ecosystem service demand and supply trends (Tarrasón et al., 2016; Vrebos et al., 2015). The emergence of new stakeholders for example landless farmers requires transforming approaches to restoration to adapt the system to accommodate their needs (Farag et al., 2017; Ocampo-Melgar et al., 2017). Literature shows that different stakeholders manage resources differently influenced by many factors such as farm typology, their preferences and values and level of interaction with other resource users (Pereira et al., 2016; L. Winowiecki et al., 2014b). Changing uses of the landscape by different stakeholders thus leads to multiple and often conflicting uses, perceptions and place values (Milligan and Polk, 2017). Hence there is need to design restoration technologies that are diverse and inclusive (Frankl et al., 2014; Januchowski-Hartley et al., 2012).

4.4.4 Agroforestry as an approach to land restoration

Deforestation was named as a major driver to land degradation. This has been reported by other author (Carvalho et al., 2017; Lemenih et al., 2005) who observed that absence of tree cover leads to the loss of critical ecological functions of landscapes. Trees play critical ecological roles through ecosystem services such as: soil erosion control, soil formation, soil nutrient cycling, micro-climatic regulation, soil water conservation, provision of genetic resources, providing habitat, water quality and quantity regulation, carbon sequestration, pollination maintenance and pest regulation (Muthuri et al., 2009; van Noordwijk et al., 2014)

Deforestation was also blamed on the shortage of provisioning ecosystem services and products. Restoring landscapes with the right trees ensures that trees continue to play direct roles in food provisioning and provide livelihood safety nets especially in times of shortage of other food sources(Verchot et al., 2007). Trees also provide indirect benefits through income generation from sale of tree crops, wood and non-wood products. Agroforestry is one of the approaches to reducing negative system feedbacks indirectly through knock-on effects within the farm system such as from the generation of ecological and provisioning services such as fodder, firewood, ground water regeneration (Luedeling et al., 2014; Mbow et al., 2014a; L. Winowiecki et al., 2014a).

Results show that farmers valued a wide range of ecosystem services provided by agroforestry systems including the non-monetary and non-tangible cultural ecosystem services. Men reported losing cultural values of their agricultural landscapes namely loss of aesthetic value and intrinsic cultural value because of land degradation most directly linked to loss of natural vegetation cover. However, contemporary land restoration activities have often ignored non-economic cultural attachments and relationships between people and their landscapes (Malinga et al., 2015; Pert et al., 2015). This calls for the need for integrated agroforestry interventions that generate diverse and holistic ecosystem services to enhance ecological and livelihood benefits.

4.5 CONCLUSIONS

Farmers had an in-depth understanding of land degradation drivers, processes and effects across four scales namely regional, national, landscape and farm level, indicating the importance of incorporating farmers' knowledge in problem analysis and identification of entry points for interventions. Farmers viewed land restoration as rehabilitation of already degraded land, and not prevention of degradation of non-degraded land, suggesting key knowledge gaps that need to be addressed in terms of approaching land restoration also from a prevention of further land degradation perspective because it is costlier to restore already degraded land than less-degraded land. Farmers' knowledge about land degradation and restoration varied by stakeholder categories namely across catchments, land-use categories and gender, indicating the need to include for full stakeholder participation from the design stage and throughout project implementation stages to ensure restoration interventions are inclusive and generate ecosystem services that meet the needs of all stakeholders. Farmers identified 12 contextual factors that influence the suitability of land restoration options to local context, highlighting the need to match restoration options to local context. Through their own experiments and observations, farmer utilized their local knowledge to modify land restoration technologies to suit local context, demonstrating the value of incorporating local knowledge into monitoring and adapting land restoration technologies to context. Overall, the research demonstrates how combining local and scientific knowledge can help to design, implement and monitor the performance of land restoration technologies to ensure they are locally adapted, appropriate and effective in delivering multiple ecosystem services for diverse stakeholders needs at scale.

CHAPTER 5: DECREASING CROP DIVERSITY LEADS TO FOOD INSECURITY AND RELIANCE ON OFF-FARM FOOD SOURCING AND VARIES WITH LAND DEGRADATION STATUS

ABSTRACT

Food security remains a critical development priority within the 2030 Sustainable Development Goals (SDGs) agenda. One of the main challenges facing global policy makers is the inability to meet all food security dimensions due to lack of customized local indicators and metrics for assessing food security needs across heterogeneous smallholder landscapes. This leads to the design of blanket food policies across different context informed by top-down approaches, without understanding local needs or adapting interventions to local context. This results in food insecurity due to inappropriate, non-inclusive and unsustainable interventions. The aim of this study was therefore to assess local drivers and indicators of food insecurity and evaluate variations by land degradation status. Local knowledge was elicited using systematic knowledge-based systems approach (AKT5) from 150 smallholder farmers through Paired Catchment Assessment of three landscapes along a land degradation gradient in Western Rwanda. Results showed a decrease in annual crop diversity or complete disappearance of some crops between 1995 and 2015, mainly due to Crop Intensification Policy launched in 2007 (76%) which led to specialization in a few 'high-value' crops. This led to 83% of farmers reporting being food insecure, with the main indicator of food insecurity being food shortage during certain months of the year (mainly July to November) when the high value crops were not mature for consumption. This has resulted in most farmers outsourcing food and over time, they have become more dependent on the market, with food produced on-farm supporting farmers for average 6.6 months annually in 2015 compared to 10.1 months in 1995. The main coping mechanism currently employed by farmers experiencing food insecurity is paid labour off-farm. The frequency of mention of all the above parameters varied with land degradation status, but there were no gender differences. Inversely, there was an increase in perennial crop diversity between 1995 and 2015, mainly attributed to access to quality germplasm (66%) and tree propagation skills (34%), with farmers noting that tree food crops played a key role in filling food gaps during 'food -insecure months. The implications of this study is that food security policies should promote crop diversity as opposed to specialization in a few crops, and should match food interventions to local context informed by local indicators to ensure the promotion of diverse and appropriate food interventions that enhance livelihood and ecological resilience of smallholder farming systems.

Key words: local knowledge, land degradation, food security, food sourcing, sustainable intensification, smallholder farmers.

5.1 INTRODUCTION

Increasing global food insecurity has resulted in vulnerable livelihoods and decreasing state of human and environmental well-being. Food insecurity is especially severe in the sub-Sahara African (SSA) countries where the Food Insecurity Experience Scale (FIES) estimates that approximately 7.5 percent (406 million) of its population aged above 15 years experienced severe food insecurity in 2014 and 2015. The sub-Saharan Africa had the highest prevalence of severe food insecurity globally, with 26% (153 million) of this age group reported as food insecure (FAO et al., 2017). Agriculture is the single largest employer in the world, providing livelihoods for 40 per cent of today's global population. With decreasing off-farm employment globally and the recent drastic global rise in food price since 2007 (Anderson and Strutt, 2014; Hadley et al., 2012), more people are likely to turn to agriculture. This calls for innovative ways to sustainably increase food production on limited land while protecting ecological well-being (Pretty et al., 2011).

In East Africa, food insecurity persists despite numerous attempts to produce more food and achieve sustainable intensification. This has been mainly blamed on threats such as population pressure and consumption per capita, land degradation, climate change and water scarcity (Cooper et al., 2008; Jayne et al., 2014; Tittonell et al., 2012). Food security[1] is a multi-dimensional composite of intertwined factors, which include: age, gender, education, per capita disposable income, resource endowment including size of arable land, food retail price index, remittances, unemployment, inflation, assets, health (Burchi and Muro, 2016; Wang, 2010). Food insecurity has also been blamed on lack of appropriate policy, technological, structural, institutional and financial measures which inhibits physical and economic access to sufficient, safe and nutritious food (Dowler and Connor, 2012; Lele et al., 2013; Seaman et al., 2014). Food insecurity has numerous and far-reaching adverse effects both on human and environmental well-being. Food insecurity is one of the major causes of poverty and conflicts (Allouche, 2011; Maystadt et al., 2014). Health impacts of food insecurity have also been widely reported and include not only physical health but also mental health (Cole and Tembo, 2011; Maes et al., 2010).

[1] According to FAO, food security is only achieved when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2010).

Food security remains a critical development priority within the 2030 Sustainable Development Goals agenda, especially SDG2 (Conceição et al., 2016). There is therefore an urgent call for production of more food but in a sustainable manner to achieve environmental-livelihood security (Biggs et al., 2015; Godfray and Garnett, 2014). Various approaches to tackling emerging global threats to food security include restoration of soil and water, adopting climate-resilient crop and livestock varieties, investing in irrigation technologies, early and late planting (Shiferaw et al., 2014; Tittonell et al., 2012). Other approaches include: reducing food system energy footprints, while others still include trade reforms or social protection such as through provision of agricultural input subsidies to boost food production, food or cash for work (Devereux, 2016; Hanjra and Qureshi, 2010). In areas with acute food insecurity, governments have come in and offered food aid (Dorosh et al., 2009).

Food policies and interventions are normally informed by various food security metrics and indicators, which policy makers refer to as a basis for meeting the four pillars of food security namely: availability, accessibility, utilization and stability. Such include: Coping Strategies Index (CSI); the Reduced Coping Strategies Index (rCSI); the Household Food Insecurity and Access Scale (HFIAS); the Household Hunger Scale (HHS); Food Consumption Score (FCS); the Household Dietary Diversity Scale (HDDS); and a self-assessed measure of food security (SAFS). These different measures are designed to address different elements of food security assessment (Maxwell et al., 2014). The challenge is that majority of metrics and indicators used are generated through top-down approach, pre-conceived and generalized across heterogeneous landscapes. Thus they fail to capture local contextual variation or adapt them to local context (P Tittonell et al., 2012). This results in inappropriate and unsustainable interventions (Haen et al., 2011). This results in the inability to meet all the dimensions of food security (Burchi and Muro, 2016).

Lack of customization of food security policies to local context is mainly caused by the lack of incorporation of local knowledge of local partners especially smallholder farmers in understanding the context in which food policies and programmes are being designed (Boratynska and Huseynov, 2016). Studies have shown that smallholder farms are highly heterogeneous ecologically, social-economically, biophysically, historically and politically (Vanlauwe et al., 2014). Hence people experience different levels of food insecurity and have varying vulnerability levels (Hahn et al., 2009). Even within one locality, there is need for customized approaches for enhancing food security for rural and urban farming systems (Barthel and Isendahl, 2013; Zezza and Tasciotti, 2010). Therefore, participatory formulation, implementation, and evaluation of food security policies and programmes leads to more appropriate and sustainable interventions that take into account heterogeneity of self-reported food insecurity indicators (Verpoorten et al., 2013).

This study was undertaken within the framework of SDG 1, 2 and 15. The aim of this study was therefore to assess local drivers and indicators of food insecurity and evaluate variations by land degradation status. We hypothesized that: 1) on-farm crop diversity has decreased over time (between 1995 and 2015) and influences food security status; 2) over time, farmers have become increasingly dependent on food sources away from their farms; 3) land degradation status influences food security levels and indicators.

5.2 METHODS

5.2.1 Study area characterization and selection

This study was undertaken in Gishwati, which is in Rubavu and Nyabihu Districts of Western Rwanda. This area is known as the Rwanda's food basket due to its sub-humid agroecology and rich volcanic soils which makes the area favourable for agriculture. Gishwati forest used to extend towards Lake Kivu at the Border of Rwanda and DRC but currently the forest consists of fragments resulting from deforestation whose drivers were three-fold namely: forest conversion to agricultural land, settlements and over-extraction of tree products for building and fuelwood for returnees and refugees following the 1994-1995 genocide (Ordway, 2015).

This research adopted a Paired-Catchment experimental design (Brown et al., 2005) and focused on three landscapes namely (Degraded, Recovering, Restored). Historical timelines revealed that although all three study sites underwent simultaneous tree cover loss after the 1994-1995 genocide, they underwent different trajectories of land degradation and restoration (Aynekulu et al., 2014; Bigagaza et al., 2002; Kuria et al., 2014). The topography of all sites is hilly with steep slopes (some areas have a slope inclination of over 50%), hence the landscape is susceptible to severe soil erosion (Byiringiro and Reardon, 1996b; D. M. Kagabo et al., 2013; Roose and Ndayizigiye, 1997). Table 5.1 provides characterization of the three study sites while Figure 5.1 shows location of the sites.

Table 5.1. Characterization of study sites selected in Gishwati, Northern Rwanda

Landscape	Agro-Ecology/ Farming Zone	Elevation (m.a.s.l.)	Rainfall (mm)	Dominant soil	Year when Restoration interventions begun	Type of interventions	Soil Conservation Organizations	Land use before 1995
Degraded (Control)	North-Western Volcanic Irish Potato Zone	1890 - 2180	900-1500	Volcanic andosols	No interventions (soil erosion occurring at a high rate)	None	None- just farmers	Farmers derived wood products and fodder from Gishwati
Recovering	Eastern Congo-Nile Highland Subsistence	2350-2540	1200-1500	Alisols	2012 (minimal siltation downslope)	Progressive terraces, trees	NGO's such as ICRAF	Farmers cultivated and derived wood products and fodder from Gishwati
Restored	Eastern Congo-Nile Highland Subsistence	2380-2570	1200-1500	Alisols	2007 (erosion controlled effectively)	Bench terraces, progressive terraces, trees, grasses	The Government of Rwanda	Farmers derived wood products and fodder from Gishwati

The Recovering and Restored landscapes were adjacent to each other and neighbouring Karago Lake and were located in Kadahenda cell, Karago sector of Nyabihu district, which lies between 1°37'38.28"S and 29°30'48.24"E (REMA, 2010). The Recovering landscape, whose study villages were Karandaryi, Gakoma and Nkomane, still experiences slight soil loss through surface run-off because it has more recent erosion control interventions (2012) compared to the Restored landscape (2007). The Recovering landscape is receiving soil and water conservation interventions and food security interventions led by ICRAF through the Australian Centre for International Agricultural Research (ACIAR) Trees for Food Security Project. The project aims at sustainably improving productivity of farming landscapes, and to recover food and nutritional security through the promotion of suitable agroforestry interventions.

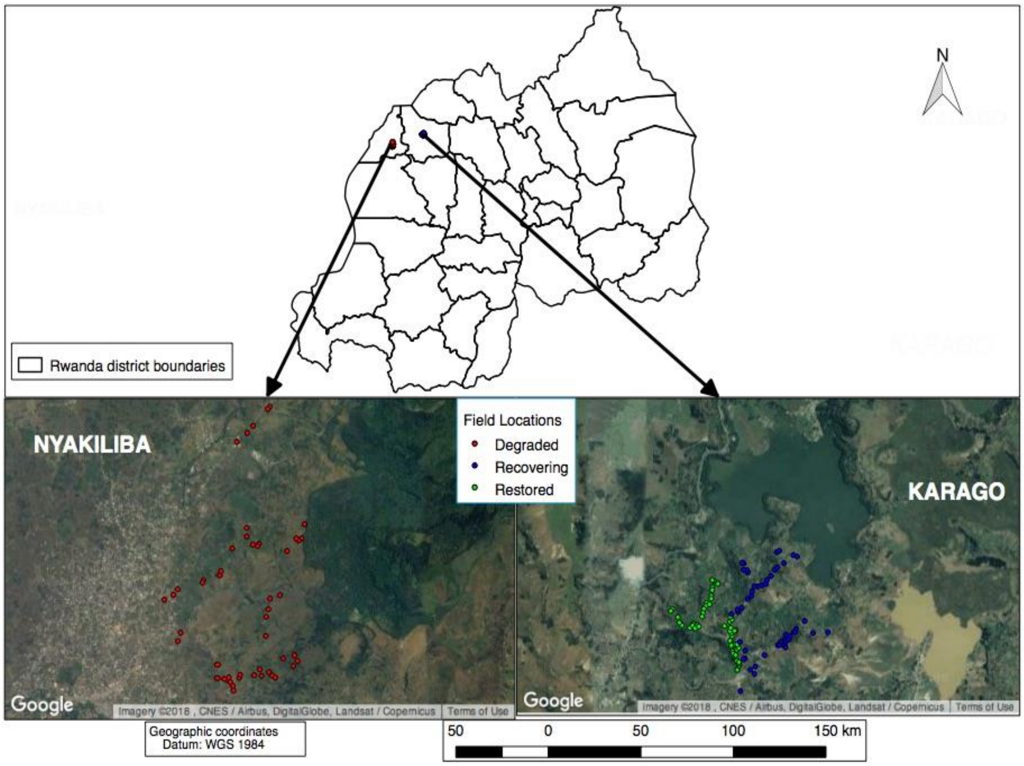

Figure 5.1: Map of Rwanda showing location of fields sampled in Gishwati

In the Restored landscape (the study village was Gihira), soil loss had been controlled through soil and water conservation interventions implemented from 2007. In 2005/2006, the government of Rwanda through the 'umuganda' community service embarked on soil erosion control as part of the national soil and water conservation programme; whereby bench and progressive terraces were established on steep slopes (Bizoza, 2014) and stabilized through planting of *Alnus acuminata* and and *Setaria sphacelata*. The interventions were also meant to protect Lake Karago and Busoro river from siltation. In addition, the government set aside 50 metres of land adjacent to the water bodies for planting trees.

The Degraded landscape was in a different farming system located in Gikombe cell, of Nyakiliba sector in Rubavu district. The study villages were: Rushubi, Nyabibuye and Nyakibande. It is located at -1°40'16.68"S and 29°21'37.44"E. The upper part of the Degraded landscape is adjacent to Gishwati protected forest while the bottom part borders Mahoko town. It is characterized by severe soil loss as a result of soil erosion, landslides and siltation as well as frequent flooding in the downslope flat areas. The area has not received any soil and water conservation interventions following the post genocide deforestation in 1995. After the government of Rwanda evicted farmers who had encroached Gishwati forest in 2010, and soil and water conservation efforts have mainly involved reforestation of the protected forest, and not the adjacent farming landscapes.

5.2.2 Data Collection Methodology

This study, which was conducted between August and November, 2015, systematic knowledge-based systems approach (AKT5) (Sinclair and Walker, 1998; Walker and Sinclair, 1998). This involved semi-structured interviews with a stratified sample of 150 willing and knowledgeable informants. The knowledge was then recorded and represented using the AKT5 software (Dixon et al., 2001). The AKT5 local knowledge methodology entails four stages. Scoping stage activities included participatory transect walks to understand and characterize the landscape biophysical, including farm typologies, community resources, annual and perennial crops grown, degradation hotspots. This also informed stratification criteria. Expert knowledge was elicited through Key Informant Interviews with crop-production related experts and local administration. Six focus group discussions were held 69 farmers from the three landscapes (Plate 4.1). While having broad discussion about ecosystem services that were locally relevant, farmers named food provisioning as their top-most priority, hence the focus of this study.

In the definition stage, stratification parameters and knowledge boundaries were determined. Six farmers from each of the three landscapes were randomly selected for in-depth interviews and probing further on the current food security status. The compilation stage involved an iterative process whereby knowledge elicited from individual farmers was re-evaluated through repeated visits to the same farmers to probe further to get additional information or clarifications; which were then recorded and entered into the AKT5 tool. This process was repeated (at least two visits per farmer) until no new information was obtained from the respondents.

Plate 5.1: Focus Group Discussion with male farmers in Gishwati

The generalization stage involved formulating key food security research questions based on issues deemed context-relevant based on the in-depth knowledge obtained during the previous three stages. Pre-testing of the questionnaire was then conducted with 12 farmers (four from each of the three landscapes). Once the questionnaire was refined, it was then administered to 150 farmers (50 farmers from each of the three landscapes). The 150 farmers were interviewed for both 1995 and 2015 food security status. Willing farmers were then selected through longitudinal and horizontal transects. The sample comprised of 83 men and 67 women. Results presented here were generated at the last (generalization) stage of AKT5 local knowledge elicitation.

5.2.3 Data Analysis Methods

AKT5 tool was used to analyse and qualitatively interpret data and knowledge elicited through the first three stages of the AKT process (Sinclair and Walker, 1998; Walker and Sinclair, 1998). It involved breaking down knowledge into unitary statements which were then represented using formal grammar and local taxonomies where applicable. This formed a basis for formulating the questionnaire for collecting quantitative data. Farmers' responses to formal questions were recorded in Microsoft Excel as whether knowledge items were either articulated or not by the farmers. The results were exported to R statistical software (R Development Core Team, 2013) for further analysis. Frequency statistics (including percentages) were run to show the number of farmers that held knowledge about a specific food security aspect. Results were also presented using bar plots generated using the ‘ggplot’ function. Due to the categorical nature of the variables, where a stratum had a sample size of at least five, a Chi-square Test of Independence was applied determine whether the sample data was consistent with the distribution that had been hypothesized (Mchugh, 2013).

5.3 RESULTS

5.3.1: Crop diversity trends between 1995 and 2015

We sought to understand whether on-farm crop diversity has changed or remained the same between 1995 and 2015 (when this study was undertaken). We requested all farmers to name the food crops they were growing in 2015 and in 1995. Results indicate that there was a general decrease and increase in the average annual and perennial crop diversity across farms between 1995 and 2015 (Figure 5.2). For annual crops, only Irish potatoes and beans have been grown consistently by most farmers over the years. In 2015, no farmer was growing sorghum, which was being grown by 68% of farmers in 1995, while only 13% is growing peas, which was being grown by over 50% of farmers in 1995. Maize too was being grown by fewer farmers (35%) in 2015 compared to 1995 (83%). However, no farmer reported growing amaranth in 1995 but it was being grown in 2015. There was an increase in the number of farmers growing perennial crops, especially avocadoes and tree tomatoes from 1995 to 2015, though the proportion of banana growers decreased. There was also an introduction in cassava (*Manihot glaziovii*) leaves which farmers used as vegetables, which was not being grown in 1995

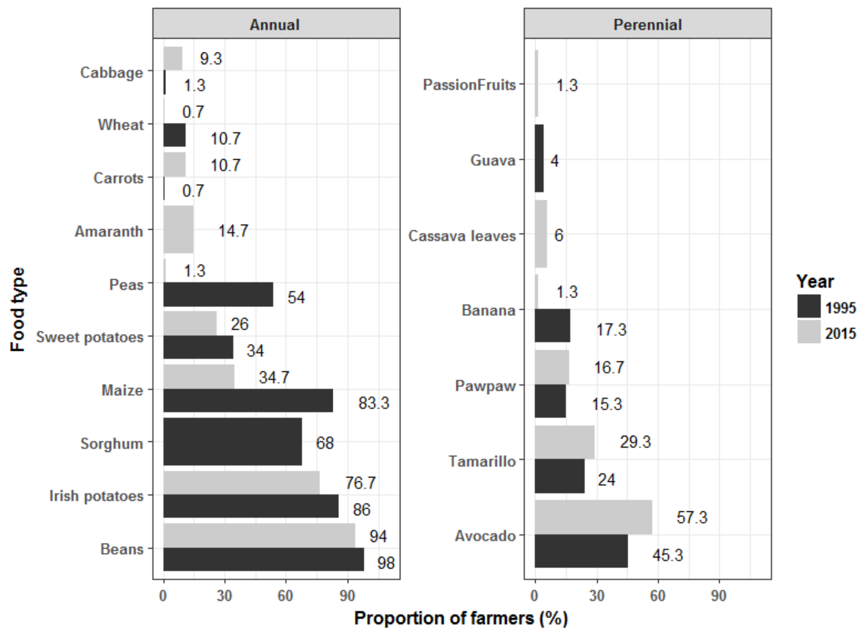

Figure 5.2: Proportion of farmers growing crops in 1995 and 2015

Annual and perennial crop diversity trends varied with degradation status. For example, in both 1995 and 2015, sweet potatoes were mostly grown in the Degraded landscape (Figure 5.3). Sorghum, which was only grown in 1995, was grown by mostly farmers in the Recovering and Restored landscapes. Maize was mostly being grown in the Restored and Recovering landscapes, while in both 1995 and 2015, Irish potatoes were mostly grown in the Recovering and Restored landscapes. In 1995, bananas were mostly grown in the Degraded landscape. In both 1995 and 2015, a higher proportion of farmers in the Degraded landscape grew avocadoes compared to other landscapes. In the Recovering and Restored landscapes, there was increased growing of tree tomatoes, which was mainly due to distribution of quality germplasm by the Trees for Food Security project.

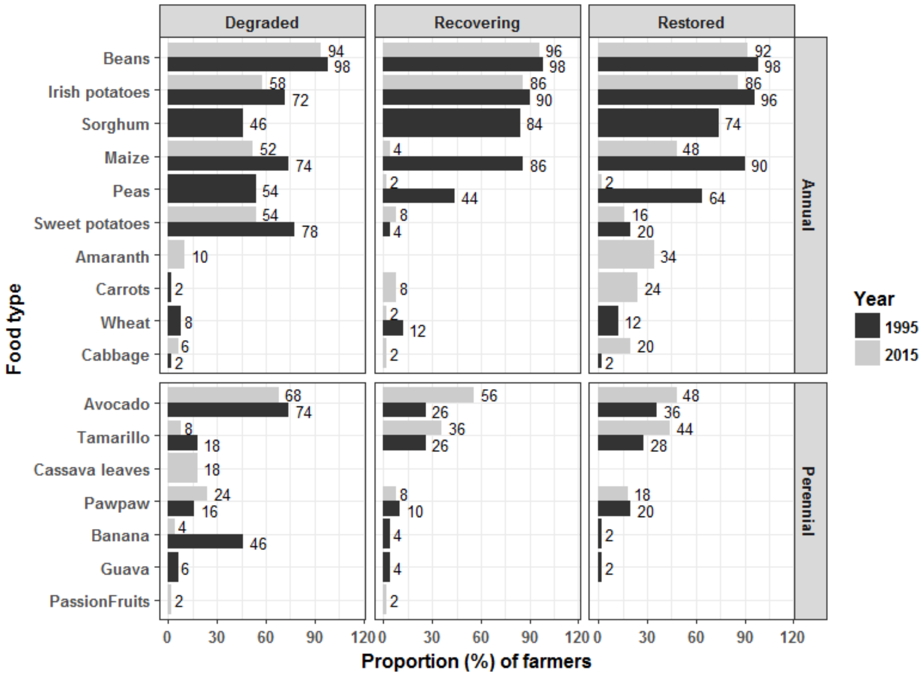

Figure 5.3 Proportion of farmers growing crops in 1995 and 2015 by degradation level

Farmers identified drivers influencing crop diversity at four scales, namely at national level (policies on crop intensification and eviction of farmers from Gishwati encroachment), farm level (land shortage and abandonment of slow maturing crops), landscape scale (crop diseases) and at the regional level (climate change). According to majority of farmers (76%), the main driver that has contributed to the decrease in annual crop diversity was the Land-use Consolidation and Crop Intensification Programme that was launched in September 2007 by the Government of Rwanda. The programme aimed at promoting high value crops namely Irish potatoes, beans and maize, which fetched high income which the government felt would improve farmers' livelihoods. Farmers however felt that specialization of a few high value crops has led to the abandonment of crops viewed as 'low value', thus resulting in decreasing diversity of low value crops across farms. Crop intensification driver was mostly mentioned in the Restored and Recovering landscapes compared to Degraded landscape (Figure 5.4).

Land shortage was the second frequently mentioned driver of decreasing annual crop diversity (55% of farmers). Farmers, mostly from the Degraded landscape, were faced with the challenge of only retaining the high-value crops at the expense of 'low-value' crops due to limited land.

Thirdly, 49% farmers reported having gradually abandoned slow growing and maturing crops such as sorghum and banana for fast-growing crops such as maize and Irish potatoes. This was mostly mentioned in the Restored landscape (Figure 5.4). The fourth most mentioned driver was eviction of farmers from Gishwati forest, which was reported by only farmers in the Degraded landscape. When farmers were evicted from Gishwati forest which sits at a high elevation of above 2200 m.a.s.l. hence crops such as wheat and peas do well, they abandoned growing such crops. This is because their farms were located downslope, a lower elevation unfavourable for such crops (Figure 5.4). There were no significant gender differences in drivers influencing annual crop diversity.

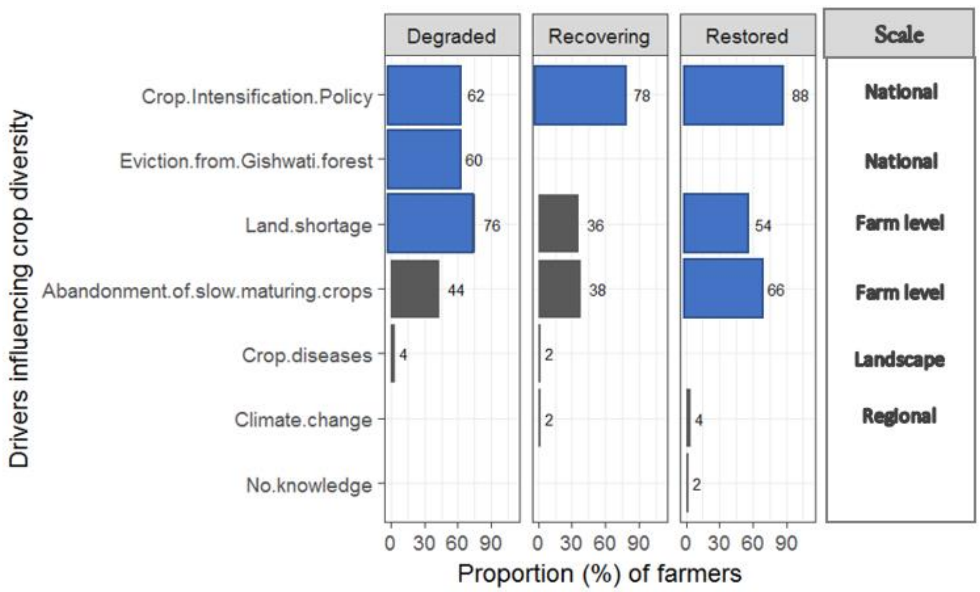

Figure 5.4: Drivers influencing annual crop diversity between 1995 and 2015 by degradation level

Contrary to the notable decrease in on-farm crop diversity, there was a notable increase in most perennial crops being grown in 2015 compared to 1995, especially for avocadoes and tamarillo. According to farmers, the two main factors affecting perennial crop diversity, including tree crops was the increase in availability of tree seedlings (66%) (Plate 5.2); and training of farmers in tree propagation including grafting of fruits such as avocadoes (34%). This according to farmers has been brought about by the interventions being brought by organizations such as the World Agroforestry Centre through the Trees for Food Security Project.

Plate 5.2: Provision of quality germplasm in Karago Rural Resource Centre

5.3.2 Temporal trends in on-farm and off-farm food sourcing

We sought to test whether over time, farmers have become increasingly dependent on off-farm compared to on-farm food sourcing to meet their food needs. Due to drivers of food insecurity and crop diversity discussed earlier in Sections 3.2 and 3.4, farmers have become more dependent on off-farm food sources. For example, food produced on-farm in 2015 was only supporting them for an average of 6.6 months compared to 10.1 months in 1995 (Table 5.2). Farmers reported relying more on the market (5.4 months) in 2015 compared to only 1.5 months in 1995.

Table 5.2: Comparison of 1995 and 2015 food sourcing proportion (months per year)

Food Source	**On-farm**		**Buy from the market**		**Buy from neighbours**		**Borrow from relatives**	
No of Months	**2015**	**1995**	**2015**	**1995**	**2015**	**1995**	**2015**	**1995**
All landscapes	6.6	10.1	5.4	1.5	0	0.1	0.01	0
Degraded	5.7	8.8	6.2	2.4	0	0.2	0.04	0
Recovering	7.8	11.4	4.2	0.6	0	0	0	0
Restored	6.3	9.9	5.7	1.5	0	0	0	0

There were variations in on-farm and off-farm food sourcing along a land degradation gradient, with farmers in the Recovering landscapes depending on their farms slightly more (7.8 months) in 2015 compared to the Restored (6.3 months) and Degraded landscape (5.7 months). In 2015, no farmer was currently sourcing food from neighbours, while a few farmers in the Degraded landscape relied on relatives for food. Figure 5.5 shows that majority of farmers in all landscapes outsourced most and higher proportions of the annual and perennial food crops they consumed compared to what they grew in their farms.

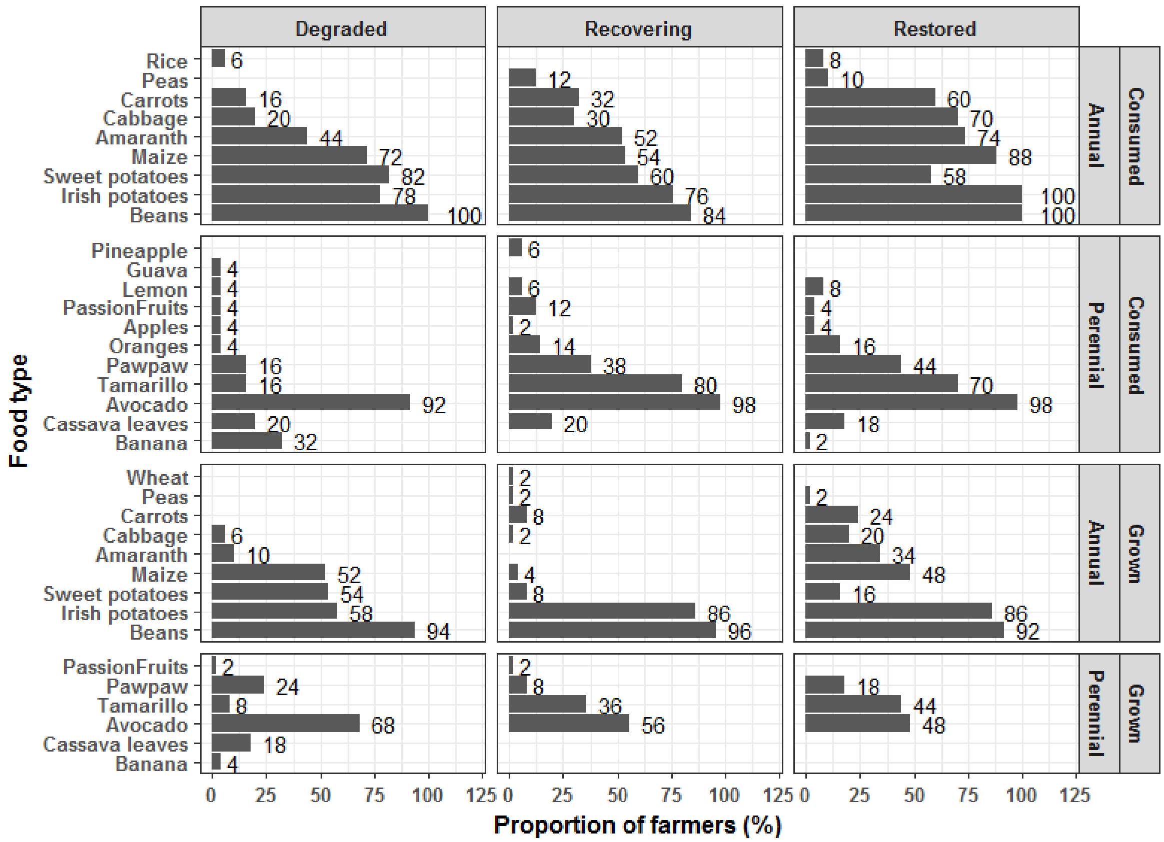

Figure 5.5. Proportion of farmers who sourced food on-farm and off-farm in 2015

In all three landscapes, out of the 11 perennial crops consumed, only six were sourced on-farm while the rest were outsourced, mainly from the market (Figure 5.8). For annual crops, apart from beans that were grown by majority of farmers, farmers depended on off-farm sources for majority of other foods they consumed. This was especially so for sweet potatoes, maize, amaranth, carrots and cabbages and avocadoes. Wheat was grown but not consumed locally but sold. Only rice was not a crop grown in the Gishwati agroecology.

5.3.3: Food availability calendar in 2015 and local indicators of food insecurity

Results from the 150 farmers interviewed in Gishwati show that 83% of the farmers reported being food insecure. However, the proportion of households who perceived themselves as being food insecure varied with land degradation status, with 96%, 86% and 68% of farmers being from the Degraded, Restored and Recovering landscapes respectively. Farmers identified four local indicators they use to assess their food insecurity status namely food shortage during certain months, taking fewer meals per day throughout the year, consuming less preferred food and reducing food portions per meal. However, although all four indicators of food insecurity were mentioned across the three landscapes, there were variations in the number of farmers mentioning each indicator.

The most frequently mentioned indicator (51% of all farmers) was food shortage during certain months of the year, mostly from July to November, with October (35%), November (31%) and July (25%) emerging as the most food insecure months (Figure 5.6). This was attributed to exhaustion of food reserves during the period when major crops (maize, Irish potatoes, beans) which farmers highly depend on are growing and not yet mature for consumption.

As shown in Table 5.3, Gishwati has two cropping (planting) seasons, with the main heavy rainy season occurring between March and May while the lighter rainy season is between September and December.

Table 5.3: Annual and perennial food crop availability calendar and food insecure months

	Botanical Name	Food Type	Main Heavy Rainy Season			Dry Season			Lighter Rainy Season				Dry Season	
			Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Degraded Landscape														
Annual Crops	*Phaseolus vulgaris L.*	Beans				■	■						■	■
	Solanum tuberosum L.	Irish potatoes				■	■					■	■	■
	Zea mays L.	Maize					■	■				■	■	■
	Brassica oleracea var. capitata	Cabbage	■			■	■			■	■	■	■	■
	Daucus carota subsp. Sativus	Carrots	■			■	■			■	■	■	■	■
	Amaranthus spp.	Amaranth	■	■	■				■	■	■	■		■
	Ipomoea batatas	Sweet potatoes	■	■	■	■	■	■	■	■	■	■	■	■
Perennial Crops	*Carica papaya*	Pawpaw				■	■					■	■	■
	Musa spp.	Banana			■		■	■	■	■	■	■	■	■
	Cyphomandra betacea	Tamarillo		■	■					■	■	■		
	Psidium guajava	Guava		■	■	■	■							
	Persea americana	Avocadoes	■		■	■					■	■		■
	Passiflora edulis	Passion fruits	■				■	■	■	■	■	■	■	■
	Manihot glaziovii	Cassava leaves	■	■	■	■	■	■	■	■	■	■	■	■
Recovering and Restored Landscapes														
Annual Crops	*Solanum tuberosum L.*	Irish potatoes					■	■	■		■	■	■	■
	Zea mays L.	Maize					■	■				■	■	■
	Pisum sativum	Peas					■	■			■	■	■	
	Brassica oleracea var. capitata	Cabbage	■				■	■			■	■	■	■
	Daucus carota subsp. Sativus	Carrots	■				■	■			■	■	■	■
	Phaseolus vulgaris L.	Beans	■			■	■	■				■	■	■
	Amaranthus spp.	Amaranth	■	■					■	■	■	■		■
	Triticum aestivum	Wheat	■	■					■	■				
	Ipomoea batatas	Sweet potatoes	■	■	■	■	■	■	■	■	■	■	■	■
Perennial Crops	*Psidium guajava*	Guava				■	■							
	Carica papaya	Pawpaw			■	■	■	■				■		■
	Cyphomandra betacea	Tamarillo		■	■	■	■		■	■	■	■	■	
	Persea americana	Avocadoes	■			■	■		■	■	■	■	■	■
	Passiflora edulis	Passion fruits	■						■	■	■	■	■	■

The dominant annual crops (beans, Irish potatoes, maize) are harvested and available for consumption only between December to February/March and from June to August. Some crops grown varied across the landscapes, for example, wheat and peas were only grown in the Recovering and Restored landscapes while cassava was only grown in the Degraded landscape. Due to the varying period when food crops matured and food types, food-insecure months in the Degraded landscapes were from March to May and August to November while in the Recovering and Restored landscapes were from March to June and September to November in the). Farmers reported they also relied on perennial crops mostly tree crops such as avocadoes and tree tomatoes and cassava leaves (Plate 5.3) to fill the food gap during the period when annual crops are not available as most perennial crops are available. Perennial crops were mostly available from June to February, including all food insecure months named above.

Plate 5.3: Cassava leaves (*Manihot glaziovii*) vegetable preparation

The second overall most frequently mentioned indicator of food insecurity was farmers resulting to taking fewer meals per day throughout the year (47%). Farmers and their dependants resulted to taking one or two meals (most important meals) instead of the usual three throughout the year, without reducing food serving proportions per meal. According to farmers, the most important meal is dinner, followed by breakfast and lastly lunch. This coping strategy ensured that food reserves were utilized sparingly to last longer. The third most frequently mentioned indicator (22%) was when farmers resulted to consuming less preferred foods such as sweet potatoes, cassava leaves and bananas, when the preferred foods such as Irish potatoes, beans and maize were not available. The fourth indicator was reducing food portions per meal (15%). This was achieved through taking three meals in a day but reducing serving portions to ensure little food is consumed.

There were variations in the number of farmers mentioning each indicator of food insecurity along the land degradation gradient (Figure 5.6). Food shortage during certain months was the main indicator mentioned in the Recovering and Restored landscapes while in the Degraded landscape, three indicators apart from consuming less preferred foods were mentioned by almost similar proportions of farmers. Taking fewer meals per day was especially common to farmers in the Recovering landscape (62%).

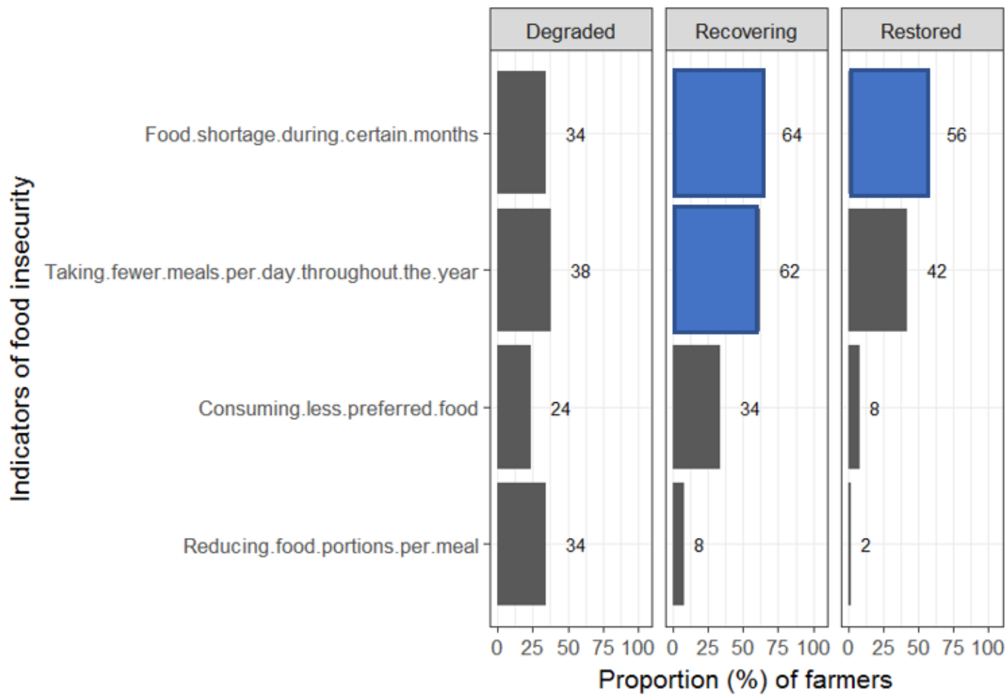

Figure 5.6: Indicators of food insecurity by degradation level

5.3.4. Local knowledge on drivers of food insecurity

Farmers identified five drivers of food insecurity across three scales, which varied with land degradation status. The three most common drivers were at the regional scale (low and unpredictable rainfall), farm level (shortage of land) and landscape scale (diseases and pests). Overall, food insecurity was blamed on crop yields, mainly associated with low and unpredictable rainfall as reported by 56% of farmers. This was blamed on climate change mainly brought about by deforestation that occurred following the 1994/1995 Rwanda genocide. Low and unpredictable rainfall was mostly mentioned in the Degraded and Restored landscapes (Figure 5.7).

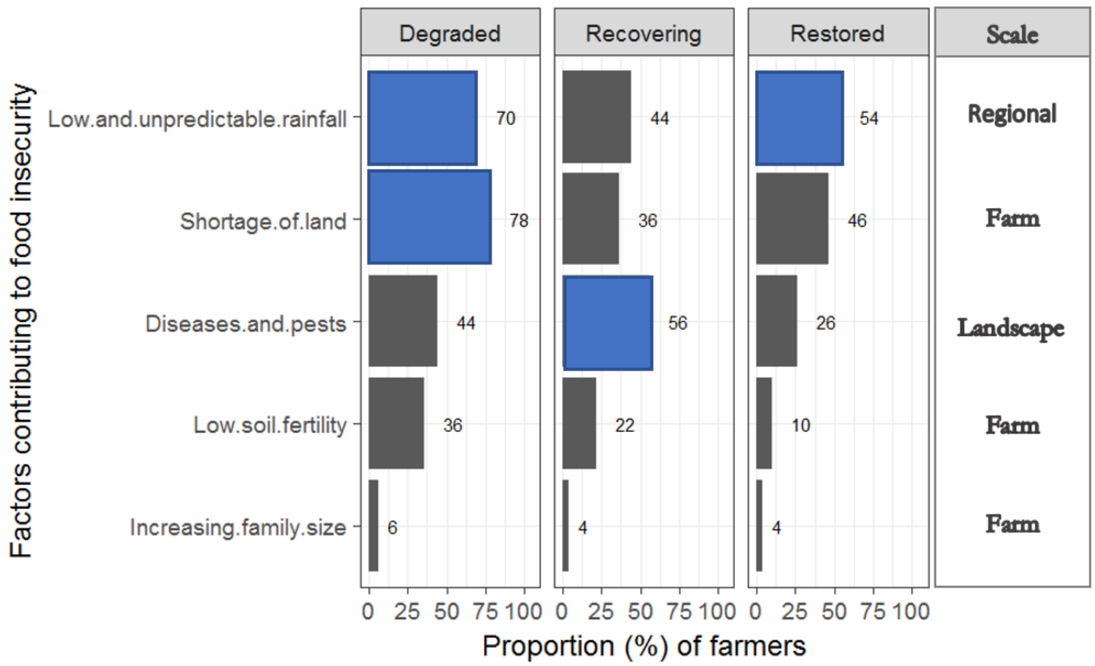

Figure 5.7: Local drivers of food insecurity

The second most frequently mentioned driver (53%) was shortage of land, with the average household land holding for the 150 households interviewed being 0.3 ha. Farmers thus reported decreasing average household land holding, land under crop cultivation has reduced, hence they resulted to mostly specializing in growing high-value crops. Land shortage was mostly reported in the Degraded landscape where the average land holding was 0.15 ha., compared to Restored landscape (0.31 ha.) and Recovering landscapes (0.44 ha.).

Crop diseases and pests was the third most frequently mentioned driver (42% of farmers). The main diseases mentioned were: Loose Smut of Maize disease (locally known as 'Chumya' in Kinyarwanda language) caused by *Ustilago maydis* fungi (Plate 5.4); potato late blight and potato bacterial wilt. The main pest mentioned by farmers was the turnip cutworms (*Agrotis segetum)* (locally known as Inanda*).* Disease and pest occurrence was mainly blamed on continuous monocropping of priority 'high-value' crops such as maize and Irish potatoes and lack of improved seed varieties. Diseases and pests were mostly reported in the Recovering landscape.

Plate 5.4: Loose Smut of Maize (*Ustilago maydis*) disease

Low soil fertility was reported by 23% of farmers who attributed it to loss of fertile soils through erosion as a result of low ground cover due to deforestation, lack of adequate soil and water conservation structures, coupled with high rainfall intensity and steep inclination of Gishwati highlands. Low soil fertility was mostly mentioned in the Degraded landscape, where farmers observed challenges of being unable to control soil erosion on their individual farms because they were not working collectively to conserve the soil. On the other hand, farmers in the Recovering and Restored landscapes reported engaging collectively in soil erosion control due to the communal nature of soil and water conservation technologies being implemented such as bench terraces and contour bunds. However, there were no significant gender differences in local knowledge of drivers of food insecurity.

5.3.5: Coping strategies employed during food insecure periods

Farmers employed three off-farm and five on-farm food insecurity coping strategies, which involved four approaches namely: rendering services off-farm for income (paid labour, engaging in petty trade), changing food consumption behaviours (taking fewer meals per day, eating less preferred food, reducing food portions per meal), social capital (relying on relatives) and sale of farm produce for income (tree products and livestock). The top three most frequently mentioned coping strategies employed by all farmers were: engagement in paid labour (55%), taking fewer meals per day throughout the year (39%) and eating less preferred food (22%).

The proportion of farmers mentioning certain coping strategies differed with degradation status. Farmers in the Restored landscape mostly reported engaging in paid labour to acquire additional income to buy additional food to supplement their food reserves, while others reported taking fewer meals per serving (Figure 5.8). On the other hand, farmers in the Recovering landscape mostly reported eating less preferred foods as sweet potatoes and amaranthus, when the preferred foods such as irish potatoes, beans and maize are not available. On the contrary, farmers in the Degraded landscape employed more widespread coping mechanisms.

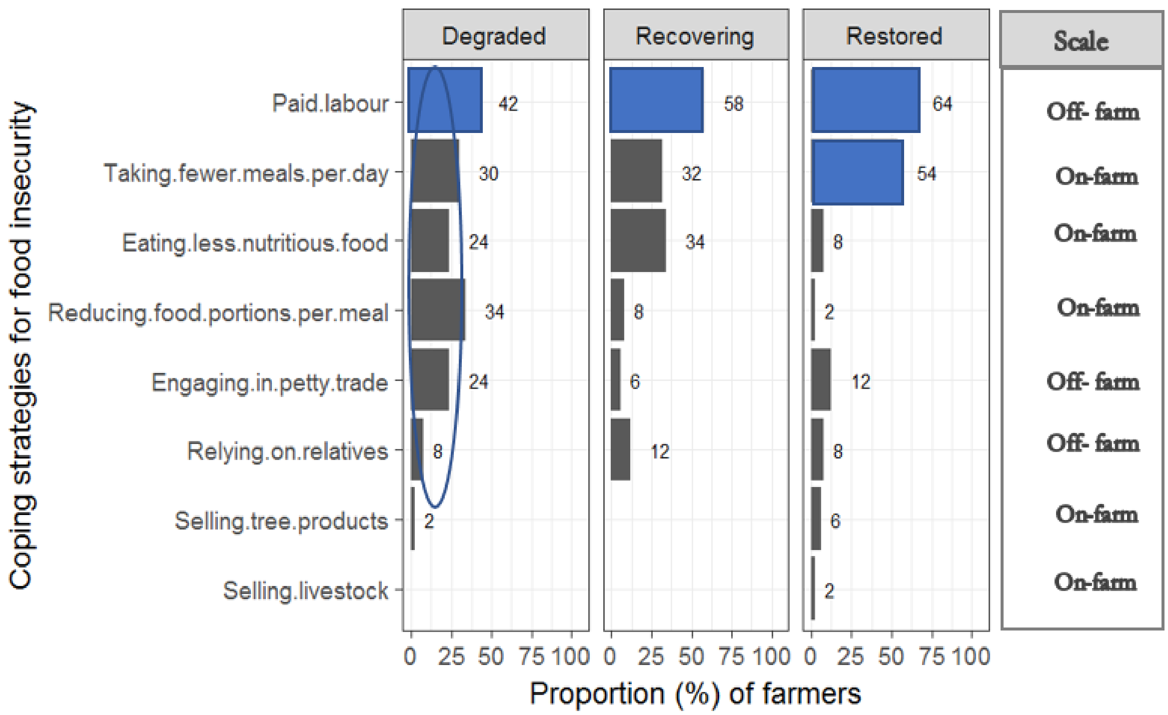

Figure 5.8: Coping strategies to food insecurity by land degradation status

5.4 DISCUSSION

5.4.1 Implications of crop specialization policies on food security and ecological resilience

Results in Figures 5.2 and 5.3 show that on farm annual crop diversity has decreased between 1995 and 2015, with some crops such as sorghum, peas and wheat disappearing from farms in Gishwati. Farmers blamed Crop Intensification Programme (CIP), one of the major agricultural reforms initiated in 2007 by the Rwandan government as the main cause of decreasing annual crop diversity. The main goals of the programme were to increase agricultural productivity in high-potential food crops (maize, wheat, rice, Irish potato, beans and cassava) and ensuring food security and self-sufficiency, across the entire country (Muhinda and Dusengemungu, 2011b).

Despite the policy increasing crop production for these priority crops, it has led to decreasing annual crop diversity due to promotion and intensification of only a few crops while other crops viewed as of 'low-value' are ignored (Cioffo et al., 2016). Decreased crop diversity led to food shortage in certain months of the year, which was mentioned as the most serious indicator of food insecurity as shown in Figure 5.4. As a result, 83 percent of farmers reported being food insecure. Rwibasira E., (2016) further notes that promoting high-value crops through CIP in Rwanda, a country where men dominate economic fronts, has led to alienation of women from crop production activities. Such form of skewed intensification has been reported in other countries including in Ethiopia (Shiferaw et al., 2014). Land shortage was reported as the second most serious driver of decreasing crop diversity and has been blamed for farmers specializing in high-value crops to maximize benefits from limited land (Makate et al., 2016).

The gradual abandonment of slow maturing crops such as sorghum was reported as one of the drivers of decreasing crop diversity (Linares, 2002). This leads to households being confined to consuming foods only a few food crops, which may have low nutritional and dietary value hence may lead to poor health (Burchi and Muro, 2016). Specialization in a few crops by the same population has been reported to cause low economic returns due to market competition (Byerlee et al., 2014). Other studies have indicated that intensification of certain high-value crops has led to gradual agricultural biodiversity loss leading to reduced resilience of agroecological systems (Barthel et al., 2013). This is because monocultures increase vulnerability of a system to adverse threats such as climatic variabilities, pests and diseases (Luedeling et al., 2014). Diverse systems are resilient because they provide year round products and ecological services (Turner et al., 2003).

Results from the seasonal calendar presented in Table 5.3 indicated that households that had higher crop diversity including perennials such as fruits were more food secure, especially during food-gaps when annual crops are unavailable. Studies indicate a positive co-relation between tree cover and dietary diversity because of availability of fruits and vegetables provided by trees (Ickowitz et al., 2014). On-farm perennial crop diversity was found to be increasing between 1995 and 2015, with the main drivers being increased access to quality germplasm and farmers acquiring tree propagation skills. This is mainly attributed to the introduction of participatory approaches that saw a move from the historical top-down seed and seedling sourcing, to a system where farmers are involved in tree species selection and have access to high quality tree germplasm and are continuously trained on tree propagation and management through ongoing initiatives such as the Trees for Food Security project , which the World Agroforestry Centre is leading.

5.4.2 The value of local knowledge in informing food security needs for heterogeneous systems

Results showed differences in various food aspects across the three landscapes namely: food crop diversity, food availability calendar; and variation in proportion of farmers mentioning various indicators of food security, drivers influencing food crop diversity, drivers influencing food insecurity and coping indicators to farmers. These findings go on to show that food security manifests in different ways in different context, with communities across the world having varying food consumption behaviours, farming practices and are affected by food insecurity differently (Kamwendo and Kamwendo, 2014). Food production heterogeneity could have also been influenced by bio-physical factors such as land degradation and soil nutrient availability, soil types, elevation and rainfall (Vlek, 2012). Other socio-economic factors include: size and age of household members, access to land (Grobler, 2016; Kuku et al., 2011). However, results showed no significant gender differences in drivers of crop diversity and drivers influencing food insecurity. This is contrary to authors who reported gender differences (Abebaw et al., 2010).

Five food security dimensions have been reported globally namely: food sufficiency, nutrient adequacy, safety, certainty and stability, and cultural acceptability (Coates, 2013). One of the main challenges facing global policy makers is not being able to meet all the five dimensions of food security which is mainly due to lack of clear and customized indicators or metrics to assess food security needs at the local level (Boratynska and Huseynov, 2016; Burchi and Muro, 2016). Food security programmes and policies should be multi-dimensional and aim at addressing food security indicators that manifest at the technology, market, institutional and policy levels (Barrett, 2008; Haen et al., 2011).

Due to the heterogeneity of smallholder farming systems, policy makers should ensure that they design food security policies informed by the local context (Coe et al., 2014). This should begin with gaining local understanding and knowledge of which measures are appropriate in each context including not only direct measures such as structural changes but indirect policy measures such as improving agricultural infrastructure, understanding the biophysical and socioeconomic, and providing farmers with new farm technologies (Berazneva and Lee, 2013). Also of importance is adapting food programmes to dynamic local indicators such as climate change; and where adaptation information is unavailable, policy makers should communicate such information to local communities (Thornton et al., 2018). Lack of multidimensional policy approaches guided by local food security gaps and needs lead to skewed, ineffective, unacceptable and inequalities.

5.4.3 Implications of off-farm food sourcing and coping strategies on system sustainability

Results in Figure 5.2 and 5.3 showed that a decrease in number of crops being grown by farmers between 1995 and 2015 or complete disappearance of some crops (sorghum, peas, wheat) that were being grown in 1995. This led majority of farmers outsourcing most of the annual and perennial crops in 2015 as shown in Figure 5.5. The implications of this trend is that over time, farmers became increasingly dependent on off-farm sources of food as demonstrated by Table 5.2. Further, Figure 5.8 showed that the main coping mechanism currently employed by all farmers when they are experiencing food insecurity is engaging in paid labour (55%). Similar trends of off-farm food sourcing and reliance on the market has been reported (Beyene, 2008; Deininger et al., 2014).

Some studies found that relying on off-farm food sources and income may have a positive effect on food security and nutrition through providing alternative sources of food especially when there are inevitable threats and uncertainties such as extremely poor and unproductive soils, climate change vulnerabilities in areas where populations depend on rain-fed agriculture or total crop failure due to pests and diseases (Babatunde and Qaim, 2010; Owusu et al., 2011). However, off-farm coping strategies have also been found to provide temporary fix-solutions to food insecurity and take farmers away from their farming system, hence less time and effort is available to restore land for future food production and is not sustainable in the long run (Bouahom et al., 2004).

There is also the looming challenge of decreasing average household land sizes resulting from population pressure. Land shortage was reported as a major driver of food insecurity and influenced crop diversity, with the overall average household land size being 0.3ha while in the Degraded landscape the average land holding was 0.15 ha. This leaves world's populations in a dilemma as to what point does land becomes too small to sustain food production and remain ecologically resilient (Henriksson et al., 2018; Mungai et al., 2016). Also, what are the options left for smallholders whose land is too small to produce enough food apart from relying on off-farm strategies. Therefore, this is a call to policy makers to have a local understanding of sustainable and appropriate mechanisms to adapt to land limitations (Holden and Yohannes, 2002b).

5.4.4 The role of agroforestry in building resilient and food secure systems

Results in Table 5.3 showed that fruit trees played a key role in filling the food gap during months of food insecurity when annual food crops were unavailable for consumption. Sale of other tree products such as timber, firewood and stakes for supporting climbing beans was also mentioned as one of the coping strategies employed by farmers as shown in Figure 5.8. This shows that having trees on farm is beneficial as trees provide numerous benefits through products such as fruits, vegetables, edible pulp, nuts; timber, fuel, fodder, and income (Jamnadass et al., 2011).

Agroforestry also plays indirect roles that help to promote ecological processes that support food production. These include: soil erosion control, soil nutrient cycling, pollination regulation, microclimate regulation, carbon sequestration and ground water recharge (Minang et al., 2014; Rosenstock et al., 2014; van Noordwijk et al., 2014). Integration of trees within farming systems therefore contributes to food security, poverty eradication and promotes livelihood and ecological resilience (Mbow et al., 2014). Systems with tree monocrops have been found to be less resilient and highly susceptible to various environmental threats such as climate variability, pests and diseases (Mbow et al., 2014). Therefore, ecological and livelihood benefits of trees are increased when there is more tree diversity and density on farms (Iiyama et al., 2017). This is because different tree species play unique roles in the system, both through provisioning ecosystem services or ecologically and products mature at different periods of the year (Carsan et al., 2014). For example, having more fruit tree species, whose fruiting phenology is varying means that fruits are available in different months of the year, hence continued access to products and income, which supplement annual food crop sources.

Studies have shown that effective scaling of agroforestry technologies in sub-Sahara Africa has been limited by various factors such as: lack of farmer participation and involvement throughout project phases from the design stage, lack of quality germplasm, and lack of tree management skills (Franzel et al., 2002; Kabwe et al., 2009). Other factors include: the inability of farmers to see tangible benefits of interventions which leads to low adoption and lack of access to markets (Bayala et al., 2010; Kiptot et al., 2007). Through initiatives from various organizations including the World Agroforestry Centre (ICRAF) through the Trees for Food Security Project, these challenges are being addressed. For example, there is a move from the conventional promotion of only a few tree species were being promoted through a top-down seed and seedling systems in Rwanda. Through participatory research approaches, farmers are now being involved in selection of diverse and inclusive tree species that suit their landscapes and needs (Dumont et al., 2017). Farmers are also provided with quality germplasm and equipped with propagation skills that promotes scaling of agroforestry across the landscapes. This is supported by Figure 5.2 and 5.3, which showed an increasing number of farmers planting tree crops in 2015 compared to 1995, attributed to access to quality germplasm (66%) and the training and skills they have received from the project on tree propagation, including grafting of fruit trees (34%).

Further, results showed that soil loss through erosion was mainly reported in the Degraded landscape where unlike other landscapes, farmers reported working individually (Kuria et al., n.d.). Scaling of agroforestry requires a move from working individually at the farm/ field level to working collectively at the landscape scale and beyond and working with multiple stakeholders (Sinclair, 2017). This is especially for ecological benefits such as soil erosion control and ground water recharge (Thornton et al., 2018). When the above constraints are addressed, coupled with the favourable conditions such as sloped terrain, high rainfall and collective action, there is great potential to scale agroforestry to enhance food security, thereby generating context-relevant multiple ecosystem services in Gishwati and Western Rwanda region in general.

5.5 CONCLUSIONS

Results show a decrease in annual crop diversity or complete disappearance of some crops between 1995 and 2015, mainly due to Crop Intensification Policy launched in 2007 which led to specialization in a few 'high-value' crops and consequently majority of farmers reporting being food insecure due to food shortage during certain months of the year (mainly July to November) when the high value crops were not mature for consumption. This highlights the importance of promoting on-farm diversification of crops including those viewed as 'low-value' to enhance ecological and livelihood resilience. Food insecurity during certain months of the year resulted in most farmers outsourcing annual crops hence over time and making them more dependent on the market because food produced on-farm supported farmers for only an average of 6.6 months annually in 2015 compared to 10.1 months in 1995, while the main coping mechanism currently employed by farmers when they are experiencing food insecurity was engaging in paid labour off-farm. This indicates a system gap whereby relying on off-farm food sourcing provides short-term quick-fix solutions that also takes the farmers away from their farming systems, which has far-reaching implications on future food production and sustainability. Despite not having gender differences, there were variations in proportion of mention of all food aspects across the three landscapes along a land degradation gradient, highlighting the need to customize food interventions to local context. Inversely, there was an increase in perennial crop diversity between 1995 and 2015, mainly due to access to quality germplasm and tree propagation skills, with farmers reporting that tree food crops played a key role in filling food gaps during 'food -insecure months, which indicates the role of agroforestry in meeting food security needs. Overall, the implications of this study is that food security policies should promote crop diversity as opposed to specialization in a few crops and should match food interventions to local context informed by local indicators to ensure the promotion of diverse and appropriate food interventions that enhance livelihood and ecological resilience of smallholder farming systems.

CHAPTER 6: SYNTHESIS AND CONCLUSIONS

This chapter synthesises the primary findings from the three data chapters (3, 4 and 5) and presents conclusions from the research. The local knowledge that informs the PhD was derived from detailed interviews with 395 farmers across two agro-ecologies (sub-humid and semi-arid) in two countries (Rwanda and Ethiopia) using a knowledge-based systems approach (Sinclair and Walker, 1998; Walker and Sinclair, 1998). The research used a paired-catchment experimental design (see Brown et al., 2005) and compared knowledge of farmers in landscapes with different land degradation and restoration status. The main aim of this research was to assess fine scale variation in local knowledge about land degradation and restoration and its importance for informing the development and promotion of land restoration options across scales from that of the field to whole landscapes.

The research generated the following three overall findings.

1. In landscapes affected by degradation, livelihood systems operate across broad landscape scales beyond the farm boundary and have wide spatial livelihood system boundaries. The local knowledge that informs livelihood decisions is informed by farmers' observations of scaling processes, which is particularly apparent in relation to soil dynamics, and food sourcing.
2. Local knowledge can be used to inform understanding about ecosystem service scaling processes (both spatial and temporal) associated with land degradation because it comprises information about how fine-scale contextual variations affect the performance of restoration options. It is also powerful in identifying critical knowledge gaps.
3. Local knowledge explains how farmers adapt and modify their land restoration interventions to better suit their needs and context; hence the acquisition and analysis of local knowledge provides an effective mechanism to track iterative development of adaptation measures and to evaluate both positive and negative consequences resulting from these actions.

These findings are discussed in detail below:

6.1 Farmers have detailed knowledge of scaling processes and system boundaries which complements scientific knowledge in filling gaps while designing land restoration options

The present research used a livelihoods approach (Mehring et al., 2017) to identify local priorities for ecosystems services which have been lost through land degradation and which can be recovered through restoration. The local knowledge derived from farmers demonstrate that farmers had detailed and sophisticated knowledge about ecosystem services that maintain their livelihood systems, and how land degradation affects this. For example, in Gishwati, Western Rwanda, farmers had detailed explanatory knowledge underpinning 12 indicators of soil quality which comprised 10 farm-level and two landscape scale indicators. For example, the location of a field along a slope; and, infiltration rate were important indicators mentioned by farmers in a degraded landscape, consistent with an underlying challenge of surface run-off along the slope and waterlogging downslope, respectively as a result of absence of soil erosion control interventions. This finding is critical because farmers knowledge of ecosystem service flows at scales beyond their own field, demonstrates that they are making observations about processes at larger scales, thereby developing understanding how soil health changes over time and landscapes dynamics in terms of flows of water and soil.

Farmers' local knowledge indicated that in both Ethiopia and Rwanda, the main direct driver of land degradation was loss of tree cover through deforestation, especially native tree species, which farmers associated with loss of critical ecosystem services such as: soil erosion regulation, ground water recharge and climate change; nutrient cycling, loss of food (including fruits and honey), timber and non-timber products. In Ethiopia, through historical timelines, farmers mentioned 57 tree species, comprising 38 native and 19 exotic species. However, the majority of native tree species have been completely lost from cropland and were only now found in the Orthodox church compounds where species such as *Lepidium sativum L*., *Parkinsonia aculeata, Schinus mole, Acacia brevispica, Albizia schimperiana, Hypoestes forskaolii* were still present. Other important multipurpose tree species are found in extremely low densities on farm such as *Olea africana/ europaaea subsp. Cuspidata* and *Cordia africana* (see Appendix 6). Similarly, in Rwanda, where farmers named 51 species (31 exotic and 20 native), important native tree species such as *Markhamia lutea* and *Juniperus procera* are also occurring in very low densities on farm (see Appendix 5). According to farmers, low tree cover not only leads to lack of products and services, but also threatens the future of such trees in their landscapes due to a lack of propagation material for future regeneration. Dumont et al., (2017) found that incorporating local knowledge led to the selection of more inclusive and diverse tree species.

Farmers also had in-depth knowledge of cause-effect interactions of drivers of land degradation across scales. In Rwanda, the national-scale 1994/1995 genocide was mentioned as the genesis of severe land degradation mainly through deforestation, while in Ethiopia, it was blamed on two regional drivers (war between Eritrea and Ethiopia and Orthodox religion) and three national drivers (national war, communal land tenure policy and land redistribution policy). Local knowledge acquisition, therefore, highlights context-specific entry points for interventions. In Ethiopia, besides the landscape scale and farm level effects of land degradation, farmers also reported indirect external effects such as outmigration of male labour to neighbouring and far away towns, which had negative effect on restoration efforts because fewer young men living locally led to lack of labour for proposed land restoration interventions, which contributed further to degradation. Similar effects of outmigration have been reported in Ethiopia, especially in drought-prone areas (Ezra and Kiros, 2006). The present research demonstrated that farmers had detailed and sophisticated local knowledge of land degradation processes, which provides an in-depth understanding that complements scientific knowledge in problem identification and needs assessment.

In Rwanda, farmers viewed climate regulation, and disease and pest regulation as originating beyond their immediate landscape. Results also indicated that over time, farmers have become more dependent on sourcing food from outside their farms as their own land has become degraded and less productive, with food produced on-farm supporting farmers for an average of 6.6 months annually in 2015 compared to 10.1 months in 1995. In 2015, farmers in a degraded landscape were more dependent on off-farm food sources (an average of 6.2 months) annually compared to those in a recovering landscape (4.2 months) and a restored landscape (5.7 months). This highlights the fact that as degradation occurred over time, farmers have greater reliance on resources outside the farm system.

Local knowledge also revealed that unlike in Rwanda, where there were no communal areas and no farmer mentioned cultural ecosystem services, farmers in Ethiopia which has both individual land and communal areas, including communal grazing areas, exclosures and church compounds which host rich native tree diversity, observed that land degradation affected ecosystem services that can be classified as belonging to all, including cultural ecosystem services. This has implications that local knowledge helps to understand the extent and interlinked nature of ecosystem services that support livelihoods across different scales and land use categories.

Local knowledge also revealed that farmers had knowledge of ecological roles that trees played. In both recovering and restored landscapes in Rwanda, farmers noted the role the trees they retained in their landscapes played in soil erosion control and maintenance of soil fertility such as: *Arundinaria alpina, Erythrina abyssinica, markhamia lutea, Alnus acuminata and Grevillea robusta*; while in a degraded landscape, where farmers neither retained trees nor incorporated tree biomass into their soil, low soil fertility was reported because of severe soil loss through erosion. Farmers also noted that farms with higher crop diversity (particularly perennial crops) were more food secure compared to farms with lower diversity. This was attributed to the fact that having higher crop diversity, including perennial crops such as fruit trees, provided year-round access to additional foods even at periods of the year when annual crops were not harvestable. Carsan et al., (2014) observed that systems that are diverse are more resilient ecologically and livelihood-wise.

Agroforestry practices played various roles in livelihood systems and explicit documentation of farmers local knowledge helped us to understand contextual factors and limitations that occurred across scales affecting agroforestry adoption. For example, in Ethiopia, farmers had in-depth knowledge of factors that influenced tree survival which occurred at different scales, namely: browsing by free grazing livestock, insecurity of land tenure, lack of quality germplasm, water shortage, lack of tree propagation and management skills and limited knowledge of the non-tangible ecological benefits of trees such as soil fertility improvement. In Rwanda, farmers blamed low adoption on the top-down government policy governing seed and seedling multiplication, lack of quality germplasm, lack of tree propagation skills, lack of tree management skills and shortage of land. Unless such limitations are addressed, scaling of agroforestry will remain a challenge (Bayala et al., 2010).

To address some of the challenges highlighted above, one of the novel contributions of the present research was the development of an innovative online tool ‘Associative Tree Species Selection and Management Tool for East Africa’ which targets a wider audience of users and makes it easy for users such as government extension officers and NGO development organisations to select a wide range of suitable tree species based on their utilities, reproduction, management, growth requirements and the field, farm and landscape niches in which they can be planted (Kuria et al., 2017). For example, the tool shows the multi-purpose uses of *Alnus acuminata* besides provisioning services (stakes for supporting climbing beans, timber, firewood, fodder, bee forage) to also include regulating services such as soil fertility improvement, and soil erosion control. The tool also provides biophysical requirements of tree species such as rainfall, temperature and soil types, propagation methods, seed shelf life, pre-sowing treatment, growth rate, management practices, germination rate, and leafing phenology. Providing such critical information equips users with the necessary skills to adopt and scale tree planting even at the individual level farmer level. The findings of this study were also instrumental in informing the establishment of Participatory Trials on tree biomass incorporation and soil erosion control, which the Trees for Food Security project is currently implementing with farmers beyond the study area and into neighbouring catchments.

This study also revealed that in Ethiopia, farmers defined land restoration as rehabilitation of already degraded land and not protection of non-degraded land, which has serious implications in that farmers will have a tendency to wait for land to be degraded before beginning restoration processes. It is more costly to restore degraded land than to avoid land degradation (Copeland et al., 2018), and it takes more time and resources to get a landscape back into a productive state the greater the degree of degradation (Stanturf et al., 2018). There is, therefore, a potential gain from land restoration implementers making farmers aware of the benefits of adopting restoration measures earlier in the degradation cycle, which would represent a profound change in both farmer knowledge and practice.

In chapter 2, knowledge was elicited about local indicators of soil quality through a novel combination of a systematic knowledge-based systems approach (AKT5) (Sinclair and Walker, 1998; Walker and Sinclair, 1998) and, a participatory knowledge integration and sharing approach for eliciting indicators of soil quality (InPaC-S) (Barrios et al., 2012). The process entailed not only farmers identifying, classifying and prioritizing local indicators of fertile and infertile soil and their associated local taxa and explanatory knowledge of their ecology, including behaviour, but also combining this with scientific collection and identification of indicator plant and soil macrofauna specimens (Eymann et al., 2010; Pelosi et al., 2009).

It was found that not only did the combination of the AKT5 and INPAC-S methodologies bring out comparability of local and scientific knowledge, which highlighted its reliability, but through farmers' own local observations and explanations, new ways of identifying fertile and infertile soils were discovered through, for example, observing the mobility and burrowing behaviour of *Dichogaster itoliensis* earthworm species. This research showed that local knowledge of earthworm behaviour was used by Rwandan farmers as an indicator of soil degradation hence earthworms could be used as a sensitive indicator in soil quality monitoring systems and highlights the benefits of combining both local and scientific methods to arrive at appropriate conclusions.

The present research also found that when conducting semi-structured interviews about, for example, local classification of soil types and indicators of fertile and infertile soil, the farmers tended to use comparison statements explicitly. For example, when comparing soil fertility status, farmers would explicitly talk about fertile soils being dark in colour while infertile soils are mostly light or yellowish. This contributed to the clarity of information gathered. Other aspects where farmers utilized comparison statements were on food secure and insecure months, high value versus low value crop diversity, fast growing versus slow growing crops and effect of elevation on crop selection. The implications of this finding is that it is often useful to elicit local knowledge using comparative discussion points grounded in what farmers can observe rather than more abstract forms of questioning that farmers may be less comfortable in answering.

6.2 Local knowledge can provide context-relevant information and identify knowledge gaps that help match land restoration options to context

This study also demonstrated that local knowledge can be used to inform understanding about scaling processes (both spatial and temporal) associated with land degradation and subsequent land restoration through providing context-specific knowledge, and identify knowledge gaps that help match land restoration to context as demonstrated below.

Through paired-catchment experimental design which was applied throughout this study, it was revealed that local knowledge differed with context, including in relation to geographical locations and the degradation status of landscapes. For example, while farmers in sub-humid Rwanda mentioned 28 and 23 indicator plants for fertile and infertile soils respectively and were able to observe earthworm behaviour that signified different levels of land degradation, farmers in the semi-arid Ethiopia had limited knowledge of indicator plants; although the plants were physically present on the soil. In addition, farmers in Rwanda had knowledge of 12 and 10 soil macrofauna taxa found in fertile and infertile soils respectively, while farmers in Ethiopia had no knowledge of specific soil macro-organisms as indicators of soil quality. This shows that local resource users have different approaches to identifying local soil degradation challenges and capacities to address them, highlighting the need to understand the local context including knowledge held by resource users in order to identify appropriate entry points for land restoration.

In Rwanda, through temporal food security status comparison between in 1995 and 2015, there were variations across landscapes of different degradation status in the cropping calendar, number of farmers who viewed themselves as being food insecure, indicators of food insecurity, the number of farmers who mentioned particular indicators of food insecurity, drivers of crop diversity, food insecurity indicators and associated drivers, and coping mechanisms during food insecure periods. Despite these variations, the national Crop Intensification Programme (CIP) initiated by the government in 2007 which aimed at improving agricultural productivity of high-potential priority food crops (Eric and Kumar, 2015), prescribed similar crops across the entire region. Farmers noted that the CIP not only led to decreasing annual crop diversity and the disappearance of low-value crops such as sorghum, peas and wheat which played a role in the food calendar of farmers back in 1995; but it also led to food insecurity due to food shortage from July to November when the priority crops were growing in the fields but not yet harvestable. The implications of this study is that policies should promote diverse options informed by heterogeneity of local context, to ensure that interventions are locally-relevant and meet the needs of farmers in a particular area.

The present research found that different actors often had different knowledge, which was apparent particularly with regard to gender. For example, in Rwanda, local knowledge revealed significant gender differences of two out of 12 indicators of soil quality whereby significantly more male farmers had knowledge of crop vigour and soil organic matter than female farmers. Gender differences were also found about five out of seven soil management practices, in that significantly more female farmers used crop residues than male farmers, but significantly more male farmers practiced: tree biomass incorporation, retention of scattered trees on farm, application of livestock manure and chemical fertilizers than female farmers. Similarly, in Ethiopia, local knowledge also revealed that land degradation and restoration was defined differently by different stakeholders based on watershed, land degradation status, gender and land-use category. Gender differences in indicators of land restoration and values and preferences, were also found, where male farmers mostly valued income-oriented and cultural benefits while female farmers valued indirect well-being benefits. Gender differences have also been reported (Christie et al., 2016). The implications of these findings is that soil management practices should be matched with local indicators of soil quality, while gaps in knowledge also influence the extent of adoption and success of restoration options and may need to be addressed as part of extension efforts.

Some context-specific knowledge gaps were also revealed, which could potentially influence uptake of interventions in certain areas because farmers lack of knowledge means that they do not understand or acknowledge that a challenge exists, or they may not see the relevance of interventions being recommended for their farms. For example, farmers in Ethiopia only viewed bees as a source of honey hence had limited knowledge of some regulating ecosystem services such as: they had no understanding of the association of bees with pollination of crops and subsequent role of bees in food production. Limited knowledge of ecological processes has also been reported elsewhere (Winowiecki et al., 2014). This highlights the need to ensure that resource users have wider knowledge and understanding of the diverse contribution of ecosystem services to their livelihoods, which will act as an incentive towards their adoption of restoration interventions.

In Rwanda, though farmers had knowledge of physical and biological indicators of soil quality, they had limited knowledge of chemical indicators except soil organic matter. For example, in the degraded landscape where no famer mentioned soil organic matter as being an indicator of soil quality, none practiced tree biomass incorporation. On the contrary, in the recovering and restored landscapes where farmers had knowledge of soil organic matter, they were incorporating tree biomass as a soil management practice.

In Ethiopia, farmers who were part of on-going projects were more knowledgeable about land restoration processes and the functions of restoration interventions such as soil bunds in soil erosion control compared to non-project farmers. One of the lessons learnt is that there is need to include non-project farmers in sensitization and knowledge-sharing processes in order to equip them with the required knowledge to successfully scale land restoration activities. I observed that identifying what farmers know and knowledge gaps that resource users have is critical in order to address such gaps because if communities do not have an understanding of the relevance of proposed interventions, they are not likely to accept and adopt them. It is imperative to first understand the knowledge gaps in the design of interventions, which will inform the nature of empowerment required for them to be locally adapted and adopted.

6.3 Local knowledge can be used to adapt and modify interventions to suit local context thus increasing the success and sustainability of land restoration interventions

From local knowledge acquisition, this research demonstrated that farmers adapt and modify land restoration interventions to suit their needs and context. This is mainly because restoration activity is largely instigated by external actors (as in the case studies presented here). It follows that land restoration technologies are usually based on landscape level understanding (increasingly informed by remote sensed data, and very rarely seeks to 'ground truth' those decisions with local knowledge. This study showed that understanding local knowledge is likely to influence the success of land restoration interventions, as farmers adapt interventions to suit local context. Understanding the knowledge that underpins these decisions is critical to assess the efficacy of these changes against the original objectives and to understand how contextual factors condition suitability of options relevant to scaling out options to new geographies.

Through talking to farmers who are already implementing land restoration interventions in the semi-arid agro-ecology of Ethiopia, the present research revealed that where a particular restoration option was deemed necessary but was not fully suited for the local context, farmers had ingenious and innovative ways of modifying and adapting the options to suit these contextual factors, derived from continuous experimentation and observations. For example, in areas where deep trenches were recommended as restoration options, but farmers' fields were mainly comprised of clay soils, farmers constructed additional drainage channels to reduce waterlogging thereby attaining the restoration goal of trapping water and soil interception through deep trenches. The explanatory nature of farmers' local knowledge including the reasons for the modifications they made to introduced interventions, uncovered understanding about complex system dynamics. Through their every-day observations, they were able to not only assess the re-emergence of desired ecosystem services but also track the challenges that may hinder success of land restoration interventions.

This kind of local experimentation and modification although acknowledged in some literature on degradation (Sinclair and Walker, 1999), has rarely been acted upon in restoration initiatives (Crossland et al. 2018), this research presents a novel approach to incorporating local knowledge in development action that can be applied by development agents, extensionists and scientists to monitor and adapt various technological options to suit local context.

The present research found that the acquisition and analysis of local knowledge provides mechanisms to track adaptation of restoration activities and to evaluate both positive and negative consequences. This research, therefore, demonstrates the significant contribution that local knowledge can play in informing project and development activities, which implies that local stakeholders should be involved throughout the project cycle to ensure local adaptation. This calls for the use coupling of bottom-up and top down knowledge exchange (Sinclair, 2017), where extension and development agents maintain a regular and close co-learning and feedback with farmers in order to observe and learn from the system dynamics that lead to interventions being locally adapted, effective and sustainable.

This study also revealed that local knowledge influenced practice and intervention activities across scales. For example, in Rwanda, local knowledge of farmers on indicators of soil quality influenced the soil management practices they adopted. For example, farmers who had knowledge about soil organic matter incorporated tree biomass unlike those who did not have knowledge pf soil organic matter. Also, farmers' assessment of soil quality also had an influence on the types of crops they grew on their land; whereby they mostly planted low-value crops such as beans and sweet potatoes on soils they perceived as being of low fertility while crops perceived to be of high-economic value such as Irish potatoes and maize was mainly grown in areas perceived as being fertile.

The implications of these findings are that matching crops to soil fertility levels acted as a disincentive to restoring degraded and infertile soils as farmers opted to plant crops that required less nutrients instead of working towards improving the fertility of such soils. The research also revealed that farmers adapted to food insecurity periods especially from July to November when 86% of farmers experienced food insecurity through consuming perennial crops (including fruit tree crops) thereby filling 'food gaps'. Farmers also relied heavily on off-farm food sources (mainly paid labour) during food insecure months, which may have adverse long-term implications on smallholder systems. This is because off-farm coping mechanisms provide unsustainable short-term solutions take the farmers away from their farming system, hence no effort is made towards restoring degraded land to make it productive in future.

Gender influenced the adoption of land restoration interventions. For example, some land restoration options in Ethiopia that involved soil excavation such as deep trenches, moisture retention micro-basins and soil bunds were not widely adopted by women farmers as they were found to be labour intensive. This highlights the fact that gender differences may require policy makers and development agents to understand and devise innovative ways of adapting socio-ecological systems to generate various and diverse ecosystem services to meet the needs of the different stakeholders. However, unlike in the previous studies (Dah-gbeto and Villamor, 2016; Mallick, 2010), I found no significant gender differences in coping strategies for food insecurity. The contrasting findings call for initial gender analysis while implementing programmes to assess whether gender-specific interventions are required and if so, design interventions that are responsive to gender-specific needs or challenges.

Acquisition of local knowledge also revealed that the smallholder farming systems are highly dynamic, which calls for adaptive land restoration interventions to suit the changing context. For example, in Ethiopia, farmers' knowledge showed that land restoration in some cases involved converting the utility or functions of one land-use category to another based on restoration goals and generation of preferred ecosystem services. For example, extremely degraded free-grazing lands where farmers could graze all year round were converted into exclosures under controlled cut and carry system by restoration implementing agents; while some restored exclosures were converted to crop fields. This therefore involved trade-offs between the different land-uses, which calls for new adaptive strategies to manage trade-offs and enhance synergies amongst land-uses. In Rwanda, farmers mentioned decreasing average household farm sizes, coupled with the emerging effects of climate change; which calls for innovative restoration approaches that ensure the system is productive meets the needs of the resource users while enhancing the ecological resilience of their livelihood systems.

The study also highlights that since local knowledge influences farmers' management practices and decisions including adaptive practices, there is need to equip farmers with knowledge and understanding of concepts being promoted (Davis and Mekonnen, 2012), in order to influence their practices (Sinclair and Walker, 1999), which enhances the adoption and sustainability of interventions.

CONCLUSIONS

Across the three chapters of this thesis, it has been demonstrated that smallholder farmers have detailed and explanatory knowledge about ecosystem services that their livelihoods depend on, which complements scientific knowledge through providing in-depth understanding about complex and context-specific system dynamics. This included the identification of a new method that farmers in Rwanda use through observing *Dichogaster itoliensis* earthworm behaviour as an indicator of soil quality. In both Ethiopia and Rwanda, it was demonstrated that in landscapes affected by degradation, livelihood systems operate across broad landscape scales beyond the farm boundary and have wide spatial livelihood system boundaries, and the local knowledge that informs livelihoods is informed by farmers' observations of scaling processes, which is particularly apparent in relation to soil dynamics and food sourcing. The extent of local knowledge that smallholder farmers have about ecosystem services varies with the scale at which they manifest. Farmers knowledge is context-specific hence it provides information about how fine-scale contextual variations context affect suitability of different restoration options and reveals knowledge-gaps. As a result, it can be used to inform understanding about ecosystem service scaling processes (both spatial and temporal) that could influence the adoption and success of land restoration interventions across scales. The present research revealed that prescription of blanket policies and programmes such as Rwanda's national Crop Intensification Programme that promotes a narrow crop diversity across heterogeneous context was a major driver of food insecurity. This study also contributed to an innovative online associative tree species selection tool that addresses major bottlenecks while adopting and scaling agroforestry as a solution to land restoration and food security. The present research also showed how the relationship between local knowledge and practice is important in determining how local knowledge can be used in the management of ecosystem services. In Ethiopia, farmers identified 12 contextual factors that influenced the suitability of land restoration interventions, with farmers modifying and adapting the options to suit their needs and context. The findings provide new knowledge that advances the role of local knowledge in promoting the 'options by context' approach to 'research in development' (Coe at al., 2014). Local knowledge provides cost-effective mechanisms to monitor and track adaptation of restoration activities (including positive and negative consequences), which are initially based on landscape level understanding that is often not locally informed. Overall, this study concludes that local knowledge can usefully inform land restoration options across scales. One of the next steps will be to explore farmers' local adaptation and modification of land restoration to suit context for a wider range of interventions across varying geographical locations and agro-ecological zones, and how this knowledge can be incorporated to make restoration interventions more context- appropriate, effective and successful.

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APPENDICES

Appendix 1: Questionnaire for Chapter 2 - Local knowledge of indicators of soil quality in Gishwati, Western Rwanda

Section A: Farmer Details

1. Questionnaire ID:……… Date…..:………..
2. Sector………………..…..Cell……………………..…
   Village……………………..………..
3. Name……………………………………..………..…………. Gender……….....
4. Age ………… Family size…….……..……
5. Farm/Field location along a slope. [Downslope], [Mid slope], [Upslope]
6. Marital status: [1]. Married, [2]. Single, [3]. Widowed, [4]. Separated/ divorced,
7. Household type: [1]. Male-headed [2]. Female-headed
8. Education level of household head: [1]. No formal education, [2].Primary, [3]. Secondary, [4]. Tertiary
9. Education level of wife: [1]. No formal education, [2].Primary, [3]. Secondary, [4]. Tertiary
10. HH Head Occupation: [1]. Farming only [2]. Farming & petty trade [3]. Farming & casual labour, [4] Farming & formal employment.
11. When did you move to this village [1]. Native, [2]. Year …………………
12. Place of origin……………………………………
13. Why did you move here? [1]. Was born here, [2]. Married, [3]. Relocated by government, [4].Bought land, [5]…..
14. Total household Farm size…………………………………………………
15. Location of parcels…………………………………………
16. Number of parcels….……………..…..
17. How land was acquired:[1]. Inherited……….., [2]. Owned-bought……..…, [3]. Rented…….., [4]. Others …………………

Section B: Soil Quality details

1. Which Soils do you have in your farm/ fields (use local names):
2. Where are each of the soils located on your farm?

3. What are the characteristics of each of the soils you mentioned?
4. Can you classify your land / parts of your soil as degraded or non-degraded?
5. How does soil degradation occur?
6. Which crops do you grow on each of the soil types? Are the crops grown on all soil types similar or different? Give reasons.
7. What indicators to you use to categorize soil as good soil?
8. What indicators do you use to classify soil as bad soil?
9. Which are the: good soils in your farm? ……………………………………
10. Which are the bad soils in your farm ……………………………
11. (*If the farmer mentioned indicator plants*), mention specific indicator plants that signify fertile or infertile soils.
12. (*If the farmer mentioned soil macrofauna*), mention specific soil macrofauna that signify fertile or infertile soils.
13. Do you currently manage soils in your farm?
14. If Yes, what are your current soil management practices?
15. Why do you apply each of the specific soil management practice?
16. Is there an indicator of soil quality that you had mentioned earlier that the soil management practice you have mentioned aim to address? If yes, how?
17. Do you have any questions?

Appendix 2: Questionnaire for Chapter 3- Focus Group Discussion on Land degradation and restoration on local knowledge of land degradation and restoration in Samre, Tigray, Ethiopia

Date ……………………. Location of the site …………………….
Woreda……………………….. Village………………..…..Sub-catchment ………………

Section A: Drivers and impacts of land cover change and land degradation

Methodology: FGDs- Historical Timelines

1. How do farmers and other resource users define land degradation?
2. What are the indicators of a healthy (non-degraded) and unhealthy (degraded) land?
3. What are the external and internal drivers of land degradation and land-use change?
4. At what scales do they describe the drivers?
5. What are the impacts of land degradation on farmers' livelihoods?

Methodology: FGD –Livelihoods and Ecosystem Flow Mapping

How does land degradation impact on the livelihoods of farmers, including ecosystem service generation across scales? (Here I will discuss 2 scenarios- Past (will discuss with farmers after discussing historical timelines of events on the reference year) and then compare with the present

Output: *Before and after livelihood mapping*

Section B: To assess whether there are variations in local knowledge and practice of land restoration along different landscapes and land degradation gradients

1. What is land restoration, and at what scales should interventions be implemented?
2. What land restoration activities are being employed on the different landscapes conditions?
3. At what levels (individual, communal) are the land restoration activities being carried out? And why?
4. How do farmers assess these land restoration activities in terms of success and effectiveness?
5. Which areas of the landscape and farms are most degraded?
6. What land restoration practices are farmers currently involved in?
7. How are you as farmers involved? What roles do you play in restoration activities?

8. What land management goals are these practices aimed at achieving? Such as: prevent initial degradation, prevent further land degradation, restore system functions or adaptive (coping) such as crop management and adaptation to degradation?
9. Which additional land restoration activities and interventions should be implemented, but are not yet implemented?
10. What is the role of trees and management in land restoration?
11. Do you have any questions?

Appendix 3: Questionnaire for Chapter 3- household interviews on local knowledge of land degradation and restoration in Samre, Tigray, Ethiopia

SECTION A: FARMER DETAILS

Interview Number: …………………………………… Date……………………….

GPS Coordinates: Elevation………… Latitude….……. Longitude…………….

Name…………………………….. Gender …..… Age………

Marital status: [1]. Married, [2]. Single, [3]. Widowed, [4]. Separated/ divorced,

Household type: [1]. Male-headed [2]. Female-headed

Education level of household head: [1]. No formal education, [2].Primary, [3]. Secondary, [4]. Tertiary

Education level of wife: [1]. No formal education, [2].Primary, [3]. Secondary, [4]. Tertiary

HH Head Occupation: [1]. Farming only [2]. Farming & petty trade [3]. Farming & casual labour,

Number of land parcels…… Distance from the homestead to the farthest land parcel……….

Total land size…….. Labour source …………………………

Livestock types and numbers….. Bee keeping?......Yes/ No..(number of hives)......................

Household water pond?............. Household compost pit?....... Individual grazing enclosure?.....

Crops grown?..

Tree species and niches………………..

SECTION B: To identify drivers of land cover change and land degradation and impacts on farmer's livelihoods.

1. Describe Soil types and other biophysical characteristics eg slope for each the land parcel
2. Which soil type is more prone to erosion and degradation?
3. Would you categorize your land/ each parcel of land? *Land degradation categories*: degraded (unproductive), degrading (decreasing productivity), no change (no change), restoring (gradual increase in productivity) and restored (increased and stable productivity)
4. Which factors / indicators/reasons for your categorizations above?
5. If degraded or degrading, what types of land degradation is your land experiencing?

6. If degraded, are there activities you used to do on your land or you still do that you think could be contributing to degradation?
7. Do/ did actions or lack of action by other farmers' activities of other farmers in the community and landscape affect your farm/s?
8. Where is the source of your livelihood all year round: food, fruits, fuel, water, fodder, timber,...?
9. Has this changed from 5 to 10 years ago? If yes, what has changed?
10. How did you cope with decreasing land productivity? grew different crops, grew fewer crops, abandoned crop cultivation, fallows,

SECTION C: To assess the extent to which the current land restoration options match local site context and farmer circumstances

1. Which parts and locations of the landscape are the most important to your livelihoods? And why?
2. How are you benefiting or have you benefited from restoration activities in cropland/ exclosures?
3. Which are the most important parts of your farm/ landscape? And why?
4. Which are the least important parts or land parcels? And why?
5. Which landuse categories are on which land parcel/ parts of the farm discussed above? Why?
6. What soil and water conservation practices are you carrying out in the most important and least important parts or parcels of your land?
7. Are you employing similar land restoration on all lands: degradation categories, soil type/ status, slope status, land parcels close or far away from home?
8. What factors determine which restoration activities you implement where?
9. Which individual soil management activities are you employing on each farm parts/parcels? E.g *Composting, Mulching, tree biomass, livestock manure, chemical fertilizer, agroforestry tree species?*
10. Which individual land restoration interventions on each farm location/ parcel?
11. Which externally- initiated interventions on each farm location/ parcel?

12. What is the frequency or manner of managing land restoration structures and interventions? *Continuous, separate or integrated, during ploughing, during weeding, regularly etc?*
13. Water harvesting? Household pond? Source of water and distance of collection?.........................

SECTION D: To explore successes and identify gaps and opportunities for successful and sustainable land restoration activities

1. Do you feel you have benefitted/ are benefitting from the exclosures?
2. How have these land restoration interventions in your cropland benefitted you?
3. How would farmers rate the success/performance of each land restoration interventions on each of the landuse categories? *e.g. very successful, not successful, no change etc…*
4. If successful or unsuccessful, what factors have contributed to this?
5. What are the priority land restoration options that needs on your farm that to be addressed?
6. Landuse and livelihood diagrams- who is responsible for each of the landuse categories and production functions
7. Who is responsible for the implementation / management of each of the land restoration activities?*(Gender roles in land restoration and the management of restoration structures)*
8. What are the challenges have you faced/ are you facing during design, planning, implementation of each of the restoration activities?
9. What are you doing to overcome those challenges?
10. Are there priority restoration interventions which you would be interested in trying out?
11. On which priority parts/parcels of your land would you implement these interventions? Why?
12. Are there additional skills or any form of assistance that you would require to enable you to successfully implement these initiatives?
13. Any Questions?....

Appendix 4: Questionnaire for chapter 4- local knowledge on food security and crop diversity along a land degradation gradient

SECTION A: SOCIAL DATA

1. Questionnaire ID:……… Date…..:………..
2. Farm/Field location along a slope. [Downslope], [Mid slope], [Upslope]
3. Sector……………….…..Cell……………………..…
   Village…………………..……….. Name………………..… Gender……….….. Age ………… Family size……..……..……
4. Marital status: [1]. Married, [2]. Single, [3]. Widowed, [4]. Separated/ divorced,
5. Household type: [1]. Male-headed [2]. Female-headed
6. Education level of household head: [1]. No formal education, [2].Primary, [3]. Secondary, [4]. Tertiary
7. Education level of wife: [1]. No formal education, [2].Primary, [3]. Secondary, [4]. Tertiary
8. HH Head Occupation: [1]. Farming only [2]. Farming & petty trade [3]. Farming & casual labour, [4] Farming & formal employment.
9. Total household Farm size…………………………………………………Location of parcels………………………………………
10. Number of parcels….………….…….. Time taken to reach the furthest parcel from homestead………………..……………
11. How land was acquired:[1]. Inherited……….., [2]. Owned-bought……..…, [3]. Rented…….., [4]. Others …………………

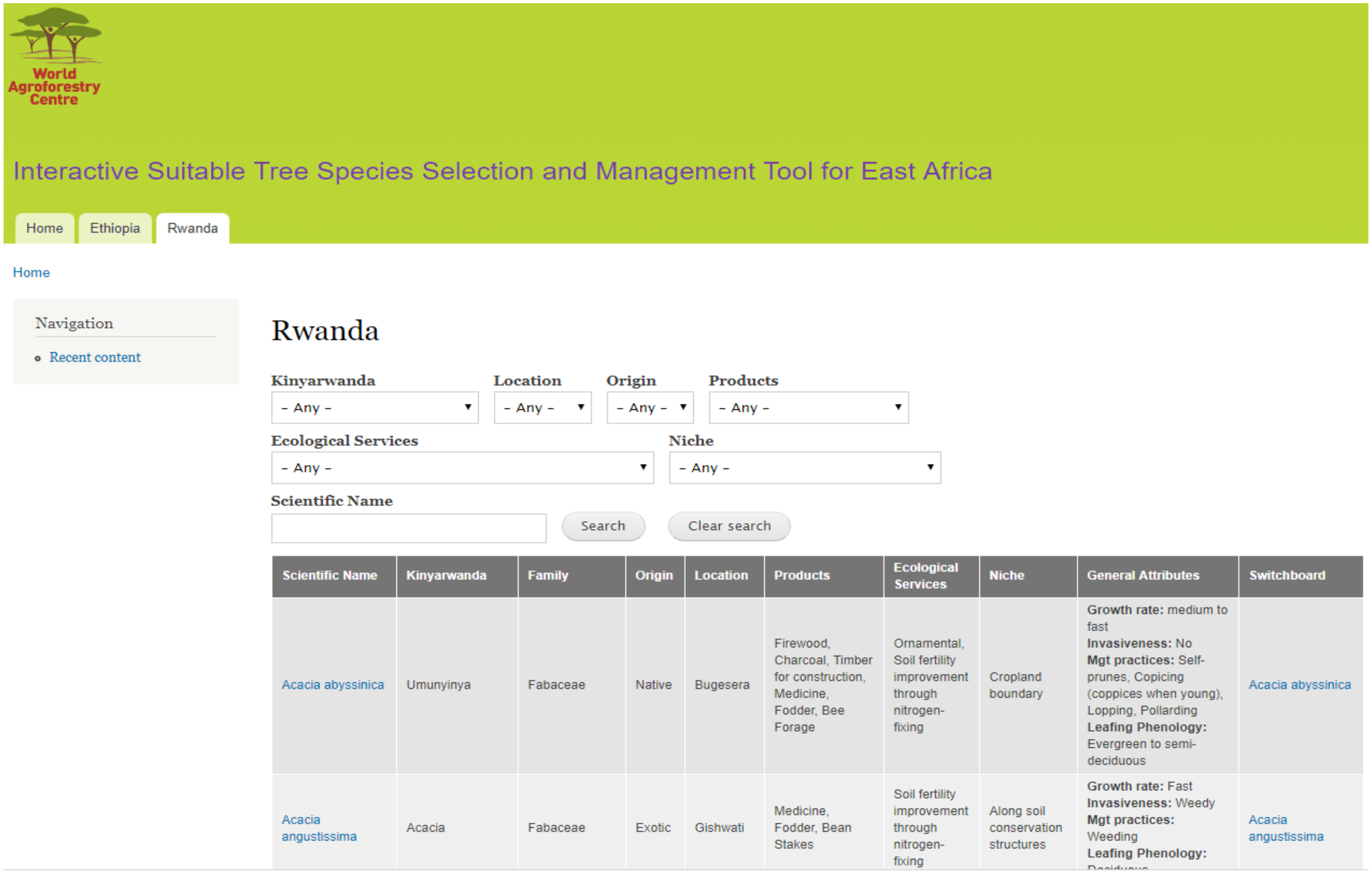
SECTION B:

12. Which crops did you grow in your farm around 1995/ when you moved to this area
13. What proportion of the food you consumed was derived from each source? [1]. Onfarm ……….%, [2]. Buying from neighbours. ……...%, [3]. Borrowing from neighbours……....%, [4]. Market ………..%, [5] Borrowing from relatives……., [6]……………………
14. Has the diversity of crops grown on your farm changed between 1995 and 2015?
15. If yes, how has the trend changed and what are the reasons/ factors for this trend?

16. Are there crops that have disappeared or are reducing from this area over time? [1]. Yes, [2]. No, [3] Don't know.
17. If Yes, which crops are affected and what reasons might have contributed to their disappearance or reduction in cultivation?
18. Are there crops that you never used to grow or were being grown at a low quantity , which are currently being grown in more amounts?
19. If Yes, which crops are affected and what reasons might have contributed to their increasing cultivation?
20. Which food has your household been consuming in the past 1 year?
21. Which of these foods do you grow on your farm?
22. What proportion of the food you consume do you get from each source? [1]. Onfarm…………….%, [2]. Market…..…..%, [3]. Borrow from neighbours …..…..%, [4]. Borrow from relatives………..%, [5] Lake, [6]……………………………………………%
23. When are each of the crops grown available for consumption?
24. Do tree crops play a role in your diet/ food security? If yes, What roles?
25. Which crops grown in your farm are also bought from the market or supplemented from off-farm sources?
26. If you sell food, how much income do you get per year/ in the last year?.[1]. Beans..……….……..…Rwf,
27. [2]. Irish potatoes……………..…..….Rwf, [3]……………..………….Rwf, [4]. …….………..………Rwf, [5]. …………..…….………Rwf,
28. Food insecurity is a serious problem in my home? [1]. Strongly agree, [2]. Agree, [3] Neutral, [4] Disagree, [5] Strongly disagree
29. What does food insecurity mean (what are the indicators of food insecurity)?:
30. What factors contribute to food insecurity?
31. How do you cope with food insecurity?

Appendix 5: An extract of the web-based 'Interactive Suitable Tree Species Selection and Management Tool for Rwanda'

The tool can be found on: http://www.worldagroforestry.org/suitable-tree/rwanda



World Agroforestry Centre

Interactive Suitable Tree Species Selection and Management Tool for East Africa

Home | Ethiopia | Rwanda

Home

Navigation

- Recent content

Rwanda

Kinyarwanda: - Any -
Location: - Any -
Origin: - Any -
Products: - Any -
Ecological Services: - Any -
Niche: - Any -
Scientific Name:

Search | Clear search

Scientific Name	Kinyarwanda	Family	Origin	Location	Products	Ecological Services	Niche	General Attributes	Switchboard
Acacia abyssinica	Umunyinya	Fabaceae	Native	Bugesera	Firewood, Charcoal, Timber for construction, Medicine, Fodder, Bee Forage	Ornamental, Soil fertility improvement through nitrogen-fixing	Cropland boundary	**Growth rate:** medium to fast **Invasiveness:** No **Mgt practices:** Self-prunes, Copicing (coppices when young), Lopping, Pollarding **Leafing Phenology:** Evergreen to semi-deciduous	Acacia abyssinica
Acacia angustissima	Acacia	Fabaceae	Exotic	Gishwati	Medicine, Fodder, Bean Stakes	Soil fertility improvement through nitrogen-fixing	Along soil conservation structures	**Growth rate:** Fast **Invasiveness:** Weedy **Mgt practices:** Weeding **Leafing Phenology:**	Acacia angustissima

Appendix 6: List of tree species farmers mentioned – the Interactive Suitable Tree Species Selection and Management Tool for Rwanda

					PRODUCTS															ECOLOGICAL SERVICES									NICHES						
Scientific Name	Kinyarwanda Language	Family	Origin	Income	Fruits	Other Foods	Firewood	Charcoal	Timmber for furniture	Timber for construction	Farm tools	Household tools	Medicine	Fodder	Bee Forage	Bean Stakes	Tannins/Dyestuff	Gums/Resins	Fibre	Ornamental	Live fence	Dead fence	Shade	Soil erosion control	Soil fertility improvement through nitrogen-fixing	Soil fertility improvement through mulch/ leaves	Riverbank stabilization	Wind break	Cropland boundary	Scattered in cropland	Scatterd in homestead	Homestead boundary/live fence	Woodlot	Along soil conservation structures	Lake/ river shores
Acacia angustissima	Acacia	Fabaceae	Exotic										x	x		x									x									x	
Acacia mearnsii	Barakatsi	Fabaceae	Exotic				x			x				x	x		x			x			x	x	x				x		x				
Acacia melanoxylon	Acacia	Fabaceae	Exotic				x			x				x						x			x	x	x			x		x	x				
Alnus acuminata	Alinusi	Betulaceae	Exotic	x			x			x	x		x	x	x	x								x	x	x		x						x	
Alnus glutinosa	Arunusi	Betulaceae	Exotic	x			x			x					x	x							x	x	x			x				x		x	
Alnus nepalensis	Arunusi	Betulaceae	Exotic	x			x	x	x	x				x		x	x						x	x	x			x						x	
Annona muricata	Mustaferi	Annonaceae	Exotic	x	x		x						x							x											x				
Yushania alpina/ Arundinaria alpina	Umugano	Gramineae	Native	x		x	x		x	x	x	x				x				x		x		x	x						x		x		
Bothriocline glomerata	Igihehe	Asteraceae	Native						x				x							x									x						
Bersama abyssinica	Umukaka	Melianthaceae	Native				x	x		x		x	x							x			x							x					
Camelia sinensis	Ichayi	Theaceae	Exotic	x		x	x																							x					
Carica papaya	Ipapaya	Caricaceae	Exotic	x	x								x																		x				
Carica cundinamarcensis	Ipapaya y'umusozi	Caricaceae	Exotic		x																										x				
Casuarina equisetifolia	Filaho/ Umubuunda	Casuarinaceae	Exotic				x	x		x	x			x			x			x			x	x	x			x	x		x	x			
Citrus limon	Indimu	Rutaceae	Exotic	x	x		x			x			x		x					x											x				
Citrus sinensis	Icunga	Rutaceae	Exotic	x	x		x						x							x										x	x				
Coffea arabica	Ikawa	Rubiaceae	Exotic	x		x			x					x	x											x				x					
Cupressus lusitanica	Sipure	Cupressaceae	Exotic	x			x	x	x	x						x				x	x		x					x	x		x	x			
Cupressus sempervirens	Sipure	Cupressaceae	Exotic						x				x					x		x			x						x			x			
Cyphomandra betacea	Ikinyomoro	Solanaceae	Exotic	x	x	x	x																							x	x				
Croton megalocarpus	Umunenge	Euphorbiaceae	Native				x	x	x	x			x		x					x			x									x			
Discopodium penninervium	Ikijojo	Sapindaceae	Exotic				x				x			x							x					x	x				x	x			
Dombeya goetzenii	Umukore	Sterculiaceae	Exotic				x	x		x	x		x		x				x				x			x				x				x	

Scientific Name	Kinyarwanda Language	Family	Origin		PRODUCTS															ECOLOGICAL SERVICES									NICHES						
				Income	Fruits	Other Foods	Firewood	Charcoal	Timmber for furniture	Timber for construction	Farm tools	Household tools	Medicine	Fodder	Bee Forage	Bean Stakes	Tannins/Dyestuff	Gums/Resins	Fibre	Ornamental	Live fence	Dead fence	Shade	Soil erosion control	Soil fertility improvement through nitrogen-fixing	Soil fertility improvement through mulch/ leaves	Riverbank stabilization	Wind break	Cropland boundary	Scattered in cropland	Scatterd in homestead	Homestead boundary/live fence	Woodlot	Along soil conservation structures	Lake/ river shores
Dracaena afromontana	Umuhati	Dracaenaceae	Exotic										x	x							x				x						x	x			
Erythrina abyssinica	Umuko	Papilionoideae	Native	x			x			x		x	x	x	x	x				x	x			x	x	x	x		x	x	x	x			
Eucalyptus globulus	Inturusu/ ruvuvu/salinya	Myrtaceae	Exotic	x			x	x		x			x	x	x	x												x			x	x	x		
Eucalyptus maculata	Inturusu	Myrtaceae	Exotic	x			x	x		x		x	x	x	x	x												x	x		x	x	x		
Eucalyptus saligna	Salinya	Myrtaceae	Exotic	x			x	x		x		x	x	x	x	x												x	x		x	x	x		
Euphorbia candelabrum	Umuduha	Euphorbiaceae	Native				x			x			x									x								x		x			
Ficus thonningii	Umuvumu	Moraceae	Native				x						x	x		x		x	x	x	x		x	x						x		x			
Grevillea robusta	Gereveriya	Protaceae	Exotic	x			x	x		x	x			x	x	x				x	x		x	x		x		x		x	x	x	x		x
Hagenia abyssinica	Umugeshi	Rosaceae	Native																											x	x				
Jasminum eminii	Umuhotora	Oleaceae	Native							x			x																	x					
Juniperus procera	Umubunda	Cupressaceae	Native				x			x			x			x				x	x		x					x	x			x			
Macaranga kilimandscharica	Umurara	Euphorbiaceae	Native				x		x				x																	x					
Malus domestica	Pome	Rosaceae	Exotic	x	x																										x				
Manihot glaziovii	Igiticy'isombe	Euphorbiaceae	Exotic	x		x							x	x	x					x			x			x			x	x	x	x			
Markhamia lutea	Umusave	Bignoniaceae	Native	x			x	x		x		x	x		x	x				x			x	x	x	x			x	x					x
Mitragyna rubrostipulata	Umuzibaziba	Rubiaceae	Native				x			x			x																						
Morus alba	Iboberi	Moraceae	Exotic		x		x				x			x	x					x	x		x	x						x	x				
Persea americana	Avoka	Lauraceae	Exotic	x	x		x	x		x				x									x	x				x		x	x	x			
Pinus patula	Pinusi/ Umubunda	Pinaceae	Exotic	x			x	x	x	x			x					x		x			x	x				x		x	x				
Polyscias fulva	Umwungo	Araliaceae	Native				x		x		x	x			x	x				x										x					
Psidium guajava	Ipera	Myrtaceae	Exotic	x	x		x				x	x											x		x					x	x			x	
Ricinus communis	Ikibonobono	Euphorbiaceae	Native				x						x																	x	x				
Solanum aculeastrum	Intobo	Solanaceae	Native																		x							x				x			
Syzygium parvifolium	Umugote	Myrtaceae	Native		x		x	x	x	x	x	x	x	x			x						x							x					
Tithonia diversifolia	Umuravumba	Asteraceae	Exotic										x	x						x	x					x			x			x			
Vernonia amygdalina	Umubilizi	Asteraceae	Native				x						x	x	x					x	x					x			x	x		x		x	
Vernonia auriculifera	Igaragara	Compositae	Native																										x			x			
Vernonia myriantha		Compositae	Native																										x			x			

Appendix 7: An extract on biophysical profile of tree species mentioned by farmers in Gishwati, Rwanda

Tree species (scientific name)	Agro ecological zone	GROWTH REQUIREMENT				GENERAL ATTRIBUTES				REPRODUCTION				
		Altitude (m.a.s.l)	**Rainfall (mm)**	**Temperature (^{0}C)**	**Soil**	**Growth rate**	**Management practices**	**Invasiveness**	**Leafing Phenology**	**Propagation Methods**	**Seed dispersal mode**	**Germination rate**	**Seed Shelf life**	**Pre-sowing Seed treatment**
Acacia angustissima	unknown	0-2600	895-2870	5 to 30	well adapted to free draining acidic, infertile soils and shows an excellent drought tolerance	Fast	Weeding	Weedy	Deciduous	Seedlings, cuttings	unknown	Medium(55 days)	unknown	Scarification
Acacia mearnsii	All zones	300-2440	500-2050	9 to 20	Flourishes in deep, well drained, light textured and moist soils. It thrives in well-aerated, neutral to acid soils, loamy soils, soils derived from shale or slate and is highly intolerant of alkaline and calcareous soils. Soils with lateritic pan close to the surface are most unsuitable	Fast	Weeding , thinning , pruning	Yes	Evergreen	Seeds , Direct sowing , seedlings ,suckers	Animals, wind, water	Fast-after pretreatment	Long (more than 23 years)	Scarification , soaking in hot water
Acacia melanoxylon	Midlands to Highlands	1500-2300	750-2300	16 to 19	Grows best in rich, saline, deep, fertile loams, forest Podsols and alluvials. It also grows on a wide range of Podsols, krasnozems, sandy loams and alluvials and will also tolerate wet, nearly swampy soil	Fast	Coppicing,lopping	Yes	Evergreen	Seedlings	Animals	Medium(63 days)	Long (20 years)	Immerse in boiling water, allow to cool
Alnus acuminata	Midlands to Highlands	1 200-3 800	1000-3000	4 to 27	Prefers deep, well-drained soils with high content of organic matter. Commonly found growing on shallow soils such as landslides. It will grow on soil of pH as low as 4.5	Fast	Thinning, weeding	No	Deciduous	Seedlings, cuttings	unknown	unknown	Short (3-6) months	Not necessary
Annona muricata	Lowlands to Midlands	0-1150	>1000	25 to 30	Prefers loose, fairly rich, deep loams with a pH range of 5.5-6.5	Slow	unknown	No	deciduous	Seedlings, transplants	Animals	unknown	Long	Not necessary
Apodytes dimidiata	All zones	0-2400	unknown	unknown	unknown	Slow	unknown	unknown	Evergreen	Seedlings,wildlings	unknown	Long (4-12 month	unknown	Not necessary
Arundinaria alpina	Highlands	2000–4000	800-3000	14–17	Well-drained humus-rich soil on gentle slopes and in ravines, with space for vigorous rhizome development, allows luxuriant growth	Very fast	Management is mainly limited to harvesting of natural stands, undertaken by area rather than by clump	No	Evergreen	Rhizomes, seedlings	unknown	unknown	unknown	unknown

Appendix 8: List of tree species that farmers named in Samre, Ethiopia (most of them have been lost)

Scientific Name	Tigrinya Name	Family	Origin	STUDY AREA			PRODUCTS															ECOLOGICAL SERVICES								NICHES								
				Bara (Maytekli Watershed)	Endagiorgis Waza Watershed	Endamariam (Waza watershed)	Income	Fruits	Other Foods	Firewood	Charcoal	Timmber for furniture	Timber for construction	Farm tools	Household tools	Medicine	Fodder	Bee forage	Tannins/Dye stuff	Gums/Resins	Fibre/Ropes	Ornamental	Live fence	Dead fence	Shade	Soil Erosion control	Soil fertility improvement	Riverbank stabilization	Wind break	Scatterd in homestead	Homestead boundary/live	Woodlot	Along soil bunds	Along Bench Terraces/ Stone	Along Gullies	Along Rivers	Church compound	Exclosures
Acacia saligna	Akacha	Fabaceae	Exotic	x	x	x	x			x			x				x			x			x		x	x	x		x						x	x		x
Argemone mexicana L.	Medafe tilian	Papaveraceae	Exotic		x	x																																
Arundo donax	Shamboko	Poaceae	Exotic		x	x																				x									x			
Azadirachta indica	Nim/Limo	Meliaceae	Exotic	x	x	x			x	x	x		x			x	x	x				x			x				x	x								
Carica papaya	Papayo/ Papaye	Caricaceae	Exotic		x	x	x	x										x												x								
Casuarina cunninghamiana	Shewshewe	Casuarinaceae	Exotic	x						x	x		x				x					x			x	x			x									
Eucalyptus camaldulensis	Keyih Qelamitos	Myrtaceae	Exotic	x	x	x	x			x	x		x	x	x			x				x	x	x	x	x			x	x								x
Eucalyptus globulus	Tseada	Myrtaceae	Exotic	x	x	x	x			x	x	x	x	x		x		x				x	x	x	x	x			x	x								x
Grevillea robusta	Grevillea	Proteaceae	Exotic	x			x			x	x	x	x	x			x	x				x			x	x	x		x									x
Helianthus annuus	Shof bahari	Asteraceae	Exotic		x	x			x									x																				
Jasminum abyssinicum	Habbi-tselim	Bignoniaceae	Exotic	x						x			x	x				x				x			x											x	x	
Lepidium sativum L.	Shenfa/ Shanfa	Brassicaceae	Exotic	x		x																															x	
Malus domestica	Apple	Rosaceae	Exotic	x	x	x	x	x																						x								
Mangifera indica	Mangus	Anacardiaceae	Exotic	x		x	x	x		x								x				x			x				x	x								
Nicotiana glauca R. Graham	Tambush/ mengededo	Solanaceae	Exotic		x	x				x																x									x		x	x
Parkinsonia aculeata	Shewit Hagay	Fabaceae	Exotic			x												x								x											x	
Persea americana	Avocado	Lauraceae	Exotic	x			x	x									x												x	x								
Psidium guajava	Zeitun	Myrtaceae	Exotic		x			x		x				x	x										x					x								
Schinus molle	Tikur Berbere	Anacardiaceae	Exotic	x		x	x		x	x	x		x	x	x	x	x	x				x	x		x	x			x	x							x	
Acacia abyssinica	Che-a	Fabaceae	Native	x	x	x				x	x		x	x	x		x		x	x				x	x	x		x	x					x	x		x	x
Acacia brevispica	Qonteftefte	Fabaceae	Native	x	x	x				x						x	x						x								x			x			x	
Acacia etbaica	Seraw	Fabaceae	Native	x	x	x				x	x		x	x		x		x					x	x	x	x				x				x	x		x	x
Acacia oerfota	Gomero	Fabaceae	Native			x				x	x		x	x			x				x		x		x				x								x	
Acacia polyacantha	Gumero	Fabaceae	Native			x							x	x			x								x				x								x	
Albizia schimperiana	Sassa	Fabaceae	Native	x			x			x	x		x		x		x	x							x	x											x	
Aloe Barbadensis	Ere	Asphodelaceae	Native	x		x										x		x								x					x				x		x	
Becium grandiflorum	Tebeb	Lamiaceae	Native	x	x	x				x								x												x				x	x	x	x	
Calpurnia aurea	H'tsawts	Papilionoideae	Native	x			x			x			x	x		x		x				x	x		x	x			x	x	x				x		x	
Carissa spinarum	Agam	Apocynaceae	Native	x	x			x		x	x		x	x	x	x	x					x	x	x	x	x		x	x					x	x	x	x	

Scientific Name	Tigrinya Name	Family	Origin	STUDY AREA			PRODUCTS															ECOLOGICAL SERVICES								NICHES								
				Bara (Maytekli Watershed)	Endagiorgis Waza Watershed	Endamariam (Waza watershed)	Income	Fruits	Other Foods	Firewood	Charcoal	Timmber for furniture	Timber for construction	Farm tools	Household tools	Medicine	Fodder	Bee forage	Tannins/Dye stuff	Gums/Resins	Fibre/Ropes	Ornamental	Live fence	Dead fence	Shade	Soil Erosion control	Soil fertility improvement	Riverbank stabilization	Wind break	Scatterd in homestead	Homestead boundary/live	Woodlot	Along soil bunds	Along Bench Terraces/ Stone	Along Gullies	Along Rivers	Church compound	Exclosures
Cirsium dender	Dander	Asteraceae	Native	x																															x	x	x	
Cordia africana	Awh'i / Ekhi	Boraginaceae	Native	x	x	x	x	x		x	x	x	x	x	x	x	x	x				x	x		x	x	x	x	x	x							x	
Croton macrostachyus	Tambuk	Euphorbiaceae	Native	x	x	x	x	x		x	x		x	x	x	x	x	x				x	x		x	x		x	x								x	
Dodonaea angustifolia	Tahses	Sapindaceae	Native	x						x				x		x	x	x				x			x	x									x		x	
Euclea schimperi	Kulea-o/ Kuliew	Ebenaceae	Native	x	x	x				x								x								x		x		x	x		x	x	x	x	x	x
Euphorbia candelabrum	Kulkual	Euphorbiaceae	Native	x		x							x					x					x								x						x	x
Euphorbia tirucalli	Kinchib	Euphorbiaceae	Native		x	x	x									x				x			x								x						x	
Faidherbia (Acacia) albida	Momona	Fabaceae	Native	x	x	x				x			x	x	x	x	x							x	x	x	x	x	x	x				x	x		x	x
Ficus vasta	Da'ro/ Da'ero	Moraceae	Native			x		x		x	x		x	x	x		x					x			x	x	x		x								x	
Hypoestes forskaolii	Girbia	Acanthaceae	Native		x												x	x																x			x	
Juniperus procera	Tsihdi/ Tsehedi	Cupressaceae	Native	x						x		x	x			x						x	x		x	x			x	x						x		
Justicia schimperiana (Hochst ex. Nees)	Smieja	Acanthaceae	Native			x										x																					x	
Leucas abyssinica (Benth.) Briq.	Sewa Kemi/ Swa kami	Lamiaceae	Native	x		x												x					x			x								x	x	x	x	
Maytenus arbutifolia	Atat	Celastraceae	Native			x				x				x			x						x	x													x	
Maytenus senegalensis	Qebqeb	Celastraceae	Native	x	x	x				x	x					x	x	x					x	x	x	x				x	x			x	x		x	
Myrsine africana L.	Kechemo	Myrsinaceae	Native	x		x																															x	
Olea africana/ europaaea subsp. cuspidata	Awuli-e	Oleaceae	Native	x	x	x				x	x	x	x	x	x	x	x	x				x	x		x	x		x	x	x							x	
Opuntia ficus-indica	Beles	Cactaceae	Native	x	x	x		x									x						x			x					x						x	
Pennisetum purpureum	Saeri harmaz	Poaceae	Native		x												x									x												
Rhamnus prinoides	Gesho	Rhamnaceae	Native	x	x	x	x		x							x														x		x						
Rhus natalensis	TeTa'lo	Anacardiaceae	Native		x	x				x	x			x	x		x									x											x	
Ricinus communis	Gulei	Euphorbiaceae	Native		x	x	x		x							x							x						x	x								
Rumex nervosus	H'eh'ot	Polygonaceae	Native	x	x	x																				x					x		x	x	x	x	x	x
Senna singueana	Hambo hambo	Fabaceae	Native	x	x	x				x													x			x		x		x	x				x	x	x	
Sesbania sesban	Sasbanya	Fabaceae	Native	x	x	x				x			x	x			x									x	x						x	x	x			
Syzygium guineense	Li'ham	Myrtaceae	Native	x		x	x	x		x	x	x	x	x		x		x	x	x			x		x	x			x	x	x				x		x	
Terminalia brownii	Weyba	Combretaceae	Native		x	x																															x	
Ziziphus spina-christi	Giba/Geba/	Rhamnaceae	Native	x	x	x	x	x		x			x	x		x							x	x		x	x			x				x	x		x	