Sustainable Land Management in Dynamic Agro-Ecosystems

An Integrated, Multi-Scale Socio-Ecological Analysis in Western Kenya Highlands

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Thesis

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Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1 Background

Nature-economy-society interactions are complex. Much research is focused on understanding their inter-relationships to design sustainable systems that would guarantee better inter-temporal human well-being (WCED 1987). Population increase and unsustainable resource use have been cited as key 'limits to [economic] growth' that need to be overcome through the systematic application of better technologies (Meadows et al. 1972, Rotmans 2005). The pessimistic Malthusian and the optimistic Boserupian hypotheses have presented contrasting broad outlooks. Both views continue to elicit scientific debate concerning the prospects for sustainable development with a rising world population (Boserup 1965, Hayami and Ruttan 1985, Lee 1986, Ruttan and Thirtle 1989, Lambin 2012). According to the United Nations (2011), world population is projected would rise with almost three billion people by the year 2050. Given this demographic prospect, sustainable growth to meet the increasing human needs should remain a central paradigm that drives the global and regional development agenda (Barbier and Markandya 1990, Daly 1994, Ayres et al. 1997). Among the environmental challenges to sustainable development is land degradation, an ancient problem that agrarian societies grapple with over time (Roose 1996). This human-environment struggle across generations is well-captured by Roose (1996): "Since the Earth first appeared.... human beings have pitted themselves against erosion, trying to defend their lands..." However, Lowdermilk (1948) found historical evidence that shows "failures are more numerous than successes." The Greeks are believed to be the earliest to recognise land degradation. Roose (1996) argues that land degradation started receiving scientific attention after the experience of the 1930's Dust Bowl in the United States of America. Empirical research on soil conservation to address land degradation is therefore recognized to have started in 1939 by the Bennett-led Soil Conservation Service.

Land degradation is affecting rural livelihoods across sub-Saharan Africa (Bationo 2004). Total population of sub-Sahara Africa (SSA) is rising rapidly— having grown from about 186 million in 1950 to around 390 million in 1980 and over 856 million people in 2010 (United Nations 2011). Even the most conservative projections indicate that SSA's population will rise to at least 1.7 billion people by the year 2050 (United Nations 2011). Many individual countries are also facing increasing population growth rates ranging between 2.4% in Mozambique and 4.4% in Zimbabwe (CIA 2012, World Bank 2013). It is essential therefore to increase land productivity from the available agro-ecosystems, given these population prospects and the reality that SSA is the only region in the world where *per capita* food consumption continues to decline (Clover 2003, Lambin et al. 2003).

Unfortunately, persistent land degradation limits such progress owing to its role in declining productivity, food insecurity and rural poverty in this region (Nkonya et al. 2009, Jayne et al. 2010). Unrelenting land degradation is driven by multiple interlinked socio-economic and environmental factors (Reardon and Vosti 1995, Knowler 2004, Hein and Fileccia 2007, Lobell et al. 2008). Land degradation accelerated by rising population pressure on land in developing countries poses challenges to sustainable resource use, poverty alleviation and rising food production (Morton et al. 2006, Pacheco 2006). To satisfy food needs for the growing population in many SSA countries requires a rapid increase of agricultural production balanced with provision of essential ecosystem services.

It is often claimed that rising rural population densities lead to improved land management and intensification of agricultural production (e.g. Tiffen et al. 1994, Pender 1998), but supportive evidence that process towards Sustainable Land Management (SLM) is taking place in densely populated areas across SSA countries is scanty (Tiffen et al. 1994, Grepperud 1996, Crowley and Carter 2000, Pender et al. 2006a, Giller et al. 2009). Yet investment in promotion of SLM strategies has the potential to reverse land degradation and improve agricultural productivity as population rises in these regions (Hurni 2000a). Nevertheless, Reardon et al. (1999) argue that past development programs aimed at reducing land degradation and increase agricultural productivity in many SSA regions have achieved only mixed results. The low success rate for such programs has called to recognize the significance of the unique biophysical, climatic, demographic and socio-economic contexts in SSA regions (Roose 1996). Even then, there is lack of comprehensive studies investigating how the interplay of these components influences the likelihood of successful application of SLM technologies in dense agro-ecosystems of Africa.

1.1.1 Land degradation challenge in the East African highlands

The East African highlands continue to experience widespread declining land productivity due to various forms of land degradation such as soil erosion, soil nutrient depletion, deforestation and biodiversity loss (Lambin et al. 2001, Pender et al. 2006b). This adversely affects agricultural production as well as the supply of a range of ecosystem services from the existing natural resources (MA 2005). For instance, ecosystem services provided by tropical forests are becoming scarcer due to continued deforestation as demand for forest benefits increases with the growing population (Lambin et al. 2003, Morton et al. 2006). Whereas land degradation is acknowledged as a key contributor to poverty and food insecurity (Reardon and Vosti 1995), SLM strategies have not however received priority consideration in the development plans of East African countries (Yesuf et al. 2005). Studies elsewhere have found that proper application of SLM practices reduces land degradation and improves productivity of ecosystem services within the targeted ecosystems (Hurni 1999, Lefroy et al. 2000, Schwilch et al. 2011). Investment in SLM practices therefore has the potential to reverse land degradation and improve agricultural productivity in the degrading highland regions of SSA. This is because the SLM approach integrates the socio-economic and ecological systems for maximum synergy that enhances long-term productivity of land while sustaining ecosystem services supply to improve human well-being (Bouma 1997).

According to the World Bank (2006a), SLM is "a knowledge-based [process] that helps integrate land, ..., biodiversity and environmental management ... to meet rising food and fibre demands while sustaining ecosystem services and livelihoods." Hence, SLM concerns with the long-term maintenance of the productive potential of agricultural lands and the better use of forest ecosystems for improved social welfare (Hein and Fileccia 2007). In this study, for operational purposes, SLM constitutes a set of improved technologies and or better practices to enhance land productivity, increase on-farm returns and forest benefits than what is currently achieved (Hurni 2000a). The locally available SLM practices for the farming system include the application of farm yard and compost manure, use of inorganic fertilisers and improved crop varieties, incorporation of crop residues and inter-cropping with legumes (Ojiem et al. 2004, Ojiem et al. 2006, Place et al. 2006, Shisanya et al. 2009). Other SLM practices are soil and water conservation (SWC) measures such as terraces, cut-off drains, grass strips (Nyangena and Köhlin 2008) and agro-forestry practices (e.g. improved fallows and hedge rows) (Jama et al. 2008). SLM strategies for the forest ecosystem include the promotion of farm agro-forestry, sustainable planting and harvesting regimes for plantations, rehabilitation of natural forest stands and protection of riparian vegetation (KFE 2012). As such broad application of SLM practices is indispensable in meeting the increasing demands for ecosystem services provision and food needs of a growing population.

1.1.2 Problem statement

Despite the implementation of several SLM projects during the past decades (Mansuri and Rao 2004, Pender et al. 2006b), empirical evidence shows that poor farm productivity remains the most important contributor to food insecurity in the East African region (Bationo 2004). Broader adoption (i.e. scaling-up) of SLM practices therefore has not yet been achieved. Scaling-up refers to "bringing more quality benefits to more people over a wider geographic area more quickly, more equitably and more lastingly" (IIRR 2000). Therefore, how can broader application of available SLM practices be fostered in degrading and densely populated highland agro-ecosystems?

The apparent inability to successfully address land degradation in a holistic manner is attributed to various important hurdles, including poor grasp of crucial barriers and system interactions (Ojiem 2006, Giller et al. 2009, Odendo et al. 2009, Guto 2011) as well as the often strict disciplinary analytical approaches. Empirical findings based on such foundations cannot be expected to support broad decision-making and wider application of promising SLM practices across multiple scales (Dumanski et al. 1998, Zeleke and Si 2006). Among the essential requirements for promoting broad application of SLM practices is to gain comprehensive insights into the complex interactions and dynamics between socio-ecological systems across multiple spatial and temporal scales (Hurni 2000a). Evaluation of prospects for promotion of SLM practices therefore requires a systems approach analysing key interactions between local stakeholders, their resource endowment and allocation in relation to changes in land resources and productivity (Smyth and Dumanski 1995, Barbier 2000, Steiner et al. 2000, Fernandes and Woodhouse 2008). Such systems approach integrating socio-ecological analysis has not been fully explored in the context of fostering SLM practices within densely populated agro-ecosystems in SSA. For example, there is a need to understand the land use system, its spatial variability and temporal dynamics, and the impacts on rural livelihoods. Only when changes in socio-ecological systems and multi-scale impacts of land degradation are known and are being considered in an active multi-stakeholder process can the broad promotion of SLM practices be expected to take place. Fostering the application of SLM practices requires the understanding of the crucial linkages between ecosystems, ecosystem services supply and human well-being from the farm household to the landscape level. Such integrated and multi-scale investigation to enhance Sustainable Land Management and improve social welfare has not been conducted in Kenyan highlands.

I address the identified empirical gap and contribute to enhanced promotion of SLM practices through application of an integrated socio-ecological analysis at multiple spatial scales (micro, meso and macro levels) and temporal scales (short, medium and long terms) to generate comprehensive systems knowledge aimed at fostering Sustainable Land Management. I choose to conduct systems analysis in one of the most densely populated rural areas in SSA where land degradation is a reality and several SLM programs have been implemented with varying degrees of success. I follow a multi-scale, trans-disciplinary approach to enhance broad acceptability and applicability of my research findings (MA

2003). Moreover, I investigate the crucial role played by local stakeholders in the implementation of SLM practices and how to enhance collaboration in order to promote wider application of SLM practices. This is the first known integrated, multi-scale socio-ecological systems analysis conducted in Africa in general and regarding land degradation problem in particular. My novel research approach and findings are therefore relevant for policies and programs aiming to promote SLM practices in the wider perspective of enhancing African rural development. The systems information I present in this thesis avails strong evidence to decision-makers on the urgency of the land degradation problem and how to enhance effective implementation of SLM policies and practices. This understanding provides new practical insights essential for better promotion of SLM programs and for the design of relevant public policies. Key decision-making processes across scales would be better driven based on a better understanding of the problem and possible opportunities to scale-up SLM practices. This knowledge is essential in creating conducive local conditions and identifying synergistic policy intervention areas at different spatial and institutional levels to facilitate wide-scale use of available SLM practices.

1.2 Research objectives and questions

This study aims to analyse interactions between socio-economic and ecological systems at multiple spatial and temporal scales to support the promotion of Sustainable Land Management practices in the western Kenya highlands.

1.2.1 Specific objectives

In this study, I endeavoured to achieve the following four specific objectives:

1) To analyse farm diversity and resource use efficiency of different farm types and their implications for SLM practices in the western highlands of Kenya.
2) To estimate local economic benefits from key ecosystem services provided by the Kakamega rainforest and examine how the information can support sustainable forest management in Kenya.
3) To analyse trends of land-use change and their impacts on agrarian livelihoods in the western highlands of Kenya.
4) To assess the prospects for fostering a transition towards Sustainable Land Management through enhanced multi-actor, multi-scale collaboration in the western highlands of Kenya.

1.2.2 Research questions

The following research questions guided the implementation of this study to achieve the study objectives:

1) How does livelihood diversity and farm production efficiency influence agricultural productivity and farmers' likelihood to implement SLM practices in the western highlands of Kenya?
2) Are the local economic benefits from ecosystem services provided by the Kakamega rainforest sufficient to support sustainable forest management?
3) What are the implications of land-use dynamics and population growth on agrarian livelihoods in a changing agro-environment in the western highlands of Kenya?

4) How can multi-level stakeholders be organised and their diverse interests harmonised to promote wide-scale application of SLM practices in the western highlands of Kenya?

1.3 Study area

Biophysical characteristics: The study focussed mainly on Vihiga District[1] covering 563 km^2 and the Kakamega rainforest located in Western Province of Kenya (Figure 1-1). The district is characterised by gently rolling hills and valleys, sloping from West to East. Altitude ranges from 1300 to 2100 m above sea level. It lies between longitudes 34°30′ to 35°0′ East and latitudes 0°0′ to 0°5′ North. Rugged granitic hills such as Maragoli, Nyangori and Bunyore dominate the Southern part of the district (Government of Kenya 2004). The district has two major rivers: Yala and Esalwa. The permanent rivers rely on a network of streams and tributaries that drain into Lake Victoria, though they face pollution from agro-chemical, industrial and urban effluents (Government of Kenya 2010). Vihiga District experiences an Equatorial climate with adequate rainfall on average 1900mm per year. Rainfall distribution is bimodal with distinct long rainy season (March – June) and short rainy season (September – November). The minimum temperature is 14 °C and the maximum is 32 °C, with a mean of 23 °C. Common soils are the deep and well drained Acrisols covering 95% of the district (Jaetzold et al. 2007). The average farm size is 0.6 hectares on which mixed crop and livestock farming is practiced. The common soils are Acrisols, which are well drained and deep covering 95% of the district area. The district has two major agro-ecological zones: Upper Midland (UM), a high potential tea-coffee zone and Lower Midland (LM), a maize-bean-sugar cane zone (Jaetzold et al. 2007).

Socio-economic characteristics: Agriculture is the most important land use in the district, followed by forestland, built-up areas and bare land. The land in agricultural and forest uses provide important ecosystem services that sustain the livelihoods of the inhabitants as well as the ecological system in the district. Over 75% of the land area of Vihiga District is arable. Average farm size is 0.65 ha on which mixed crop and livestock farming is practised. The main farming systems in the district reflect the two major agro-ecological zones namely Upper Midland (UM), a high potential tea-coffee zone and Lower Midland (LM), a maize-bean-sugar cane zone (Jaetzold et al. 2007). Major food crops grown include maize, beans, bananas, potatoes and sorghums while tea, coffee and sugar cane constitute the main cash crops. Most cattle are local zebus with some improved dairy cows.

The district has Mudete Tea Factory and good infrastructural network with tarmac and all-weather roads. Different local businesses and government agencies are located in urban centres at Mbale, Luanda, Emuhaya and Hamisi. Some residents are employed in the existing institutions as teachers, nurses, administrators and general workers. Whereas others run home-based small businesses such as shops, flour milling, vehicle and motorbike transportation and retailing in agricultural produce.

[1] During this study, the original geographical boundary of Vihiga District was subdivided into 4 districts namely Emuhaya, Hamisi, Sabatia and Vihiga. Since 2010, the original Vihiga District was renamed Vihiga County. However, in this thesis we choose to use Vihiga District instead of Vihiga County.

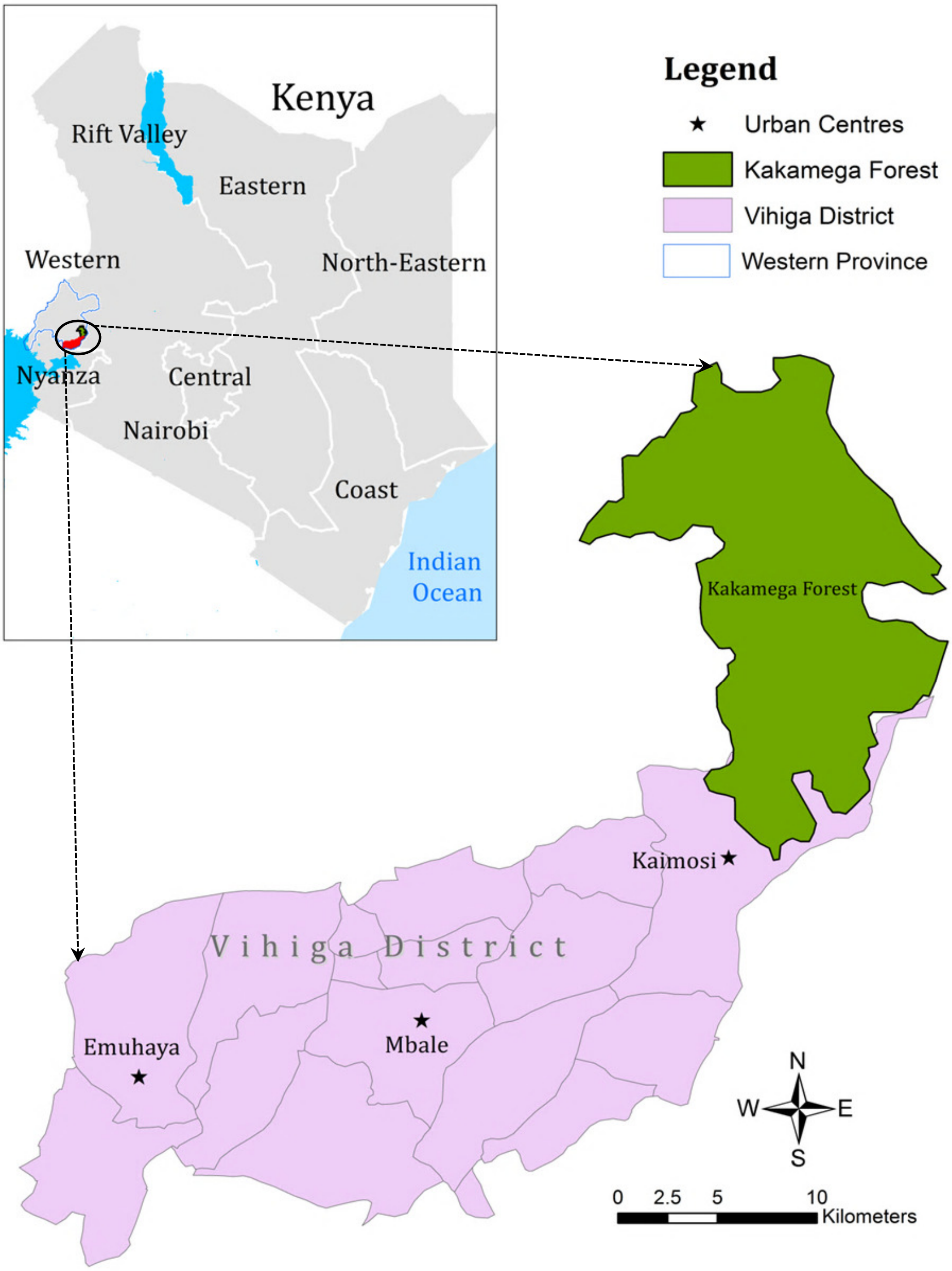

Figure 1-1: Map of Kenya (inset) showing the location of Vihiga District and Kakamega Forest that constitute the study area in the western highlands of Kenya
Source: Author's mapping in ArcGIS10.1 based on ESRI spatial data

Administratively Vihiga District has four sub-districts: Emuhaya (Emuhaya and Luanda), Hamisi (Tiriki West and East), Sabatia and Vihiga. The residents of Vihiga District are predominantly of Luhya ethnic community made up of the Tiriki found in Tiriki, the Maragoli of Sabatia and Vihiga and the Banyore residing in Emuhaya (Government of Kenya 2005). Vihiga District is one of the most densely populated and poorest parts of Kenya. The overall population density of the district is 1045 people/km^2. Even though literacy level is over 95%, poverty incidence (*per capita* daily income of less than a dollar) is estimated at 65% of the population (KNBS 2010).

The Kakamega forest system: Forest ecosystem examined covered the entire Kakamega tropical rainforest stretching from Vihiga District to the neighbouring Kakamega County. The Kakamega rainforest was first gazetted as a Government Forest Reserve in 1933, then covering about 23780 ha. The protected forest area currently covers 17838 ha out of which indigenous forested area is about 14000 ha (Müller and Mburu 2009). There are two Nature Reserves and one National Forest Reserve, where all extractive activities are prohibited. The forest is endowed with rich biodiversity of plants, endemic primates, birds and insects (Government of Kenya 2004). The high biodiversity value of this forest is important for both international and local tourism as well as research purposes. The forest is also a natural sink for CO_2 sequestration thereby contributing to mitigation of global climatic change (MENR 1994), a major source of charcoal and firewood, livestock grazing, medicinal extracts and wild honey, and provides ground for local community to practice their cultural activities such as circumcision rites (Ouma et al. 2011).

The available SLM practices for better farming include a wide range of improved technologies such as construction and maintenance of SWC measures (e.g. terraces and cut-off drains), establishment of vegetative barriers (e.g. Napier grass and hedgerows), soil fertility management options (e.g. application of organic manure, use of inorganic fertilisers and incorporation of crop residues), agroforestry practices (e.g. improved fallows and hedge rows)(Ojiem et al. 2004, Jama et al. 2008, Guto 2011). Other practices are planting improved seed varieties, timely implementation of agronomic practices, mulching, contouring on slopes, planting multi-purpose farm trees and livestock integration (Place et al. 2006, Shisanya et al. 2009). The SLM strategies for conservation of the forest ecosystem include the promotion of farm forestry, sustainable planting and harvesting regimes for plantations, rehabilitation of natural forest stands and protection of riparian vegetation (KFE 2012).

1.4 Research methodology

I designed and applied a research framework that integrates socio-economic and ecological systems and evaluates feedback effects in order to gain holistic insights with practical implications on the application of SLM practices. In this framework, I consider key cross-scale interactions within the target socio-ecological systems in temporal and spatial perspectives. Following Miser and Quade (1997), I applied the framework in step-wise, multi-scale, multi-periodic way by analysing changes in the provision of ecosystem services, allocation and use of available asset endowments and resultant implications on people's welfare from the farm (household) to the landscape (community) scales. I also investigated the feedback effects (positive and negative externalities) on prospects for implementing SLM practices and improving rural livelihood opportunities.

1.4.1 Conceptual framework for integrated, multi-scale systems analysis

The framework has three interlinked tiers corresponding to the spatial (i.e. micro, meso and macro) and temporal (i.e. short-term, medium-term and long-term) scales of systems analysis. I focus analysis at the interconnections between economic and ecological systems interfaced with population along the social scale (i.e. household, community and district-level stakeholders and population). These interactions are intermediated by the economic activities pursued by the relevant target population. The conceptual framework is shown in Figure 1-2.

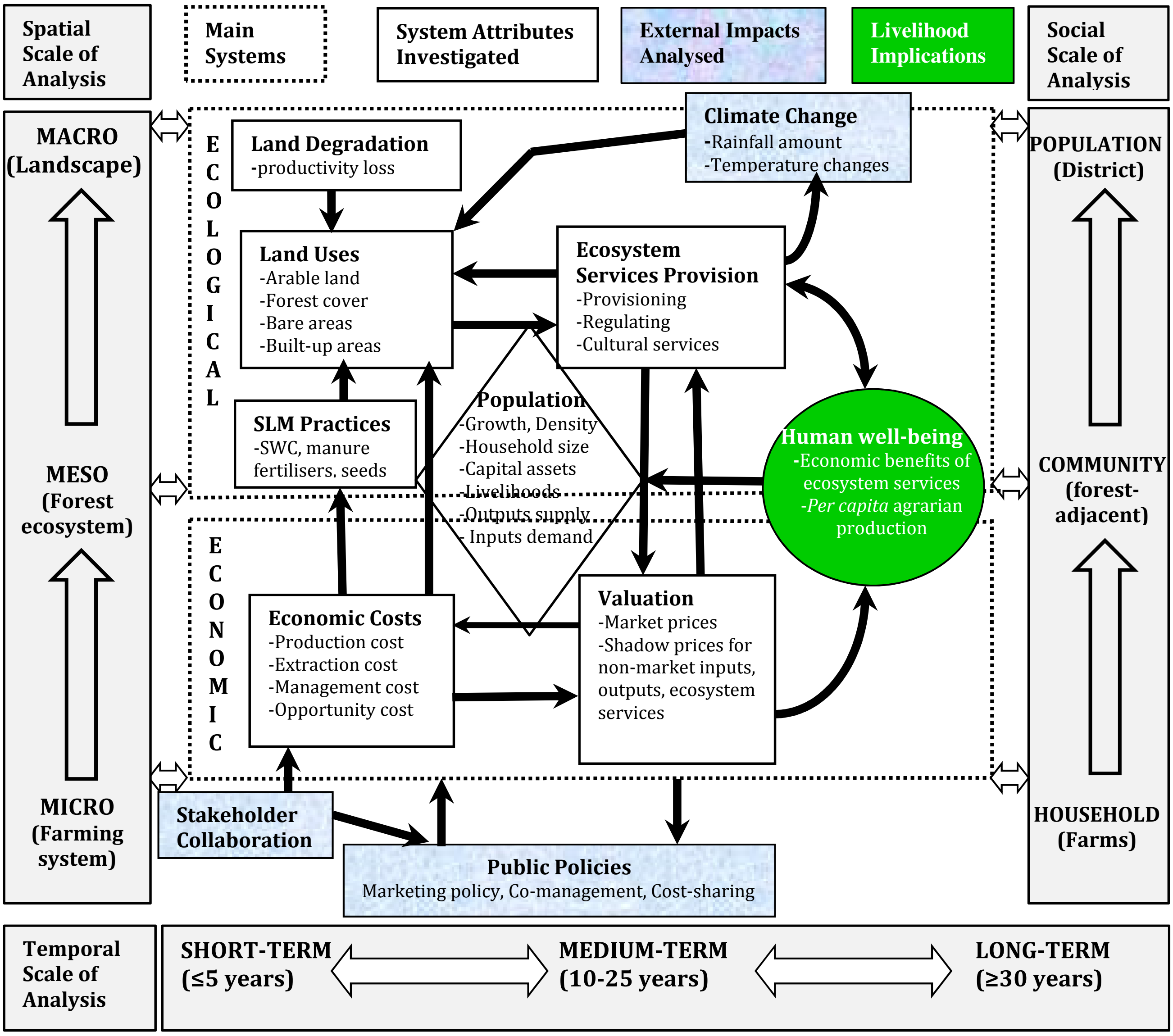

Figure 1-2: Conceptual framework for integrated, multi-scale systems analysis of prospects for implementation of SLM practices, ecosystem services provision and welfare impacts in the western highlands of Kenya. At the centre of the framework is the target population whose livelihood activities mediate between the two systems while broad influences cross over the boundary of the systems from public policies, external stakeholder collaboration and climate changes. Arrows indicate interactions investigated at multiple social, spatial and temporal scales.

At each socio-ecological scale, I clearly define the relevant systems boundary, resources, key actors, activities and possible interactions that would impact on the application of SLM practices. In the ecological system, I investigate management practices that determine agricultural productivity from two farming systems as well as extraction rates of non-timber products and provision of other ecosystem services from the forest ecosystem. In the economic system, I analyse allocation and efficiency of resource endowments to various livelihood activities, economic costs incurred in production, extraction and management as well as opportunity cost. Besides, I estimate economic benefits generated from ecosystem services provision, using various market and non-marketing valuation approaches. I link economic benefits to human well-being and analyse feedback effects important for promotion of SLM practices (Figure 1-2). Basically the framework is interconnected through ecosystem service flows and land management activities across micro, meso and macro scales.

Micro-scale systems analysis focusses on interactions between households and their farms and how they allocate the resources they have across different livelihood activities in the short-term period. At the micro-scale, I analyse the interactions among the households (labour, capital and consumption stocks), livestock activities (grazing and milk production), productivity of crop fields (cereals and cash crops, fodders), woodlots and hedges for fuel wood and land management practices (organic and inorganic fertilisers, SWC measures, crop varieties) at the farming system level. Important ecosystem flows across these farming household compartments and transactions across the farm boundary are quantified and valued. In addition, the net inflows from other farms (e.g. manures, fodder, and fuel wood), the market (e.g. fertilisers, seeds, minerals, hired labour) and natural ecosystems (e.g. fuel wood, pastures) are quantified and valued at the average local market and imputed prices (Figure 1-2).

Meso-scale analysis focusses on the relationships between the forest-adjacent community and the forest system based on ecosystem services provision and forest management assessment. At the meso-scale, economic benefits derived by the community from the Kakamega rainforest are aggregated based on the proportion of the total population around the forest, amount of forest products obtained in a year and extraction cost. Prices for this valuation are based on average willingness to pay (WTP) values, which I collected during a quantitative household survey. Additional local economic benefits are calculated from tourists using the travel cost method for domestic visitors. In this study, I only consider recreational value added by international tourists and the potential economic value for carbon capture service.

Macro-scale analysis tracks dynamic land-use and land-cover (LUC) changes in light of rapid population growth, high market demand, and availability of improved farming technologies in the medium-term. At the macro-scale, I analyse in an integrative manner, landscape dynamics covering the entire western highlands system (i.e. farming, forest, built up and bare areas) over a 25-year period. I assess how these interrelated dynamics have affected rural agrarian livelihoods at the backdrop of rapidly growing population and evaluate external impacts of climate variability (temperature and rainfall amounts) and past public policies and draw policy implications for poverty alleviation and promotion of SLM practices in changing agro-environments (Figure 1-2).

Finally, I assess how collaboration of diverse stakeholders can foster scaling-up of SLM practices across multiple scales (Figure 1-2). I analyse local conditions for initiating collaborative action towards technological transition to improved agricultural productivity and sustainable forest conservation and draw long-term implications for transformative policies and practices in the Kenyan highland systems.

The innovative feature of this conceptual framework enabled the generation of comprehensive information through integrated assessment of ecosystem services provision, prospects for wider application of SLM practices and implications on human welfare, across multiple scales. In addition, given that the framework is inherently linked across spatial micro-, meso- and macro-scales, it is possible to evaluate the impact of future policy and institutional settings on the likely changes in the socio-economic and ecological systems at these levels.

1.5 Thesis outline

The subsequent parts of this thesis present four empirical chapters, which can also be read independently and a general discussion of key findings generated in the entire study. The chapters are arranged as described next.

In Chapter 2, I investigate farming households' responses to a changing agro-environment and examine practical implications of the main livelihood strategies for the promotion of SLM practices. I conducted an elaborate household survey, applied multivariate analyses (principal components, cluster and stochastic frontier analysis) of farm resources and allocations to distinguish key livelihood strategies. Based on the diversity of farm assets and income-earning strategies, I classified the sample into five different farm types, established the efficiency with which they use their resources in farming, and their likelihood of using SLM practices.

Chapter 3 provides a classic case of conflict between conservation and exploitation goals through ecosystem services analysis of Kakamega rainforest. I carried out elaborate household and visitors surveys to collect data used to estimate the economic value of key ecosystem services provided by this forest. I argue that continued protection of this forest is only justified based on the unknown value of its rich biodiversity. I demonstrate why in the light of increasing population pressure on land around the forest, there is need for enhanced public-private partnerships and local collaboration in the promotion of broad environmental programs to achieve sustainable conservation of such unique forest ecosystems in Kenya.

Chapter 4 presents integrated analyses of land-use and land-cover (LUC) dynamics and their impacts on rural livelihoods against the backdrop of an ever-increasing population density. I tested an integrated approach combining remote sensing analysis, detailed interviews and local time-series data through trend analysis, as a key step to understanding the complexity and dynamics of LUC change and agrarian livelihoods over time. I discuss the link of LUC changes to agrarian livelihoods and drivers of LUC change to draw conclusions on the effective SLM strategies and policies for addressing rapid LUC changes and rural poverty in densely populated areas.

In Chapter 5, I evaluate prospects for wider promotion of SLM practices in the western highlands of Kenya. I recognize that successful scaling-up of SLM technologies requires collaboration of diverse stakeholders across multiple scales. I show in a conceptual model, the desired transition pathway to a socially optimal level of ecosystem services provision, with conceivable compensation arrangements. Applying a multi-level framework of transition management, I establish the existence of local conditions for triggering the technological transition process. I advocate for the application of a context-specific transition management approach in the study area in order to gain practical learning experiences on effective governance of transformative environmental programs for other similar socio-ecological systems in sub-Saharan Africa.

Chapter 6 delivers a concise synthesis and draws insights with broad practical and policy implications from key findings presented in the empirical chapters of this thesis. I discuss why rising population density has failed to induce an agricultural intensification process in the western highlands of Kenya. I make evident how a 'maize-centred' poverty trap and shrinking farm sizes have constrained prospects for wider application of SLM practices. I argue for a drastic change in the established approach for tackling the problem of land degradation in sub-Saharan Africa. I make a strong case why SLM projects may need to consider a broader approach, rather than only focus on improving agriculture as the mainstay of rural livelihoods. I underscore the need for a paradigm shift in the implementation of poverty alleviation and conservation strategies to encompass the conjoint pursuit of agricultural and off-farm income opportunities. Finally, I identify key areas for further research to foster the promotion of SLM practices and explore possibilities for practical implementation of findings of my study in densely populated and degrading agro-ecosystems of Africa.

Environmental challenges facing the people of Vihiga District in the western highlands of Kenya

Photos courtesy of Prof Chris Shisanya's gallery (2012)

Chapter 2 Livelihood Diversity and Resource Use Efficiency: Implications for the Application of SLM Practices[2]

2.1 Introduction

In order to feed a growing population, land productivity and *per capita* food production need to increase in the coming decades in Sub-Saharan Africa (SSA) (Clover 2003, Lambin et al. 2003). It has been postulated that rising rural population densities lead to intensification of agricultural production (Boserup 1965, Hayami and Ruttan 1985, Tiffen et al. 1994, Pender 1998). However, at the same time, there is a concern that increasing population pressure on agricultural land, in the absence of better land management, leads to land degradation. A range of studies point to land degradation constraining agricultural output in many parts of the continent (e.g. Pender 1998, Barbier 2000, Crowley and Carter 2000, Longley et al. 2006, Nkonya et al. 2009, Odendo et al. 2009, Jayne et al. 2010). Consequently, widespread promotion of more efficient and sustainable agricultural techniques, for the purpose of this study termed Sustainable Land Management (SLM) practices, is required to reconcile increasing population density and increased agricultural productivity (Pender 1998, Odendo et al. 2009, Lambin 2012). A variety of development programs has been implemented aiming to promote SLM and related concepts has been implemented (Tiffen et al. 1994, Bationo and Buerkert 2001, Drechsel et al. 2001, Nkonya et al. 2009, Nyssen et al. 2009).

However, these programs have generally had mixed results (Place et al. 2002, Longley et al. 2006, Pender et al. 2006b, Wanyama et al. 2010). It has been argued that one of the main reasons limiting replication of localised successes of SLM interventions is the socio-economic and ecological variability within African agro-ecosystems (Kruseman and Bade 1998, Shepherd and Soule 1998, Giller et al. 2011). Recent research has provided evidence against blanket recommendation of SLM measures within such heterogeneous regions (e.g. Tittonell et al. 2005, Ojiem 2006). Better knowledge of farm diversity and farm efficiency is therefore essential in understanding processes driving agricultural productivity and for designing policies and programs aiming to enhance sustainable production. Moreover, because of the temporal dimension of land degradation (Kimetu et al. 2008), there is a need to examine how rural livelihoods change over time and how this affects farmers' interest in SLM practices.

The specific objective of this study is to analyse farm diversity and resource use efficiency of different farm types and their implications for sustainable land management strategies in the western highlands of Kenya. Specifically, we examine farm diversity and efficiency of farming systems between two sites as well as the changes in livelihood strategies in two study periods in Vihiga District. We selected the western highlands of Kenya because this area has seen one of the fastest increases in population density in SSA and land degradation and its impacts are relatively well documented (e.g. Shepherd and Soule 1998, Crowley and Carter 2000, Salasya 2005, Place et al. 2006, Vanlauwe et al. 2006, Odendo et al. 2010). This study generates new insights on the broad implications of changes in livelihood strategies and farm resources on the extent of implementing these practices at the farming systems level, where important interactions exist among the different SLM practices available in the study area. The novel contributions to literature include investigation of inter-temporal changes in livelihood strategies, resource use efficiencies of different farm types and assessment of their

[2] Based on Morgan C. Mutoko, Lars Hein and Chris A. Shisanya. Farm diversity, resource use efficiency and sustainable land management in the western highlands of Kenya. Submitted

implications for the promotion of SLM practices. We analyse the stochastic production frontier (which goes beyond the physical relationship between output and inputs) to determine whether farmers across the established farm types are allocating available resources optimally in farm production. Furthermore, we assess the implications of our detailed analysis of the heterogeneity and dynamics of farm types in Western Kenya for the promotion of SLM practices across sub-Saharan Africa. Our study thereby expands the current understanding of specific socio-economic factors that influence adoption of some of the SLM practices, which have to date been mostly analysed at the household level (Salasya 2005, Odendo et al. 2009).

Our study is relevant for policies and programs aiming to promote SLM practices in the wider perspective of enhancing African rural development. SSA's population grew from about 390 million in 1980 to over 856 million people in 2010 (United Nations 2011). Even the most conservative projections by the United Nations (2011), indicate that SSA's population will rise to at least 1.7 billion people, almost doubling by the year 2050. Many individual SSA countries are facing ever-increasing population growth with recent annual rates ranging between 2.4% in Mozambique and 4.4% in Zimbabwe (CIA 2012, World Bank 2013). Given the expected population increase in SSA in the coming decades, the population density currently encountered in Vihiga (on average 1045 people/km^2) will be representative for many other rural parts of SSA. It is clear that many parts of rural Africa are becoming more densely populated, with increasing population pressure on land becoming more common and that SLM practices will become more crucial in the foreseeable future (Ruttan and Thirtle 1989, Lambin 2012).In addition, a range of SLM interventions has been attempted in Vihiga District, with varying degrees of success (Place et al. 2006, Marenya and Barrett 2007, Odendo et al. 2009).

2.2 Methodology

2.2.1 The study area and sampling procedure

Study sites: This study covered two sites in Vihiga District located in the western highlands of Kenya (Figure 2-1). The district lies between longitudes 34°30′ to 35°0′ East and latitudes 0°0′ to 0°5′ North and is characterised by a gently undulating landscape sloping from West to East, with an altitude between 1300 and 2100m above sea level. Vihiga District experiences an Equatorial climate with average rainfall ranging between 1750 and 1950 mm per year. Rainfall distribution is bimodal with a distinct long rainy season (March – June) and a short rainy season (September – November) (Jaetzold et al. 2007, Government of Kenya 2010). The average farm size is 0.6 hectares on which mixed crop and livestock farming is practiced.

The major food crops grown include maize, beans, bananas, potatoes and sorghums. Tea, coffee and sugar cane constitute the main cash crops. Most of the cattle owned are local zebus with some improved dairy cows (Government of Kenya 2010). The district has Mudete Tea Factory and good infrastructural network with tarmac and all-weather roads. Different local businesses and government agencies are located in urban centres at Mbale, Luanda, Emuhaya and Hamisi. Some residents are employed in the existing institutions as teachers, nurses, administrators and general workers. Whereas others run home-based small businesses such as shops, flour milling, vehicle and motorbike transportation and retailing in agricultural produce.

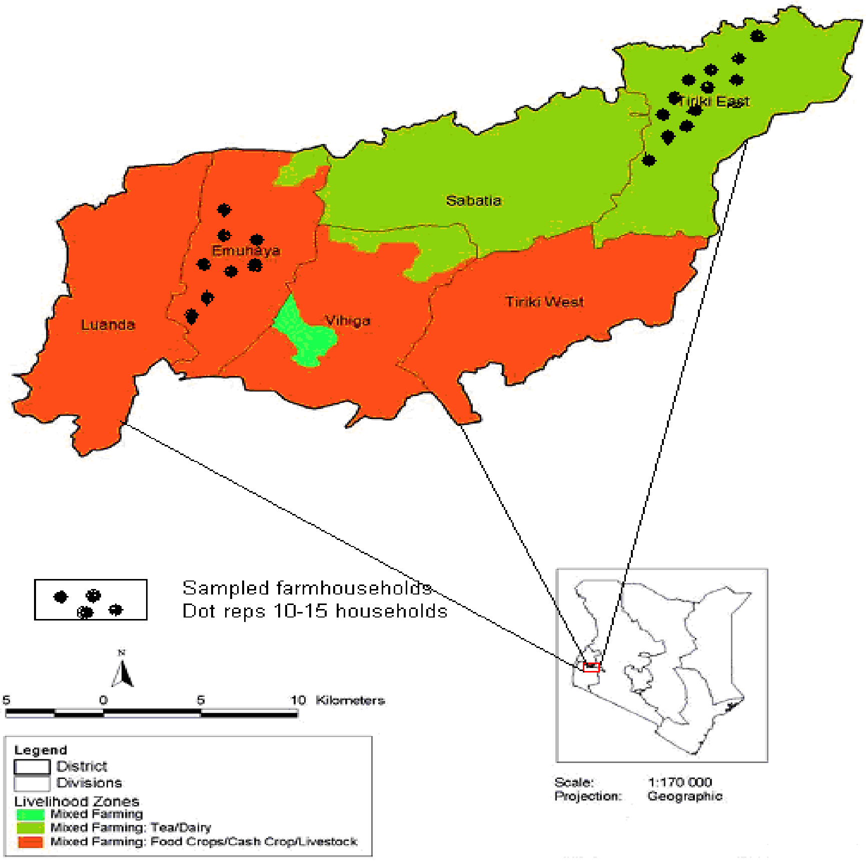

Figure 2-1: Map showing the two study sites in Vihiga District of Western Kenya.
Source: Adapted from Government of Kenya (2005).

Sampling design: We selected two study sites—Tiriki and Emuhaya—with a slightly different farming environment for detailed household level investigation (Figure 2-1). The basic unit of our sampling was the household. We adapted a working definition for a household from Ellis (1993) as a group of individuals (relatives and workers) belonging to the same rural residential place where distinct economic activities of production and consumption simultaneously occurs. Other household members also included the yet-to-detach family members working away from home but contributing to the household's assets e.g. through remittances. This is a common feature among rural households in Kenya.

For our household survey, stratified sampling was applied to demarcate areas made of groups of villages and we selected four villages from each stratum making 16 villages. In each village, we positioned a Y shaped sampling frame at a central point. We applied a random sampling technique to select five households in each direction of the Y frame, and this led to a sample of 15 households per village. Finally, we selected a total sample of 240 households but we dropped four households from the sample because they did not engage in farming activities at all during the 2009 agricultural year. At each of the sampled households, we collected detailed household and farm-level data between January and March 2010. The household head or member knowledgeable about farm and off-farm activities of the family was interviewed using a pre-tested, semi-structured questionnaire (Appendix A1). For purposes of statistical analysis, we identified during survey the main person within the household who makes key decisions on agricultural activities as the household head interchangeably referred to as farmer.

Data collection: At household level, data were collected on amounts of purchasable farm inputs, total household labour and land allocation to various enterprises. Farm outputs from the enterprises were quantified and evaluated at average selling market prices prevailing at the village level. In cases where specific prices were not reported by households that did not actually sell their produce, we imputed prices based on the averages computed from the sample at the village level. Actual prices that such households could face are likely to vary across different local markets and the timing of sale, however we assumed that any household that did not sell a specific farm output but instead consumed actually 'sold to itself' at the prevailing average local prices. Besides, we collected data on household composition, income from the farm and off-farm activities, value of farm assets and investment in crop and livestock production activities. At the field level, we established the extent of implementation of selected SLM practices e.g. use of improved seeds, presence and maintenance of terraces and application of organic/inorganic fertilisers. This dataset though providing only a snapshot view of the dynamic highland systems supplied key variables used to categorise farm typologies, analyse the current farm diversity in livelihood strategies and examine land management practices.

We used previously collected data to investigate inter-temporal changes within farm types at the village level in Emuhaya. In particular, we compared the outcome of our survey with the 2003 data from Tittonell et al. (2010) who also analysed farming systems in Emuhaya. A local field assistant who participated in the earlier study reported in Tittonell et al. (2010) assisted in retracing the same villages where households were interviewed in 2003. In this earlier (2003) study, the same sampling procedure was followed, i.e. based on Y-frames. Since we lacked specific geo-referenced information on exact positions of the previous Y frames, we approximated the actual positioning of the Y sampling frames in the field. In the 2010 sample, we interviewed 120 farmers out of a total of 38,700 farm households in Emuhaya (Government of Kenya 2009). In 2003, a total of 50 farm households were interviewed in Emuhaya (Tittonell et al. 2010). In addition, we applied similar Y sampling frames recognised for enhancing spatial distribution of the sample thereby reducing possibility of sampling bias even with few sampling points (Tittonell et al. 2010). The main advantage of the Y sampling frame in the random selection of households is that it eliminates the possibility of sampling bias particularly concentrating the sample in accessible areas within villages. This approach guarantees that sample is fairly distributed across the sampled village. A possible weakness is related to the researcher's arbitrary orientation of the Y sampling frame in the field but since the actual interviewed households are picked randomly, this bias has no analytical effect on the representativeness of the sample. We also increased the sample size of households per Y sampling frame to account for demographic changes as well as to control for the random physical features (e.g. slopes, soils) and variable individual-specific factors relating to farmers' choice of land management practices, allocations of farm resources to various farm and off-farm activities(Tittonell et al. 2010). Given that both samples were based on an efficient stratified random sampling technique (with villages as strata at this level and the Y frame for random selection of households), they are scientifically representative of the study area and allow for valid statistical comparisons across time. The drawn samples in both years were considered representative of households in Emuhaya thus allowing us to carry out a comparative inter-temporal analysis of livelihood changes. Further details of the collection procedures of the 2003 data are provided in Tittonell et al. (2010).

2.2.2 Farming systems analysis

Farming systems analysis included investigation of the current farming practices, diversity in livelihood activities and key features of the main farm types in Tiriki and Emuhaya. Descriptive statistics were used to summarise selected variables important for the characterisation of the farming households. Before estimations we conducted standard tests to investigate presence of multi-collinearity using variance inflation factors (Maddala 2001) and endogeneity of suspected explanatory variables in the production function using Durbin-Wu-Hausman test (Davidson and MacKinnon 1993, Verbeek 2008). Independent samples t-tests were used to determine statistical difference on key variables between the two study sites. We sequentially applied principal component analysis (PCA) and cluster analysis (CA) consistent with Tittonell et al. (2010) to assign farm households into five distinct classes based on predominant livelihood activities they engaged in both on the farm and off the farm.

During PCA, we generated fewer uncorrelated principal components (PCs) that contained most information and captured maximum variability as the original variables (Stanimirova et al. 2007). The variables used in PCA included: total land size (ha), total cultivated area (ha); cash cropped share (% of cultivated area), number of livestock kept (tropical livestock units according to Jahnke 1982), household size (# of people living and eating in the household) and family labour (# of members working full time on-farm). Other variables also included were farmer's age (years), off-farm income (% of total household income from non-farming activities) and production orientation (% of farm produce sold). We used the same variables included in a PCA by Tittonell et al. (2010) in order to generate farm types that could be validly compared as we intended in our study. Then in cluster analysis, we used the first two PCs that described 99% of data variability as input variables in a non-hierarchical procedure as recommended by Righi et al. (2011). Our data pointed to five clusters of farm households, which we labelled based on their key farming characteristics. These classes correspond to the types found in Tittonell et al. (2005, 2010).

2.2.3 Inter-temporal livelihood analysis

In our analysis, we examined inter-temporal changes within farm types with respect to resource endowment and livelihood orientation. We applied multivariate analysis, which confirmed the same farm typology proposed and described by Tittonell et al. (2005). Mean values for ownership of farm, livestock, arable farm to family farmer ratio and proportion of off-farm income were compared between 2003 (from Tittonell et al. 2010) and 2010 (our survey). We applied Y error bars at 5% significance level to determine statistical difference of the values between the two periods.

2.2.4 Farming efficiency analysis

In theory, farmers can be presumed to be rational producers who aim at maximizing farm output at minimum cost in order to increase profits (Debertin 1986). In practice, smallholder subsistence farmers may produce at sub-optimal levels as they may also pursue other aims such as minimizing risk. However, when production and consumption decisions are interdependent (Singh et al. 1986), it can be expected that farmers would still pursue better use of available resources to increase farm productivity in order to meet their main goal of food self-sufficiency.

Determination of efficiency in maize-bean production, the main farming activity, is useful in understanding how well farmers allocate scarce resources to various livelihood activities. Maize-bean production is practiced by 98% of farmers, takes the greatest share of farmed land and is ranked as the most important activity in meeting subsistence needs and to some extent contributing to income generation of farming households in Vihiga District (Salasya 2005). In the case of Vihiga District where absolute poverty incidence is about 62% and 60% of the population is food insecure during a part of the year (Government of Kenya 2005), inefficient resource allocation may contribute to inadequate food availability. Inefficient resource allocation may also contribute to land degradation because farmers lack resources to invest in land productivity and get trapped in the vicious cycle of poverty-degradation (Reardon and Vosti 1995, Barbier 2000).

The economic theory of production provided the analytical framework for efficiency analysis in this study (Debertin 1986). The basic principle in the measurement of economic efficiency is that of attaining highest possible returns at the least cost of available production inputs. Consequently, a farmer was considered economically inefficient if little output value was realised from a given bundle of inputs and cost (Ellis 1993). In our analysis, 100% efficiency corresponds to the highest output value achievable, given a set of available inputs, and using the best existing technology. The estimation that generated economic efficiency values for individual farmers was specified as Equation (2.1).

We specified a stochastic Cobb-Douglas function with efficiency effects such that part of inefficiencies could be attributed to the household's livelihood strategies and land management practices at farm level (Coelli 2006).

$$\boldsymbol{ln(y_i) = \beta_0 + \sum_{i=1}^{3} \beta_i ln(x_i) + \beta_4 site + (v_i - \mu_i)} \qquad \text{Equation 2.1}$$

Where y_i is the total value of maize and bean output (KES/ha) and x_i are variable input costs (seed, fertiliser and own family and hired labour) per hectare. Site is a binary variable (1=Tiriki; 0=Emuhaya) accounting for the inherent physical attributes important for farm production such as natural soil fertility, rainfall and temperature (that differ between the two sites). β_0 is the technology parameter and β_i and β_4 are unknown coefficients, estimated within the model. v_i is the ordinary error term assumed to be normally distributed and u_i is the one-sided error term (measuring economic inefficiency) and assumed to be half-normal and asymmetrical.

We specified the production function using monetary units and not the traditional physical quantities for the dependent variable and the explanatory input variables. The rationale for this specification is that we faced analytical challenge while modelling a predominantly maize-bean inter-crop production system, where inputs applied to the maize crop are also shared with the bean crop and vice versa. The input-output relationship is therefore one-to-two in this case. The measurement challenges for output in situations like this are only overcome through comparable conversions based on food calories or by market prices (Liu 2006, Kamau 2007). We adopted for the conversion and aggregation of crop output using the average reported selling prices at village level. In households that did not report sale of any maize and or bean crop, we applied average village-level prices reported by other farmers within the same village. We also converted input quantities to input costs because of the high variability in the quality of the inputs used by the farmers. For example various fertiliser types as well as both local/recycled and improved seeds were used in maize-bean production. Besides, we confirmed strong correlation between plot sizes and the amount of inputs applied as well as the total crop output realised. Land is an important input in this production process hence we could not simply drop it, instead we expressed all the remaining variables as ratios to plot sizes (in acres) and converted to standard unit of hectare (ha).

Since we are interested in the likely efficiency gains leading to improved productivity in maize-bean production, we specify an efficiency effects function with a set of land management practices and household characteristics of interest in Equation 2.2

$$\boldsymbol{\mu_i = \alpha_0 + \alpha_1\, MANUSE + \alpha_2 FAMLAB + \alpha_3 ORIENT + \alpha_4 SWC + \alpha_5 CRED + \alpha_6 INC + \alpha_7 FAMEXP + v_i}$$

Equation 2.2

We specify the estimated inefficiency score for each farmer (u_i) based on Equation 2.1 as a function of use of manure the previous year (MANUSE), number of family members fully engaged in own farm activities (FAMLAB), production orientation (ORIENT), number of SWC measures on the best field (SWC), credit access (CREDIT), *per capita* income (INCOME), and relative farming experience (FAMEXP). These indicators were selected from literature based on their recognised influence on the uptake of better land management practices (e.g. Longley et al. 2006, Odendo et al. 2009) and increased farm productivity by enhancing efficiencies in resource use (Tchale and Sauer 2007, Mutoko et al. 2008, Olowa and Olowa 2010).

We created a binary variable for reported manure use for the previous year because of the diverse quality and quantities actually applied. Again, the application of manure is labour-intensive and is positively correlated with labour input (in Equation 2.1) in the current production period. Production orientation (subsistence or market) is intuitively correlated to crop output over time. To overcome possible endogeneity of this variable, we opted to express the quantity of output reportedly sold as a fraction of total output realised. Then we created a binary variable for production orientation such that a household that sold more than half of the output was classified as market-oriented (i.e. ORIENT = 1; otherwise = 0). Credit access for farming purposes was also expressed as a binary variable because only few farmers actually obtained credit as physical inputs or money. We also included an income variable to account for the influence of household resource ownership on farm productivity (Ellis 1993). We expressed the household income in *per capita* terms recognizing that given the same income level, large households are likely to spare little from consumption needs to actually invest in farming activities. Transformation of this variable not only eliminates possible endogeneity of farm income but also accounts for the effect of total farm income and household size jointly. Finally, we included relative farming experience expressed as the ratio of years of farming to biological age of farmer (household head) to capture possible gains due to implementation of farming activities and accumulation of agrarian knowledge over time (Odendo et al. 2009). In theory, gender is acknowledged as an important factor is farm resource ownership, actual implementation of farm activities and achieved farm output (Ellis 1993), but we did not investigate its influence because recent empirical studies in Vihiga District have found that gender of the household head is not a significant factor in farming choices (Salasya 2005, Kamau 2007, Odendo et al. 2009). We applied a one-step maximum likelihood estimation procedure (Wang and Schmidt 2002) to simultaneously explain economic inefficiency. This is the normal way of estimating efficiency models, which not only estimates the coefficients between the dependent variable and the explanatory variables in the production function (Equation 2.1) but also the statistical effects of other factors of interest on the estimated efficiency scores(Equation 2.2) (Coelli 2006, Liu 2006, Mutoko 2012). We used Statistical Package for Social Scientists (SPSS 19) for descriptive, principal component and cluster analyses and FRONTIER 4.1 for efficiency estimation.

2.3 Results

2.3.1 Farming practices in Tiriki and Emuhaya

Significant differences existed between households within the two study sites on household characteristics, farming practices and main income generating activities (Table 2-1). Subsequently, we analyse the following key characteristics of farm households: (i) farmer's age, (ii) household sizes, (iii) farm sizes, (iv) use of soil and water conservation (SWC) measures and (v) use of fertilisers and manures.

Table 2-1: Summary of farm household characteristics in Tiriki and Emuhaya sites

Characteristic	Mean (SD[a])				
	Tiriki		Emuhaya		Sig.
Farmer's age (years)	48.6	(13.9)	53.2	(13.1)	***
Household size (numbers)	6.7	(2.5)	8.4	(3.7)	***
Full-time farming members (numbers)[b]	2.2	(0.9)	1.7	(0.8)	***
Farm size (ha)	0.8	(0.5)	0.6	(0.4)	***
SWC measures on field (#)	2.4	(1.4)	2.1	(1.3)	*
Maintenance of SWC measure (KES'00/yr.)	4.3	(4.9)	2.5	(2.3)	**
Fertiliser use (kg)	50.6	(43.7)	24.2	(31.0)	***
Manure use (ton)	0.8	(0.5)	0.9	(0.5)	ns

Sig is significance level of differences between sites; *= at 10%, **= at 5%, ***= at 1%, ns=not significant;
[a]SD is standard deviation, figures contained in brackets.
[b]Full-time farming members accounted only for adult members who effectively engaged in agricultural activities during the study period. Part-time farming members also contributed labour to the farm but were mostly involved in off-farm engagements such as schooling, petty businesses or casual employment. We included part-time labour in the calculation of total labour input use in the efficiency equation.

Source: Author's analysis of the 2010 survey data. In all the Tables and Figures that follow, the source remains the Author unless otherwise specified.

(i) Farmer's age. Results in Table 2-1 show that farmers were relatively old in both sub-districts i.e. on average 49 years in Tiriki and 53 years in Emuhaya. This is consistent with Salasya (2005) who found that average age of farmers in Vihiga District was over 50 years indicating that mainly the older generation practiced farming with minimal direct participation of the youthful farmers. This could reflect both limited options of older farmers to hand over farmland to their children as well as better income opportunities for younger generations elsewhere. Through lethargy, old age can slow down farming as farmers may be less willing to experiment with innovative techniques thereby influence the degree of interest among them to test new farming technologies including SLM measures.

(ii) Household sizes. Household sizes were on average significantly larger in Emuhaya with more adults but fewer full-time labour-providing members. The smaller number of members working full-time on the family farm signifies that most resident household members either engaged in off-farm activities or were dependents. Ordinarily, more than five people resided and relied on the small farms for their livelihoods during the study period.

(iii) Farm sizes. Average farm sizes are 0.6 ha and 0.8 ha in Emuhaya and Tiriki, respectively. The median farm size is 0.66 hectares. The small farm sizes are due to rapid population increase and continued sub-division of the parcels among family members in the study area. This has led to high pressure on the fragmented farms to produce adequate food supplemented with off-farm sources to meet the growing demand by large families.

(iv) Use of soil and water conservation measures. The two sites have comparable soil and rainfall patterns and only slight differences were noticed on physical land management practices. The majority of households (over 80%) reported to have one SWC measure on at least one of the fields. Common SWC measures included terraces, cut-off drains and Napier grass lines. The majority of SWC measures (76%) were implemented in the period after 1988. This is the period when the government of Kenya through the Ministry of Agriculture extensively promoted conservation of soil and water resources using initially the Catchment Approach and later the Focal Area Approach based on community participation, voluntary choice and implementation of the measures (Longley et al. 2006). The rest of the measures were implemented in the 1970s and 1980s possibly under the National Soil and Water Conservation program enforced by government administrators and agricultural extension officers. About 14% of the farmers reported to have no SWC measure in place and on average, there were only two SWC measures on the farm. Field visits to farms indicated that many of these measures were not well maintained. The intensity of the measures was higher in Tiriki due to greater elevation differences and tea production. Initial establishment cost for a single measure was equal in both sites though maintenance cost was reported to be lower in Emuhaya.

(v) Use of fertilisers and manures. Assessment of fertiliser and manure use for the preceding three years reflected significant differences between the sites. The average amount of fertiliser used in Tiriki was twice that used in Emuhaya due to more tea production (for which farmers get advance fertiliser) in the former site. However, quantity of manure applied did not significantly differ between the two sites (Table 2-1). In both sites, the total amount of fertiliser used per household decreased even as the proportion of households applying some fertiliser increased during the previous three years. For example, average fertiliser consumption per farming household declined by 30% whereas the segment of farmers who applied some fertiliser increased marginally by 4% in Tiriki. In contrast, manure application largely increased during the same period both in proportion of households and average quantities applied per farm. This result indicates that farmers have resorted to use more manure as a coping strategy for the relatively high cost of chemical fertilisers as pointed out by Odendo et al. (2009).

2.3.2 Diversity in livelihood activities

Table 2-2 provides a summary of the economic activities to which households allocated their land, labour and finances. Land was allocated more to food crops (i.e. crops grown mainly to meet household's food requirements such as maize, beans and sorghum) than to cash crops (i.e. crops primarily grown for income generation such as tea, coffee and sugar cane) and less to fodders (mainly Napier grass) in both study sites. Due to land scarcity, farmers in Vihiga District can be expected to focus more on cash crop production to earn better returns and spend part of that income on the purchase of food from surplus districts through the marketing system. Indeed lack of adequate inputs due to high poverty levels is a key constraint in the entire farming system, but in the case of tea production farmers are provided with fertilisers, seedlings and their cost are deducted from the value of the harvested tea. However, farmers preferred to meet their domestic food needs mostly through own production because they were averse to marketing risks such as high transaction costs and uncertain commodity prices.

Table 2-2: Main economic characteristics of farming households in Tiriki and Emuhaya sites

Economic activity	Mean (SD)				
	Tiriki		Emuhaya		Sig.
Food crops production (ha)[c]	0.5	(0.3)	0.3	(0.2)	***
Cash crops production (ha)	0.2	(0.3)	0.1	(0.05)	***
Napier grass production (ha)	0.1	(0.05)	0.2	(0.2)	***
Livestock keeping (TLU[d])	2.4	(1.2)	2.2	(1.1)	ns
Unskilled off-farm income (KES '000/yr.)	21.3	(12.4)	44.4	(21.0)	***
Skilled off-farm income (KES '000/yr.)	173.0	(71.0)	185.9	(139.1)	**
Income from business (KES'000/yr.)	67.7	(37.8)	79.3	(31.8)	ns
Income from other sources (KES'000/yr.)	14.1	(3.0)	15.3	(8.7)	ns
Remittances received (KES'000/yr.)	7.0	(5.6)	15.2	(8.7)	***
Amount borrowed for farming (KES '000)	7.2	(2.2)	6.4	(2.3)	*
Value of farm assets owned (KES '000)	18.7	(3.9)	19.1	(6.3)	ns

Sig is significance level of differences between sites: *= at 10%, **= at 5%, ***= at 1%, ns=not significant.
[c]Food crops are grown mainly to meet household's food requirements (e.g. maize, beans and sorghum) whereas cash crops are primarily grown for income generation (e.g. tea, coffee, sugar cane).
[d]TLU is tropical livestock unit equivalent to 0.70 cattle, 0.10 sheep, 0.10 goats, 0.20 pigs, 0.01chicken (Jahnke 1982).

Most of the households had some members engaged in off-farm income generating activities to supplement proceeds from their own farms. The proportion of households that had at least one member engaged away from their farms was significantly higher in Emuhaya compared to Tiriki. Emuhaya is better connected to major urban centres, hence off-farm opportunities are greater there than in Tiriki. In the latter, farmers still have land of better quality for farming. Consequently, households in Emuhaya engaged more in off-farm income activities such as casual labour supply, unskilled employment and businesses in nearby urban centres as well as skilled employment within or outside the district. Off-farm engagements mainly consisted of unskilled, seasonal employment for close to half of the households in both study sites.

On average households in Emuhaya earned twice as much income from unskilled employment as those in Tiriki. Interestingly, the *per capita* annual income from unskilled employment contributed the least to total off-farm income earnings by households across the study sites. This may be due to dwindling casual opportunities leading to lower wages earned by workers in this category owing to over-supply of cheap labour in these densely populated areas. Although the proportion of households with a skilled, high return employed member was smaller, actual off-farm earnings to such households were greatest across sites. The average skilled employment income constituted about 63% of all annual off-farm earnings per household in both study sites.

Diversification in livelihood strategies was demonstrated in the significant proportion of households that had some business activities to complement their income earnings. Close to one-quarter of households in Tiriki and one-third in Emuhaya operated a business entity (Table 2-2). Common businesses that locals engaged in included petty trading in cereals, bananas, vegetables and second-hand clothes (55%) and shop keeping (20%). Others were motorbike transport, tailoring and selling of bricks and charcoal. The average annual income generated from businesses was about 40% of the average annual income from high-return skilled employment. This indicates that engaging in some business provided an important off-farm livelihood strategy to households in the district. Remittances were received mostly by households in Emuhaya with an amount on average double that in Tiriki (Table 2-2). This can be attributed to the higher number of members engaged in off-farm economic activities found in Emuhaya.

Farmers in both sites had low access to credit to finance farming activities. Only 16% of farmers borrowed funds or inputs for agricultural purposes. The main reasons given for low credit access included stringent borrowing conditions such as need for collaterals, fear of defaulting due to poor farm returns, lack of information on credit providers or simply lack of interest to seek for loans. Loan amounts were small mainly sourced from relatives, informal groups, or micro-finance institutions. Generally, each surveyed household owned some farm assets essential for carrying out agricultural activities (Table 2-2).

2.3.3 Main farm types

Our multivariate analyses confirmed the same farm typology distinquished in Tittonell et al. (2005, 2010). The characterisation of the five farm types is summarised in Table 2-3. We explain the distribution of households, farm and off-farm activities and income levels across the farm types and study sites below.

The distribution of farm types varied with more Farm Type 4 households prevalent in Tiriki while Farm Type 1 formed the majority in Emuhaya (Table 2-3). Households in Tiriki farmed relatively larger areas compared to those in Emuhaya. This is due to the relatively recent conversion of farms from previously open spaces or sparse forest areas and less land sub-division in Tiriki. Crop production activities were mostly carried out by Farm Types 2, 3 and 4 because they relied mostly on farming as their main livelihood activity. These farm types also owned a higher number of livestock and received more income from farming than any other farm type (Table 2-3). On average farmers owned only two animals (in tropical livestock units) due to scarcity of grazing space and fodders. Farmers mainly kept local zebus though there is an increasing number of crossbreed and graded dairy cattle under zero-grazing to cope with diminishing pastures.

Farm Type 1 had the highest off-farm income averaging about 90% in both sites. Contrary to our expectation that Farm Type 2 mainly relied on agricultural income, off-farm income in Farm Type 2 averaged over 60% of total income across study sites. The diversified Farm Type 3 received significant contributions from both on-farm and off-farm income activities but relatively more off- farm income than Farm Type 2. Generally, across the five farm types, farm income was less important than off-farm income suggesting a labour transition away from agriculture.

Table 2-3: Farm types, resource endowment and *per capita* daily income in Tiriki and Emuhaya sites

Site / Farm type[e]	Distribution (%)	Crop land (ha)	Cash crops (ha)	Cattle kept (TLU)	Farm income (KES'000)	% Off-farm income	Salaried members (number)	*Per capita* income (KES/day)
Tiriki								
1. High-resource, permanent off-farm	11.6	0.6	0.03	1.3	20.5	89.7	1.3	73.2
2. Medium-resource, mainly on-farm	17.9	1.0	0.16	2.5	50.4	64.0	1.0	66.3
3. Medium-resource, diversified	16.1	0.7	0.08	1.6	42.7	77.1	1.2	82.4
4. Low-resource, some off- farm	42.0	0.8	0.11	1.9	48.4	7.2	0.0	24.5
5. Low-resource, casual off-farm	12.5	0.6	0.04	1.0	33.5	43.4	0.0	28.7
Emuhaya								
1. High-resource, permanent off-farm	29.0	0.5	0.04	1.6	23.1	89.9	1.8	72.0
2. Medium-resource, mainly on-farm	22.6	0.7	0.07	2.0	53.5	61.1	1.5	58.2
3. Medium-resource, diversified	21.8	0.4	0.04	1.7	37.1	78.2	1.8	52.8
4. Low-resource, some off- farm	19.4	0.5	0.04	1.5	37.1	18.0	2.5	30.1
5. Low-resource, casual off-farm	7.3	1.2	0.05	0.8	52.2	43.1	1.3	31.3

[e]Farm types were classified according to the typology advanced by Tittonell et al (2005).

Per capita daily income was highest in Farm Type 1 in Emuhaya and Farm Type 3 in Tiriki. This reflects that Tiriki has better farming opportunities especially for tea production (i.e. land holding size and soil quality) and Emuhaya is better connected to urban centres for off-farm income activities. The higher *per capita* daily income within Farm Type 3 underscored the significance of diversification in enhancing households' livelihood opportunities. That largely households across farm types had *per capita* daily income less than KES 80 (exchange rate averaged KES 77 to 1US$) pointed to pervasive poverty prevalence in the district. High poverty levels in turn led to insufficient use of farm inputs (see Table 2-5). For example, across all farm types, average fertiliser rate was below 50kg/ha and less than 30% of planted seeds were of improved varieties. The resource-poor Farm Type 5 recorded the least use of fertiliser (on average 20kg/ha), improved seeds (<10%) and fewer SWC measures compared to the medium-resource Farm Types 2 and 3.

Based on our findings we deduced that livelihood strategies have become more distinct on the basis of the kind of off-farm activities to which households allocated their resource endowments (Figure 2-2). In general, over 90% of households in each farm type owned less than one hectare of land. There were some areas of overlap in the clusters but clearly the proportion of off-farm income discriminated farm types better compared to the amount of land owned (Figure 2-2). Besides, PostHoc test test (Table B-1 in Appendix B), indicate highly significant (i.e. distinct between farm types) variation based on off-farm income than farm area, which is significantly different only between Farm types 1 and 4. Analysis of variance (ANOVA) results show that categorisation of farms into the five farm types account for significant differences ($p \leq 0.05$) across a majority of key variables within the farming system (Table B-2 in Appendix B), which also confirms that the proportion of off-farm income is a good indicator to distinquish farm types.

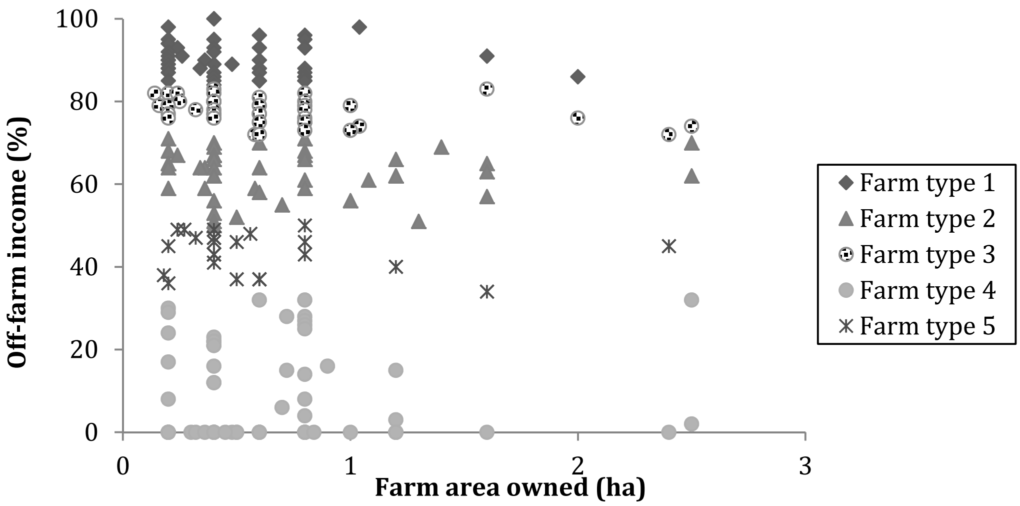

Figure 2-2: Dispersion of farm types based on farm area owned and proportion of off-farm income earned. The arrangement of the clusters is from top to bottom as Farm Type 1, 3, 2, 5 and 4.

2.3.4 Inter-temporal changes in farm types and livelihood orientation

We carried out inter-temporal comparative analysis for Emuhaya, where similar past research was conducted in 2003 (see Tittonell et al. 2010). Comparison of the five farm types across key resource indicators and predominant economic strategies revealed major changes in households' distribution and livelihood orientation during the past seven years (Figure 2-3).

Comparing our analysis with that of Tittonell et al. (2010) shows net shifts in the number of farmers classified in specific groups and average changes within farm types.

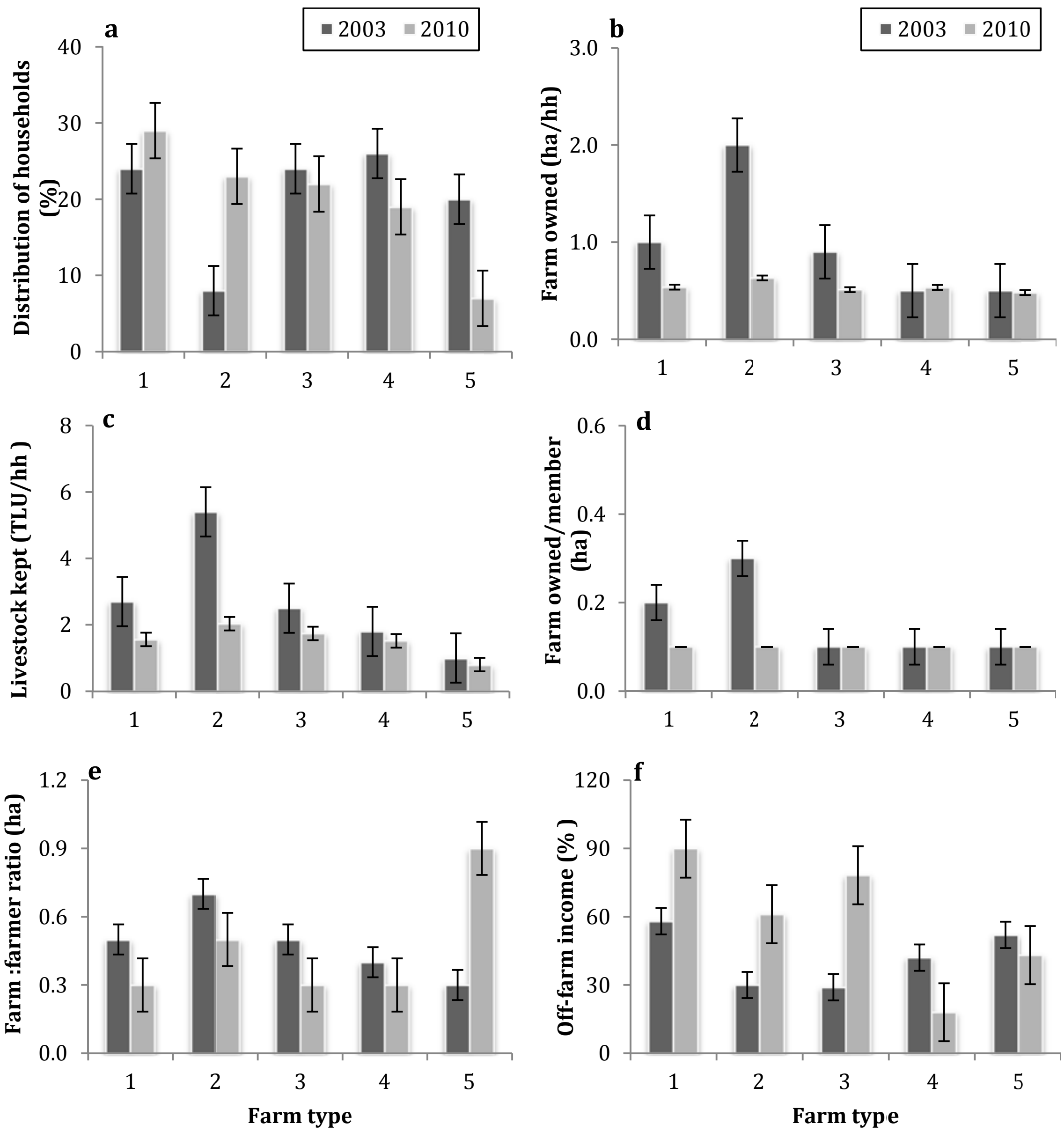

Figure 2-3: Inter-temporal changes by farm type in (a) distribution of households, (b) farm sizes owned, (c) livestock kept, (d) *per capita* farm owned, (e) farm to farmer ratio and (f) proportion of off-farm income in total household earnings between 2003 (from Tittonell et al., 2010) and our 2010 survey in Emuhaya.
Notes: hh stands for household and Y error bars indicate statistical difference at 5% level of significance.

Our results show that significant changes took place in the Emuhaya farming system in the period between 2003 and 2010. Our findings demonstrate that off-farm income gets more important over time. There were noticeable increases in proportion of Farm Types 1 and 2

(Figure 2-3a). This was attributed to the significant decline in land holdings and livestock numbers thereby reducing reliance of these households on farming. The majority of households across all farm types owned significantly less land and livestock resources in 2010 (Figure 2-3(b-c)).

Land per household member declined across all farm types, and halved within Farm Types 1 and 2 (Figure 2-3d), an indication of increased family sizes and more land fragmentation during the study period. Similarly, labour allocation to own farming activities decreased. In Farm Type 5, the arable area available per full-time family farmer, that is the number of adults engaged in farming over the farm area of the family, increased (Figure 2-3e). Since farm sizes within this farm type remained stable, the change in land available per farmer was intuitively due to re-allocation of more labour to off- farm activities as casual income sources became unreliable and less remunerative. According to views of the local stakeholders, in the past it was easier to find casual work within the relatively large farms. However, with continued sub-division, the plots have progressively become smaller such that there is rarely need to hire additional labour. Besides, the number of people seeking the fewer casual opportunities has increased with population growth and high unemployment of the youth. This over-supply of casual labour has depressed real daily wages. Conversely, there are emerging off-farm activities such as motor bike transportation, with relatively better income prospects that have contributed to the rising of shadow wages for farm labour especially during the peak planting season. The changes for the other farm types indicated that over time households shifted part of their family labour to off-farm activities as land sizes reduced. This shift was more evident in the medium-resource Farm Types 2 and 3, which previously depended mostly on farming and own family labour supply.

The increase in off-farm income within Farm Types 1, 2 and 3 pointed to the growing importance of off-farm economic activities as a livelihood strategy in the western highlands of Kenya (Figure 2-3f). Surprisingly, changes in share of off-farm income were highest within Farm Type 3 due to their diversified nature that provided synergy between farm and off-farm economic activities. The low-resource Farm Types 4 and 5 had negative changes in off-farm income earnings during the past seven years. This is because of the dwindling opportunities for casual labour supply to neighbouring farms that their family members typically engaged in. Interestingly, based on Figure 2-3 and Table 2-3, the coping strateges of the farm types can be summarised as follows: Farm Type 1 has reduced reliance on agriculture, Farm Types 2 is diversifying both in farm and off-farm activities, Farm Type 3 is increasingly focussing on off-farm income sources in addition to farming, while Farm Types 4 and 5 simply practice low input-low output farming.

2.3.5 Efficiency in allocation of resources in maize-bean production

Our results show significant positive coefficients for inputs in the first part of the production model, indicating that farm inputs were used at sub-optimal levels. It was possible for net farm revenues to increase from additional application of fertilisers and labour use (Table 2-4). The significant coefficient for site shows that farmers in Tiriki achieved higher net returns compared to those in Emuhaya. This indicates the significant contribution to farm efficiency of favourable agro-ecological location and or higher soil fertility- largely related to the more recent conversion of land to agriculture- in Tiriki. However, the overall efficiency level was only 40%, which means that farming returns were less than half of the potential at current levels of resource use (Olowa and Olowa 2010 found a comparable result). Although inadequate land and capital resources are key constraints within the smallholder farming system in the study area, the output realised with the available inputs is nevertheless too low. We summarise the results on production efficiency and actual use of selected SLM practices in Table 2-5 below.

The application of manure reduced inefficiency by 30%, indicating the beneficial effect of organic matter to farm productivity. Farmers in the study area do not have sufficient finances to purchase adequate quantities of fertilisers therefore increased use of manure can be a desirable coping strategy. However, the effectiveness of manure in farm production is dependent on its quality, quantity and labour availability during utilisation.

The presence of a single SWC measure such as a terrace, contour bund, or Napier grass strip lowered inefficiency by 7%. The result indicates that it is economically beneficial for farmers to practice better land management options that not only augment nutrients in the soil but also reduce their loss through erosion. The low productivity effect of SWC measures on efficiency compared with manure use is due to the high cost incurred to establish and maintain the physical measures.

Table 2-4: Stochastic production frontier estimated for economic efficiency and determining factors in maize-bean farming activity

Variable	Coefficient	SE[f]	t-ratio	Sig
Production frontier model (Equation 2.1)				
Dependent variable: Crop output value (KES/ha)				
Intercept	3.67	1.13	3.25	***
Fertiliser use (KES/ha)	0.17	0.06	3.05	***
Seed use (KES/ha)	0.10	0.10	0.95	ns
Labour input (KES/ha)	0.55	0.11	5.22	***
Site (1=Tiriki; 0=Emuhaya)	0.60	0.12	4.82	***
Efficiency effects function (Equation 2.2)				
Dependent variable: Production inefficiency score (%)				
Constant	2.09	0.27	7.61	***
Lagged manure use(1=yes; 0=no)	-0.29	0.16	-1.84	**
Per capita income (KES/day)	-0.01	0.00	-2.53	***
#Full-time farming members	-0.20	0.09	-2.16	**
Production orientation (1=market; 0=subsistence)	-0.31	0.25	-1.27	*
#SWC measures on best field	-0.07	0.05	-1.35	*
Efficiency measures				
Gamma (γ)	0.95	0.04	24.80	***
Likelihood ratio test	36.71			***
Mean efficiency (%)	40			

Sig is significance level; *= at 10%, **= at 5%, ***= at 1%, ns=not significant.
[f]SE is standard error of estimate.

Our result shows that involving one more family member in farming on a full-time basis reduced inefficiencies by 20%, *ceteris paribus*. This was attributed to closer management of the farm and effective implementation of agronomic practices in the farm enterprises. However, even though employing an extra labourer on the farm increased efficiency, the return to this labour was low given the small sizes of the farms.

Commercial orientation in farming, (that is, production mainly for the market calculated as the average share of farm produce sold), reduced inefficiency by 30% (Table 2-4). This indicates that expectation to generate income as opposed to meeting subsistence needs alone creates motivation to produce efficiently. Market participation provides price incentives that motivate farmers to produce higher output at low production cost in order to increase net revenues. Farm efficiency is enhanced when such farmers afford to plant better quality seeds, implement agronomic activities on time, apply adequate manures and or fertilisers and invest in conservation measures to control soil loss. Therefore, for efficient and sustainable farming to take place in this area there is need to enhance farmers' access to remunerative markets through approaches that reduce transaction costs and enhance timely access to market information (Omamo 1998, Mose 2007).

Table 2-5: Summary of economic efficiency and selected SLM practices by farm type

Site/Farm type	Economic efficiency (%)	Fertiliser use (kg/ha)	Improved seed (%)	SWC measure(#)
Tiriki				
1. High-resource, permanent off-farm	36.3	28.8	28.2	3.3
2. Medium-resource, mainly on- farm	41.6	49.4	24.4	2.6
3. Medium-resource, diversified	39.3	48.6	22.6	2.3
4. Low-resource, some off-farm	35.4	48.8	17.3	2.2
5. Low-resource, casual off-farm	40.5	29.3	7.4	1.8
Emuhaya				
1. High-resource, permanent off-farm	26.5	22.4	9.2	2.0
2. Medium-resource, mainly on- farm	38.2	29.7	14.9	2.4
3. Medium-resource, diversified	41.6	48.0	9.9	2.0
4. Low-resource, some off-farm	39.2	37.0	1.7	2.1
5. Low-resource, casual off-farm	38.3	18.4	12.1	1.9

2.4 Discussion

In this chapter, we showed that households' orientation towards primarily on-farm or off-farm strategies influenced prioritisation of land management activities, intensity of external inputs used on the farms and influences the process of intensification at the farming system level. This was demonstrated in farm diversity and inter-temporal changes in livelihood choices between and within the five farm types investigated in this study.

Our study found significant farm diversity within smallholder farming systems as expressed through differences in household characteristics, main production activities and economic strategies between the two study sites in Vihiga District. The diversity of farm types and livelihood strategies has important implications for the design of suitable sustainable land management (SLM) interventions (Holden et al. 2006, Shisanya et al. 2009, Righi et al. 2011). Farm diversity also presents both the greatest challenge and opportunity to the implementation of policies and programs that aim to enhance agricultural productivity (Solano et al. 2001, Berkhout et al. 2011, Giller et al. 2011) in densely populated regions of SSA.

Research findings show that the main livelihood strategy pursued by the household determined actual land management practices at farm level. For instance, Farm Type 1 is predominantly high return, off-farm oriented and relatively well-endowed, but land related investments exemplified in use of improved seeds, chemical fertilisers and conservation structures were unexpectedly low on their farms. This implies that such farm types are unlikely to be keen on implementing SLM practices. This is perhaps due to the high prominence they place on resource allocation to improve competitiveness of their human capital to maintain higher returns from off-farm activities, such as investment in education of the children. This view is consistent with findings in the East African region by Tittonell et al. (2010).

Farm Type 5 on the other extreme, consists of poorly endowed, casual-labour supplying households but also off-farm oriented. Similarly this farm type could have limited participation in farming programs due to either severe production constraints they face or social differentiation associated with abject poverty and high dependence on their neighbours for survival (Crowley and Carter 2000). For farmers in this category to embrace SLM practices they need long term technological and policy interventions that minimise these constraints such as cost-effective marketing systems to access fertilisers, seeds and other inputs as well as the availability of integrated soil fertility management options (Tchale and Sauer 2007). This farm typology is structurally trapped in a vicious cycle of poverty and is likely to relapse to unsustainable farming practices once such packages are beyond reach, as recognised by Giller et al. (2009). Hence, our study shows that both the richest and the poorest resource owners are least likely to invest in SLM practices on their farms. This is because farming is not a priority livelihood activity within the richest households, while the poorest do not own necessary resources to do so.

Generally, efficiency levels were lowest in the predominantly off-farm oriented Farm Type 1 across sites whereas Farm Type 2 in Tiriki and Farm Type 3 in Emuhaya realised the highest efficiency levels. The efficiency differentials mirrored actual farm practices. Households that relied mainly on activities away from the farm (i.e. Farm Types 1 and 5), recorded the lowest levels of fertiliser use in both sites and they had fewer SWC measures on their farms in Emuhaya. This finding is consistent with Odendo et al. (2009) disputing the conventional expectation that off-farm income sources lead to more investment in land management and higher farm resource use efficiency (e.g. Mochebelele and Winter-Nelson 2000, Mutoko et al. 2008). Even though this may be the case, Farm type 5 are also categorised as low-resource group hence they are constrained to make meaningful investments to farming activities. The low use of fertiliser and improved seed in this farm type across sites is more due to resource scarcity than livelihood orientation. Hence there is a need to make a deliberate distinction between constraints to adoption of SLM practices associated with predominant livelihood orientation and general lack of farm resources.

Our findings identify the medium-resource, diversifying Farm Types 2 and 3 as the most dependent on agriculture and having higher interest in improving farm productivity. Households constituting each of these farm types pursued complementary livelihood strategies with potential to provide necessary synergy to drive better land management and agricultural transformation at the farming system level. This is because Farm Types 2 and 3 realised the highest income from farming, owned moderate farm assets and achieved higher efficiency necessary for effective agricultural transformation through improved knowledge transfer. These farm types (2 and 3) therefore have the necessary potentials to take up SLM practices much faster than types 4 and 5. The resource-poor Farm Types 4 and 5 also rely on farming although they are trapped in a vicious cycle of poverty. Hence, these farm types (4 and 5) require a different intervention strategy that not only enhances their access to better technologies but also improves their affordability of key inputs such as fertilisers and certified seeds. The comprehensive National Agricultural Accelerated Inputs Access Program (Simbowo 2009) that aims to enhance access to farm inputs by vulnerable farmers should target mostly Farm Types 4 and 5. Therefore, given the evidence of increasing land scarcity across most SSA regions (Jayne et al. 2010), policies and programs aimed at enhancing the uptake of SLM measures should prioritise and target support to these farm types to improve agricultural productivity. Concisely, we recommend that the first-line approach for pure technological promotion alone targets Farm Types 2 and 3, whereas a second-tier strategy embracing combined approach targets Farm Types 4 and 5. Off-farm income appeared as a good single proxy for clustering farm types, which could be applied by development agents promoting SLM programs to target specific households.

It was not possible to identify which specific households got worse off or moved to higher income farm typologies. However, collectively there was significant increase in the proportion of off-farm incomes except in the resource-poor Farm Types 4 and 5. The majority of the households prioritised allocation of resources to activities that improve their returns mainly from off-farm engagements. The underlying factor in this shift away from agriculture is likely to be the low returns from farming as compared to other economic activities. In turn, this is related to the small land holdings, consistent with the findings by Jayne et al. (2010). For the farm dependent and poor households, the low returns from agriculture in turn may accentuate the negative impacts of land degradation (Barbier 2000, Barrett et al. 2001a, Nkonya et al. 2009). Our findings indicate a need to consider an additional aspect of the poverty trap. The poorest farmers have the least possibility to invest in sustainable agricultural productivity, but also the lowest prospect to enhance off-farm incomes by investing in education, business or capital goods. In addition, the decreased farm sizes within the relatively well-endowed Farm Types 1 and 2 affected other poorer households that used to supply labour to these Farm Types, which contributed to increased resource poverty across all categories in just under a decade.

It is generally stipulated that making farm production an attractive economic activity on increasingly smaller fields entails the promotion of high-value, horticultural crops such as vegetables and zero-grazing livestock systems (Ndufa et al. 2005, Berkhout et al. 2011). Nevertheless, even with a multitude of projects promoting such developments in Vihiga e.g. African Indigenous Vegetables Project, Livestock Development Project, Heifer Project International (Abukutsa-Onyango 2009, Walingo 2009), our study shows that this improvement has not taken off on a sufficient scale to transform the farming systems in the district. Hence, the postulated intensification of the farming system as population density increases (Tiffen et al. 1994, Pender 1998) has not taken place in the study area. Instead, over time farmers have increasingly focused on off-farm income activities. Overall, our study shows that farmers make only limited use of SLM measures, in spite of the small and still diminishing farm sizes and the implementation of several conservation programs in the area. These new insights contribute to better understanding of a dense African agro-environment, with potential to improve targeting of SLM practices. Better targeting is likely to enhance the application of SLM practices, boost agricultural productivity and improve rural livelihoods. Time and investment are required for SLM practices to be adopted and maintained, hence there is need to focus promotion of SLM practices in areas where agriculture continues to be a source of expanding wealth and where returns to investment in agriculture can yield enhanced livelihoods. Our study found that potentially promising techniques include the promotion of integrated livestock (with or without zero-grazing) – cropland farming systems, since these types of farms reached significantly higher efficiency levels, partly due to the availability of manure. The availability of SWC measures on the farm, however, did not lead to significant efficiency gains (Table 2-4). This is most important especially for agrarian livelihoods in the light of agro-based economies and prospects for an ever-increasing population growth in sub-Saharan Africa.

Inter-temporal changes within farm types revealed worsening availability of land and labour for agriculture due to land subdivision and increased off-farm orientation among most households over time. However, we could not directly link changes in resource endowment at farm level to actual land management behaviour across the farm types over time because we did not access the original data collected in 2003 by Tittonell et al. (2010). Instead, our analysis was limited to comparison of their results on farm assets by farm type with our own to gain insights into the implications of inter-temporal changes in livelihood strategies and farm resource endowments on likelihood of using SLM practices over time. We therefore based econometric analysis on our 2010 data to show how the efficiency with which current farm assets are allocated in the main agricultural activity pans out in space across the five farm types. This is important especially within an agro-environment where traditional household resources such as land, livestock (proxy for capital) and labour for farm production are diminishing (Tchale and Sauer 2007, Mutoko 2012). Our results clearly show that these changes are affecting the five farm types differently and successful promotion of SLM programs would benefit more from improved targeting of relevant interventions to suitable areas and relatively efficient farm types to have the highest likelihood of resulting in greater impact.

Increased application of SLM practices within the farming system could also contribute to ecological benefits in the wider area. For example, the use of SWC measures controls soil loss, thereby reducing silting of water reservoirs; the application of manure minimises dependence on chemical fertilisers blamed for eutrophication of water bodies and organic nutrient sources are less harmful to biodiversity and enhances soil micro-fauna activity in the agro-ecosystems. Hence, promotion of SLM contributes to the maintenance of ecosystem services supply and also brings a number of positive externalities (Ansink et al. 2008, Daily et al. 2009). However, they are not analysed in this study.

2.5 Conclusions

In the context of a need to foster sustainable land management across sub-Saharan Africa (SSA), we examined farm diversity and resource use efficiency in densely populated highland agro-ecosystems of Western Kenya. Using multivariate analysis, we identified five farm types across two study sites in Vihiga District, based on farmers' resource endowments and their main economic activities. Our study found that livelihood strategies were very heterogeneous and also dynamic in response to changing socio-economic, demographic and environmental conditions. Faced with diminishing farm sizes, most households allocated their scarce resources more to off-farm activities than to the implementation of sustainable land management practices and agricultural intensification. Agricultural proceeds were low with farm efficiency level on average only 40% of potential returns from available productive inputs used within the examined farms. Households that relied less on the farm for overall income earning tended to invest little in sustainable practices that would enhance farm productivity and resource use efficiency. Making farming an efficient activity would not only minimise wastage of the scarce farm resources but also would make farming more competitive and remunerative. We conclude that increased population pressure on land does not necessarily lead to better land management and efficient resource use in agriculture. This also has repercussions for the design of policies and programs aimed at promoting sustainable land management practices in similar regions in SSA. Such policies and programs are likely to be most successful if they manage to target areas that are highly dependent on agriculture and farm opportunities are growing, and within these areas to reach households mostly reliant on farming to sustain their income. Directing efforts to areas where agriculture is the mainstay and farming households have greater interest in improving farm productivity, has high chance of succeeding than spreading thinly assuming that all rural households are dependent on farming and therefore interested in implementing SLM practices. There is also need to focus on SLM measures that make a significant contribution to farm efficiency such as integrating livestock and cropping as in the case of Vihiga. Hence, lessons that can be derived from our analysis of the diversity of farming systems and farmer's strategies in Vihiga are relevant for the design of SLM programs in many other parts of Africa.

Balancing high local dependency, rich biodiversity value and recreational potential of Kenya's only rainforest—Kakamega forest

Photos courtesy of KFS and KWS, Kakamega (2011)

Chapter 3 Conservation versus Conversion—Economic Trade-offs in the Management of Kakamega Forest Ecosystem[3]

3.1 Introduction

Natural forests constitute an important ecosystem that provides not only private goods for direct human use, but also public services with indirect use or non-use benefits (MA 2005, Glenday 2006, Daily et al. 2009). The supplied ecosystem services contribute to the maintenance of both the ecological functions and improvement of human well-being across space and over time. Ecosystem services have previously been defined as the tangible and intangible benefits derived from ecosystems that "produce human well-being" (MA 2005, Fisher and Turner 2008, TEEB 2010b). Three main categories are distinguished: provisioning services such as timber and non-timber products harvested from the ecosystem; regulating services such as carbon sequestration and cultural services including the intangible benefits people derive from ecosystems for spiritual, cultural heritage and recreational purposes (TEEB 2010a, Haines-Young and Potschin 2011).

Ecosystem services provided by tropical forests are becoming scarcer due to the supply side stressors and the demand side pressures. For example, deforestation threatens the supply of essential ecosystem services by compromising functional capacity of the forests. At the same time, population driven demand for ecosystem services exerts unprecedented pressure on the forest ecosystems (Lambin et al. 2003, MA 2005, Morton et al. 2006, Schmook and Vance 2009). It has been postulated that analysis and valuation of ecosystem services can support the design of sustainable management alternatives(Freeman 1991, Bockstael et al. 2000, Hassan 2003, Glenday 2006, Wunder 2007, Ansink et al. 2008, Benhin and Hassan 2008, Hein 2011). However, it is not always clear how ecosystem services translate into stakeholder incentives in forest management and whether the knowledge of economic value of ecosystem services is sufficient to trigger better ecosystem management practices (Hein et al. 2006, Daily et al. 2009).

The objective of the study is to estimate the local economic value of ecosystem services provided by Kakamega forest (Kenya) and examine how this information can support sustainable forest management. In particular, we analyse to what degree local ecosystem benefits provide a motivation for conservation and sustainable use of Kakamega forest. We first analyse the local and selected national benefits provided by the forest, and subsequently analyse the way stakeholders are involved in management of the forest. Kakamega forest is a national park, and is the only remaining Guineo-Congolian rainforest in Kenya. The forest is selected for this valuation study for three main reasons. First, Kakamega forest provides a bundle of important ecosystem services. It has biodiversity of international significance, serves as a tourist attraction, is a carbon sink, and is a source of several rivers that drain into Lake Victoria (Glenday 2006, Ouma et al. 2011). Secondly, the areas around Kakamega forest exhibit high population densities (e.g. 1045 people/km^2 in Vihiga District). The forest is threatened by over-exploitation and encroachment as recently established in an analysis of land use change based on remote sensing images of the past 25 years (Mutoko et al. submitted). Increasing dependence of local residents on the forest — for firewood, poles,

[3] Based on Morgan C. Mutoko, Lars Hein and Chris A. Shisanya. Tropical forest conservation versus conversion: Economic trade-offs in the management of Kakamega rainforest. Submitted

charcoal and grazing — provides a classic case of conflict between conservation and exploitation goals (Fashing et al. 2004). Trade-offs involving these goals requires a thorough analysis that we explored in this study. Thirdly, Kakamega forest is the easternmost patch of the equatorial rainforests of Africa that once stretched from Ivory Coast to Kenya (Müller and Mburu 2009). Some forests remain in Gabon, Congo and Uganda (Lovett and Wasser 2008). Hence, the ecosystem services generated by this forest are regionally representative and their comprehensive valuation has potential policy and management implications for similar forest ecosystems in Africa.

We carry out an analysis of the economic value of Kakamega forest with regards to the two institutions that drive management of the forest: (i) official management by government institutions, in view of the national importance of the forest; and (ii) community co-management by a multitude of local stakeholders as a function of community interests and local perceptions. Innovative aspects of this study are that we focus on an ecosystem that has received to date little attention in the ecosystem services literature, that we compare local economic benefits and opportunity costs of conservation, and that we examine both the ecosystem services used by local communities and their interests in and perceptions of local forest management.

3.2 Materials and methods

3.2.1 The case study area

Kakamega forest is located in Western Province of Kenya. The forest lies between latitudes 0°10′ and 0°21′ North and longitudes 34°47′ and 34°58′ East (Figure 3-1). The area has altitude ranging from 1500 to1700 m above sea level, receives an average annual rainfall of 2000 mm and the maximum temperature is 26 °C (Müller and Mburu 2009, Ouma et al. 2011). Kakamega forest was first gazetted as a Government Forest Reserve in 1933, then covering about 23780 ha. The protected forest area currently covers 17838 ha out of which indigenous forested area is about 14000 ha (Müller and Mburu 2009). The forest is endowed with rich biodiversity of plants, endemic primates, birds and insects. The high biodiversity value of this forest is important for both international and local tourism as well as research purposes. The forest is also a natural sink for CO_2 sequestration thereby contributing to mitigation of global climatic change (MENR 1994).

The local communities rely on the forest for ecosystem services such as firewood, charcoal, pole wood, pastures, medicinal extracts and wild honey that supplement their livelihood needs (Ouma et al. 2011). They also conduct cultural activities such as circumcision rites in secluded parts of the forest. According to the 2009 population census administrative locations (units below the sub-district) neighbouring the forest counted 191,490 people in about 32,000 households (KNBS 2010).

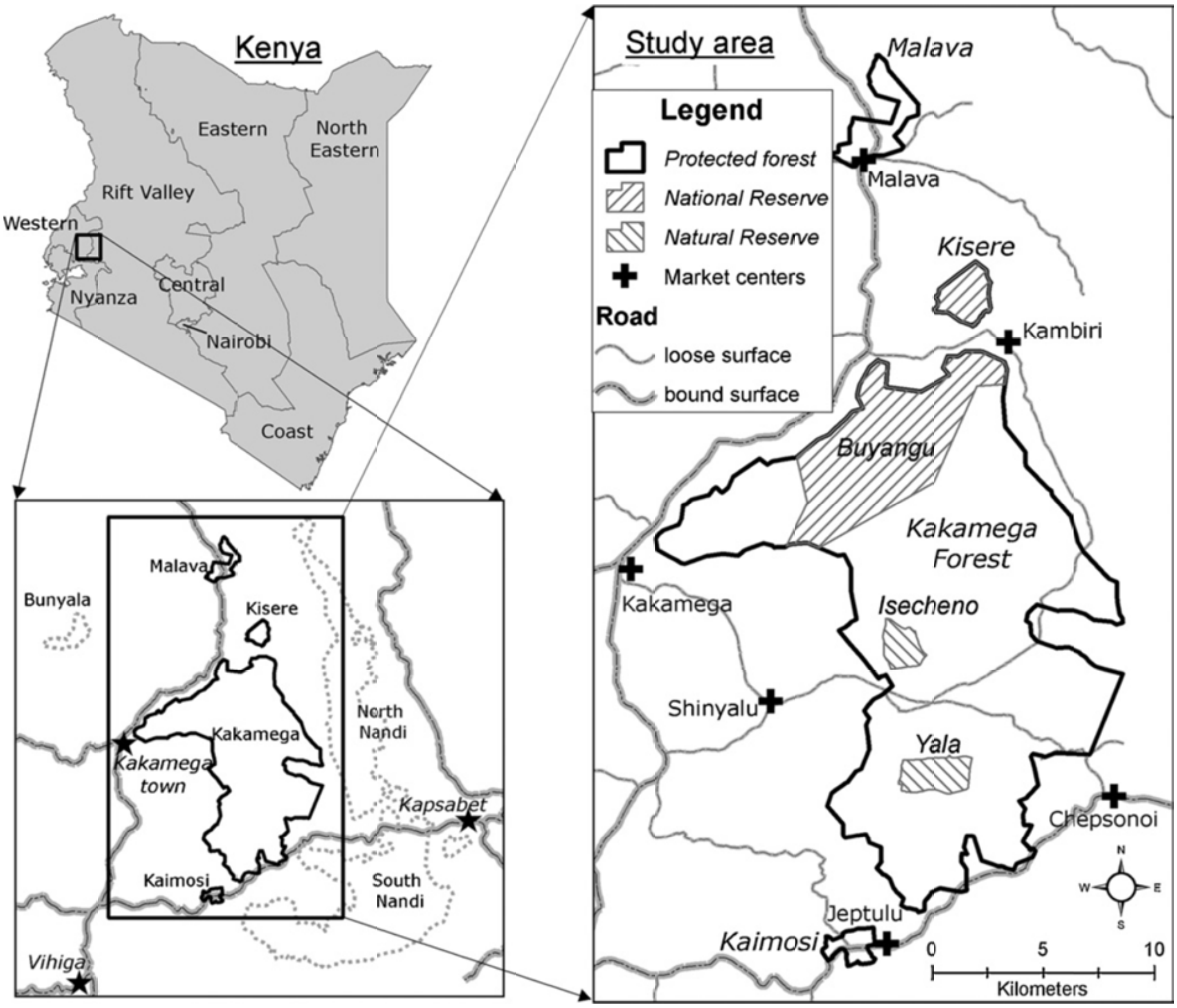

Figure 3-1: Map showing the location of Kakamega rainforest in Western Kenya.
Source: Müller and Mburu (2009).

3.2.2 Definition of indicators and spatial scale of beneficiaries from ecosystem services

Proper physical quantification and economic valuation of ecosystem services provided by the forest ecosystem requires careful selection of the benefit indicators, classification and identification of appropriate scale of beneficiaries for valuation (Daily et al. 2000, Hein et al. 2006, TEEB 2010a). This was important for the application of suitable valuation techniques to retrieve the correct estimate of the monetary value of a complete bundle of the supplied ecosystem services. Based on the available knowledge and local stakeholder consultations, we defined 10 distinct ecosystem services across the broad categories found in literature (MA 2005, Brander et al. 2010, TEEB 2010a). For each ecosystem service, we identified the measurable benefit indicators, the main consumer groups and their spatial reach (Table 3-1). We then designed appropriate research methods to collect relevant data for proper quantification and valuation of the key ecosystem benefits.

3.2.3 Data collection and quantification of ecosystem services

We adopted the general frameworks provided by the Millennium Ecosystem Assessment (MA 2003) and TEEB (2010a). The local and selected national scale ecosystem services generated from Kakamega forest were quantified and valued based on interviews with forest-adjacent community and the analysis of secondary data. We selected ecosystem services for our analysis based on their relevance for local forest management. In particular, we included in our analysis all local provisioning services and the local cultural service (as described below). Since part of the forest is managed as a national park, under the responsibility of the Kenya Wildlife Service (KWS), we also examined tourism and biodiversity conservation as two key services that are considered in the management of the park. We do not analyse other important ecosystem services provided by the park such as carbon sequestration and water regulation since they do not result in local benefits or disservices. However, we do discuss their relevance and how they may influence forest management in the Discussion section.

To analyse local provisioning and cultural services, we conducted an elaborate household survey of the forest-adjacent community, from September through December 2011, using a detailed, pre-tested questionnaire (Appendix A2). Stratified random sampling technique was applied in the survey to select 240 residents within a radius of 10 km from the edge of Kakamega forest in Vihiga District. We limited the spatial coverage of the survey within 10 km distance from the margin of the forest because prior knowledge showed that direct dependence on forest products is highest within this region (Mutoko et al. submitted). Cognizant of the sensitivity of the illegal forest extraction activities common in the study area, we deliberately assured the respondents about the confidentiality of the information before they consented to provide it. During the survey, we collected data on all aspects involving the interaction of the local community with the forest resource, such as the type and amount of products extracted, frequency and intensity of access and number of people and collection time involved. Besides, we included questions to estimate economic benefit of the forest as a ground for cultural rites such as circumcision. This was assessed based on the number of people involved, distance covered to the cultural sites in the forest, time spent on the cultural activities. All the ecosystem benefits directly accruing to the forest-adjacent communities were quantified as the product of amount extracted, frequency and number of people involved, over the proportion of the total beneficiary population. To extrapolate survey data to annual estimates for each of these forest benefits, we asked for the actual number of months in a year that each household accessed a specific ecosystem service. Other information collected included local perceptions on the availability and drivers of ecosystem services over time, views on the effectiveness of existing management arrangements and suggestions for maintaining a sustainable supply of benefits from the forest ecosystem. Specific questions for revealed preference (i.e. market price-based) and stated preference (i.e. based on willingness to pay) pricing of ecosystem services were in-built in the questionnaire (Adamowicz et al. 1994). The household survey generated primary data for eight ecosystem services (Table 3-1).

Data on the recreation service was collected during a tourist survey of both domestic and international visitors, conducted between December 2011 and August 2012 at Kakamega Forest National Reserve. We applied the basic steps of a zonal Travel Cost Method (TCM) for domestic tourists based on survey data on the number of visitors, distance covered, direct cost of and time taken to travel to the park, for quantification and valuation of this service (King and Mazzota 2000). A total of 159 domestic visitors filled in the survey questionnaire.

We defined domestic tourists as visitors whose nationality is Kenyan and non-Kenyan visitors as international tourists.

Table 3-1: Classification and assessment methods for ecosystem services provided by Kakamega forest

Ecosystem service[a]	Benefit indicators	Assessment method
Provisioning		
1. Fuel wood supply	Firewood quantities collected	Household survey
2. Charcoal production	Charcoal quantities extracted	Household survey
3. Natural pasture provision	Livestock grazing/day	Household survey
4. Construction materials supply: Poles	Pole wood quantities extracted	Household survey
5. Construction materials supply: Thatching grass	Thatching grass quantities extracted	Household survey
6. Wild edibles provision	Fruits, vegetables, honey	Household survey
7. Ethno-medicines	Herbal medicine extracted	Household survey
Cultural		
8. Cultural heritage	Cultural rites by number/period	Household survey
9. Recreation: wildlife viewing, trail walks, camping	Tourist visitation numbers, distance travelled, time spent, direct costs	Tourist survey
10. Nature conservation: Biodiversity	Species richness, rare/endangered species, naturalness	Household survey Secondary sources

[a]Classification based on typology in literature (MA 2003, TEEB 2010a)

In addition, we calculated the money spent locally by international tourists. In the survey we asked foreign tourists to indicate the money that they spent locally in association with their visit to Kakamega Forest National Park. In particular, we elicited information on local expenses on transport, park services, meals, accommodation and purchases of souvenirs. Since we did not get relevant data to correct for the production costs, this estimate only includes gross value that accrued to the local economy attributable to recreational experience they enjoyed at this national park. Some specific questions were also included in the questionnaires to determine the visitors' willingness to pay for improved quality of the recreational service within the park (Kling 1997, National Research Council 2004). A total of 59 international tourists participated in the survey.

Finally, we analysed the biodiversity service provided by Kakamega forest (e.g. Mace et al. 2012). However, we did not attempt a monetary valuation of this service due to the inherent difficulties in monetising the value of rare and endemic species and ecosystems (Farley et al. 2010, TEEB 2010a) Biodiversity of the forest is appreciated at the local and national and is also of international significance (KFE 2012), however an additional complexity of valuing the biodiversity service is that its appreciation may well vary between these scales. For instance, local people may also be confronted with the negative impacts of biodiversity such as crop damage from wildlife. In our study, quantification of biodiversity preservation was based on species richness, species rarity and presence of endangered species in a given ecosystem (TEEB 2010b). We analysed biodiversity service of the forest based on a literature review (e.g. Ouma et al. 2011, KFE 2012, KWS 2012), and examined local perceptions in the stakeholder survey conducted among people living adjacent to the forest. In particular, we included in the survey a question on the most important aspects of the forest they consider valuable to be preserved and for what purpose.

Note that there was no timber logging in the forest 2011 because cutting of trees in protected indigenous forests was outlawed since 1986 (Müller and Mburu 2009) and we therefore not consider timber production in our study.

3.2.4 Valuation of ecosystem services

Economic valuation of ecosystem services needs to consider the consumer and producer surpluses generated by the supply and use of ecosystem services, and is best aligned with calculating the value of marginal changes in ecosystem services supply (Pearce and Turner 1990, Fisher et al. 2008). The analysis of economic values of ecosystem services at the margin is important because economic decisions and policy interventions are based on trade-offs at the margins, between alternative ecosystem states or uses (Turner et al. 1998). Therefore, we explicitly incorporated the concept of marginal WTP in our analysis of economic values (Balmford et al. 2002, Turner et al. 2003, Pearce 2007, Cho et al. 2011). Our valuation approach is based on National Research Council (2004) and we only calculate annual benefits generated by the park.

For most provisioning services, the consumer is the total forest-adjacent population and the producer is the Kenya Forest Service (KFS), which manages Kakamega forest. We calculated the monetary value of the marketable ecosystem benefits based on the generated consumer surplus, assuming that the market prices reflect the true marginal willingness to pay for the ecosystem benefit. In particular, we first analysed the gross revenue from provisioning services, based on multiplying quantities of product harvested and the price paid in village markets for these products as reported by the respondents. For the non-marketed benefits such as pastures for cattle grazing, we used prices for their substitutes (i.e. Napier grass) according to the survey respondents. Second, we deducted all costs related to harvesting the product including labour costs and the permit fees that villagers paid to KFS management for access to the forest. Access costs borne by the consumer were calculated by valuing the total time spent for the round-trip for extraction of forest products using average local wages (valued at hourly wages of KES 20 based on farming activities). We did not consider the costs of local materials (e.g. gunny bags, sickles, machetes) since our survey showed that these costs were very small compared to the other costs.

For the provisioning services we also examined the producer surplus accruing to KFS management, and assumed that these equal the permit fees. The forest management does not invest specifically in regeneration of species used for the extraction of provisioning services (such as firewood or thatch grass). Management costs incurred by KFS are related for the large majority to facilitating tourism and monitoring and protecting biodiversity. Besides, total revenue collected in permits represents net benefit for the provision of these NTFPs because the local communities through community forest associations (CFAs) also co-manage the forest. Hence, we assumed that the permit fees equal the surplus generated through the extraction of provisioning services to the forest management (i.e. the 'producer').

For the recreation services, we analysed two aspects. The consumer surplus generated for domestic visitors and the producer surplus generated to the forest management. In addition, we considered the local added economic benefit from international tourists accruing to local providers of tourism facilities, in particular: transport, restaurants, hotels and handicraft sales. We opted for this approach because it is consistent with our interest in revealing the local values generated by the Kakamega Forest National Park (which means we exclude the consumer surplus generated by the local tourism businesses). We applied a zonal TCM to retrieve the value of domestic recreation. We followed the following steps in zonal TCM following King and Mazzota (2000): i) We established zones according to distance to the park and existing geographical boundaries; ii) estimated annual visit rates for each zone based on zonal population and total domestic visitors from our survey data. iii) in regression analysis we estimated visit rates as a function of actual travel cost incurred with assumed opportunity cost for time of US$ 0.90/hour; iv) constructed the demand curve from the regression equation by varying entry fees and v) estimated area under the demand curve to calculate total consumer surplus of the park.

To retrieve marginal WTP values for the cultural benefits for which market-based valuation was inapplicable (Mitchell and Carson 1989, Haab and McConnell 2003), respondents were asked to give the lowest price they were willing to accept to forego the access to the forest for a cultural rite and to give reasons for that price (Perman et al. 2003, List 2004). In some cases, we also used avoided cost, for example to estimate the value of the forested ground for traditional rites such as circumcision, which is also done in hospitals. However, the actual value for traditional rites for boys is likely to be higher than that provided in hospitals though the latter is done under better hygienic conditions. Time spent in the forest during the rites is a reflection of higher benefit (than opportunity cost of labor withdrawn from productive activities) that the participating households attach to this cultural activity facilitated by the forested ground. We realize that the retrieved value is an under-estimate for this service but reliable WTP values for traditional circumcision rite were difficult to collect.

3.3 Results

3.3.1 Physical supply of ecosystem services

Non-timber forest products and cultural benefits

Forest-adjacent community extracted seven NTFPs and one cultural service from Kakamega forest. The households surveyed around the forest obtained on average 240 head lots of firewood per year (Table 3-2). Firewood remains the main source of energy for cooking in most homes. Charcoal burning though illegal was reported in over 20% of the sample households with an annual average of about 200 bags per household for the 20% of the total households in the study area. Continued charcoal production is attributed to its high demand in the nearby urban centres.

Livestock grazing in the forest was reported by more than half of the households for almost the whole year. On average, each household grazed three cattle almost daily in the forest. This indicates scarcity of fodders and pastures on farms due to shrinking land sizes and high population pressure (Mutoko et al. submitted). Herbal medicines were extracted by slightly more than one-third of the households. The practice of traditional medicine is well established among the local people and they rely on roots, leaves and barks for the treatment of various ailments.

Over one-quarter of households obtained wild fruits, vegetables, mushrooms, insects and honey from the forest for consumption. This indicates that Kakamega forest is an important source of wild food that supplements farm production. Thatch grass and ground for cultural rites of passage are the least forest benefits as construction of thatched houses is currently uncommon and traditional circumcision is not done in every household. Generally, the local community obtained mainly livestock grazing and firewood benefits from the forest. This is because of high population pressure on land and poverty that limits the capacity of households to access alternatives from the farms and through the markets.

Table 3-2: Non-timber forest benefits obtained by the local community from Kakamega tropical forest

Forest benefit	Unit of measure	Beneficiary households (%)	Trips/ month	Months	Quantity/ household/ yr.	Total quantity/ yr. (000)
1.Firewood	Head lot	95.8	11.5	8.1	241.2	7376
2.Charcoal	Bag	21.3	5.2	7.8	192.5	1306
3.Grazing	Number	56.7	25.6	11.0	784.3	14184
4.Poles	Number	13.8	4.1	3.6	334.4	1467
5.Thatch grass	Bale	7.9	1.7	1.8	12.3	31
6.Herbal medicines	Kg	37.1	2.0	4.0	18.6	220
7.Wild edibles	Kg	26.3	8.8	6.7	41.6	348
8.Cultural rites	Number	9.6	1.1	1.0	1.0	0.2

Biodiversity conservation

Kakamega forest has high biodiversity value in terms of species richness and habitat rarity (MENR 1994). According to Round-Turner (1994) cited in Ouma et al. (2011), over 50 woody indigenous trees, 80 monocotyledonous and 90 dicotyledonous herbs are found. KFE (2012) lists the rare plant species as the 'African Mahogany' (*Entandrophragma angolense),* shrub *Vernonia conferta*, orchids like *Oeceoclades ugandae*, a herb species *Aframomum zambesiacum*, and Ficus bubu. The threatened tree species found in this forest such as Elgon teak and *Prunus africana*, "are species of special conservation concern" (KFE 2012).

Besides, the forest is renowned for its diverse birds and butterflies consisting of about 350 bird and 400 butterfly species. Rare birds found in the forest include the African Grey Parrot and the Black-Billed Turaco. Besides, globally threatened birds such as Chapin's Flycatcher (*Muscicapa lendu*) and Turner's Eremomela (*Eremomela turneri*) are found in this forest (KFE 2012). The forest is also home to over 27 species of snakes and seven species of primates (KWS 2012). The rare de Brazza monkey (*Cercopithecus neglectus*) with a small population of only 30 animals is endangered in the country (KFE 2012). Kakamega forest also provides a habitat for rare primates such as the black and white Colobus monkeys, olive baboons, as well as the red-tailed and blue monkeys. The Potto (*Perodicticus potto ibeanus*), the world's slowest mammal, duikers and Dik diks are also found in the park. Kakamega forest therefore contains a rich diversity of fauna and flora species and is habitat for rare and threatened species. Biodiversity conservation is of particular national interest since this forest constitutes an important habitat for many species including the endangered *Prunus africana,* the rare Black-Billed Turaco and about 46 bird species are only found in Kenya from this forest (KFE 2012).

Recreation: Tourism

Both domestic and international tourists visit Kakamega forest for viewing birds and butterflies, nature trail walks and camping. Kakamega Forest National Reserve is a site solely reserved for recreational tourism activities. Visitors pay an entrance fee at the gate to the park. The gate charges in during the study period were KES 200 (about US$ 2.5) for domestic and US$ 20 for international visitors. According to estimates, 15244 domestic tourists visited the park for recreational purposes during the year. In addition, during the study period 215 international tourists visited Kakamega National Forest Park as one of their touristic sites. Based on our survey data, eight in every ten visitors were Kenyans from several counties, indicating the growing domestic appreciation for nature.

3.3.2 Economic valuation of ecosystem services

Economic values were estimated for the ecosystem services provided by Kakamega forest, comprising: the seven non-timber forest products (NTFPs), one cultural benefit and recreational tourism. Biodiversity conservation was not valued due to due the difficulty to generate reliable monetary estimates. We applied different valuation approaches to derive economic values for these ecosystem benefits as described in the Methods section.

Non-timber forest products and a cultural benefit

Valuation of ecosystem services derived from the forest by the neighbouring community was calculated based on consumer and producer surplus (Table 3-3).

Table 3-3: Economic value of forest benefits obtained by the local community from Kakamega forest

Forest benefit	Gross value/yr. (KES)	Round-trip travel cost (KES)	Annual permit fee paid (KES)	Net value/ household/yr. (KES)	Total annual value (US$ '000)[c]
1.Firewood	52288	8582	605	43101	1551
2.Charcoal	94178	20182	608	73389	586
3.Grazing	118177	42446	1150	74581	1587
4.Poles	22243	1262	213	20768	107
5.Thatch grass	1747	494	575	678	2
6.Herbal medicines	1516	1056	283	178	2
7.Wild edibles	37144	4732	877	31535	311
8.Cultural rites	7558	1338	255	5966	21
TOTAL			4565	250195	4167

[c]Indicative exchange rate: US$ = KES 85.00

The total consumer surplus generated by all the NTFPs and the cultural benefit obtained from Kakamega forest by the local community is estimated at US$ 4.17 million per year (in 2011). Most of these economic benefits accrued from livestock grazing, firewood collection and charcoal production. According to the KFS records, a total of US$ 38 850 was collected in permits. The local economic value generated by Kakamega forest for the benefit of local community was therefore around US$ 4.21 million in 2011.

Recreational value: Tourism

The total recreational value for Kakamega forest was obtained by summing the producer surplus i.e. net revenue from gate collections and the consumer surplus generated for the local visitors. Our findings show that only 25% of international visitors indicated that this park motivated their travel to Kenya, even though they also visited other tourist destinations in the country. Even those who visited spent on average only 7% of their tour time visiting this park. Besides, a majority (86%) of international tourists said that visiting alternative touristic sites in the country would give them matching or higher recreational experience.

Based on regression analysis of data in Table 3-4, the relationship between visit rates and total travel costs is specified in Equation 3.1.

Table 3-4: Domestic visitor rates and travel cost to Kakamega Forest National Park

Zone (km)	Population[d]	Total visitors/ year	Visit rate/1000 people	Transport cost (US$)	Cost of travel time (US$)	Travel cost/trip plus entrance fee (US$)
0-50	2215273	7340	3.3	14.9	4.2	21.7
50-100	4748979	3576	0.8	26.0	5.4	33.8
100-200	5827896	2164	0.4	31.1	11.5	45.1
200-400	3043413	1600	0.5	40.5	12.3	55.3
>400	4605793	565	0.1	53.8	25.7	82.0

[d]Calculated based on national census figures by KNBS (2010)

$$\boldsymbol{Visit\ rate = 5.66e^{-0.05*Cost}} \quad \boldsymbol{R^2 = 0.86} \qquad \text{Equation 3.1}$$

Assuming that the visitors viewed the entrance fee as an added travel cost, we derived the demand curve by hypothetically increasing the gate fee from US$ 5 to US$ 125 per visit (Figure 3-2). The area under the demand curve is equivalent to the total consumer surplus. The total consumer surplus from recreational service of the park is US$ 3.11 million per year. In addition, international tourists contributed around US$ 38600 to the local economy attributable to their visits to Kakamega forest for recreational experience. The KWS collected US$ 35868 from all tourists in gate revenues hence the total economic value for recreational service of the park is US$ 3.853 million per year.

The economic value for each of the ecosystem services is summarised in Table 3-5. The total economic value of key locally beneficial ecosystem services provided by Kakamega tropical rainforest is around US$ 8.06 million per year. Given that the forest covers 17838 ha, this translates to an average value of US$ 452 ha^{-1}

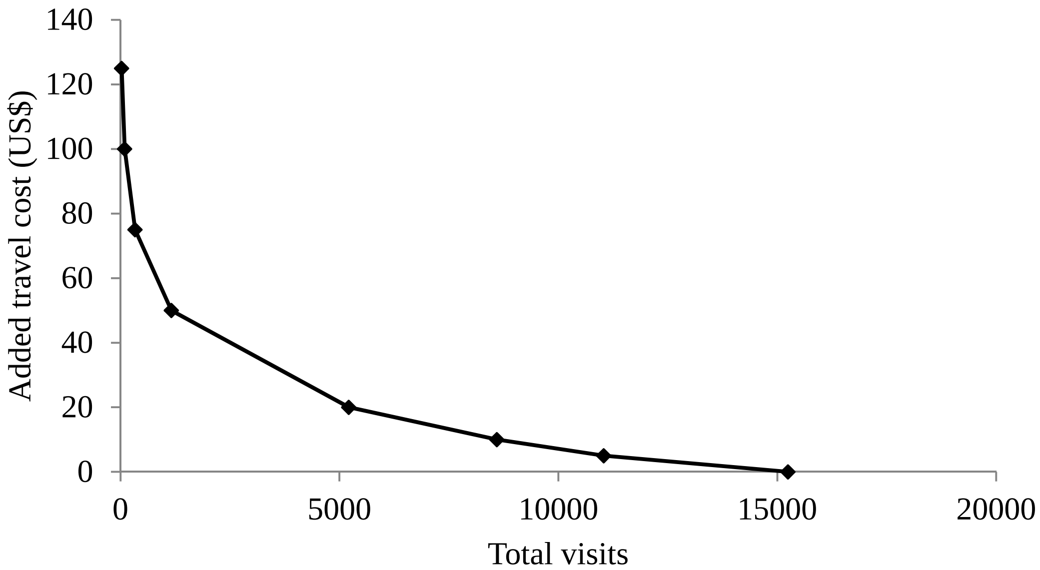

Figure 3-2: Derived demand curve for recreational service at Kakamega Forest National Park

Table 3-5: Summary of economic value for ecosystem services provided by Kakamega rainforest

Ecosystem benefit	Total value (US$ '000)	Average value (US$ $ha^{-1}yr^{-1}$)
1.Firewood	1551	87
2.Charcoal	586	33
3.Grazing	1587	89
4.Poles	107	6
5.Thath grass	2	0.1
6.Herbal medicines	2	0.1
7.Wild edibles	311	17
8.Cultural rites	21	1.2
9.Recreation: tourism	3853	216
10.Biodiversity conservation	Not valued	Not valued
Producer surplus	39	
TOTAL BENEFITS	8059	452

3.3.3 Effectiveness of the current forest management arrangement

Improving the supply of the key ecosystem services estimated in this study is dependent on the nature and effectiveness of the forest management system put in place. According to the views of the residents who participated in our 2011 survey, the responsibility of conserving Kakamega forest is vested in two main institutions: the Kenya Forest Service (68%) and the local community (29%). The KFS co-manages the forest together with surrounding CFAs.

Majority of the local people (77%) perceived a general decrease in availability of ecosystem benefits particularly for their direct use. Even though the decreased amount of obtainable benefits from the forest was attributed to the high extraction rate by the increasing population, most of the respondents (about 90%) indicated that the main factor was the decline in forest cover due to unregulated deforestation and encroachment. According to KFS records, an estimated 520 ha of the forest has already been excised mainly for human settlement over time. Despite that, there is no clear indication of how much forest cover would be adequate for the continued supply of which ecosystem service or whether some species could disappear with decreased forested area. For the NTFPs, decreased forest area has led to less availability of firewood, charcoal, medicinal herbs and natural pastures. This study found that about two-thirds of the local people are dissatisfied with the performance of the current management system. This is because of poor enforcement of forest protection rules. We elicited satisfaction levels for six management features by asking respondents to give a score from among five different ranks: 1 = very poor, 2 = poor, 3 = fair, 4 = good and 5 = very good. The results of the weighted scores are provided in Figure 3-3.

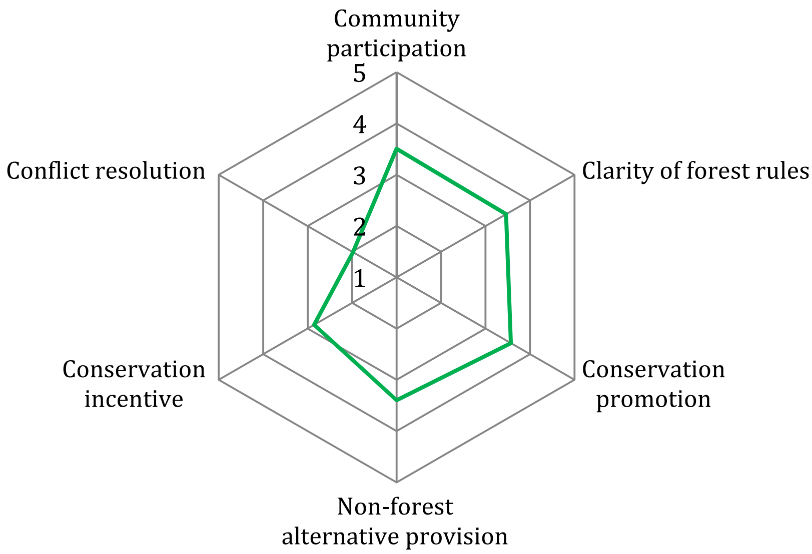

Figure 3-3: A spider diagram showing satisfaction levels with the prevailing forest management system for Kakamega rainforest

The management arrangement in place scored fairly on four aspects: community participation, clarity of rules on forest utilisation, promotion of conservation programs and provision of livelihood alternatives to reduce dependency on the forest. This is attributable to the existing forest policy and co-management institutional framework through CFAs that harness multi-stakeholders' efforts towards fostering forest conservation. However, the respondents ranked the forest managers poorly on conflict resolution due to lack of effective stakeholder involvement and compensation mechanisms. The respondents also indicated that the forest management performed poorly on provision of conservation incentives. Except for the temporary employment of few youths as forest guards and tour guides, the local community did not directly receive a share of income from the forest. Moreover, when wild animals damage their crops and kill their livestock they get no compensation for the loss.

Under the prevailing management scenario, forest conservation is neither effective nor optimal for sustainable provision of ecosystem services. The KFS management is blamed for continued illegal activities in the forest such as charcoal burning and logging due to ineffective policing attributed to resource constraints. On the other hand, CFAs are perceived as institutionally weak to make conservation rules binding on the neighbouring communities. According to KFE (2012), only five out of the 60 CFAs formed so far are active. Our study found that CFAs lack the capacity to control the illegal activities as some members feel that there is no motivation for them to assist in forest patrols without any remuneration. Still most of the respondents (96%) considered sustainable forest conservation essential not only for the maintenance of present livelihoods but also for bequeathing a biodiversity legacy to the future generations.

3.4 Discussion

3.4.1 Uncertainties in calculations

The physical quantification and economic valuation of the ecosystem services was done with some degree of uncertainty. The provisioning services obtained by the local community were quantified in a straightforward way even though the quantities extracted each time could vary widely. The average economic value of non-timber forest products extracted from tropical forests range from US$ 5 to over US$ 100 $ha^{-1}yr^{-1}$ (Pearce 2001, Guthiga 2007). In this study, the highest values were for firewood collection and livestock grazing estimated at around US$ 90 $ha^{-1}yr^{-1}$, comparable to about US$ 72 $ha^{-1}yr^{-1}$ found by Guthiga (2007).

The estimation of the recreation value of Kakamega forest relied on information on actual travel cost provided by individual visitors. Possible sources of uncertainty in the calculations include the estimated time allocated to visiting the site and its valuation based on the national average wage. We attempted to minimise this uncertainty by excluding visitors with multiple destinations during the analysis of average consumer surplus unlike the Mugambi (2007) study. Mugambi (2007), estimated the recreational benefits of Kakamega forest at US$ 3.7 million per year. This economic value could be an over-estimate because Mugambi's study was based on travel cost of predominantly international tourists and did not control for multiple sites that they also visited. Cognisant of the difficulty to attribute correctly the consumer surplus by international tourists who also visited multiple sites in the region, we only included the value added to the local economy as they visited Kakamega Forest National Reserve. We applied this approach because we believe that if we were to estimate the consumer surplus for international visitors based on the travel cost method, it would over-estimate the recreational value of Kakamega forest.

Failure to estimate the monetary value for the rich biodiversity conservation service due to data limitations, excluded possibly a large portion of economic value provided by Kakamega forest. Recent valuation studies also acknowledged the difficulty of retrieving the correct monetary value for biodiversity preservation (e.g. TEEB 2010b, Hein 2011). Despite the highlighted uncertainties, the information on ecosystem services generated in this study provides useful insights for decision-making concerning the trade-offs between forest conservation and conversion options in Kenya.

3.4.2 Comparison of local benefits and opportunity costs

Forest conservation is only one of the existing alternative economic land-use options in the study area. Maximisation of the present value of societal welfare is dependent on choosing those land use patterns that are socially optimal. According to Bulte et al. (2000), the net returns from sustainable forest management at the margins should compete with those of best alternative land uses such as agriculture. The foregone benefits from using the forestland for alternative purposes constitute the opportunity cost of conservation. The main opportunity cost for Kakamega rainforest is the foregone returns from farming (Mburu and Birner 2002). Such opportunity cost can be substantial and if not fully considered could compromise the need for sustainable forest conservation (Norton-Griffiths and Southey 1995). Farmers around the forest produce tea and sugar cane for income generation. According to local agricultural statistics, the average yields are 9 tons ha^{-1} for tea and 60 tons ha^{-1} for sugar cane, generating net income of about US$ 953 ha^{-1} from tea cultivation and US$ 847 ha^{-1} from sugar cane production. This translates to an average net income of around US$ 900 $ha^{-1}yr^{-1}$ (Government of Kenya 2010). The net economic return from agricultural activities is double when compared with the average economic value of ecosystem services obtained by the local community. This indicates that potential economic returns from agricultural uses (were the forest to be converted) provides more incentives than the local value of ecosystem services provided by the forest *in-situ*. This finding show that based on economic motives alone, private entities will have less incentive to invest their resources in forest conservation efforts. The implication is that the society should bear the greatest obligation in biodiversity conservation for the benefit of the present and future generations.

However, our analysis did not include several important services. First, we did not include any timber extraction, which was not reported to take place in 2011 in line with forest management regulations aimed to increase coverage of native trees for non-extractive economic and environmental purposes. Nevertheless, the forest also has plantations of exotic species such as cypress (*Cupressus lustanica*) pine (*Pinus patula*) and eucalyptus (*Eucalyptus saligna*); hence there is scope to generate additional formal revenue from timber exploitation. In addition, we did not consider the monetary value of biodiversity conservation and the services of CO_2 sequestration and carbon storage.

Glenday (2006) estimated the total carbon stock of Kakamega forest at 5.7 ± 0.6 million tons. This carbon stock is substantial and continued preservation of the forest is necessary to avoid future emissions, but we did not value it because of uncertainties around the distribution of carbon stocks, alternative land uses, soil carbon content and timeframe as carbon is gradually released over time. There are no reliable estimates of mean annual biomass increment and therefore an indication of carbon sequestration in Kakamega forest can be based on comparable studies. Clark et al. (2001) examined net primary production in tropical forests around the globe and estimated average carbon sequestration of 3 tons C $ha^{-1}yr^{-1}$, depending among others on the forest type, the climate and soil conditions, and the health and condition of the forest. If this figure is used as a tentative indication for carbon sequestration rate in Kakamega forest, the amount of C sequestered annually would amount to 14,000 ha of indigenous forest multiplied by 3 ton ha^{-1} $year^{-1}$, i.e. 42,000 tons C $year^{-1}$. Using marginal damage costs of carbon of US$ 10 per ton CO_2 i.e. US$ 37 per ton C (Hein 2011, Tol 2005), a very tentative indication of the potential value of carbon sequestration in Kakamega would be 37 x 42,000 = US$ 1.554 million per year (i.e. US$ 110 ha^{-1} $year^{-1}$). Hence, the value of carbon sequestration could reduce the gap between local costs and local opportunity costs for a substantial part of the forest. However, of course, there is at present no payment for ecosystem services (PES) mechanism for carbon sequestration service in the forest. Since it is a protected area, it is hard to make the case for a baseline involving extensive deforestation and thereby justifying a Reducing Emissions from Deforestation and forest Degradation (REDD+) project (Angelsen et al. 2012, Pistorius 2012).

According to the Kenya Forestry Master Plan (MENR 1994), the forest has low environmental value for water catchment protection and it is likely that the water regulation service is less economically valuable. The forest is a watershed for some rivers such as Yala and Isiukhu, which drain into Lake Victoria (KFE 2012). However, these rivers are not used for irrigation activities. In addition, owing to insufficient understanding of the hydrology involved, it is not clear how they maintain the groundwater levels and thereby regulate water levels in wells in Kakamega and Vihiga Districts. Therefore, at present there is no compensating mechanism in the surrounding areas, even though such mechanisms have been developed, in the form of PES schemes in other countries, in particular in Latin America (Pagiola et al. 2005b, Wunder 2006, Wunder 2007, Pagiola 2008). It is, however, a practical challenge to craft and set up such a PES mechanism in the study area due to institutional constraints and a lack of experience with PES in Kenya. Besides, there are a large number of downstream water users each with different levels of benefits of this service, which would make a PES system subject to high transaction costs (Pagiola 2007, Engel et al. 2008). Given the high poverty levels in the study area, around 62% in the case of Vihiga District (Government of Kenya 2005, Claessens et al. 2008), most of the downstream water users are poor and therefore have limited capacity to pay for maintaining the hydrological service provided by Kakamega forest (Pagiola et al. 2005a).

Hence, a critical service in the economic justification of maintaining the forest is biodiversity conservation service (Mace et al. 2012). Clearly, Kakamega forest contains unique biodiversity found in Kenya and it is the only rainforest ecosystem in the country. Even though this makes viewing wildlife more difficult compared to the open savannah systems, there is a general interest in visiting the park by the Kenyan people (as well as foreign visitors), as demonstrated by the significant, and increasing visitor rates. Enjoying the biodiversity of the park is one of the main reasons for visiting it because there are few other recreational products offered in the park. Mace et al. (2012), reveal that the value of biodiversity or nature preservation *per se* is the most important but often excluded in ecosystem services analyses; sometimes it is argued that this is not an ecosystem service. According to our study, the appreciation of the monetary value of the biodiversity conservation service would have to amount to US$ 448 ha^{-1} $year^{-1}$ (or US$ 338 ha^{-1} $year^{-1}$ in case payment for carbon sequestration service is also considered), to offset the difference between the local economic value generated by the forest and the opportunity costs. It is not possible with our research to answer the question of whether this amount would be considered an acceptable compensation by Kenyans to preserve the biodiversity in this forest. However, this finding does highlight one of the main weaknesses of the ecosystem services approach: it does not allow valuing biodiversity conservation as such in a sufficiently scientifically robust way, and this service may justify the conservation of biodiversity and the maintenance and sustainable use of forest ecosystems. This may in particular be the case in developing countries, given that willingness to pay for tourism-related activities is relatively high in some OECD countries (e.g. Hein 2011), but funds for biodiversity conservation are relatively scarce in developing countries (Hein et al. 2013).

3.4.3 Policy and institutional implications

Kakamega forest is a valuable ecosystem generating varied ecological and economic benefits to beneficiaries at the local, national and global levels. An integrated institutional framework is therefore required to ensure that conservation and livelihood interests of stakeholders at multiple scales are considered. Therefore, the management strategy should balance local resource requirements and the need for biodiversity conservation. Such a strategy should recognise the need to manage Kakamega forest for multiple uses. Successful implementation of the strategy would depend on how effectively multiple stakeholders get involved in the management activities to guarantee sustainable provision of both extractive and non-extractive ecosystem services. Conservation of biodiversity and promotion of sustainable forest utilisation for economic and socio-cultural purposes calls for an integrated management approach akin to the Biosphere Reserve model (UNESCO 2011). The approach centres on forest demarcation into protection zones with high concentration of biodiversity for non-extractive uses and utilisation zones for regulated extractive activities permitted to local communities. According the current forestry master plan (MENR 1994), a multiple-use zoning management strategy has been proposed for all indigenous forests, but since the 1990s it is yet to be fully implemented for this forest. There is urgency for implementing an integrated strategy given the increasing local dependence on extractive forest products. We expect that active participation of the local people in planning activities, setting extractive rules and management decisions on the forest will likely empower them and increase their conservation awareness. In addition, promotion of environmental education projects in the neighbouring community and schools may eventually achieve to reduce human disturbances within the core zones.

Reduced disturbances coupled with re-afforestation of degraded areas and increased forest patrols would enhance natural regeneration of indigenous trees for non-extractive uses. Sizable areas of plantations could be managed mainly for extractive purposes; harvested at a sustainable rate to help meet the local resource needs (KFE 2012). Planting fast-maturing species coupled with promotion of energy-saving technologies could help achieve sustainable provision of both fuel wood benefits and biodiversity conservation service (Glenday 2006). The actual implementation of this kind of integrated forest management strategy requires a facilitative policy and institutional environment.

At the national level, the existing forestry policy (Government of Kenya 2007) provides for systematic participation of the local community in forest management and conservation for they are recognised to possess rich indigenous knowledge. Co-management arrangements with the community and their leaders in all forestry activities would contribute to sustainable forest conservation in two ways: lessen population pressure on the forest through promotion of suitable farm forestry technologies and control destructive activities in the protected core zones of the forest.

The local community adjacent to Kakamega forest are expected to organise themselves into CFAs to not only regulate extraction amounts but also enforce conservation rules in their areas (Government of Kenya 2005). The CFA members are also encouraged to undertake income-generating activities including eco-tourism, butterfly and silkworm farming, bee-keeping and on-farm tree nurseries as alternative livelihood sources aimed at reducing pressure on the forest. Our study found that the formation of CFAs around the forest is underway although what is required for their effective participation is a clear institutional arrangement to coordinate with the forest managers and enforce conservation decisions.

Active participatory forest management is another essential approach for successful collaboration with communities in conservation programs.

Effective stakeholder collaboration can be enhanced through the application of the transition management framework that has been effectively applied in addressing societal sustainability challenges in the Netherlands (Rotmans et al. 2001, Loorbach and Rotmans 2010). We explore systematically the potential for applying transition management approach in Chapter 5. The need for financial resources can be met if the society pays the true amount for the non-marketed, non-extractive ecosystem services such as biodiversity conservation and CO_2 sequestration (Wunder 2006, Pearce 2007). The prospect to pay for ecosystem services such as carbon capture can be explored through innovative PES mechanisms. Even though the forest is already a protected area, resource constraints continue to compromise its proper management. For the case of Kakamega forest the lack of sufficient information on carbon sequestration to estimate accurately the economic value of biodiversity and CO_2 sequestration services, and the protected status of the area (possibly driven by the high biodiversity value of the forest) are significant barriers for establishing a feasible PES mechanism. The rich biodiversity contained in Kakamega forest certainly has its own economic value even as it also contributes to values of other ecosystem services. Conversely, correct monitoring reporting and verification is a constraint in general and actual data collection for this exercise is expensive for these essential services (CO_2 sequestration and biodiversity value). With these barriers, there is yet no effective payment mechanism, so a PES for both biodiversity conservation and carbon storage services is now unlikely.

Notwithstanding the institutional challenges and a lack of experience with PES in Kenya, there is need to get an indication based on WTP values for biodiversity perhaps at the national level to as a basis to craft PES mechanisms. There is now urgent motivation to start thinking innovatively about how to design mechanisms to pay for biodiversity preservation because further delays will lead to more loss of the rare and valuable biodiversity (Hein et al. 2013). PES is often seen as an approach to achieve sustainable ecosystem management (Wunder 2006, Farley et al. 2010). New PES arrangements would establish economic incentives for local land users to manage the forest ecosystem in a sustainable manner or in a way that involves preserving it (Wunder 2007, Murillo-Luna et al. 2011). In particular, such arrangements would generate necessary funds for direct conservation efforts as well as creation of alternative livelihood possibilities for the neighbouring community. In the fullness of time, the community would embrace and support forest conservation as opposed to over-extraction or conversion to agriculture.

3.5 Conclusions

Ecosystem services provided by tropical forests are dwindling due to unrelenting deforestation attributable to increased demand from the growing human population. Besides, rationing of public budgetary resources for conservation programs limits the realisation of sustainable forest management targets in many developing countries. We estimated the local economic value of the forest ecosystem services in order to inform policy makers on the existing economic trade-offs involving this natural resource and suggest management alternatives that would enhance the supply of multiple ecosystem services and improve social welfare of the local community. Local economic values are analysed based on all the locally provided ecosystem services. The national value for recreational service is analysed with a travel cost method for domestic visitors to the park. At the national-level, non-use value of biodiversity is excluded from valuation. This study found that the local economic value of ecosystem services generated from the forest *in-situ* was much lower than the potential returns if the forest were to be converted to the best farming activities. Results also established that the existing management system was less effective in ensuring sustainable forest conservation. We conclude that the estimated local economic benefits are insufficient to encourage sustainable conservation considerations but offers useful insights on real trade-offs concerning the management of Kakamega forest. Carbon sequestration and biodiversity conservation are important services provided by this forest, but they do not yield local benefits. Besides, they are difficult to transform into a PES arrangement because of data shortages and institutional constraints. Therefore, there is a need to design innovative PES mechanism for biodiversity conservation and carbon capture at the national or global levels. We suggest a management strategy that balances local resource requirements and biodiversity conservation purposes in recognition of the need to manage this forest for multiple uses. In the light of increasing population pressure on land around the forest, there is need for strong public-private partnerships and local collaboration in the promotion of broad and transformative programs. Such collaborative, multi-actor conservation programs can likely foster sustainable forest management when carefully integrated with convincing livelihood opportunities for the local community.

Chapter 4 Land Use Dynamics, Temporal Drivers and their Impacts on Agrarian Livelihoods[4]

4.1 Introduction

Land degradation is a function of complex and dynamic interactions between human and natural systems, and is of particular concern in sub-Saharan Africa (SSA) because of a still increasing population and the important role of agriculture in SSA economies (Morton et al. 2006, Pacheco 2006). Intensification of agriculture in combination with investment in sustainable land management (SLM) has the potential to reverse land degradation and improve agricultural productivity (Hurni 2000a). Previous studies indicate that increasing population density can be expected to lead to intensification of land use (e.g. Roose 1996, Pender 1998). A high population density, it is argued, induces innovation and investment to enhance land productivity and increase agricultural returns (Boserup 1965, Ruttan and Thirtle 1989, Tiffen et al. 1994, Mortimore et al. 2005). However, there is lack of empirical evidence that such intensification actually occurs in many SSA countries (Tiffen et al. 1994). Various quantitative analytical approaches have been applied in the analysis of land-use and land-cover (LUC) changes (Veldkamp and Lambin 2001, Paré et al. 2008, Verburg et al. 2008, Wyman and Stein 2010). Analysing LUC changes generally requires an integrated approach that considers multiple disciplines, data sources and methodological constructs. One of the greatest constraints to determining LUC change and its impacts is that reliable data are missing in most African countries (Rembold et al. 2000, Kline 2003, Hietel et al. 2007). Although detailed information may be available locally at field and farm level, these local data do not generally provide sufficient information for understanding LUC changes over time and over larger areas. Also the application of remote sensing technique alone has limitations and is sometimes difficult given the heterogeneous mosaic of the landscape character in African farming zones (Pontius and Lippitt 2004, Jellema et al. 2009).

The objective of this study is to analyse land use change, drivers of land use changes and effects of land dynamics on agricultural production, in the western highlands of Kenya. We test a trans-disciplinary approach integrating remote sensing imagery, local statistics on climatic, demographic and agricultural variables and an in-depth household survey to examine LUC changes and their implications at the district level. Our approach involves the use of five different data sets, and cross-referencing and counter-checking results across these data sets. We generate LUC change maps for 1984, 1988, 2000 and 2009 from remote sensing imagery. These data were supplemented with primary data from a quantitative survey and stakeholder interviews, and secondary statistics from various sources. We analyse changes in demography, climate and agricultural productivity to determine how people's livelihoods have been affected by the dynamics in environmental conditions.

Our approach makes a novel contribution to understanding the implications of LUC changes on agrarian livelihoods. First, we test an innovative approach combining remote sensing, statistical data and stakeholders' perspectives to explain the impacts of LUC changes on livelihoods. Second, we focus on one of the most densely populated rural regions in SSA to

[4] Based on Morgan C. Mutoko, Lars Hein and Harm Bartholomeus. Integrated analysis of land use changes and their impacts on agrarian livelihoods in the western highlands of Kenya. Submitted

understand the influence of population growth on landscape dynamics, which is relevant for understanding LUC change in comparable parts of Africa.

4.2 Materials and methods

4.2.1 The case study area

The study focuses on the Vihiga District (the current Vihiga County) covering 563 km^2 in Western Province of Kenya (Figure 4-1). The district lies between longitudes 34°30′ to 35°0′ East and latitudes 0°0′ to 0°5′ North. Vihiga District experiences an Equatorial climate with rainfall ranging between 1800 – 2000 mm per year. Rainfall distribution is bimodal with a distinct long rainy season (March – June) and a short rainy season (September – November). The district is characterised by gently rolling hills and valleys, sloping from West to East. Altitude ranges from 1300 to 2100 m above sea level, and rugged granitic hills dominate the Southern part of the district (Government of Kenya 2004, Jaetzold et al. 2007).

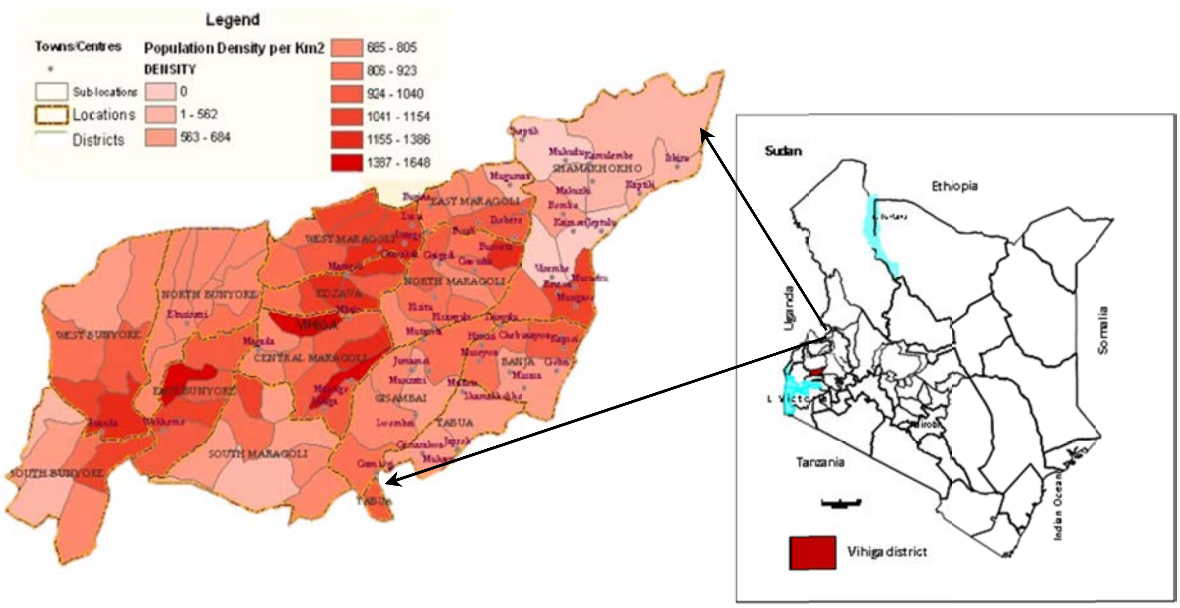

Figure 4-1: Map of Kenya (inset) showing the location and demography of Vihiga District. Source: Modified from Government of Kenya (2005).

Agriculture is the most important land use in the district, followed by forest cover, bare land and built up areas. About 75% of the land area of Vihiga District is arable with an average farm size of 0.65 ha per household (Government of Kenya 2010).

The main forest block found in the North-eastern tip of the district is part of the larger Kakamega tropical forest. The forest is part of the last remaining rainforest in Kenya and is an important provider of wood and non-timber forest products. It also contains significant biodiversity (indigenous flora and a variety of fauna species) and is important for cultural activities of the neighbouring communities (Government of Kenya 2004).

Vihiga District is one of the most densely populated and poorest parts of Kenya. The overall population density of the district is 1045 people/km^2. Even though literacy level is over 95%, poverty incidence (*per capita* daily income of less than a dollar) is estimated at 62% of the population (Government of Kenya 2005, KNBS 2010).

4.2.2 Remote sensing analysis

Land cover changes in Vihiga District for the past 25 years were determined based on a classification of four remote sensing images. We used geo-referenced Landsat satellite images with 30m resolution, acquired from Regional Centre for Mapping Resources for Development (RCMRD), Nairobi supplemented with online downloads from the Landsat archive in Geotiff format. Data were re-projected to the Universal Trans Mercator Projection, zone 36, using the WGS-84 spheroid. The metadata of the used images are described in Table 4-1. Only unclouded scenes were selected. The image preparation and processing was done in Erdas Imagine 9.3 and ArcGIS 9.3.1 to prepare the LUC maps.

Table 4-1: Metadata of the used Landsat scenes and the prevailing mean rainfall amount received and temperature during the months they were captured

Year	Date (DD/MM)	Sensor	Satellite	Season	Mean rainfall (mm)	Mean temperature (°C)
1984	10/09	TM	Landsat 5	Transition dry to wet	78.9	20.1
1988	18/02	TM	Landsat 4	Dry	55.4	22.0
2000	06/03	ETM+	Landsat 7	Dry	49.9	22.4
2009	13/07	TM	Landsat 5	Transition dry to wet	91.0	20.2

Data source: Meteorological Department, Kakamega Station for data on rainfall and temperature.

Satellite images were overlaid on digitised topographical maps to delimit the spatial area of the study for LUC classification. Maximum likelihood classification was applied on the satellite images based on the extracted LUC map for 2009 (Lillesand et al. 2008). Training areas were defined for each time-step separately and each land-use/cover was classified and visually inspected iteratively to control for map quality. For each classification, we selected a variable number of training areas for each time-step that is 39 for 2009, 24 for 2000, 27 for 1988 and 44 for 1984. The main LUC types classified included agriculture, forest, bare, tea and built up areas. We defined agricultural land as arable land used for the cultivation of cereals, legumes, fodders and horticultural crops. 'Tea' consisted of areas used for the cultivation of tea, which is the only perennial crop grown on a significant area in the district. Areas with a canopy cover of at least 95% were classified as 'Forest'. Bare areas included open spaces such as land covered with perennial grasses, in particular along the river courses, rocky hillsides, roadsides and playgrounds. Finally, the class 'Built up' consists of urban centres, rural markets, schools, roads, hospitals, offices and factory buildings.

We calculated several specific LUC measures such as area under each class and its proportion to total land area. The magnitude of change in each LUC class was expressed as the ratio of the difference in area over time to that of the initial area. Further division by time interval yielded the measures of average annual rate of change, using a modified specification from Long et al. (2007) in Equation 4.1:

$$\Delta = \left\{\left(\frac{A_2 - A_1}{A_1} \times 100\right) \div (T_2 - T_1)\right\} \qquad \text{Equation 4.1}$$

Where: Δ = average annual rate of change (%)
A_1 = area coverage of land-cover type in time 1 (T_1)
A_2 = area coverage of land-cover type in time 2 (T_2)

We also estimated long-term changes between LUC classes using a transition matrix. A transition matrix was constructed to evaluate overall change across the key land-cover and uses between the initial and final periods of study (Biondini and Kandus 2006). Change in a transition matrix is represented by off-diagonal elements P_{ij}, which contains the proportion of pixels of each LUC type that changed to a different class during that time interval. The diagonal elements P_{ii} are the proportion of pixels that persisted. The transition matrix of overall landscape change is represented in the reduced form as specified in Equation 4.2, following Koomen et al. (2008):

$$\boldsymbol{M} = [\boldsymbol{P_{ij}}], \boldsymbol{i}, \boldsymbol{j} = \mathbf{1}, \mathbf{2}, \dots, \boldsymbol{K} \qquad \text{Equation 4.2}$$

Where the relative land-cover transition rates $\boldsymbol{P_{ij}}$ are defined as,

$$\mathbf{0} \leq \boldsymbol{P_{ij}} \leq \mathbf{1};\ \sum_{i,j=1}^{K} \boldsymbol{P_{ij}} = \mathbf{1}$$

$\boldsymbol{P_{ij}}$ = percentage area changes from land-cover class *i* to class *j* and *K* is the total number of landscape units in a given period.

Since ground truth observations were only available for the recent image, an independent validation of the classification result could not be done, but we crosschecked calculated area under agriculture with available district statistics. For the 2009 classification result, we assessed the classification accuracy based on 336 randomly selected land cover locations, using fine resolution aerial photographs of 17 December 2010 as surrogate for ground observations, available in Google Earth (Figure B-1 in Appendix B). Aerial photographs were not available for the earlier years. We compared how well the 2009 image classification matched with the actual ground data by calculating percentage correct as a measure of classification accuracy (Foody 2002).

4.2.3 Analysis of factors driving land-use and land-cover changes

Selected socio-economic and environmental factors responsible for the detected LUC changes were analysed based on secondary statistics and local survey data collected using participatory approaches (e.g. Castella et al. 2007, Bakker and van Doorn 2009). We started the selection of key drivers of LUC change based on the broad classification of drivers developed by Geist and Lambin (2002), which includes demographic, technological, economic, institutional, cultural and biophysical drivers. Based on open interviews with 10 key informants we selected the main drivers in each category for detailed analysis in our study. The informants included four local resource persons, two each for local administrators, agricultural extension staff and NGO workers and they were interviewed using a checklist. The checklist contained open-ended questions on perceived changes in the landscape, effect on agricultural and forest systems, and key driving factors. They identified drivers in each category as population growth, technological practices, market changes for food products and climatic variability. In addition, the key informants provided information on perceived changes in area and quality of arable land, forest cover and community land. They also indicated resultant changes in the farming system and the impacts on agricultural production.

We gathered data on agricultural production and technological changes in the district with a detailed household survey. Vihiga District has five sub-districts, which we stratified in two strata according to agro-ecological zones and main farming types. We selected Tiriki and Emuhaya sub-districts for detailed investigation due to their different farming systems and location in representative highland agro-ecological zones i.e. Upper Midland and Lower Midland. In each sub-district, we demarcated two areas made of group of villages and randomly selected four villages from each stratum making 16 villages. In each village, we applied random sampling technique to select a sample of 15 households. Finally, we selected a total sample of 240 households but we dropped four households from the sample because they did not engage in farming activities at all during the 2009 agricultural year. Between January and March 2010, we conducted a detailed survey of the 236 households using a pre-tested questionnaire (Appendix A1), to provide a broader local view on changes in land use and farming practices. The respondents indicated the actual application of improved technologies, general land quality status of their farms and agricultural output.

Time-series of agricultural production and climatic data were collected from various sources. Monthly data on rainfall, evaporation and temperature were collected from the local Meteorological Department for the 1979 – 2010 period and annual averages calculated. We also collected annual crop productivity data on area, total output and yields between 1992 and 2009 from the local Ministry of Agriculture offices. These were aggregated district statistics from various monthly field reports by the field extension staff, which we cross-referenced with relevant data reported in independent empirical studies in the area.

In order to analyse demographic changes, we extracted total population figures from census reports and estimated population density of Vihiga District for 1979, 1989, 1999 and 2009. In particular, population data were sourced from various census reports of the Kenya National Bureau of Statistics (KNBS 2010) and online databases (ILRI 2007, WRI 2010).

Additional information on technological change, market demand, and relevant public policy changes that took place in the 1990s was accessed from literature (e.g. Place et al. 2006, Mose 2007, Smale and Olwande 2011). Moreover, cross-checking of our results was done with studies related to land management previously conducted in the western region of Kenya (e.g. Shepherd and Soule 1998, Crowley and Carter 2000, Longley et al. 2006, Jaetzold et al. 2007, Odendo et al. 2009, Walingo et al. 2009, Tittonell et al. 2010).

We conducted a trend analysis of these drivers of LUC change. We first tested for trend stationary in time-series data using the augmented Dickey-Fuller test for unit roots and transformed the non-stationary series through differencing where necessary following Verbeek (2008). The variables analysed included mean annual rainfall between 1984 and 2009, mean annual temperature between 1984 and 2009, population between 1979 and 2009 and population density between 1979 and 2009. Other variables were crop yields, intensity in the application of fertilisers, manure, improved seeds and physical measures on farms.

Descriptive statistics such as means and frequencies were subsequently estimated in Statistical Package for Social Scientists (SPSS 19) and MS Excel 2010 for trend analysis.

Potentially important additional drivers for land use change are policy and institutional factors (including shifts in land tenure), and cultural changes (Geist and Lambin 2002). These factors were not quantitatively assessed. The open interviews with 10 key stakeholders revealed that there have been no major changes in land tenure in Vihiga District in the past three decades — most land was and remains privately owned. That land tenure is generally secure in the study area is confirmed by Place et al. (2002). Cultural drivers include attitudes, beliefs and traditional activities within the community in relation to land use. The respondents did not report any significant changes in cultural drivers, and these were therefore not quantified in this study. There were, however, a number of relevant changes in the policy framework in the country, which have influenced land use in Vihiga District. These changes have not been quantitatively assessed, but their implications are examined in the Discussion section of the chapter.

4.2.4 Assessing implications of land-use/cover changes

We examined implications of LUC changes on agrarian livelihoods of the residents through analysis of *per capita* land availability and agricultural production. Agriculture is one of the main sources of income in the district, accounting for 80% of the households' income (Government of Kenya 2005). However, our findings in Chapter 2 shows that reliance on agriculture is reducing since inhabitants of Vihiga District are increasingly also pursuing different off-farm strategies of obtaining an income. For example, about 30% of farming households also engaged in businesses and or had salaried employment in 2010 and the proportion of total income from off-farm livelihood activities considerably increased in just under a decade (see Chapter 2, Section 2.3.4 and Figure 2-3f). Hence, our analysis in this chapter provides a partial indication of the impacts of LUC changes on local livelihood strategies.

In order to calculate *per capita* measures, we compared available cropland and food production with census data. We also accessed agricultural producer prices from 1991 onwards from the Food and Agriculture Organisation (FAO), statistics database (FAOSTAT 2012) and annual inflation rates for inflationary adjustment of cash crop incomes from the KNBS (2012). We used population figures, remote sensed data and agricultural statistics to compute changes in land area, food crop output and cash crop income per person during the study period. Statistical significance of the trends in *per capita* food crop production and *per capita* cash crop income was determined by the augmented Dickey-Fuller test applying the procedure suggested by Verbeek (2008). We conducted this test with the software package STATA 11.

4.3 Results

4.3.1 Land use dynamics in Vihiga District

Visual interpretation of land cover maps for Vihiga District in different years depicts a heterogeneous and dynamic landscape (Figure 4-2). Over the study period, agriculture was the predominant land use in Vihiga. Agricultural area covered about three-quarters of the entire landscape during the study period, except in 1984. The initial low coverage of agriculture in the 1984 map (i.e. 50% compared to over 75% in the other periods) was perhaps partly due to the 1983/84 drought that affected the region, and which may have caused temporary abandonment of part of the cropland. In addition, a lower population at that time indicates lower pressure on land for farming activities compared to the recent years. The trend based on remote sensed data aligned well with that of the available district statistics for agricultural land as shown in Figure 4-4 (a). Both the remote sensing analysis and the district statistics show a marked increase in agricultural land in the period 1984 – 2009.

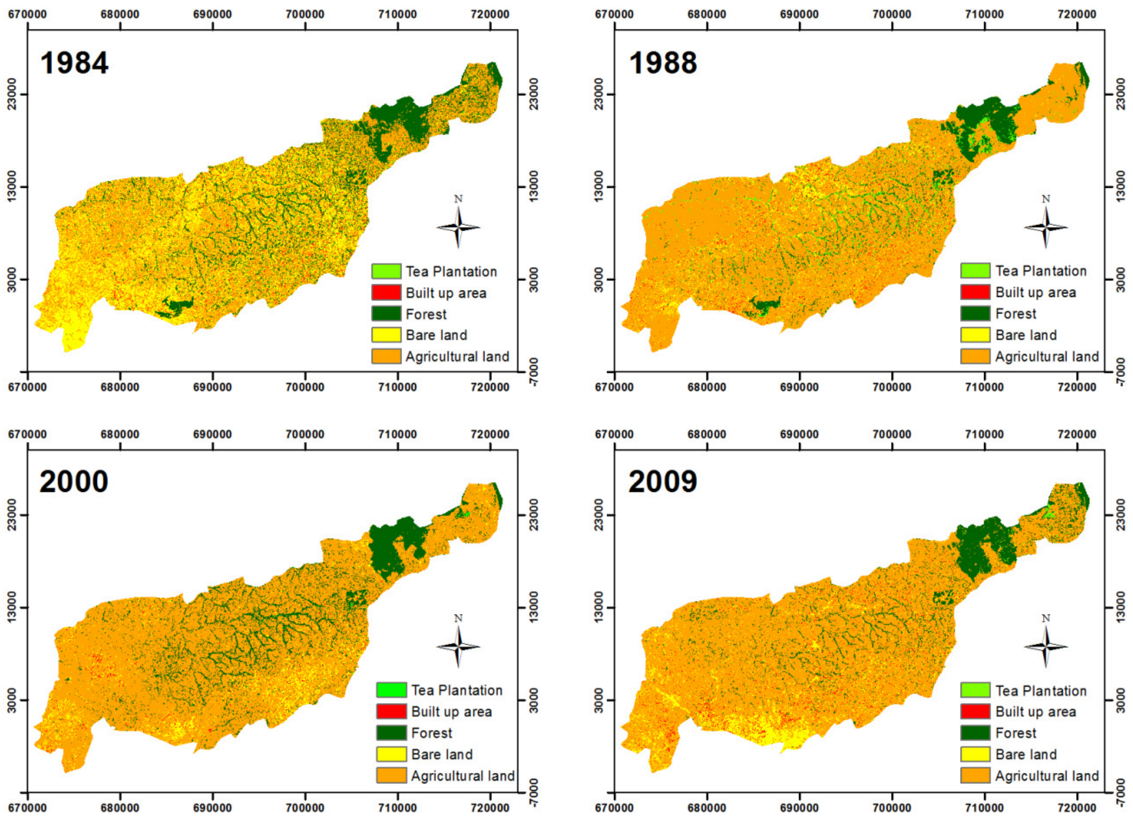

Figure 4-2: Land use/cover change maps based on classified Landsat images for Vihiga District from 1984 through 2009.
Map projection: Universal Trans Mercator Projection, zone 36, WGS-84

Forests covered 17% of the district in 1984, but the forest cover gradually declined over the period 1984 to 2009 (Table 4-2). In the Southern part, entire hills were deforested by 2000. Substantial forest conversion occurred between 1984 and 1988 when tea zones were introduced around indigenous forests in Kenya (Figure 4-2). Moreover, there is evidence of agricultural expansion and new settlement into forested areas to the North-eastern tip of the district between 1988 and 2000. Public policy at the time promoted the 'shamba' system, which allowed non-resident farmers to cultivate open spaces within the forest and create tea zones around the forest as conservation strategies. Though unintended, these strategies encouraged serious forest encroachment visible in the 1988 map. Conversely, the 2009 map shows that forest cover gained slightly from agricultural areas (Figure 4-2).

According to local stakeholders, the modest increase in forest cover of about 3% was due to farm forestry, especially under Eucalyptus trees, re-afforestation efforts and enhanced joint forest protection by the Kenya Forest Service and the local community. Furthermore, they confirmed the overall loss of forest cover in the last decades, indicating also that this has reduced the cultural services provided by these forests (e.g. for initiation rites and ethno-medicines).

Initially, bare lands were considered unsuitable for cultivation and they served only as livestock grazing areas. However, the proportion of bare lands declined rapidly from about 31% to 9% between 1984 and 2009 pointing to agricultural expansion into fragile hills, road sides and riparian areas. Between 1984 and 2009, large areas that were initially bare were converted to agriculture (Table 4-2). A modest increase in bare lands from 6% in 2000 to about 9% in 2009 indicates the prevalence of exposed rocks in the wake of accelerated erosion in the encroached marginal areas.

The share of built up area increased considerably in the period 1984 to 2009, from an initial 1.6% to 2.5% of the land cover of the district (Table 4-2). Population increase led to a high demand for housing and other infrastructure. In addition, the maps point to an increasing urbanisation in the district, with a growing concentration of houses and urban infrastructure such as schools, other public buildings, shops and rural markets, in Vihiga District (Figure 4-2).

All the ten key informants (i.e. local resource persons, local administrators, agricultural extension staff and NGO workers) contacted in the stakeholder survey also indicated that the landscape of Vihiga District has experienced considerable changes over the past 25 years. Analysis of the remote sensing images reveals that between 1984 and 2009, the greatest net increase was for agriculture (27%) while bare areas were the most converted (22%). Agriculture land-use mainly gained from both forest and bare areas (Table 4-2). Initially forest cover lost around 9% to agriculture, but about 3% of agricultural area reverted to (plantation) forest cover by 2009. Overall, about half (48%) of the highlands landscape switched to a different land-cover in the past 25 years (Table 4-2).

Table 4-2: Land-use/cover transition matrix showing long-term changes (%) in Vihiga landscape from 1984 to 2009 state

Land-cover/use class	To final state (2009) Forest	Tea	Bare	Agriculture	Built up	Total 1984	Loss
From initial state (1984)							
Forest	6.8	0.1	0.8	9.0	0.2	16.8	10.0
Tea	0.2	0.0	0.0	0.7	0.0	1.0	1.0
Bare	0.8	0.0	3.9	25.0	1.1	30.8	27.0
Agriculture	3.4	0.2	4.2	41.1	1.2	50.0	8.9
Built up	0.0	0.0	0.3	1.2	0.2	1.6	1.5
Total 2009	11.0	0.3	9.2	77.0	2.6	52[a]	
Gain	4.4	0.4	5.3	35.8	2.4	48[b]	
Net change	-6	-1	-22	27	1		

[a]Sum of the diagonal proportions that persisted in the landscape between 1984 and 2009
[b]Overall change i.e. the landscape that switched to new class by 2009
Source: Own calculations based on satellite-derived data for 1984 and 2009

4.3.2 Drivers of land-use/cover changes

Key drivers of LUC change were examined qualitatively and quantitatively. They include technological changes for farming, population growth, market changes for farm and forest products and climatic variability.

(i) Technological changes. In the last decades, there has been continued support to farmers by the government and other organisations to improve farming practices and land productivity. Various SLM technologies have been promoted (Place et al. 2002, Ojiem et al. 2004, Longley et al. 2006, Place et al. 2006), including organic and inorganic fertiliser use, improved crop varieties, agro-forestry practices and soil and water conservation (SWC) measures. However, our 2010 survey across 236 households revealed scanty evidence on the ground of technology driven agricultural intensification in Vihiga District. Crop productivity has been oscillating around 1 ton ha^{-1} for maize, the predominant crop. Despite promotion of improved farming practices, technological impact on yields was minimal: less than 20% of seed planted was of improved variety and on average only 37 kg ha^{-1} of inorganic fertiliser was used. Moreover, just about 0.7 ton ha^{-1} of manure was applied and fewer terraces were maintained on most of the examined farms. Furthermore, the yields of beans were stagnant, less than1 ton ha^{-1} throughout the study period. Around 64% of the respondents in the household survey indicated that there is a low application of improved agricultural technologies, and that technological advances are not being applied in a scale sufficient to lead to agricultural intensification.

According to official agricultural statistics, yields in tea and local vegetables however improved considerably indicating input intensification and increased use of new technologies over time. Yields for tea almost tripled rising from 3.4 to 9.5 tons ha^{-1} (Figure 4-4b). This is because tea farmers get inputs (e.g. fertilisers and improved seedlings) from the local Kenya Tea Development Authority (KTDA) and the cost deducted later from the crop revenue. Marketing conditions for tea produce are also relatively certain and remunerative — tea leaves are readily collected by the local Mudete Tea Factory (MTF) and farmers earn an annual bonus based on total quantity sold. The positive impacts of agricultural intensification through tea and local vegetables are however limited to a small area since the combined area under these crops remained just about one-tenth of the maize-bean area during the study period.

Our study found that the large majority (89%) of farmers depend on maize-bean farming, that there has been a very limited uptake of SLM technologies in the past 25 years and that there are no signs of an upward trend in agricultural production. These points to an absence of a general agricultural intensification process driven by improved technologies in the study period. Instead, our results show that households mostly dependent on maize production attempted to cope with low productivity and increased food demand by expanding into areas that are marginal and fragile, for instance because of a high vulnerability to water erosion.

(ii) Population growth. According to the survey information, about 20% of the respondents identified population increase and high poverty levels as important drivers of LUC dynamics in Vihiga District. Total population of Vihiga District grew at an estimated annual rate of 3.7%, almost doubling between 1979 and 2009 (Figure 4-3). Consequently, estimated population density increased from 664 to 1045 people/km^2 during the study period (Figure 4-3). The population growth rate of 3.7% measured against an annual increase of 1.2% in built up areas, point to possible mounting pressure on social infrastructures in the district.

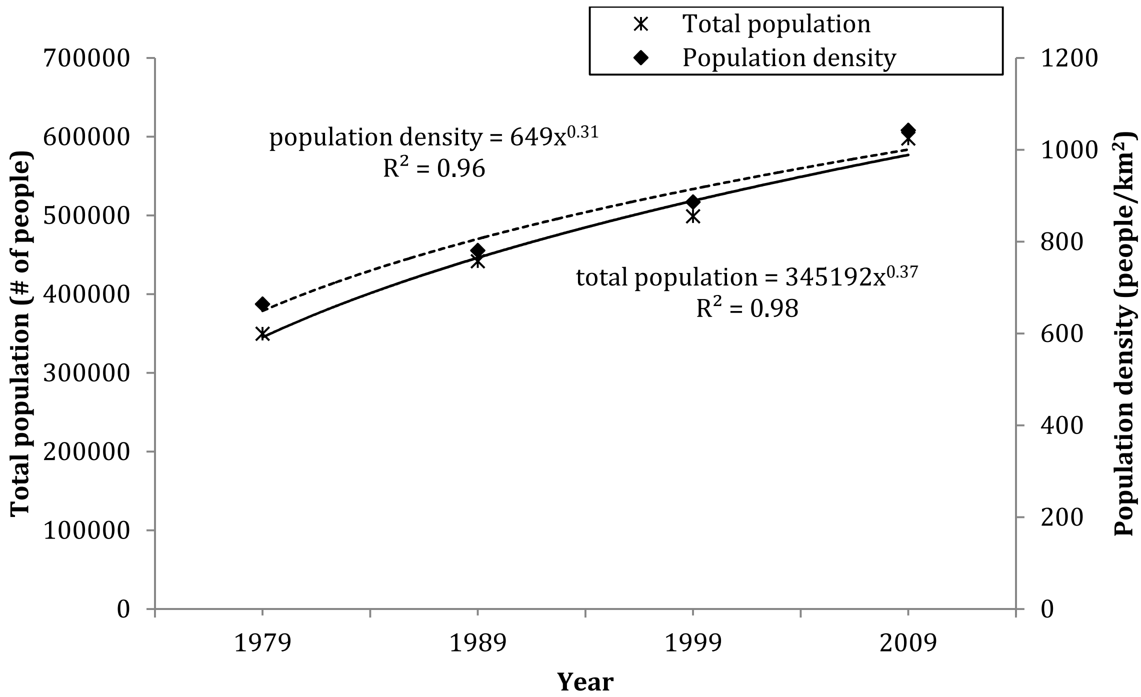

Figure 4-3: Decadal changes in total population and population density in Vihiga District from 1979 through 2009.
Data source: Census reports by the Kenya National Bureau of Statistics for 1979, 1989, 1999 and 2009.

(iii) Market changes for farm and forest products. Vihiga District is connected to three urban centres (Eldoret, Kakamega and Kisumu), which are market outlets for products such as cereals, vegetables and charcoal. Population increase and expansion in these towns, increases the local demand for agricultural and forest products. In addition, market prices for tea are of importance to the Vihiga farming systems, given that tea constitutes the main cash crop in the district. Higher demand could therefore lead to increased production in Vihiga District. However, our survey indicates that very little of the maize and beans production is sold by the farmers as most of it is for home consumption. Hence, an increasing demand for these food crops at the scale of Western Kenya has not influenced the Vihiga farming system. Yields for tea and vegetables, mainly produced for income generation almost tripled during the period 1984 – 2009 (Figure 4-4b). The combined area under tea and vegetables production however, remained less than 5% of total farmed area from 1992 to 2009. A decline of 28% in area planted to tea between 1996 and 1999 is likely to be associated with a 26% drop in producer prices between 1994 and 1995 (FAOSTAT 2012) that may have encouraged farmers to abandon the least productive plots in tea cultivation.

As for forest products, based on our 2010 household survey, the majority of the respondents (75%) perceived a general scarcity of forest products. Only 36% of the sampled households accessed forest products on average for less than half the year. Most of the accessed products were fuel wood and charcoal (52%), herbal medicine extracts (19%) and livestock pastures (13%), mainly for domestic consumption. Local output market changes for forest products were therefore least perceived by the inhabitants (7%) to have influenced forest cover changes over time.

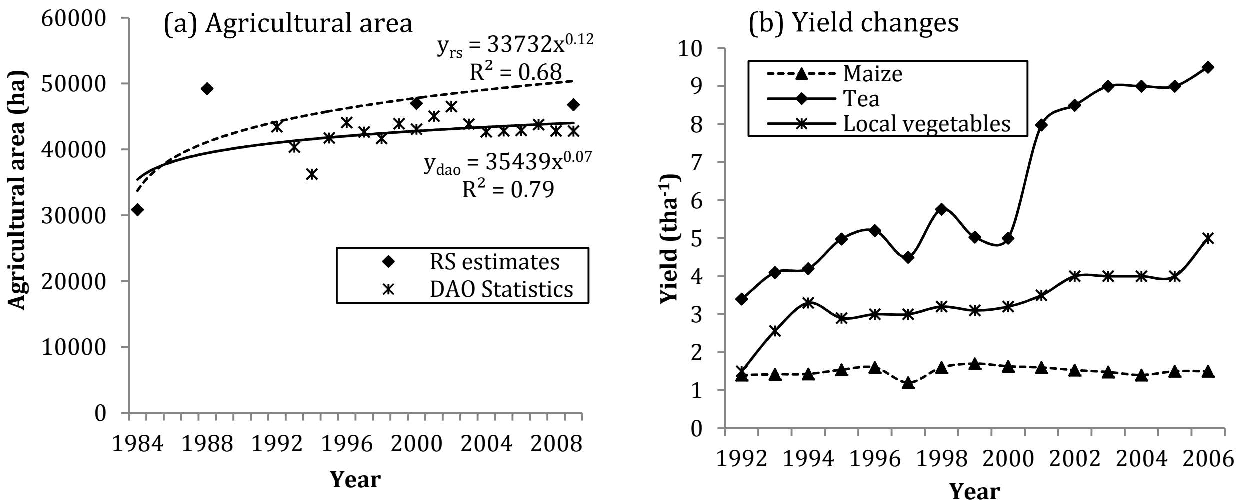

Figure 4-4: Comparative trends in agricultural area based on Remote Sensing (RS) estimates and District Agricultural Office (DAO) statistics (panel a) and yield changes for selected crops (panel b) in Vihiga District, 1984 – 2009. In the estimated equations (panel a), we compare the predicted agricultural area (y) based on remote sensing data (y_{rs}) and local statistics available at Vihiga District Agricultural Office (y_{dao}).
Data source: Crop production statistics from various annual reports for Vihiga District; remote sensed data from Landsat images for 1984, 1988, 2000 and 2009.

(iv) Climate variability. We also examined trends in temperature and rainfall as potential causes for land use changes. Compared to the 1980 – 1990 period, an average increase of 0.7 °C in mean annual temperature was recorded in the last decade, 2000 – 2010. However, an augmented Dickey-Fuller test showed that the trend in mean temperature was not significant (Test statistic=-3.02; MacKinnon approximate p-value for Z (t) = 0.13). Both trends for temperature and rainfall are shown in Figure 4-5 (a). Annual rainfall variability appeared to increase during the examined period (Figure 4-5a). About 35% of the household survey respondents indicated that unreliable rainfall was an important factor affecting the production of rain fed crops. We also examined the average monthly rainfall, and found that there appears to be a shift at this level, with February and July getting drier while September and December getting wetter (Figure 4-5b). Hence, there may be a shift in the timing of agricultural activities in the two rainy seasons, but the data collected so far are not sufficient to prove the likely disruption of cropping calendar in the district due to the overall seasonal trend.

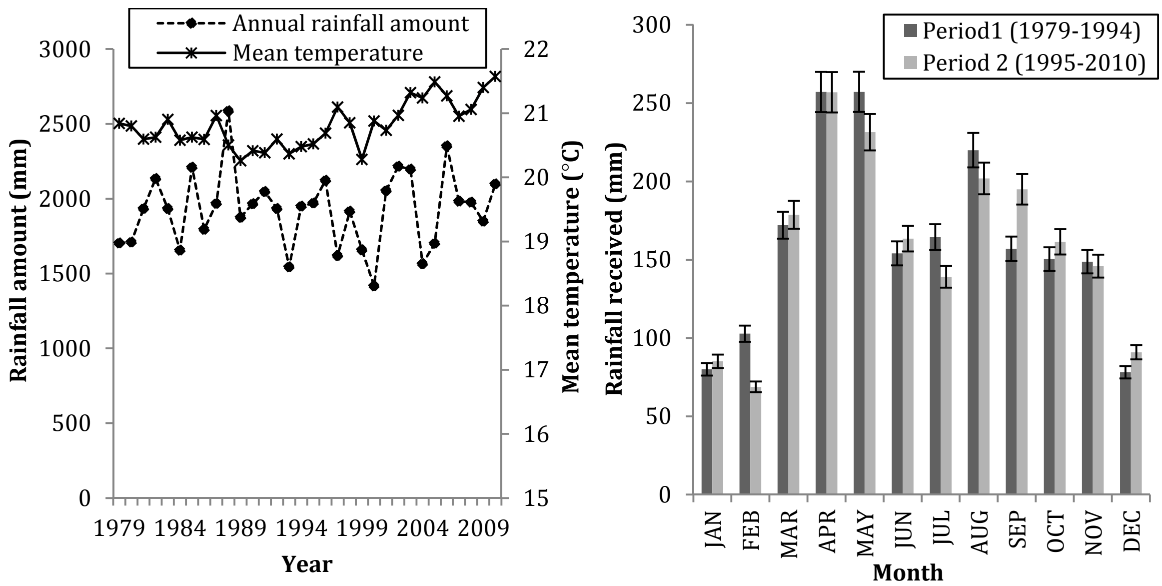

Figure 4-5: Changes in annual rainfall amount and mean temperature (panel a) and average monthly rainfall distribution by period (panel b) in Vihiga District from 1979 through 2010
Data source: Meteorological Department, Kakamega Station

4.3.3 Implications of land-use and land-cover changes

Results in Figure 4-6 (a-b), indicate a steady decline in land availability, steep drop in cash crop incomes and erratic food crop output per person in Vihiga District. The decline in these *per capita* measures is linked to a general scarcity of productive resources necessary to improve agricultural productivity within this dynamic agro-enviroment, thereby threatening rural livelihoods. Agricultural land *per capita* dropped by about one-third during the 1988 – 2009 period whereas that for forest shrunk by over a half. By 2009, bare land had decreased to about one-fifth of the area previously available per person in 1984 (Figure 4-6a). The changes in land available per person coupled with low technology use indicates poor agricultural productivity over time. Agricultural output for maize, the common crop, oscillated around 1 ton ha^{-1} (Figure 4-4b). This led to a 28% fall in *per capita* food production in the district during the last two decades alone. There was drastic decline in *per capita* cash crop income from tea, coffee and sugar cane mainly due to decreased total output and market price instability (Figure 4-6b). Perceptions of most residents (75%) indicate that also availability of key forest products such as fuel wood and natural pastures has reduced over time. Moreover, an increasing proportion of the population is poor and a majority of the households do not produce food that lasts throughout the year. Consequently, cash they earned was spent mostly on food purchases and little (if any) was invested in improved farming practices on the farms. This indicates poor land management and deteriorating agrarian livelihood prospects owing to LUC changes and population increase over time.

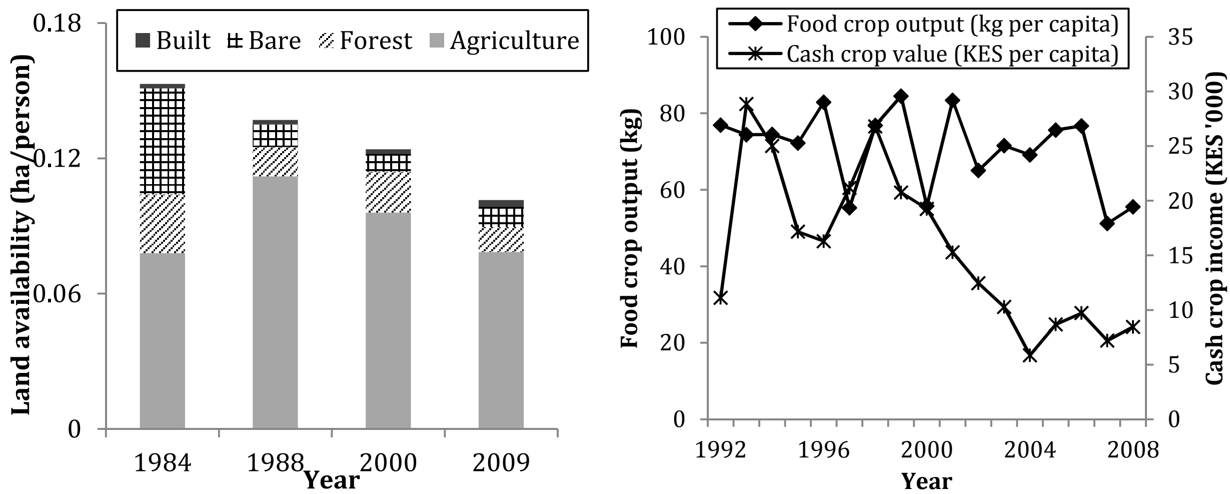

Figure 4-6: Changes in *per capita* land availability based on satellite derived data (panel a) and agricultural productivity based on local statistics and FAO producer prices (in KES), adjusted for inflation with 2009 as the base year, (panel b) in Vihiga District, 1984 – 2009.

Food crops comprised of maize, sorghums, beans and millets while main cash crops included tea, coffee and sugar cane.
Data sources: Crop production statistics from various annual reports from Ministry of Agriculture, Vihiga District; land availability data from Landsat images for 1984, 1988, 2000 and 2009; population and inflation figures from Kenya National Bureau of Statistics (KNBS 2010, 2012) complemented with online databases (ILRI 2007, WRI 2010) and producer prices from FAOSTAT (2012).

Formal statistical tests confirmed declining trends in *per capita* food crop production and cash crop income over time (Table 4-3). The Augmented Dickey-Fuller test statistic of -5.4 was less than the critical value of -4.4 (p = 0.001), indicating that estimated *per capita* food crop production followed a significant trend over time. The coefficient for lagged term of *per capita* food crop production (-1.4) was highly significant, confirming that *per capita* food crop production declined over time. A statistical test of the trend in per capita cash crop income also revealed similar results (Table 4-3). These statistical tests confirmed that agrarian livelihoods got worse as Vihiga District experienced considerable LUC changes and population pressure on land increased during the study period.

4.4 Discussion

4.4.1 Uncertainties in the analysed data

We recognise the existence of uncertainty related to the consistency of the data and to the extent to which the integrated approach used in this study can be applied elsewhere. First, given the high spatial variation in the examined landscape, which includes many small-scale land cover and land use elements (Cihlar and Jansen 2001), the 30 m spatial resolution of the satellite images used is rather coarse, but it is the most accurate data available for this period of study. This uncertainty could affect accuracy of changes in the line-shaped forest stands delimitating the valleys. Besides, elongated narrow elements like roads and treelines could not be classified properly, since these pixels included other adjacent landscape elements as well. These small areas are easily misclassified and very sensitive to the selection of the training areas. Although changes may take place here, they are difficult to capture over time except with very fine resolution images. This lowered the overall classification accuracy to 62%, which is below the commonly recommended 85% target (Foody 2002). This result was unsurprising, given the large spatial variation in land use elements due to fragmentation in the study area. The large landscape units were well classified and recorded high accuracy levels with actual ground data (e.g. 90% for agriculture), but the main confusion between classes was found for most landscape elements which had a size in the magnitude of the Landsat pixel size or smaller.

Table 4-3: Statistical test of the significance of trends in *per capita* food crop production and *per capita* cash crop income using Augmented Dickey-Fuller test

Variable/ Statistic	Coefficient	Standard Error	Interpolated Dickey-Fuller value Z(t)		MacKinnon p-value Z(t)
			Test statistic	1% Critical value	
1. Dependent variable: *per capita* food crop production			-5.35	-4.38	0.000
Lagged *per capita* food crop production	-1.41***	0.26			
Trend term	-1.07**	0.56			
Constant	108.63***	20.84			
2. Dependent variable: *per capita* cash crop income			-4.72	-4.38	0.001
Lagged *per capita* cash crop income	-0.91***	0.19			
Trend term	-1.24***	0.29			
Constant	24.97***	5.22			
Number of observations		16			

Asterisks indicate significance level: *** at 1%, **at 5%.

Second, another source of uncertainty in remote sensed data related to dissimilar acquisition dates of satellite images. There were no cloud-free images captured in similar months, hence we had to combine the available quality images to cover the temporal scope of our study. The use of images from different seasons influences the appearance of the land cover classes, but we attempted to minimise the negative effects of this choice by selecting training areas for each time-step individually as described in the Materials and methods section 2.2. Differences in seasonality could have affected mostly the separation between the agricultural and bare areas, but by comparing the post-classification results and not the original reflectance data, we minimised this problem and trust that this has limited implications for comparison of LUC changes between different periods. Besides, the trend analysis adopted in this study was useful in reducing the effect of variability due to diverse seasons of image coverage (Bonilla-Moheno et al. 2013).

Third, there is a possibility of low accuracy in the crop statistics obtained from the district database. The local statistics however showed a good degree of consistency with remote sensed data and were also aligned with empirical studies that covered small geographical areas in the district (e.g. Shepherd and Soule 1998, Crowley and Carter 2000, Jaetzold et al. 2007, Odendo et al. 2009, Tittonell et al. 2010). Fourth, Vihiga existed as a district from 1991 hence we estimated population figures for the earlier two census periods (i.e. 1979 and 1989) from the statistics for Kakamega District based on the names of locations. These locations may not exactly fall within the existing geographical boundaries of the district. As a result, our estimate of annual population growth rate of 3.7% was somewhat higher than the official annual rate of 3.3%, according to the KNBS (2010). Cognisant of these possible sources of uncertainty, we find that careful cross-referencing across different datasets and counter-checking with other available empirical research, is required to enhance data reliability of LUC studies.

4.4.2 Key drivers and the role of government policies

This study established considerable evidence of changes in land-use and land-cover in the western highlands of Kenya during the past 25 years. Close to one-half of the landscape experienced persistent changes between 1984 and 2009. The detected changes in the Vihiga landscape are consistent with those recently documented in the East African region, reported for instance by Kashaigili and Majaliwa (2010) in Tanzania and by Tsegaye et al. (2010) in Ethiopia. Our study found that the two most prominent changes in Vihiga District in the past 25 years involved: (i) a decrease in forest cover and (ii) an increase in agricultural land at the expense of both forest and bare land. Changes in forest cover were strongly influenced by past policies, whereas the increase in agricultural land, which is generally privately owned, was due to a combination of population growth and lack of technological innovation, as discussed below. Market changes affected in particular the cultivation of tea. Lower international market prices in the mid-1990s possibly forced farmers to abandon the least productive areas to increase production in remaining tea plantations. However, better support from local stakeholders in tea production (e.g. KTDA, MTF, extension agents) enhanced famers' access to fertilisers and high-yielding tea seedlings thereby creating necessary incentives to boost tea yields in the subsequent period. There were several changes in temperature and rainfall patterns over the past 25 years, but these were yet too small to have a significant impact on agricultural productivity. Even though, annual crop yield levels fluctuate with, in particular annual rainfall amount and distribution.

Changes in forest areas were driven mainly by past public policies. Protection of Kenyan forests is guided by government regulations (MENR 1994, Government of Kenya 2005, 2007). In 1982, the government banned any form of human activity in all indigenous forests (Müller and Mburu 2009). Our analysis shows that since 1984, the forest cover in Vihiga has been declining. Three main factors that played a role were: i) the establishment of tea zones intended to cushion forests from deforestation but actually accelerated encroachment; ii) re-settlement of people in forested areas and iii) illegal cutting of trees by local people.

Tea zones were established to create buffer belts around the fringes of gazetted forests, as a conservation strategy to check human encroachment into forestland. The implementation of this conservation strategy started around 1986 and intended not only to protect the forests but also help to rehabilitate the surrounding ecologically fragile areas through re-afforestation (NTZDC 2012). The forest-adjacent community would also earn an income from tea farming and made custodians other than destructive agents of the forests.

However, establishment of tea zones encouraged encroachment into forestland particularly in areas where official supervision was weak (Müller and Mburu 2009). Large areas of natural forest were cleared for agricultural activities during the period that official policy allowed non-resident cultivation within the forest areas (Müller and Mburu 2009). In the Southern part of the district, weak enforcement of government policy allowed local people to reside in a gazetted forest reserve, which they cleared bare by 1996 (Government of Kenya 2004). As already revealed in Chapter 3 (Section 3.3.3), deforestation in other areas was worsened by illegal cutting of trees for charcoal and timber production for sale, exacerbated by poor forest patrols and non-involvement of forest-adjacent community in conservation efforts. Wanton cutting of trees was attributed to the increased demand for food production because of population growth (Government of Kenya 2004). The increased land demand for agricultural activities heightened encroachment into marginal, previously bare areas such as steep slopes and riparian areas, exposing the fragile soils to serious erosion. Several of the formerly forested hills are now characterised by dense human settlement and bare rocky outcrops. The protruding rocky ridges evident in the Southern region mark the enduring impact of LUC changes in the study area.

In the past three decades, doubling of human population occasioned the expansion of area under agriculture by 36% out of which 25% was gained from bare lands. Thus additional farming areas were not necessarily selected on the basis of their suitability for agricultural productivity (Serneels and Lambin 2001). When agricultural productivity declined in years with unreliable rainfall, residents resorted to survival strategies that involved intense extraction of forest products such as timber, charcoal and poles (Garedew et al. 2009). According to Rembold et al. (2000) during such climatically adverse periods, farmers could boost crop output through additional farmlands. In the case of Vihiga, expansion of cultivated area slightly improved output, however in the long term it accelerated soil erosion and yield decline. Agricultural area initially expanded steadily but later stagnated as available arable land diminished. Our analyses showed that new farming technologies have become available, and that output markets have improved, in particular for tea, and to some degree for vegetables, but that there was no evidence or even indication for a general trend towards intensification in Vihiga District — even though improved technologies have been promoted in the district for a long time (Longley et al. 2006, Place et al. 2006, Tittonell et al. 2010). Instead, in order to cope with population growth and variable rainfall, the local people expanded their farming activities to forested and marginal areas. Our research findings are in line with those of Crowley and Carter (2000), who also investigated the process of agricultural intensification in Vihiga District. Now that there remain very little bare areas in the district (9%), it is unclear whether agricultural intensification can be expected to start taking place.

4.4.3 Impacts and policy implications

The impacts arising from these LUC changes on agrarian livelihoods are far-reaching. Due to high population growth, *per capita* agricultural area drastically declined over time consistent with Jayne et al. (2010). As a result of low yields, *per capita* food crop output dropped by 28% between the 1990s and 2000s. A similar trend was observed in the real *per capita* income from cash crops as population increased and poverty became more pervasive affecting around 62% of the population (Government of Kenya 2005). Increasing population density is argued to induce agricultural intensification and better land management (Tiffen and Mortimore

1994, Roose 1996, Pender 1998). For example, population growth accompanied by investment in better farming technologies, incorporation of high-value crops, linkage to remunerative markets and supportive public policy, were found to drive improved productivity per land unit and income *per capita* in Machakos District, Kenya (Tiffen and Mortimore 1994). In contrast, our results showed a lack of general intensification process, confirming the low actual farm level practices across five farm types established in Chapter 2, even though there was rapid population growth in Vihiga District. This lack of intensification is expressed through stagnant yields of maize and beans, the main crops and low adoption intensity of improved farming technologies.

The lack of intensification process in Vihiga District may be attributed to the largely subsistence-based farming system of the district, which contrasts with the market-oriented farming system prevalent in the Machakos District (Tiffen 1993). Subsistence production is mostly prefered in Vihiga District and is related to market uncertainty and risk averseness among the local farmers (Omamo 1998, Ndufa et al. 2005, Bhandari and Grant 2007). Historical evidence on agrarian transformation shows that Vihiga was a surplus maize-producing region during the 1930s, but has consistently been struggling to meet its food needs throughout the past decades (Maxon 2003). Food insecurity still persists among the majority of households who can hardly supply their own food needs for 4 months entirely from their crop harvests (Tittonell et al. 2010). Vihiga District can be described as 'a net-importer of food' that hardly saves income for improved land investments. Our study found that diminishing plot sizes (currently on average around 0.66 ha per household of seven members) may also limit the possibility for making input intensification profitable. This is consistent with Jayne et al. (2010) who found that small land units limit the application of improved crop technologies. As a result, shrinking plot sizes constrain smallholders to produce surplus output for meaningful participation in commodity markets (Jayne et al. 2010). Consequently, in line with our findings in Chapter 2 (Section 2.3.4), agrarian livelihood options have become precarious due to the diminished *per capita* arable land, low use of improved technologies and poor farm productivity during the last 25 years. Consistent with Ndufa et al. (2005), this study found that majority of the households are caught up in a 'maize-centred' poverty trap. Our results clearly show that farmers prioritised own maize production to meet increased food demand, yet poor maize yields and unreliable returns made it difficult for them to invest in soil fertility improvement, concurring with Barbier (2000). Low investment in better land management practices in turn limited the productivity impact from available improved technologies. Although production of high-value crops has greater potential to enhance farm returns, ironically a meaningful shift can only be realised when maize yields sufficiently increase (Ndufa et al. 2005). This partly explains the decline in area under cash crops to boost food production as maize yields oscillated around 1 ton ha^{-1} in Vihiga District during the study period. Hence, it cannot be assumed *a priori* that intensification will take place in Vihiga District now that the possibilities for bringing new (marginal) land under cultivation are exhausted.

Our findings have several policy implications for better land productivity and improved rural livelihoods in the western highlands of Kenya. In order to enhance land management in Vihiga District, policy options include checking further land sub-division, preventing forest encroachment and expansion of non-farm income opportunities such as informal business enterprises and formal employment. Given the interrelatedness of land-use and other income generating activities (Lambin et al. 2003, Pollock 2009), our research findings suggest a need for a broader, integrated and multi-stakeholder intervention approach. There is a need to equally promote off-farm income to ease population pressure on land and reduce over-reliance on forest resources. Off-farm economic activities have steadily increased in importance in Vihiga District due to its relative proximity to the urban centres of Eldoret, Kakamega and Kisumu (see Chapter 2 and Figure 2-3f). Moreover, improvement within those households whose livelihoods still rely mostly on farming may require the promotion of innovative and commercialised agriculture, which breaks away from the unsustainable low input-low output maize system. The cost of policy inaction could be large if the current trend continues unchecked. Our empirical findings agree with Jaetzold et al. (2007) that agriculture may become untenable and heightened deforestation may excerbate local vulnerability to climate change in future, thereby putting in jeopardy rural agrarian livelihoods.

4.5 Conclusions

This study examined trends and livelihood implications of land-use and land-cover changes in the western highlands of Kenya, between 1984 and 2009. Our study found that land use in Vihiga District has considerably changed — agricultural land expanded at the expense of forest and bare land. We found that improved farming technologies have become more available and that population density almost doubled during the study period. Interestingly, this study shows that there has been no significant intensification of agriculture in response to the strong growth in population pressure. Low intensity in the application of improved technologies and declining yields indicate that there is no process of broad intensification in maize-bean production, the main farming system of the area. There was also a decrease rather than an increase for land dedicated to the main cash crops, tea and vegetables, even though yields for these crops significantly increased. It appears as if a growing population has increasingly converted marginal areas to agriculture in the district, besides pursuing other livelihood strategies including some forms of off-farm income rather than intensification. Factors that play a role include shrinking plot sizes that have become too small for many farmers to make intensification profitable. In addition, the availability of off-farm income opportunities in the nearby urban centres may be a factor, but further research is needed to reveal the shifting patterns away from agriculture to other livelihood strategies. Our research findings have implications for development projects and programs in Vihiga District and potentially other densely populated rural parts of Africa. Rather than focussing on agriculture as the main source of rural livelihoods, these projects may need to consider a wider approach where poverty alleviation strategies are based on the conjoint exploitation of agricultural and off-farm income opportunities. Our research findings are therefore relevant to programs that promote better land management and policies for sustainable livelihoods in sub-Saharan Africa

Chapter 5 Prospects for Managing a Transition to SLM: Does Effective Stakeholder Collaboration Matter in Technological Diffusion?[5]

5.1 Introduction

Continued degradation of arable farmlands, deforestation of indigenous forests and biodiversity loss is blamed for the loss of essential ecosystem services and increasing poverty levels in the East African highlands (Reardon and Vosti 1995). Even though technological interventions have been promoted to reduce land degradation (Pender et al. 2006b), successes in sustainable land management (SLM) programs have mostly been limited to the contact areas (Okoba and De Graaff 2005, Ojiem et al. 2006). Broader adoption, i.e. scaling-up of SLM practices, is therefore not yet achieved. Scaling-up refers to "bringing more quality benefits to more people over a wider geographic area more quickly, more equitably and more lastingly" (IIRR 2000). The geographical diffusion of SLM practices and innovations would require an enabling institutional environment with supportive policies and active multi-stakeholder partnerships to ensure sustainability.

Human and natural systems are inherently interlinked across temporal and spatial scales (Gunderson and Holling 2002). Therefore, integrated socio-ecological knowledge on key implications of past landscape dynamics presented in Chapter 4, current livelihood diversity in Chapter 2 and economic value of ecosystem services contained in Chapter 3, provides new insights essential for initiating wider application of SLM practices in the western highlands of Kenya (Sardar 2010). Comprehensive information from integrative assessment of the target system is useful in the strategic selection of the most active actors, efficient approaches and diffusion pathways to achieve the desired sustainable societal changes (Loorbach 2007). In addition, collaboration of a diverse range of stakeholders may influence the successful implementation of broad SLM programs. This is because co-operation between interested and affected groups is necessary for better understanding of the opportunities and challenges involved in achieving conservation goals at multiple scales (MA 2003). As argued in Chapter 1, there is a need for multi-scale and inter-disciplinary information as well as multi-actor collaboration in order to develop sound management strategies and successfully implement broad development programs within the western highlands of Kenya.

Development programs are likely to succeed when organised based on informed, participative decision-making and collaborative implementation processes (Bingham et al. 1995). The key question however is how can we organise multi-level stakeholders and harmonise their diverse interests to promote wider application of SLM practices in the study area? In practice individual farmers make their own unique decisions within the constraints of resource endowments, institutional arrangements and marketing opportunities, to satisfy mostly their private welfare needs (Kruseman and Bade 1998, Pearce 2007). Besides, many households could be willing but incapable of embracing the best sustainable practices due to either poverty traps or high investment requirements to implement them (van der Brugge and van Raak 2007). We support their finding in Chapter 2. The diversity of stakeholders involved with SLM activities at different scales requires a more systematic way to harmonise macro-level visions, coordinate meso-level implementation of programs and guide micro-

[5] Based on Morgan C. Mutoko, Chris A. Shisanya and Lars Hein. Fostering technological transition to Sustainable Land Management through stakeholder collaboration in the western highlands of Kenya. Submitted.

level choices and practices. It is postulated that societal transformations are better triggered from bottom-up by changing individual practices facilitated by a favourable institutional environment sensitive to the local socio-ecological conditions (Rotmans et al. 2001). The recently developed transition management concept provides a multi-level framework as a governance tool for organizing cross-scale interactions to achieve such sustainable outcomes (Loorbach 2010).

Transition theory describes how and explains why societal systems transform over time (Rotmans et al. 2001). Transition management deals with the changing aspects of societies, particularly concerning when to initiate and how to enable transformations to occur (van der Brugge and van Raak 2007). The transition management (TM) approach was developed in the Netherlands as a novel governance tool to support the achievement of societal sustainability goals (Loorbach 2010). The TM approach is learning-oriented and underscores the value of continuous social learning, monitoring and flexible adjustment of activities. The novelty of TM approach originates at the micro-scale of local actors and practices (Rip and Kemp 1998). This is because improved technologies are promoted at this local level within an environment of existing practices and landscapes. Their dissemination is determined by the co-evolution of the technology and the social environment at the meso-scale as influenced by the macro-scale changes (Rip and Kemp 1998, van der Brugge and van Raak 2007). The multi-level framework of TM addresses multi-scale dynamics of system transformation by examining such key cross-scale interactions (Rip and Kemp 1998). We explore how to promote scaling-up of SLM practices through the transition management approach. The rationale for this innovative case of exploring the transition management include the inherent complexity and multi-faceted nature of socio-ecological system components whose interactions influence the broad dissemination of SLM practices (Lambin et al. 2003) and the heterogeneous rural livelihood strategies (including diverse off-farm activities) in the study area (see Chapter 2). Moreover, to realise a significant shift in the existing system, there is need to reach high thresholds in diffusion and application of improved knowledge, technologies and innovations. This calls for systematic organisation and direction of the diverse stakeholders' effort and activities in order to realise effective system transformation to the desired level.

The objective of this study is to assess prospects to trigger scaling-up of SLM practices through enhanced stakeholder collaboration using transition management approach in the western highlands of Kenya. Specifically, we use a stylised theoretical economic model to envision the transition path to sustainable demand-supply conditions for ecosystem services provision. The novelty of our model is the integration of investment requirement to spur the diffusion of SLM practices, linked to potential societal welfare improvement resulting from better economic benefits, associated with increased ecosystem services provision. We also relate ecosystem services provision level with either unsustainable or sustainable steady states in temporal perspective. We explore qualitatively the possibility of creating economic incentives to facilitate the capture and payment of non-marketed ecosystem benefits for investment in SLM practices. Based on stakeholder views, we evaluate the necessary local conditions for the desired transformation to occur using the multi-level framework of transition management. We also evaluate the position of the socio-ecological system on the transition curve, possible local triggers and suggest how to overcome obstacles to foster wider implementation of SLM practices. In order to achieve the desired transition, there is a need for large-scale transformation in the way local resources are managed by local stakeholders. We explore how this can be done following the multi-level framework, in which we assess the potential of TM approach to organise multiple actors and harmonise multi-scale activities. This is the first known attempt to apply the transition management framework to foster large-scale transformation to sustainable land management in the context of a developing country. Finally, we draw key insights from the transition management approach in order to facilitate organised multi-level stakeholder actions towards better land management and improved livelihoods in the western highlands of Kenya.

5.2 Methodology

This study combined both theoretical modelling and empirical approaches. The empirical methods involved stakeholder interviews and discussions in Vihiga and Kakamega Districts (Appendix A4). Combination of the approaches aimed to contextualise the application of the transition management approach within the unique socio-ecological conditions prevailing in the western highlands of Kenya. Besides, combining approaches is consistent with the trans-disciplinary nature of transitions research, requiring a mix of broad knowledge from systems analysis, history, innovation science, economics and local perspectives (Rotmans 2005).The approaches adopted in this study are described in Sections 5.2.1 – 5.2.3.

5.2.1 Conceptual modelling to envision sustainable provision of ecosystem services

We developed an economic model for the provision of ecosystem services to emphasise the relationship between investment levels in SLM practices and social benefits involved in ecosystem management. We also examined the implications of demand-supply optimality conditions on sustainable provision of ecosystem services and improvement of social welfare. In this conceptual model, we explored the potential impact on SLM investment were the benefits of non-marketed ecosystem services harnessed through payment for ecosystem services (PES) schemes or other suitable market instruments (see Chapter 3, Section 3.4.3). We envisaged that compensation arrangements would spur investment of the captured benefits in conservation and livelihood programs thereby foster the desired transformation towards sustainable land management and improved social welfare. This model formed the basis for exploring the potential for applying the transition management framework to organise multi-level stakeholders. The underlying assumptions in the model are described next.

We assumed that aggregate demand and supply of ecosystem services are associated with externalities that need to be internalised to achieve overall social welfare improvement. The potential capture and payment of benefits generated by the non-marked ecosystem services using relevant economic payment mechanisms, provides the additional investment resources to achieve the desired optimal level of ecosystem services provision. Uncertainties within the ecological system relating to the safe minimum standard (SMS) for proper ecosystem functioning are assumed to be given (Hein and van Ierland 2006, Fisher et al. 2008).

Another assumption is that individual preferences are additive such that social welfare is simply the sum of all individuals' economic benefits from the ecosystem services and social cost is the sum of all individuals' investment costs in SLM practices.

We also assumed that beneficiaries from improved supply of ecosystem services could hypothetically compensate the providers who incur both ecosystem management costs and opportunity costs. When net gains are positive after compensation is complete, then the necessary condition that benefits exceed costs is satisfied (Pearce et al. 2006). This assumption satisfies the Kaldor-Hicks theoretical principle of potential compensation requiring that the gainers from an action compensate the losers for the outcome to be a welfare improvement regardless of whether actual compensation takes place (Hanley and Spash 1993). This implies that if actual compensation occurs then no one becomes worse off, hence satisfying the criterion for Pareto improvement in overall well-being. It follows then that actual compensation need not occur in reality, but should be potentially conceivable (Pearce et al. 2006).

5.2.2 Stakeholders analysis to enhance local collaboration

Initial analysis using participatory stakeholder methodologies was carried out to identify active stakeholders involved in natural resources management in the western highlands of Kenya (Grimble and Wellard 1997, Castella 2009). At the local level, we interacted with selected individual farmers, farmer groups and opinion leaders through focus group discussions, field visits and observations. We held focus group discussions with 20 – 25 individuals in three locations (Shaviringa, Mwilonje and Tigoi) in Vihiga District (Figure 5-1). At each locality, we divided the participants in two small groups of 10 – 12 consisting farmers, local administrators, opinion leaders, agricultural extension staff and environmental NGO workers, for guided discussions. After each discussion, we carried out rapid rural appraisals of five selected farms to assess the actual management practices of the fields. We collected data on actual SLM practices implemented, constraints to and opportunities for diffusion of SLM practices at the farming system level.

At the regime level, we identified key actors from several organisations and actor groups working on the management of natural resources and improvement of livelihoods in the study area. They included district-level staff in relevant government ministries of agriculture and environment; public institutions such as Kenya Forest Service (KFS), Kenya Wildlife Service (KWS) and Kenya Agricultural Research Institute (KARI); Masinde Muliro University of Science and Technology (MMUST); Resource Projects Kenya (RPK), an environmental NGO, AVENE community-based organisation (CBO) and Vihiga District Farmers' Umbrella Forum. We held a kick-off workshop with 18 stakeholders from these groups in 2009 and interviewed 10 randomly sampled key informants using a brief questionnaire in 2012. In the questionnaire, we elicited responses on on-going and completed conservation projects, level and nature of collaboration with other stakeholders, the realised success levels and new strategies required to transform the socio-ecological systems of Western Kenya to a sustainable state. These stakeholders also provided information on the local conditions necessary for successful scaling-up of SLM practices. The information was useful in understanding the desired changes and assessing the preconditions required for applying the multi-level framework of transition management to organise multiple stakeholders to scale-up SLM practices.

5.2.3 Assessing prospects for transition to wider SLM application using a multi-level framework

The multi-level framework (MLF) has evolved into a generic tool used to analyse not only the innovations at the micro-scale and systems at the meso-scale but also long-term developments at the macro-scale (van der Brugge and van Raak 2007). According to them, the

MLF also has the potential to analyse the obstacles to and opportunities for occurrence of the desired changes across scales. This flexibility allowed us to assess how multiple stakeholders can be organised at the meso-level to boost broader adoption of improved SLM practices at the micro-level (Figure 5-2).

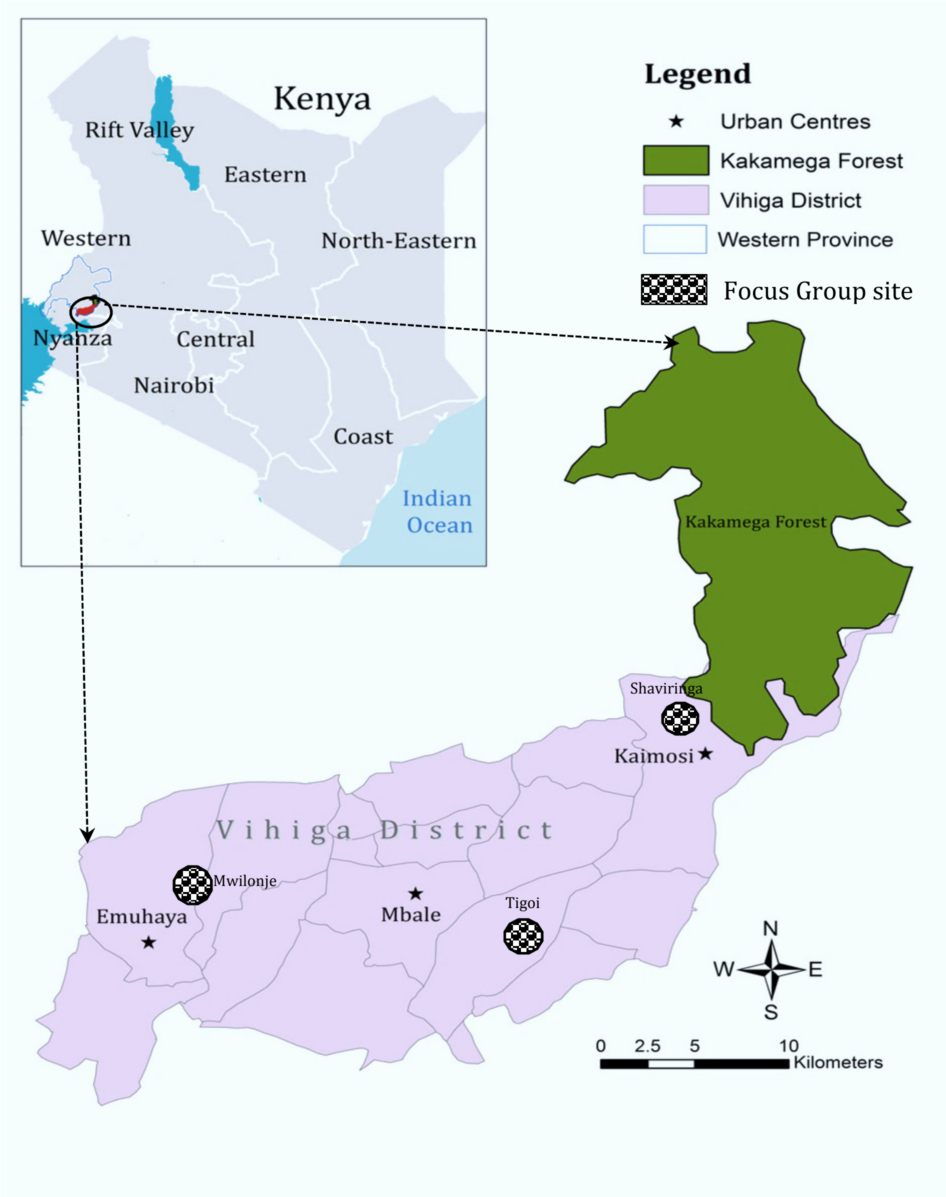

Figure 5-1: Map of Kenya (inset) showing the location of focus group discussion areas in Vihiga District and Kakamega Forest in the western highlands of Kenya.
Source: Authors' mapping in ArcGIS10.1 based on ESRI spatial information (2013).

We also examined in the adapted MLF the conditions that could influence the possibility for a technological transition process to occur in the socio-ecological systems of Western Kenya. The framework harmonises activities of multiple actors and processes at strategic, tactical and operational levels (Figure 5-2). In addition, transition activities are systematically organised into four co-evolving clusters (Loorbach 2007). They are (i) the diagnosis of the environmental problem, establishment of a transition arena and formulating long-term, integrated visions; (ii) the creation of networks, transition pathways and agendas; (iii) the mobilisation of actors and resources for experimentation and implementation of collaborative projects; and (iv) the monitoring, evaluation, learning and adjusting the transition arena, vision and agenda. We followed these steps and levels of the multi-level framework to assess the prospects for the application of the transition management approach to scale-up SLM practices in the western highlands of Kenya.

At the strategic level, small groups of innovators and opinion leaders are expected to organise themselves in social networks to initiate debate at the abstract societal level concerning the environmental issue such as land degradation (Figure 5-2). Such actors constituting the transition arena possess certain relevant competencies, experiences and are concerned with the increasing future uncertainty in the socio-ecological systems. The discussions have potential to generate new ideas that offer innovative alternatives, which would influence the long-term goals and direct the transition process to wider SLM application (Loorbach and Rotmans 2010).

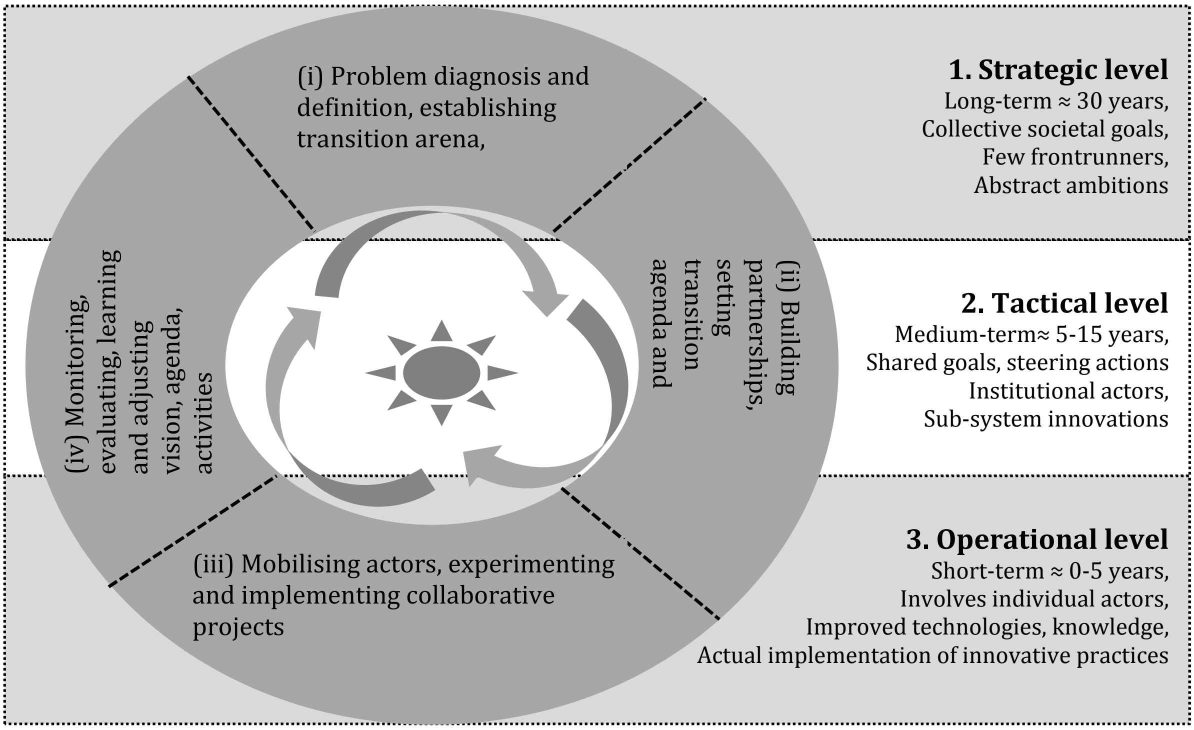

Figure 5-2: Cyclical, multi-level transition management framework to enhance organisation of multiple actors and cross-scale activities towards wider application of sustainable land management practices in the western highlands of Kenya. Activities of multiple actors and processes at strategic, tactical and operational levels are structured systematically into four co-evolving clusters.
Source: Modified from Loorbach (2007).

The steering activities that translate the long-term, strategic visions into short-term, operational actions are organised at the tactical level (Figure 5-2). Activities at the tactical level are dependent on stakeholders' interests and encompass actions such as consultations, joint planning and fund-raising for collaborative SLM projects. In addition, there should be deliberate integration of institutions such as informal rules and formal regulations, organisations and networks, in the transition management process. Transition process at this level, is driven by actors with specific capabilities, affiliated to institutions such ministries, state corporations, NGOs, farmer groups and have particular interest in contributing to overall sustainable development (Loorbach 2010).

The actual implementation of improved technologies, innovative practices and new knowledge usually takes place at the operational level. Individual actors mostly motivated by their own short-term objectives, would explore better alternatives and implement suitable innovations through experimentation process (Figure 5-2). Transition management is needed at this level to link and guide the innovative activities and practices towards the desired direction of wider SLM application. Multi-actor governance is not only important for showing that the prospects for the desired changes can materialise but also in providing a favourable setting for new technologies to develop into established practices at the micro-level. Ultimately the new practices may become firmly entrenched for scaling-up into system wide networks (Loorbach and Rotmans 2010).

Continuous monitoring, evaluation and adaptation are integral activities carried out in each level and could determine the outcome of any transition management process. The multi-level framework shown in Figure 5-2 will remain relevant in guiding system transformation through scaling-up of SLM practices when always harmonised with actual experiences and adjusted according to the dynamic realities on the ground. It is essential that involved actors re-evaluate their own activities and even reflect on their interactions during the scaling-up process. Periodic re-evaluation and reflection generates new insights through social learning helpful for retaining local support, participatory decision-making and refining the transition management activities to enhance chances for eventual success of the SLM transformation process (Loorbach 2007).

5.3 Results

5.3.1 Theoretical model envisioning the impact of scaling-up SLM practices

Using a conceptual model, we examine societal changes required to achieve wider application of SLM practices and improve social welfare in the western highlands of Kenya. We present an economic model in which we envision two steady states concerning the provision of ecosystem services. In this model, we emphasise the potential impact on SLM investments and economic benefits from conceivable compensation mechanisms between providers and beneficiaries of the non-marketed carbon capture and biodiversity conservation services. This provides the basis for assessing the existing opportunities to trigger scaling-up SLM activities using an adapted multi-level framework of transition management in Sub-section 5.3.2.

Within the conceptual model, we examine the unsustainable and sustainable demand-supply conditions for ecosystem services linked to social welfare from an economic perspective. This type of conceptualisation visually demonstrates the current need to shift the equilibrium conditions through technological transition to ensure continued provision of ecosystem services for sustainable social welfare in the future. We link ecosystem services supply with social welfare and investment requirement for broad SLM practices in this stylised model (Figure 5-3). This is because society depends on the natural and semi-natural systems to provide for their welfare within certain economic costs and benefits thereby affecting the functioning of ecological systems.

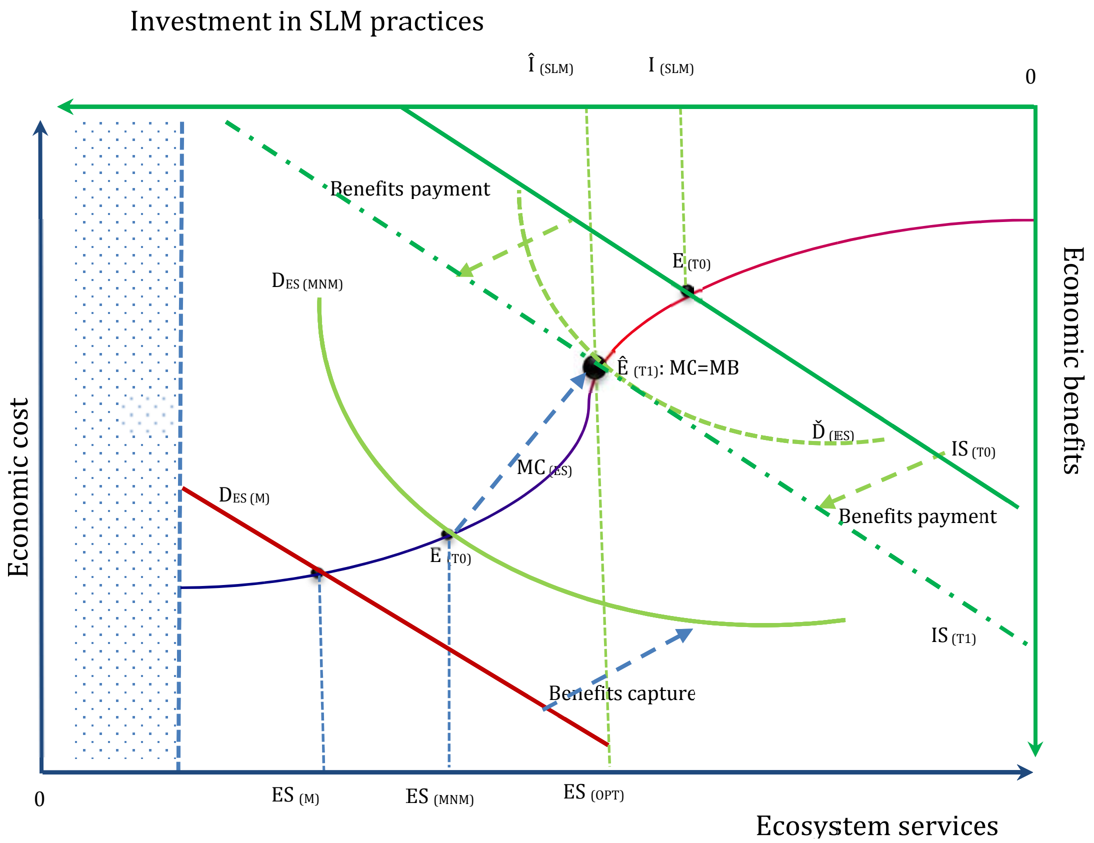

Figure 5-3: Conceptual model for ecosystem services provision and economic cost on the left-hand plane coupled with investment in sustainable land management (SLM) practices and associated economic benefits on the inverted right-hand plane — showing SLM transition possibility between the current unsustainable, $E_{(T0)}$ and the future desired sustainable, $\hat{E}_{(T1)}$ steady states. Conceivable compensation schemes involving benefits capture and payment that could facilitate this transition by increasing local investment in SLM practices.
Source: Author's model extension based on Pearce (2007) and Fisher et al. (2008).

On the left-hand plane, we present levels of total ecosystem services and economic cost associated with their utilisation (Figure 5-3). This is the demand side for ecosystem services. In the model, we reflect with a dotted line the uncertainty around the safe minimum standard (SMS) i.e. the minimum level of ecosystem structure required to sustain its functioning and provision of ecosystem services (Fisher et al. 2008). Beyond this unknown level, the ecosystem could unpredictably flip to a new state or collapse. The upward-sloping marginal cost curve, $MC_{(ES)}$ represents the increasing investment cost required to cover management and opportunity costs for the provision of an additional unit of ecosystem service with rising scarcity.

Demand curve for marketed ecosystem services, $D_{ES\,(M)}$ indicates that higher extraction level of ecosystem services, $ES_{(M)}$ occurs when only direct, marketed benefits such as food, timber or non-timber forest products are considered. However, the aggregate demand curve substantially shifts upward to $D_{ES\,(MNM)}$, when non-marketed ecosystem services such as carbon capture and biodiversity values that confer indirect benefits to society are included. This leads to a general equilibrium state where only $ES_{(MNM)}$ ecosystem resources are exploited, such that $ES_{(MNM)} < ES_{(M)}$. Equilibrium point, $E_{(T0)}$ associated with $ES_{(MNM)}$ level of ecosystem services represents the unsustainable state of ecosystem services provision in the current period. However, initiating a transition to a sustainable state is possible if the unharnessed economic benefits (i.e. the difference between $D_{ES\,(M)}$ and $D_{ES\,(MNM)}$) were captured through some institutional mechanisms (e.g. environmental taxes, user fees or PES schemes), and re-invested in both environmental conservation and livelihood improvement programs. In the Discussions section 3.4.2 (Chapter 3), we estimated this non-monetised value for carbon storage alone at about US$ 25 million per year and we now conceptually explore the possibility of re-investing this amount in the promotion of SLM practices on the inverted plane.

The inverted right-hand plane represents economic benefits from a bundle of ecosystem services and the investment requirement in SLM practices to sustain their continued provision for the present and future social welfare. This is the supply side of ecosystem services. Like in the traditional market for goods and services, the value of a bundle of ecosystem services can be estimated from the shadow price that beneficiaries are willing to pay for the provision of one more unit or prevention of losing that unit. Willingness to pay (WTP) values reflects not only the cost invested in the provision of the ecosystem benefits but also the associated externalities and foregone returns from possible alternative uses of the resource. In the current period, both private individuals and the society make some investments in SLM practices subject to prevailing budgetary constraints bounded by an aggregate investment line $IS_{(T0)}$ in Figure 5-3. Investment level made by private individuals is lower due to low resource endowment, low disposable income and high opportunity cost associated with the long-waiting period to recoup the investment outlay in the SLM practices. Low private investment and inefficient resource allocation reduces provision of ecosystem services reflected in the current low economic benefits and associated social welfare level.

The society invests in conservation programs of public nature such as protection and rehabilitation of forests for biodiversity preservation, promotion of soil and water conservation and provision of information on better forestry or improved farming practices through the research and extension systems. The aggregate societal investment level at $I_{(SLM)}$, assuming a given government expenditure in SLM programs, would be sub-optimal. The current investment equilibrium point, $E_{(T0)}$ is associated with the unsustainable provision of ecosystem services at $ES_{(MNM)}$ level. There is a need therefore to create economic incentives for increased individual investment in profitable SLM practices to boost farm productivity and lessen pressure on natural ecosystems. At the same time, we could also explore the application of suitable institutional mechanisms to capture economic benefits from the non-marketed ecosystem services and avail the resources to relevant stakeholders to spur investment in wider implementation of SLM practices.

In our model, we consider conceivable compensation arrangements particularly for the unharnessed economic benefits for carbon capture and biodiversity value provided by Kakamega rainforest found in the study area. If the forest-adjacent community and the managers received subsidies and payments from an environmental fund created from the provision of carbon sequestration and biodiversity preservation services, the likely implication would be increased investment level to $\hat{I}_{(SLM)}$ bounded by the new investment line $IS_{(T1)}$. Reduced dependency on extractable forest benefits and improved investment in better farming practices would considerably increase ecosystem services provision from $ES_{(MNM)}$ to $ES_{(OPT)}$ (Figure 5-3). Broad application of SLM practices would then enhance the supply of ecosystem services to a new socially optimal equilibrium. The new equilibrium state, $\hat{E}_{(T1)}$

results in additional ecosystem services associated with higher economic benefits leading to social welfare improvement. The investment level at point Î ($_{SLM)}$ is optimal because it satisfies the equimarginal principle (i.e. marginal cost (MC) of providing one more unit of ecosystem service just equals the marginal benefit (MB) derived from that unit). Compensating providers of the essential ecosystem services would spur technology adoption and farm productivity thereby ensuring that both social welfare improvement and sustainable conservation goals are realised jointly.

Attaining the desired steady state, $\hat{E}_{(T1)}$ characterised by sustainable conservation, increased ecosystem services provision and improved social welfare represented in Figure 5-3, requires deliberate arrangements that would systematically guide actual activities and effectively harness stakeholder synergies towards a more sustainable transition path. We envisaged that well-organised actors and co-ordinated activities would boost the implementation of broad SLM programs to achieve optimal levels of ecosystem services provision, demonstrated in this theoretical model. To this end, we applied the multi-level framework of transition management to analyse the local conditions and strategies required to enhance collaboration across key stakeholder groups to trigger wider diffusion of SLM practices (see Figure 5-2).

5.3.2 Prevailing local conditions concerning scaling-up SLM practices

We explore qualitatively specific opportunities to boost scaling-up of SLM practices in the western highlands of Kenya. First, we position the socio-ecological system on the S-shaped transition curve and examine the main barriers to and triggers of the transition process towards the take-off phase characterised by wider application of SLM practices (Figure 5-4). Secondly, based on stakeholders' views, we summarise the existing conditions and required stimuli to initiate the SLM transition process in Table 5-1. Our multi-level analysis of existing conditions around the four clusters and the prevailing local indicators reveal a system in the predevelopment phase, just before the take-off phase on the transition curve (Figure 5-4).

Field observations and stakeholder views indicated the existence of few areas with visible changes on improved land husbandry pointing to some successful implementation of available SLM practices. Most stakeholders concur that several local experimentations and adaptations of available SLM technologies are taking place across the farming system. However, at the position indicated on the S-curve, there are opposing forces i.e. barriers and triggers. The speed with which the system would shift to more sustainable transition pathway visualised in Figure 5-4, depends on the effectiveness of overcoming the identified barriers by boosting the triggers. The identified barriers against successful application of SLM practices include high poverty levels, a predominantly low input-low output maize-based farming system, diminishing land sizes and low involvement of the youth in farming activities. Others include less co-ordinated government policies on farming and forest conservation issues e.g. uncontrolled brick making that worsens soil erosion or unregulated charcoal trading that accelerates deforestation, unavailability of smaller quantities of farm inputs and lack of simplified technical information on soil nutrient status of farms, suitable fertilisers and correct rates. These barriers create negative feedbacks in the SLM transition process. For example, since smaller quantities of fertilisers are not available, there is no demand for them leading to low fertiliser consumption especially among majority poor farmers, which in turn affects the supply in the next season. The vicious cycle can be broken by testing an extension program providing such smaller packages to stimulate effective demand and actual application in farming activities.

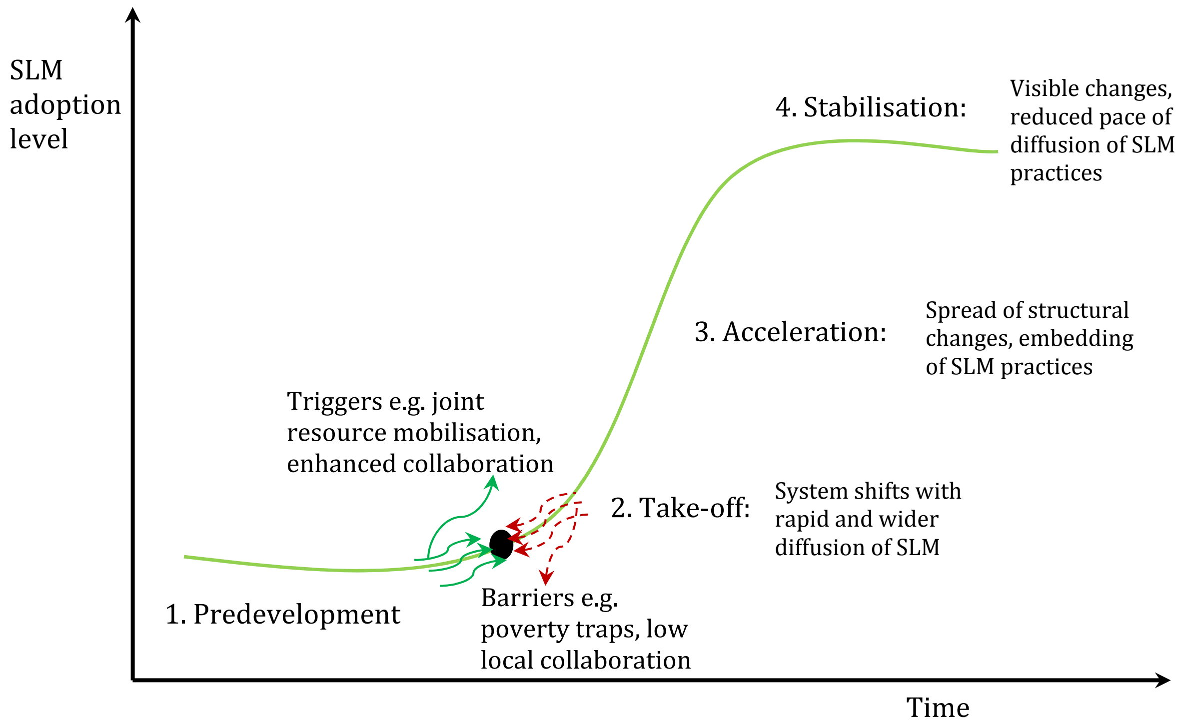

Figure 5-4: Four phases of transition cycle indicating with a dark spot the likely position of the socio-ecological system and the opposing forces at play — triggers and barriers — regarding scaling-up of Sustainable Land Management (SLM) practices in the western highlands of Kenya.
Source: Adapted from Loorbach (2007).

Transition triggers identified include the provision of simplified information on suitable, niche-specific SLM practices and hybrid crop varieties for improved land productivity. Others are enhanced local awareness on the collective need for embracing SLM practices, to boost interest and willingness to adopt new technologies. Networking, collaboration with interested partners and exchange visits to successful areas would also likely create synergies to harness collective action in the communities. Resource mobilisation by accessing credit facilities through groups and collective marketing strategies that encompasses value addition to farm produce could improve incomes for re-investment in better land management practices. At the farm household level, crop-livestock integration is an essential component that can create positive feedback effect in SLM transition process. Improved crop-livestock integration would lead to Napier grass cultivation and manure availability, which together can enhance effectiveness of terraces and efficiency in crop production as demonstrated in Chapter 2 (Section 2.3.5). As a result, better crop and livestock productivity would contribute to the household's farm income providing new financial capacity for the purchase of farm inputs (e.g. hybrid seed varieties and inorganic fertilisers).

In addition, a deliberate shift in the farming system away from predominantly subsistence maize production to high value crops such as tea, horticulture and dairy enterprises would improve farm profitability and perhaps motivate youths to engage in active farming. Moreover, harnessing local institutions and indigenous knowledge has potential to support public effort particularly in forest management. Stakeholders suggested that to ensure sustainability of the SLM transition process, there is a need to empower farmers to not only own but also disseminate the improved technologies amongst themselves. Lastly, infrastructural improvement may enhance marketing efficiency and indirectly create some non-farm livelihood opportunities for youth. This would reduce population pressure on available land resources and possibly increase remittances to augment investment in SLM practices.

The speed of the transition process beyond the current socio-ecological position would depend on the effectiveness of overcoming the existing barriers coupled with efficiency of the triggers to foster scaling-up of SLM practices. In Table 5-1, we present distilled stakeholders' views on the necessary actions for initiating the transition process and directing it towards wider application of SLM practices in this region.

Table 5-1: Essential conditions to trigger transition process through scaling-up SLM practices

Governance level	Aims	Prevailing conditions	Required actions
Strategic	Stakeholder integration to give long-term direction to achieving SLM	Two separate groups exist: one for the farmers and another for forest stakeholders	Integrate the two groups into a single but smaller transition arena to guide SLM promotion
	Better systems understanding for clear problem setting	Recent comprehensive socio-ecological information available	Package the information in usable format for problem structuring or guiding how to realise wider practise of SLM
Tactical	Building transition agenda	Collective, shared agenda for scaling-up SLM lacking	Joint formulation of goals, exchange of ideas across key stakeholders
	Creating effective stakeholder networks	Stakeholder collaboration to champion SLM strategies weak	Enhance networking and partnerships for effective SLM promotion
Operational	Development of new SLM innovations	Technology development and information generation active	Refine innovations for the specific socio-ecological niches
	Implementation of new SLM practices	Innovations adoption low and their diffusion sluggish	Focus on frontrunners Reduce systemic inefficiencies and ineffectiveness
Monitoring, Evaluation and adaptation	Social learning from SLM promotion experiences for adjusting the vision, agenda, innovations	Systematic inventory of learning experiences lacking across stakeholder groups	Design participatory monitoring and evaluation framework for documentation of key experiences

5.3.3 Transition prospects towards wider application of SLM practices

We followed the four co-evolving activity clusters identified in the multi-level framework of transition management (Figure 5-2), to assess prospects for initiating a transformation process towards sustainable land management in the western highlands of Kenya. At each level, we describe the existing local situation and indicate how to realise the actual application of the transition management approach in line with these four clusters.

(i) Problem diagnosis, envisioning and establishment of SLM transition arena

We found the existence of some common interest groups in the western highlands of Kenya, but they were not organised clearly as transition arenas and lacked strategic agenda to champion for long-term transformation of the farming and forest ecosystems through scaling-up of SLM practices. For example, there is Vihiga District Farmers' Umbrella Forum, also organised at sub-district levels and the recently created Kakamega Forest Ecosystem Stakeholders, aimed at collaboratively promoting better forest management. Selected active, visionary members from these existing groups can be transformed into convenient transition arenas through enhanced self-organisation and participatory visioning, with legitimate obligation to oversee the scaling-up of SLM practices in this region.

(ii) Building partnerships, setting transition agenda and policy advocacy

According to the key informants interviewed, several public and private organisations are involved in the promotion of environmental conservation activities and improved farming practices to increase agricultural productivity within the western highlands of Kenya. These include ministries of agriculture, livestock and environment, KWS, KFS, KARI, RPK, and an environmental NGO, among others. However, our study found only moderate collaboration among these stakeholders, associated with about 50% success level in SLM projects implemented during the past decade. A strong positive correlation (rho = 0.83) was found between the rating of collaboration reported by the stakeholders and the success level of SLM projects they implemented. There is need therefore to identify and organise individuals with tactical abilities to build networks, set clear agendas and advocate for enabling institutional support in order to harness synergy for successful implementation of broad-based projects to drive the SLM transition cycle at the system level.

(iii) Mobilisation of actors, experimentation and implementation of collaborative SLM programs

The development of improved technologies to enhance sustainable land management has been conducted by several organisations over time in the western highlands of Kenya (Mureithi et al. 2002, Pender et al. 2006b). Participants in the focus group discussions defined SLM as the best farming practices characterised by high crop productivity, non-declining soil fertility and healthy livestock and forestry integration. They identified 10 SLM practices including construction and maintenance of soil and water conservation structures (e.g. terraces and cut-off drains); contouring on slopes, application of inorganic fertilisers, use of compost/farm yard manure and establishment of vegetative strips (e.g. Napier grass and hedgerows). Other practices are planting improved seed varieties, timely implementation of agronomic practices, mulching, the practice of multi-purpose farm forestry and livestock integration. The identified SLM strategies for the forest ecosystem included the promotion of farm agro-forestry, sustainable planting and harvesting regimes for plantations, rehabilitation of natural forest stands and protection of riparian vegetation.

Stakeholders distinguished four SLM classes based on the estimated number and observed geographical spread of the SLM practices implemented across the farming system (Table 5-2). SLM1 farmers practised most of the improved practices on their farms and maintained the physical structures. SLM4 farmers partially implemented just few measures due to severe resource constraints they faced.

Table 5-2: Stakeholders' classification of a set of SLM practices into clusters according to actual implementation levels

SLM[a] practice	SLM 1	SLM 2	SLM 3	SLM 4
Contour cultivation	Yes	Yes	Yes	None
Cut-off drains/terraces	Yes	Yes	None	None
Compost manure use	Yes	Yes	Yes	None
Livestock integration (farm yard manure)	Yes	Minimal	None	None
Application of inorganic fertilizers	Yes	Little	Little	Little
Presence of Napier grass lines	Yes	Yes	Yes	For sale
Mulching	Yes	Minimal	None	Yes
Maintenance of physical measures	Yes	Yes	None	None
Use of quality seeds	Yes	Yes	Recycled	Local
Improved fallows with multi-purpose trees	Yes	Some	Some	None

[a]SLM is Sustainable Land Management.
Source: Own focus group discussions.

According to stakeholder estimates, on average only one in every ten farmers in Vihiga District has properly implemented the available SLM practices (Table 5-3). Although they are in the minority, they constitute a small group of frontrunners and their successful farm management and agricultural productivity can offer useful lessons for social learning to motivate the majority of farmers to adopt the best SLM practices. However, our findings indicate that effective multi-stakeholder collaboration to consolidate individual efforts and initiate wider promotion of SLM practices was still lacking. In fact, the contacted stakeholders hold the general view that many of the actors operate in several diverse, sometimes conflicting ways with minimal collaboration across their activities. For example, poor farming practices by farmers located on the higher side of Maragoli hills accelerated soil erosion making conservation efforts by those residing at the lower side futile. In other instances, sometimes the government agency concerned with road maintenance open drains for run-off at inappropriate locations thereby accelerating soil erosion on farms. Better collaboration between the affected farmers in the former case and among agricultural extension, road works and local residents in the latter, can facilitate harmonious implementation of activities, which would eventually contribute to sustainable land management.

Table 5-3: SLM practices by proportion of farming households (%) with varying levels of adoption estimated by local stakeholders at three locations in Vihiga District

SLM group	Rating	Shaviringa	Mwilonje	Tigoi	District average
SLM 1	Best	10	5	3	6
SLM 2	Good	20	12	20	17
SLM 3	Fair	50	32	45	42
SLM 4	Poor	20	51	32	34

Source: Own focus group discussions.

(iv) Monitoring, evaluation, learning and adjustment of the transition process

Our results show that only 30% of the key informants interviewed indicated the presence of some monitoring and evaluation activities in the SLM projects they implemented. At farm household level, maintenance of up-to-date records is uncommon. The lack of organised process to document those experiences that enable or restrict the diffusion of available technologies, may limit fine-tuning of SLM activities to achieve broad impacts more quickly and more lastingly. Nevertheless, there is opportunity to develop simple participatory monitoring and evaluation framework to institutionalise the process of documentation and sharing of transition experiences.

5.4 Discussion

Research in likely societal transitions is inter-disciplinary and requires broad knowledge from various disciplines integrated with local perspectives (Rotmans 2005, Sardar 2010). We combined systems analysis, economic modelling of ecosystem services provision and stakeholder views in an attempt to understand how to initiate the transition process towards wider application of SLM practices. We applied an adapted multi-level framework of transition management to analyse prospects for triggering broader scaling-up of SLM practices in the context of a developing country.

Concerted efforts to increase the geographical spread of the available SLM practices have been made in the western highlands of Kenya. As we discussed in Chapter 1, identification of socio-ecological niches to enhance better technological targeting and application of participatory dissemination approaches such as conservation by local committees, farmer field schools or catchment approach (Longley et al. 2006, Mureithi et al. 2006, Ojiem et al. 2006, Wanyama et al. 2010). Yet, in Chapters 2-4 our results show that the level of actual implementation of SLM practices across scales was still too low, consistent with other studies that have pointed to the existence of barriers against rapid transition to sustainable systems (Kemp et al. 2007, Ruben et al. 2007, van der Brugge and van Raak 2007). Barriers such as weak institutional support and high short-term cost of adopting better practices make transition a gradual process requiring enabling policy environment, stakeholder networking and social learning. Overcoming the obstacles and initiating the transition process towards wider application of SLM practices would require strong stakeholder collaboration and smooth governance of the diverse activities (Kemp 1994, Loorbach and Rotmans 2010). Besides, given the diminishing land sizes as showed in Chapter 2 (Section 2.3.4 and Figure 2-3b) and Chapter 4 (Section 4.3.3 and Figure 4-6a), input suppliers ought to avail fertilisers and seeds in smaller quantities in order to enhance intensity of their use in farm production. Packaging of farm inputs in large quantities has been identified as one of the obstacles to investing in SLM practices in sub-Saharan Africa, where over 80% of farmers are smallholders (Knowler 2004, Hein and Fileccia 2007, Jayne et al. 2010). Scaling-up of SLM practices could also benefit from policy intervention aimed at raising awareness among local farmers because well-informed stakeholder groups make better choices that contribute to environmental conservation (van Kempen et al. 2009).

There is need therefore for a supportive institutional environment and stakeholder synergy to drive the scaling-up process for SLM practices. Transition to wider application of SLM practices is possible when actors reinforce each other and direct their activities towards a collective objective of conserving the natural resources and improving local livelihoods. Our assessment indicates that there is local potential to enhance organisation of the many actors for improved interaction, integration and co-evolution between their activities in a "more rapid, efficient and directed" way towards scaling-up of SLM practices as postulated by Loorbach (2007). From this transition management analysis, we draw four new insights that when carefully considered have potential to foster scaling-up of SLM practices in the western highlands of Kenya.

5.4.1 Transition arena is a key determinant of the transition process

The central role performed by the transition arena — a small strategic group of actors with long-term vision — in guiding the transition process has been documented (Loorbach and Rotmans 2010). They established that at the strategic level, a transition arena provides a niche for incubating new ideas whereas at the operational level, early adopters of new practices constitute a small group of frontrunners, who offer useful experiences important for a successful transition process. Potential actors for the two types of pioneering groups were identified in the study area. It is possible to establish transition arenas and identify niches for initiating transition process toward sustainable land management in the western highlands of Kenya, given the presence of these groups and availability of current integrated systems information presented in this thesis.

5.4.2 Collective demand for major changes is an effective trigger

Existence of a new demand for different behaviours, technologies or approaches is essential in triggering the transition process (Frantzeskaki et al. 2009). As Loorbach and Rotmans (2010) established, the new demand would be for enhanced co-operation as was the case in the Dutch Parkstad Limburg or a need for sustainable waste and resource management in Belgium. In the case of Western Kenya, there is urgent need to manage the agro-ecosystems in a more sustainable manner given the socio-ecological dynamics characterised by declining farm yields, increasing population pressure, high dependency on extractive forest products and climatic variability, based on the new evidence presented in empirical Chapters 2-4.

Some stakeholders in Western Kenya are not only convinced of the urgency to act but they are also positive about the prospects of transforming the region through guided collective action. Sentiments from one key informant seem to reflect the collective desire to transform the agro-ecosystems to increase agricultural productivity and enhance environmental conservation, thus "...our landscape is now dotted with 'growing' rock outcrops due to high erosion as a result of poor farming practices. Many people have engaged in brick making business to earn quick income as farming becomes less attractive to our youths. We should realise that the rapid loss of the richness of the very resources that sustains our livelihoods exposes us to uncertain future. But when we join efforts it is possible for us to reverse this worrying trend" (L.S. Kamonya, personal communication, 2012). However, it is essential to consider local interests, secure co-operation of multiple actors and integrate capacity building strategies to guarantee sustainability of the SLM transition process in this region, as suggested by Sarkis et al. (2010). This because some farmers may not prioritise farming as a livelihood activity, which in turn influences actual use of available SLM practices, as we already demonstrated across five farm types in Chapter 2.

5.4.3 Adapt innovations to the prevailing societal circumstances

A transition process is sustained by innovations, practices and ideas, which even though are usually new, ought to be socially acceptable and provide economic prospects for societal improvement (Rotmans et al. 2001). Analogously, the transition process is akin to a vehicle moving to a new destination, the transition arena would be the driver; the local communities would be the engine whereas the innovations would be the oil and petrol that powers the vehicle. Putting in the vehicle wrong type of oil and petrol would not guarantee arrival at the desired destination even with a competent driver. This insight is essential for successful scaling-up of SLM practices because despite the promising economic returns and ecological benefits from the new SLM technologies, they will unlikely diffuse widely without adapting them to the existing socio-ecological conditions. A variety of SLM technologies have been promoted for the past two decades, with varying degree of adoption in the western highlands of Kenya (Pender et al. 2006b, Odendo et al. 2009). Therefore, our research findings concur with Schwilch et al. (2012) that there is need to involve local stakeholders in the development of a current inventory of those technologies that have high success prospects and design strategies to promote their wider dissemination in line with the transition management approach.

5.4.4 Mobilise sufficient resources for the SLM transition process

Societal transformations are very costly because they are long-term processes that entail drastic changes beyond the ordinary ways of doing things. The transition process therefore requires a lot of resources — financial, human and time — for experimentation of innovative practices and their broader diffusion to reach the desired sustainable levels. For example, the cost of transition experiments carried out for a period of only two years in the Dutch health-care transition process was over € 3 500 million and involved over 1 000 professionals (Loorbach and Rotmans 2010). This calls for strategic partnerships for joint fund-raising to mobilise sufficient resources to facilitate the transition arena and empower the niche frontrunners.

However, scarcity of financial resources certainly constitutes the major obstacle to initiating and sustaining SLM transition process in the western highlands of Kenya. Most of the key stakeholders interviewed identified availability of adequate financial resources as one of the decisive success factors in SLM programs. The region has some of the highest poverty levels in rural Kenya estimated at around 62% of the households in Vihiga District (Government of Kenya 2005, Claessens et al. 2008). Poverty traps are blamed for unsustainable land management practices leading to low agricultural productivity and poor management of the farming system (Chapter 2). In Chapter 3, our study found that poor households are highly dependent on the forest ecosystem for extractive benefits thereby accelerating deforestation (KFE 2012). In addition, the socio-ecological environment is very dynamic characterised by ever-increasing population, high soil erosion and climatic variability with the associated falling agrarian livelihoods as shown in Chapter 4. Therefore, embracing group approaches, such as farmer field schools, catchment approach, collective marketing and least-cost farming options, possibly will enhance efficiencies and effectiveness in the allocation of scarce resources thereby reduce the effect of resource constraints to scaling-up of SLM practices (Mureithi et al. 2006, Wanyama et al. 2010, Mutoko 2012). Carefully targeted pro-poor subsidy programs for farm inputs could also boost the shift to more productive and profitable farming practices as recently evidenced in Malawi (Dorward and Chirwa 2011, Javdani 2012). Nevertheless, as argued by Mhango and Dick (2011), a holistic systems understanding should be integrated in such subsidy programs to avoid increasing agricultural productivity at the expense of provision of other key ecosystem services.

5.5 Conclusions

There is an urgent need to reverse continued degradation of farmlands, deforestation of natural forests and declining social welfare, in the densely populated highland agro-ecosystems of Kenya. Due to interrelatedness of the challenges of land degradation and poverty, a multi-level organisation of actors and activities is required to trigger broad changes in land management practices to enhance sustainability of the landscapes and livelihoods. Applying theoretical modelling and participatory empirical approaches, our study found the presence of conditions with potential to initiate a technological transition process towards wider application of sustainable land management (SLM) practices in the western highlands of Kenya. We conclude that this socio-ecological system is at the predevelopment phase on the transition curve, where ecosystem services provision is unsustainable but reasonable local prospects for take-off exist. We suggest the application of a contextualised multi-level framework to initiate and direct wider scaling-up of SLM practices. In addition, joint resource mobilisation and agricultural subsidisation programs would spur technology adoption and expedite the transition process. Such collective transition management process would provide useful learning lessons on effective governance of transformative environmental programs for other similar agro-ecosystems in sub-Saharan Africa.

Chapter 6 General Discussion and Conclusions

6.1 Introduction

Recent empirical investigations have focused on understanding how the application of Sustainable Land Management (SLM) practices can reduce adverse impacts of land degradation and improve human well-being in SSA countries (Shiferaw and Holden 2000, Salasya 2005, Holden et al. 2006, Longley et al. 2006, Ojiem 2006, Pender et al. 2006b, Vanlauwe et al. 2006, Tittonell 2007, Nkonya et al. 2009, Odendo et al. 2009, Banadda 2010). Studies elsewhere have found that proper application of SLM practices reduces land degradation and improves provision of ecosystem services within the targeted ecosystems (Hurni 1999, Lefroy et al. 2000, Holden et al. 2004, Schwilch et al. 2011). Broad application of SLM practices therefore has the potential to reverse land degradation and improve agricultural productivity in degraded regions of SSA (Hurni 2000a). Generally, broader and proper implementation of SLM practices has potential to contribute to the realisation of two Millennium Development Goals (MDGs). These are MDG 1 on eradicating extreme poverty and MDG 7 on ensuring environmental sustainability (United Nations 2012). Even so, past development programs aimed at enhancing agricultural productivity in SSA region have not achieved broad application of SLM practices (Reardon et al. 1999, Knowler 2004). The lack of broad success with SLM programs is attributable to multiple interlinked environmental and socio-economic factors (Reardon and Vosti 1995, Knowler 2004, Lobell et al. 2008). Yet to keep up with food needs for the growing population in many SSA countries, a rapid increase of agricultural production balanced with provision of ecosystem services is required.

Evaluation of SLM prospects should be broad to consider changes in land quality, ecological and socio-economic aspects (Dumanski 1994). As such, SLM evaluation therefore requires a systems approach analysing key interactions between local stakeholders, their asset endowment and allocation to improve land management practices and productivity across spatial and temporal scales (Smyth and Dumanski 1995, Steiner et al. 2000, Fernandes and Woodhouse 2008). While adopting a multi-dimensional, multi-stakeholder systems approach, this study also contextualised the examined SLM practices. The locally known SLM practices considered include the application of farm yard and compost manure, use of inorganic fertilisers, improved crop varieties and incorporation of crop residues (Shisanya et al. 2009). Others are Soil and Water Conservation (SWC) measures such as terraces, cut-off drains, grass strips, hedge rows (Nyangena and Köhlin 2008, Guto 2011) and agro-forestry practices (Nkonya et al. 2006, Jama et al. 2008). This study focussed in Vihiga District, one of the most densely populated rural areas in SSA with current population density of 1045 people/km^2 (KNBS 2010). The choice of this study area was informed by the established postulation that rising rural population density would induce intensification of agricultural production (e.g. Boserup 1965, Hayami and Ruttan 1985, Ruttan and Thirtle 1989, Tiffen et al. 1994, Pender 1998). However, supportive evidence on the possibility of a technology-driven intensification process occurring in densely populated regions of SSA is scanty (Tiffen et al. 1994, Grepperud 1996, Crowley and Carter 2000, Pender et al. 2006a, Giller et al. 2009). In the next sections therefore, the main findings of this research are revisited and discussed against this backdrop and in light of the body of scientific knowledge.

6.2 Advancing the population-environment debate with new evidence from a dense and degrading agro-ecosystem of sub-Saharan Africa

The environment avails natural capital, the most important stock that provides ecological and economic benefits to people in a given region (Pearce 1988, Collados and Duane 1999). Because of the linkage between natural capital and the quality of human life, empirical attention is given to understanding its components and dynamics in relation to population dynamics (Daly 1994, Pretty 1999, Hamilton and Ruta 2009, Lambin 2012). At the global level, evidence is now available confirming that natural capital forms a major portion of human wealth (Hamilton and Dixon 2003, World Bank 2006b).

In scientific discourse, there remains a longstanding dichotomy on the likely outcome of population-environment relationship with increasing population growth. The pessimistic Malthusian and the optimistic Boserupian hypotheses have presented contrasting broad outlooks that continue to elicit scientific debate concerning the prospects for sustainable development with rising world population (Boserup 1965, Hayami and Ruttan 1985, Lee 1986, Ruttan and Thirtle 1989, Lambin 2012). According to Malthusian postulation, the environment has a carrying capacity, which, when exceeded through exponential population growth, would result in lower food productivity and negative environmental impacts. These possibly set off a vicious cycle of poverty and degradation (Malthus 1809, Lee 1986, Todaro 1989, Pender et al. 2006a). This view holds that negative changes in land use and cover directly affect the quantity and quality of accessible natural capital and ecosystem services supplied from a given land unit. In turn, this could hamper the benefits derived from ecosystem services provision for human welfare improvement. A poor population would then have weak capacity to invest sufficiently in better land management practices to address land degradation (Knowler 2004, Todaro and Smith 2008). In Africa, land is a key natural resource and its continued degradation compromises the capacity of terrestrial ecosystems to supply ecosystem services for improvement of human welfare (Barbier 2000). On the other hand, Boserupian hypothesis advances compelling counter-argument that population growth cannot necessarily be associated with adverse environmental outcomes. Instead, population growth has the potential to induce improved innovations and widespread application of better land management technologies, which would lead to higher land productivity (Boserup 1965, Boserup 1974, Hayami and Ruttan 1985, Boserup 1989, Ruttan and Thirtle 1989, Boserup 1992, Barbier 1998, Lambin 2012). Sustainable Land Management (SLM) is a recent approach to realise the Boserupian outcomes in tropical countries (Hurni 2000a, Hurni 2000b, Pender et al. 2006b, World Bank 2006a).

6.2.1 What is already known on land degradation in sub-Saharan Africa?

Past empirical studies have analysed and documented the linkage between the nature of land degradation and potential for SLM practices across sub-Saharan Africa (e.g. Eweg et al. 1998, Stoorvogel et al. 2004, Cohen et al. 2005, Hurni et al. 2005, Tittonell et al. 2007, Reed and Dougill 2010). However, empirical evidence on how landscape changes are affecting rural livelihoods, especially in densely populated agricultural areas remains rare in SSA. Assessment of interactions between society and the environment must take into account forces at multiple scales and in particular economic prospects and policy dimensions that may expand or limit adaptation of the land use system to localised changes such as population growth (Campbell et al. 2003, Todaro and Smith 2008).

Land degradation in SSA remains a debatable issue since there is no broad consensus on its extent, severity, underlying causes and effects (Pender et al. 2006b). For instance, biophysical quantification of the extent of land degradation based on expert opinions (Oldeman 1998) or few plot-level experiments (de Jager et al. 1998) suffer from methodological and conceptual weaknesses (Place et al. 2006). As a result, many studies are difficult to compare and some provide divergent findings on actual cost of land degradation (Yesuf et al. 2005). Even then, none of such studies has investigated the implications of land degradation on human welfare following a broad ecosystem services approach. This means therefore that they provide little economic incentives to local farmers and other stakeholders to promote SLM practices (Cohen et al. 2006). Consequently, they have limited applicability in formulation of efficient land use policies to support better land use in SSA countries. Notwithstanding the quantification challenges, land degradation is estimated to lead to crop yields decline of 12 – 80% at the global level (Pimentel et al. 1995, Roose 1996). The recent estimate of economic cost of soil erosion and resultant losses in crop productivity in Kenya, is put at 3.8% of the country's Gross Domestic Product (Cohen et al. 2006). Even with these estimates, can we tell whether people's welfare and environmental conservation are improving with population growth? I addressed this key research question in Chapter 3 through empirical determination of inter-temporal *per capita* economic welfare as suggested by Dasgupta (2001) and Arrow et al. (2004). I also linked changes in the agro-environment to actual application of SLM practices at different scales in Chapters 2-5.

6.2.2 Positioning our findings in the bigger population-environment debate

Our analyses showed that population density doubled and new farming technologies have become more available in Vihiga District in the period 1980—2010, yet there was no strong evidence for a trend towards a general intensification as manifested in low intensity in the use of improved SLM technologies. Instead, in order to cope with population growth and variable rainfall, the local people expanded their farming activities to forested and marginal areas, comparable with previous findings (e.g. Grepperud 1996, Drechsel et al. 2001). Empirical findings presented in this thesis are also in line with those of Crowley and Carter (2000), who found that periodic, sometimes contrary processes may occur simultaneously, disputing the possibility of a uniform intensification process taking place. Results show that despite the rising population density, the constrasting intensification process is attributable more to farm diversity, resource poverty, increasing reliance on non-farm livelihood opportunities and a changing agro-ecosystem. Notwithstanding the rapid population growth, Vihiga farmers manage their farms both more and less intensively in response to this interplay and this may create a heterogeneous pattern of technological effects in land management on spatial and temporal scales (Crowley and Carter 2000).

Whereas I did not expect to replicate the findings of Tiffen et al. (1994) that also investigated population-environment relationships and whose results support the Boserupian claim, I made careful comparison to unravel the role of prevailing unique socio-economic and ecological conditions in Vihiga District. This comparative knowledge can assist in elaborating useful policy lessons for promoting SLM practices in other similar areas in SSA countries, which are likely to experience high population pressure in the coming years. Tiffen et al. (1994) found that population growth coupled with availability of improved technologies and institutional support triggered agricultural intensification in Machakos District of Kenya. Population density and investment capital were identified as interrelated drivers of sustainable, intensive agriculture in Machakos District. When population increased, they argued, local people became more conscious about the deteriorating environmental quality thereby they planted more trees and adopted effective soil conserving options such as terraces (Tiffen and Mortimore 1994). In addition, local innovative and adaptive successes in Machakos perhaps benefited from the strong role played by a supportive policy and institutional environment, such as for example, availability of market opportunities in Nairobi City, infrastructural development and effective community participation (Tiffen et al. 1994).

The lack of broad intensification process in Vihiga District then could be attributed to the largely subsistence-based farming system, which contrasts with the market-oriented system prevalent in the Machakos area (Tiffen and Mortimore 1994, Tiffen et al. 1994). Subsistence production is mostly preferred in Vihiga District perhaps due to market uncertainty and risk averseness among the local farmers as argued in comparable studies (Omamo 1998, Ndufa et al. 2005, Bhandari and Grant 2007). This study found that farmers prioritised own maize production to meet increased food demand, yet poor maize yields and unreliable returns made it difficult for them to invest in soil fertility improvement. In line with the findings by Barbier (2000), low investment in better land management practices in turn limits the productivity effects from available improved technologies. This predicament affects a majority of the farming households who can aptly be described as caught up in a 'maize-centred' poverty trap, consistent with Ndufa et al. (2005). Consequently, agrarian livelihood options have become precarious due to the shrinking *per capita* arable land, low use of improved technologies and poor farm productivity as population doubled during the past 25 years. In particular, this decline indicates a general scarcity of productive resources necessary to improve agricultural productivity, thereby threatening rural agrarian livelihoods. The change in land available per person coupled with low technology use indicates poor agricultural productivity over time. Accordingly, *per capita* food production and farm income drastically declined whereas dependence on extractive forest products increased during the same period.

Our findings in one of the most densely populated rural regions of SSA therefore do not support the generally optimistic outlook advanced by the Boserupian hypothesis (Boserup 1965, Hayami and Ruttan 1985, Ruttan and Thirtle 1989, Tiffen 1993, Tiffen and Mortimore 1994, Tiffen et al. 1994, Mortimore and Harris 2005). Instead, empirical results demonstrate that intensification will not automatically take place at all scales experiencing population increase and that poverty traps could stifle intensification. Achieving wide application of SLM practices in dense and degraded but poor regions of developing countries will remain a major challenge unless there is a drastic change from the traditional approach of addressing land degradation across local, national and global scales (Grepperud 1996, Pender 1998, Drechsel et al. 2001, Knowler 2004, Pender et al. 2006a). This realisation poses important implications on rural livelihood strategies and the prioritisation of resource allocation essential for mediating the provision of key ecosystem services, as discussed in the next section.

6.3 Resource endowment and livelihood strategies—creating synergy for sustainable ecosystem services provision

Sustainable development at any socio-ecological scale is dependent on the quantity and quality of five essential capital assets: natural, human, social, physical and financial capital (Pretty 1999). At the micro-scale, households allocate these capital endowments to various economic activities to attain the best possible welfare standards for their members. The pursued combination of assets and activities determined by the prevailing socio-economic and environmental conditions constitute the main occupation of any given household. This main occupation is referred to as the household's livelihood strategy (Brown et al. 2006). Households have been found to undertake diverse livelihood strategies motivated by various reasons such as diminishing returns from certain activities, complementary returns from distinct activities or imperfect marketing system that make self-production to meet own subsistence needs desirable (Ellis 2000, Barrett et al. 2001b). Despite the accumulating evidence on increasing challenges concerning improvement of farm management and productivity in the densely populated East African highlands (Holden et al. 2004, Tittonell et al. 2005, Vanlauwe et al. 2006, Ngoze et al. 2008), it is not clear whether the main livelihood strategies influence actual implementation of SLM practices aimed at augmenting the productive capacity at the farm level in this region.

It is indisputable that there is a link between persistent land degradation and food insecurity as well as poverty within agrarian economies of SSA (Reardon and Vosti 1995, Nkonya et al. 2009). Past discipline-specific studies have attempted to unravel constraints and alternatives to reduce land degradation by focusing on low use of fertility-replenishing interventions (Ojiem et al. 2004, Kimetu et al. 2008, Shisanya et al. 2009), inherent or induced heterogeneity in farm fertility gradients (Tittonell et al. 2005, Tittonell et al. 2006), and the influence of economic diversity and demographic changes (Crowley and Carter 2000, Drechsel et al. 2001, Brown et al. 2006). Unlike these studies, I adopted a systems approach focused on the main livelihood strategy pursued by the household as a key determinant of actual land management practices at farm level, as proposed by Ellis (1998).

6.3.1 Are livelihood strategies affecting actual application of SLM practices?

This study clearly show that diversification in livelihood strategies poses important implications for the promotion of SLM practices and general agricultural prospects within two main agro-ecosystems of western Kenya. Results in Chapter 2 show that those households that are predominantly off-farm oriented and relatively resource-endowed have surprisingly low SLM related investments, as manifested in low intensity in the use of improved seeds, inorganic fertilisers and manure. Even the fewer SWC measures on their farms are poorly maintained and less effective in controlling soil erosion. This implies that such farm types are unlikely to be keen on implementing SLM practices. A similar trend was found among the resource-poor farmers who also relied on off-farm casual livelihood activities. This findings concur with the regional study by Tittonell et al. (2010), in demonstrating that both the richest and the poorest resource owners are the least likely to invest in SLM practices on their farms. This is because farming is not a priority livelihood activity within the richest households, while as argued by Reardon and Vosti (1995), the poorest do not own necessary resources to invest in better farming practices. Conversely, farming households with medium resources were the most dependent on agriculture and show potential to improve farm productivity through enterprise diversification. Households constituting each of these farm types pursue complementary on-farm and off-farm livelihood strategies with potential to provide necessary synergy to drive better land management and agricultural transformation at the farming system level, as suggested by Barrett et al. (2001b).

Inter-temporal changes in livelihood orientation across different farm types established in this study, reveals an increasing importance of off-farm income over time. As demonstrate in Chapter 2, livelihood strategies have become more distinct based on the kind of off-farm activities to which households allocate their resource endowments. The underlying factor in this shift away from agriculture is likely to be the low returns from farming as compared to other economic activities. This partly explains a general lack of agricultural intensification process propelled by available SLM practices. This study shows that some farm types could be deserting agriculture as indicated by their reduced reliance on farm livelihoods, others are concurrently diversifying in farm and off-farm activities, whereas the majority who constitute poor households, simply practice destitution farming noticeable in low input use and poor yields realised from their farms. In turn, low agricultural returns relate to diminishing land holdings, which constrain the prospects for convincing input intensification. Comparable findings by Jayne et al. (2010) in five countries in eastern and southern Africa demonstrated that small land units limit the application of improved crop technologies. This makes resource-constrained smallholders unable to produce surplus output for meaningful participation in commodity markets (Jayne et al. 2010). The consequence is that many small farming households are unable to escape from poverty and get trapped in a vicious cycle, where poverty leads to further land degradation that exacerbates even more poverty (Barbier 2000, Todaro and Smith 2008).

Findings in this thesis indicate a need to consider an additional aspect of the poverty trap. The poorest farmers have the least possibility to invest in sustainable agricultural productivity, but also the lowest prospect to enhance off-farm incomes by investing in education, business or capital goods. The farm-dependent and poor households are the most likely to experience low returns from agriculture, which in turn may accentuate the negative impacts of land degradation (Barbier 2000, Barrett et al. 2001a, Nkonya et al. 2009). According to KNBS (2010), the study area faces a general resource-poverty but we show that there exists an additional aspect of poverty trap—the 'maize-centred' poverty trap. Agrarian livelihoods could be in jeopardy if the group of farmers faced with 'maize-centred' poverty trap does not receive targeted support from the government to cheaply access adequate inputs such as fertilisers and seeds for them to improve agricultural productivity and break out of the poverty traps, as recently demonstrated in Malawi (Dorward and Chirwa 2011). Equally, there is need to enhance efficiency levels in allocation of the scarce farm resources at their disposal.

6.3.2 What does low efficiency in the allocation of scarce farm resources portend for implementation of SLM practices?

The efficiency level achieved in maize-bean production—a predominant farm activity— was estimated as a key step to understanding how well farmers allocate scarce resources to various livelihood activities in relation to SLM practices (Chapter 2). This is essential in an area where absolute poverty incidence is over 60% and an equal proportion of the population is food insecure during a part of the year (Government of Kenya 2005, Claessens et al. 2008). Besides, inefficient resource allocation may contribute to further insufficient food production. Farmers in the study area preferred to meet their domestic food needs mostly through own production. This is because as argued by Bhandari and Grant (2007), they face either agricultural production risks such as high transaction costs or uncertain commodity prices due to market inefficiencies (Omamo 1998). Inefficient resource allocation may also exacerbate land degradation because farmers, who lack resources to invest in SLM practices to improve farm productivity, are most likely to be trapped in a vicious cycle of poverty-degradation (Reardon and Vosti 1995, Barbier 2000, Todaro and Smith 2008). In inter-temporal perspective, ownership of farm resources—land, livestock (proxy for financial capital) and labour for agriculture—have drastically reduced just under a decade. This study found in particular, worsening availability of land and labour for agricultural activities due to land fragmentation and increased off-farm orientation among most households over time.

Results presented in Chapter 2 (Section 2.3.5) demonstrate that efficiency levels are too low (averaging 40%) and that only little resources are allocated to farming activities in the western highlands of Kenya. Results show that the common maize-bean farming system is a low-input – low-output production system that perpetuates a 'maize-centred' poverty trap. This additional aspect of poverty trap not only constrains actual investment prospects in SLM practices at the farm level but also makes it difficult to shift to a high-value farming system at the regime level. The farming system characterised with increasingly smaller fields could be more economically attractive with the promotion of high-value crops and zero-grazing livestock systems (Ndufa et al. 2005, Berkhout et al. 2011). Nevertheless, to realise a successful shift in the farming system, the process should incorporate deliberate measures with potential to raise sufficiently the efficiency in the predominant maize-bean production system.

6.3.3 Creating synergy for SLM application through efficient allocation of the scarce resources

This study shows that farmers make only limited use of available SLM measures, in spite of the small (and still diminishing) farm sizes and the implementation of several conservation programs in the area during the past decades. Given the scarcity of productive resources, it is essential for farmers to achieve maximum production potential from the little farm resources at their disposal in order to trigger improved farm productivity. To this end, efficiency gains can be harnessed from better use of manure, fertilisers, hybrid seeds, enhanced timing of labour allocation, maintenance of existing SWC measures on farmers' fields and group marketing initiatives (Kamau 2007, Mutoko 2012).

Ultimately, resource constraints would be lessened when incremental efficiency gains are sustained in the predominant maize-bean farming system (Liu 2006, Mutoko et al. 2008). I envisage that improved maize-bean production is a necessary step towards wider application of SLM practices. In the fullness of time, this would facilitate the required shift to high-value, intensified agriculture. The transition process driven by wider application of SLM practices therefore ought to be in harmony with the local dynamics in terms of resource endowment and their efficient allocation to different livelihood activities. This attention is noteworthy if we have to succeed in changing agro-ecosystems that exhibit unique co-evolving socio-economic environment. Moreover, the facilitative role of relevant public policies and institutional support is indispensable in this process.

6.4 Policy and institutional support: effective stakeholder collaboration for technological transition towards sustainable land management

The need for an enabling institutional environment created through enhanced stakeholder collaboration across scales is informed by three main reasons. First, I established that diverse actors are involved in land management programs but lack a common forum for championing directed efforts and that their activities are typically disjointed. In addition, empirical findings from this study show that the level of actual implementation of SLM practices was still too low, consistent with other studies that have pointed to the existence of barriers against rapid transition to sustainable systems (Kemp et al. 2007, Ruben et al. 2007, van der Brugge and van Raak 2007). I have reported in Chapter 5 that the low level of collaboration across the many stakeholders is a limiting factor that contributes to dismal performance of past programs aimed at environmental conservation and increased agricultural productivity in the western highlands of Kenya. This state of affairs calls for systematic collaboration because better-organised and co-operative stakeholders can provide necessary impetus that would accelerate the diffusion of available SLM technologies. Several organisations continue to promote various components of SLM practices in this area. For example, World Agroforestry Centre promotes agro-forestry and improved fallows; Kenya Agricultural Research Institute focusses on integrated organic and inorganic soil fertility replenishment and improved crop varieties; Ministry of Agriculture provides extension services on the establishment of SWC measures, better farm planning and agronomic activities while KFS is engaged in the protection, rehabilitation and co-management of Kakamega forest. In a bid to boost success of these individual efforts, innovative strategies have been applied such as identification of socio-ecological niches to enhance better technological targeting and application of participatory dissemination approaches such as conservation by local committees, farmer field schools and the current catchment approach (Longley et al. 2006, Mureithi et al. 2006, Ojiem et al. 2006, Wanyama et al. 2010). KFS has been implementing a co-management arrangement that incorporates Community Forest Associations in line with the requirements of the current forest policy (Government of Kenya 2007). I suggest however that when these independent efforts are organised in a more directed and synergistic way, the expected impacts are likely to be realised more rapidly and cost-effectively.

Secondly, many local farmers carry out various economic activities in the pursuit of their livelihoods (see Chapter 2). For instance, different rural households make their own independent decisions considering the resources they possess, the likely marketing opportunities and the existing institutional arrangements at the micro scale (Kruseman and Bade 1998). Such individual decisions may contradict with the main objectives set by policy-makers and cumulatively conflict with the desired societal goals at the meso and macro scales. The integrated research approach adopted in this study to analyse various cross-scale interactions between the socio-economic and ecological systems contributes to achieving the main aim of supporting harmonised promotion of SLM practices. Integrated information contained in Chapters 2-5 may be useful to decision-makers at various levels for them to objectively consider alternative suggestions that have promising prospects for the improvement of environmental conservation and rural livelihoods (Bingham et al. 1995). Multi-scale knowledge is also required in development of sound management strategies and land use policies (MA 2003). The new information presented in Chapters 2-5, on the nature of livelihood implications associated with human alterations of ecosystems, existing economic-ecological trade-offs and the magnitude of those impacts across multiple scales is hardly available in developing countries. The generated comprehensive information was previously scanty or at best spread in several disciplinary studies. This thesis also provides practical suggestions on how to structure initial engagement of multiple stakeholders to harmonise livelihood strategies, farm practices and relevant land use policies.

Third, SLM is an approach that aims not only to optimise ecosystem management within the current context but also to effect radical changes that would eventually transform the existing system (Hurni 2000a, Pender et al. 2006b, World Bank 2006a, Cowie et al. 2011). Achieving sustainable land management in the future therefore would entail a socio-ecological transition. Although generally desired, societal transformations—long-term processes that involve drastic changes—are costly. As documented by Loorbach and Rotmans (2010), a transition process requires large resources — financial, human and time — for experimentation of innovative practices and their broad diffusion to reach the desired sustainable levels. Besides, specific households could be willing but incapable of embracing the best sustainable practices due to either poverty traps as already discussed in Chapter 2 or high investment requirements to implement them (van der Brugge and van Raak 2007). Consequently, resource limitations could slow down the transition process thereby requiring enabling policy environment and effective stakeholder networking. For instance, the shift away from the use of hydro-carbons, has been slow because of weak institutional support and high short-term cost of adopting the alternative energy sources (Kemp 1994). While generally in agreement with Loorbach and Rotmans (2010), on the need for transition management, specifically this thesis recognises that strong stakeholder collaboration coupled with smooth synergy across the diverse activities are central to unlocking the process towards wider application of SLM practices in the western highlands of Kenya (see Chapter 5). This is because implementation of SLM practices at wider geographical scales would require additional investments. Organised resource mobilisation involving various stakeholders is therefore indispensable in a region faced with severe scarcity of key capital assets. This recognition justifies the need for deliberate efforts to contribute to enhancing stakeholder collaboration across multiple scales, harmonise diverse activities and synergise individual efforts during future implementation of SLM programs in the study area.

In Chapter 5, I argue that SLM programs are likely to succeed when organised based on informed, participative decision-making and collaborative implementation processes, consistent with the view by Bingham et al. (1995). The diversity of stakeholders involved with SLM activities at different scales requires a more systematic way to harmonise macro-level visions, coordinate meso-level implementation of programs and guide micro-level choices and practices. Some insightful ways of fostering collaboration across multiple stakeholders to scale-up SLM practices are suggested based on presented scientific results. For instance, transforming and strengthening the existing stakeholder groups (farmers' forum and community forest associations) into transition arenas with clear mandate to systematically coordinate efforts and direct activities on scaling-up SLM practices in the western highlands of Kenya. The integrated information contained in this thesis can in general serve as a discussion tool to enlighten and consolidate views on land management among different stakeholders. In particular, empirical findings of this study make specific contribution to the creation of a facilitative policy and institutional environment. For example, better organisation of existing common interest groups into transition arenas will provide them with a strategic agenda and general legitimacy to champion for long-term transformation of the farming and forest systems. In addition, when properly constituted and linked, such transition arenas would enjoy broad support essential in lobbying for favourable policies.

At the public policy level, carefully targeted pro-poor subsidy programs for farm inputs can facilitate the desired shift to productive and profitable farming practices (Dorward and Chirwa 2011, Javdani 2012). Nevertheless, there is need for integration of a holistic systems understanding in such subsidy programs in order to increase agricultural productivity jointly with continued provision of other key ecosystem services (Mhango and Dick 2011). Besides, given the diminishing land sizes, input suppliers may consider to avail fertilisers and seeds in smaller quantities in order to enhance intensity of their use in farm production. Packaging of farm inputs in large quantities has been identified as one of the obstacles to investing in SLM practices in sub-Saharan Africa, where over 80 per cent of farmers are smallholders (Hein and Fileccia 2007). Scaling-up of SLM practices could also benefit from policy intervention aimed at raising awareness among local farmers. This is because well-informed stakeholder groups make better choices that contribute to environmental conservation (van Kempen et al. 2009, Sarkis et al. 2010). Moreover, I recommend cost-effective strategies including increased use of group approaches such as farmer field schools, catchment approach, collective marketing and least-cost farming options to reduce the effect of resource constraints during the scaling-up of SLM practices (Mureithi et al. 2006, Wanyama et al. 2010, Mutoko 2012).

There is need therefore for enabling policy and institutional environment to harness stakeholder synergy to drive the process of scaling-up SLM practices. Transition to wider application of SLM practices is possible only when actors reinforce each other's efforts and direct their activities towards a collective objective of conserving the natural resources and improving local livelihoods. Detailed assessment in Chapter 5 indicates that there is local potential to enhance organisation of the many actors for improved interaction, integration and co-evolution between their activities in a more rapid, efficient and directed way towards scaling-up of SLM practices, in line with the view by Loorbach (2007).

6.5 Reflections on the integrated, multi-scale socio-ecological systems approach

Because of the difficulty to find complete and reliable data on land degradation in many SSA countries, I chose to investigate agricultural productivity effects and livelihood impacts of landscape dynamics through an integrated approach. In this study, people were placed at the centre of the integrated approach in four interlinked ways (see Figure 1-2 in Chapter 1). First, the local people were analysed, using principal components, cluster and stochastic frontier techniques, as decision-makers in allocation of scarce resources at their disposal among different livelihood activities and implementers of improved SLM practices at the farming household level (Chapter 2). Second, at the community level ecosystem services analyses were applied to investigate them as both custodians and beneficiaries of the forest system focussing on conservation-conversion trade-offs and co-management possibilities (Chapter 3). Third, at the landscape level the entire population was assessed as the key driver and vulnerable recipient of negative impacts from landscape dynamics combining remote sensing analysis and dynamic welfare economics (Chapter 4). Finally, I explored how local people as the ultimate holders of solutions to environmental challenges they face, can unlock the SLM technological transition process through collective action and following the transition management approach (Chapter 5). Such people-centred, integrated, socio-ecological systems analyses are rare. This thesis therefore provides comprehensive new knowledge, on how landscape changes have affected livelihoods in densely populated agro-ecosystems and the role played by population changes in shaping the application of SLM practices within the examined socio-ecological systems.

6.5.1 The systems analysis approach

There exists some uncertainties related to the systems approach applied in general and the data analysed in particular (see the first Discussion sections of Chapters 3 and 4). Like all systems analyses, the demarcation of systems boundaries is guided by the main objectives of a given study (see Figure 1-2 in Chapter 1). Even though this arguably is the strength of all systems approaches, it is in my view, ironically a major weakness at the same time. Systems studies aim at providing complete information concerning a particular system of interest, yet these studies are themselves incomplete (Miser and Quade 1997). This is because defining the boundaries of a system of interest understandably excludes other possible key actors, activities and outcomes that the analyst considers external to the system or have only marginal effect on the studied system.

In this study, I only investigated to some degree the influence of off-farm opportunities on rural livelihoods in general and on actual farm practices in particular. Even as I attempted to infer the increasing importance of off-farm livelihood activities in Chapter 2, the focus in this thesis was on how to improve agro-based livelihoods through better application of SLM practices in this rural setting. Yet, results consistently showed that the agro-focussed approach might not be the panacea of the land degradation and poverty challenges in densely populated rural areas. With the benefit of hindsight, I propose an expanded systems analysis that would investigate this phenomenon alongside other localised socio-cultural issues. For instance, delayed transfer of land ownership rights to the younger people was a key socio-cultural issue that featured prominently as I interacted with various stakeholders during fieldwork activities. This explains why the average age of a farmer in Vihiga District as reported in Chapter 2 is over 50 years. What I found (albeit informally as I interacted with the residents and inquired why the average farmer is over 50 years old), was that the elderly are unwilling to grant the youth full land ownership rights. (It could be that the available farms are just too small to sub-divide among the sons). Consequently, most of the youth do not see the incentive to participate actively in farming activities. This is an interesting land tenure related issue I did not investigate in detail but clearly deserves careful research. The caveat is that this problem of a land-attached but aging farming population versus a bourgeoning 'squatting' and rather passive youth is not unique to the study area alone; it is also evident at the national level. Kenya's former president Mwai Kibaki, expressed this increasing national challenge during the ASD Forum (2012) thus: "It is a matter of concern, that the average age of the Kenyan farmer is 60 years, and yet the vast percentage of our population is under 35. The youth are neglecting agriculture in a big way. If this trend continues, the agricultural sector will experience a decline in the years to come and we will continue to struggle with high unemployment." Perhaps Kenyan youth are neglecting farming because they are not given the possibility to do so. Further detailed research in these areas therefore is highly desirable to generate additional information with important implications on the future of Kenyan agriculture in general and the likelihood of embracing broad SLM practices in dense agro-ecosystems in particular.

6.5.2 Diverse data types and analytical techniques

Uncertainties associated with the analysed data emanate mainly from their lack of completeness. The 13 different datasets I analysed created a rich mix of database in a rather data-poor research environment typical of many developing countries, a view shared with Oyake-Ombis (2012). The strength inherent in this study is the development and integrated analyses of a broad database. Nevertheless, I recognise (in Chapter 4) the effect of inherent uncertainties in secondary data especially the agricultural statistics and satellite-derived spatial data I used.

Overcoming this challenge entailed combining and cross-referencing across different data types and sources. In order to generate comprehensive information contained in this thesis, I interactively analysed the following data types:

1) Cross-sectional data collected from 236 farmers, 240 forest-adjacent households and 209 tourists who visited Kakamega National Forest Park. These formed the bulk of primary data I judiciously collected for this study.
2) Time-series data including 18-year agricultural statistics (area, output, yields), 20-year produce prices, 20-year inflation indexes, 30-year climatic data (precipitation, evaporation, temperature) and 30-year demographic data (population, population density). I sourced these data from various government offices complemented with online databases.
3) Spatial data spanning a 25-year period, derived from four Landsat satellite images and fine resolution aerial photos for validation, which I purchased from the Regional Centre for Mapping Resources for Development (RCMRD), Nairobi, supplemented with online downloads.
4) Participatory data I gathered during stakeholder workshops, three focus group discussions and survey of 10 key informants.

Apart from the constant cross-referencing across the different data types, the integrated analyses I applied also contributed in minimising the likely negative effect of the uncertainties on the general findings generated by this study. The main motivation for carrying out this study—as reviewed and recognised in Chapter 1—was the puzzlingly low and localised implementation of available SLM practices despite the urgent need to reduce both land degradation and general poverty levels in the study area. This study therefore aimed to not only answer the important question—why has geographical diffusion of SLM practices been restricted—but also make concrete contributions to foster the promotion of SLM practices. Clearly, this thesis contributes to the process of scaling-up SLM practices by augmenting knowledge about complex dynamics of the socio-economic and ecological systems at multiple levels. Besides, new insights are generated relating to the prospects for promoting SLM practices as they cascade from the farm level to the landscape scale (Paré et al. 2008). To this end, various analytical techniques were applied to achieve the specific objectives and to answer the research questions specified in the Chapter 1 (Section 1.2).

To analyse farm diversity and resource use efficiency of different farm types and their implications for SLM practices in the western highlands of Kenya (objective 1), principal component and cluster analyses were applied sequentially to classify households into near-homogenous groups, in order to identify those to target best with SLM practices. In addition, stochastic frontier analysis was used to estimate efficiency levels of each farmer and identify significant factors including key SLM practices that have the greatest potential to improve farm productivity. These farm-level and farming system results are contained in Chapter 2.

To estimate local economic benefits of key ecosystem services provided by the Kakamega rainforest and examine how the information can support sustainable forest management in Kenya (objective 2), ecosystem services analyses focussed on the forest system and neighbouring community. Specific analytical techniques included travel cost method, cost-benefit analysis and management assessment. These analyses were applied to unravel trade-offs and conflicts around the management and utilisation of the unique Kakamega rainforest ecosystem, which faces constant threat of deforestation with rising population pressure on land. The intriguing findings are provided in Chapter 3 of this thesis.

On a long temporal scale and at the landscape level, I analysed trends of land-use changes and their impacts on agrarian livelihoods in the western highlands of Kenya (objective 3). To achieve this objective, integrated remote sensing and trend analyses were applied to track land use changes, key drivers and implications of these broad dynamics on land management and agrarian livelihoods in the study area. Trend analysis was important in determining whether—with the evidence generated from analyses done in Chapters 2-3 and controlling for demographic and climatic changes—rural agro-based welfare was improving or not. Detailed, integrated findings from these analyses are presented in Chapter 4 of this thesis.

Finally, assessment of the prospects for fostering a transition towards sustainable land management through enhanced multi-actor, multi-scale collaboration in the western highlands of Kenya (objective 4), was achieved through transition management analysis. Cross-scale assessment was based on an adapted multi-level framework that facilitated a systematic evaluation of the local prospects to trigger a technological transition process. Complemented with targeted stakeholder analysis, special analytical emphasis was given to the potential for purposeful co-operation of local stakeholders as a decisive cog in the transition wheel. This transition analysis was enriched with extended economic-ecological conceptual modelling to demonstrate possible strategies needed to boost investment in SLM programs in order to initiate the desired transition process. This futuristic information is provided in Chapter 5 as a broad synthesis of new evidence from all analyses.

6.5.3 Back to a beginning: setting stage for future research

Despite the highlighted uncertainties, I applied the integrated, multi-scale socio-ecological systems approach properly and elaborately analysed the diverse types of data to generate new comprehensive information presented in this thesis. Interesting insights from this information have been drawn, which I consider vital for the promotion of SLM practices in the western highlands of Kenya and other similar parts of sub-Saharan Africa. However, I recommend for further research to extend frontiers of knowledge in this area. For example, we need to know what the interplay between increasing importance of off-farm livelihood activities, high pressure on land around the only rainforest in Kenya and low participation in agriculture of a largely unemployed youth, portends for the future of agrarian livelihoods in general and land management in particular.

Moreover, I make a modest attempt to address the lingering question in a many empirical studies: Now that we have the new evidence, so what are the possible workable solutions relevant for future practice and policy? While agreeing with Sardar (2010) that the future of human behaviour is uncertain to forecast, I have suggested—based on the evidence presented in this thesis—several ways to harness potential opportunities to improve the implementation of SLM practices and maximise technological impacts on rural livelihoods. The testing of key recommendations from my research was however beyond the scope of this study. Hence, there is both empirical and pragmatic motivation for further studies to establish whether the radical proposal I have advanced to apply a context-specific transition management approach co-joined with off-farm livelihood strategies, could provide the much-needed synergy. This recommendation has practical implications for the design and possible success of future SLM programs that also may require empirical investigation. I strongly believe that the implementation of this broad approach will harness collective action and unlock local potential to overcome, in a sustainable manner, the growing intertwined challenges of land degradation and poverty. Ultimately, this is my passionate desire: to contribute to the realisation of sustainable landscapes and better livelihoods within this and other similar socio-ecological systems.

6.6 Conclusions

Making informed decisions about sustainable management of dynamic and heterogeneous land use systems of SSA, requires comprehensive knowledge on key interactions and feedback effects across multiple scales. Successful promotion of SLM practices in particular, requires a better understanding of land use system, its spatial variability and temporal dynamics, and the impacts on agrarian livelihoods. Moreover, effective policies are likely to be formulated when we understand the drivers of land use change, key trade-offs from competing land uses and *per capita* availability of productive resources over time. I tested an integrated, multi-scale and inter-disciplinary systems analysis, combining ecological, socio-economic and institutional processes into one interlinked framework. This approach aimed to generate empirical information to answer four main research questions that guided this study in the western highlands of Kenya. They include: 1) how does livelihood diversity and farm production efficiency influence agricultural productivity and farmers' likelihood to implement SLM practices? 2) Are the local economic benefits from ecosystem services provided by the Kakamega rainforest sufficient to support sustainable forest management? 3) What are the implications of land-use dynamics and population growth on agrarian livelihoods in a changing agro-environment? 4) How can multi-level stakeholders be organised and their diverse interests harmonised to promote wide-scale application of SLM practices?

On the first research question, this study found that livelihood strategies are very dynamic in response to changing socio-economic, demographic and environmental conditions and that farm production efficiency is low. Farm capital assets are becoming scarcer and livelihood choices are less focussed on agriculture as the mainstay of rural economies. Rural households are either deserting agriculture, diversifying in on-farm and off-farm activities, or simply trapped in destitute farming practices. Results indicate that actual application of SLM practices varied across farm types, with off-farm oriented and resource-strapped households the least adopters. The significant effect of manure application on efficiency in maize-bean production indicates the need for better livestock-crop integration in the farming system to foster SLM practices.

On the second research question, this study showed that local economic benefits were insufficient to support sustainable conservation of the Kakamega rainforest without carefully crafted funding arrangements such as payment system for the globally beneficial ecosystem services (i.e. biodiversity conservation and carbon storage). Besides, the growing dependency on extractive forest products is threatening the conservation of this only remaining rainforest in Kenya. There is urgent need therefore for provision of alternative economically beneficial opportunities to the forest-adjacent community to create incentives for their active co-management of the forest.

Empirical evidence to answer the third research question indicates that arable land is increasingly fragmented and the expansionist strategy to increase agricultural output from bare areas is no longer feasible as open spaces are already overstretched. Most strikingly, this study established that even with the increasing population density and availability of improved SLM technologies promoted by various agencies, a process of intensification has not yet taken place in the study area. Instead, faced with diminishing farm sizes and worsening agrarian livelihoods, most households allocate their scarce resources more to off-farm economic activities than to the implementation of SLM practices on their farms. This study reveals failure with expected technology-driven intensification despite continuous efforts and the increasing importance of off-farm income in the wake of shrinking *per capita* land availability.

The fourth research question was addressed through a novel application of an adapted multi-level framework of transition management and theoretical modelling. Results showed that reasonable local conditions existed to create effective transition arenas to govern the desired technological shift. The application of a contextualised multi-level framework accompanied with creative resource mobilisation and pro-poor agricultural subsidisation programs, would spur technology adoption and wider scaling-up of SLM practices. Hence, these findings emphasise the need for a drastic change in the approach of addressing the twin challenges of land degradation and rural poverty in similar SSA agro-ecosystems.

To conclude, the difficulty with achieving wider geographical diffusion of SLM practices in the western highlands of Kenya can be explained in four ways. First, there is a practical challenge in properly targeting the technologies to the right rural farming households to realise the greatest, visible impacts. Second, the common shrinkage of farm resources coupled with low efficiencies as they are allocated in agricultural production has created an additional aspect of poverty traps—a 'maize-centred' poverty trap, which makes it difficult for a majority of farmers to invest meaningfully in SLM practices. Third, the increasing population pressure on land may not necessarily lead to better land management and efficient resource use in agriculture, within environments where the community can attempt to make for the shortfall by accessing 'free' public natural resources and or off-farm income sources. Finally, the low collaboration level across diverse stakeholders involved in the promotion of various components of SLM practices indicates a thin spread of efforts on the ground and unexpectedly delays an accelerated technological transition process.

In order to enhance the application of SLM practices in the western highlands of Kenya, policy options include checking further land sub-division by determining an enforceable minimum acreage, preventing forest encroachment through enhanced co-management with the forest-adjacent community and expansion of off-farm income opportunities, such as informal business enterprises and formal employment facilitated with the devolved funds. Given the interrelatedness of land-use and other income generating activities, findings in this thesis suggest a need for a broader, integrated and multi-stakeholder approach to solving the problem of land degradation in SSA. Policies and programs aimed at promoting SLM practices in similar regions of SSA are likely to succeed if they manage to target areas that are highly dependent on agriculture and within these areas to reach households mostly reliant on farming to sustain their livelihoods. Even then, improvement within those households whose livelihoods still rely mostly on farming may require the promotion of innovative and commercialised agriculture, attractive to the youth and which breaks away from the unsustainable low input-low output subsistence system. In addition, there is an equal need for creation of off-farm income opportunities to ease population pressure on land and reduce over-reliance on forest resources in such areas.

Summarising, this thesis provides new insights and non-conventional suggestions for promoting sustainable land management. They include enhanced targeting of promising SLM technologies to farm-dependent households to bolster technological impacts and improved efficiency in maize-bean production to shift gradually the farming system to high-value crop and livestock enterprises. Other recommendations are encouraging the relocation of population relying on the small farms through off-farm opportunities facilitated by deliberate infrastructural development and structured co-management of the forest with the local community for multiple uses accompanied with alternative gainful economic activities to resolve the real conservation-conversion conflict around this resource. Most importantly, there is need to strengthen local institutional environment through effective stakeholder collaboration and systematic organisation of cross-scale SLM related activities. Finally, for practice I suggest coupling the application of a contextualised multi-level framework of transition management with joint resource mobilisation and carefully targeted agricultural subsidisation programs. This will not only initiate and direct the scaling-up of SLM practices but also spur technology adoption and expedite the transition process. Such a practical, collective transition management process would provide useful learning lessons on effective governance of transformative environmental programs for other similar agro-ecosystems in sub-Saharan Africa.

References

Abukutsa-Onyango, M. O. 2009. Development and promotion of technologies for sustainable production and utilization of indigenous vegetables for nutrition security and wealth creation in Kenya. African Technology Policy Studies Network, Nairobi.

Adamowicz, W. J., J. Louviere, and M. Williams. 1994. Combining revealed and stated preference methods for valuing environmental amenities. J. Environ. Econ. Manag. 26:271.

Angelsen, A., M. Brockhaus, W. D. Sunderlin, and L. V. Verchot, editors. 2012. Analysing REDD+: Challenges and choices. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Ansink, E. J. H., L. G. Hein, and K. P. Hasund. 2008. To value functions or services? An analysis of ecosystem valuation approaches. Environmental Values 17:489 - 503.

Arrow, K., P. Dasgupta, L. Goulder, G. Daily, P. Ehrlich, G. Heal, L. Simon, K.-G. Maler, S. Schneider, D. Starrett, and B. Walker. 2004. Are we consuming too much? The Journal of Economic Perspectives 18:147-172.

ASD Forum. 2012. Official Opening of the 3rd Agricultural Sector Development Forum. ASD Forum Today. ASCU, Nairobi.

Ayres, R., B. Castaneda, C. J. Cleveland, R. Costanza, H. Daly, C. Folke, B. Hannon, J. Harris, R. Kaufmann, X. Lin, R. Norgaard, M. Ruth, D. Spreng, D. I. Stern, C. Jeroen, and J. M. van den Bergh. 1997. Natural Capital, Human Capital, and Sustainable Economic Growth. Centre for Energy and Environmental Studies, Boston.

Bakker, M. M., and A. M. van Doorn. 2009. Farmer-specific relationships between land use change and landscape factors: Introducing agents in empirical land use modelling. Land Use Policy 26:809-817.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and R. K. Turner. 2002. Economic reasons for conserving wild nature. Science 297:950-953.

Banadda, N. 2010. Gaps, barriers and bottlenecks to sustainable land management (SLM) adoption in Uganda. African Journal of Agricultural Research 5:3571-3580.

Barbier, B. 1998. Induced innovation and land degradation: Results from a bioeconomic model of a village in West Africa. Agricultural Economics 19: 15-25.

Barbier, E. B. 2000. The economic linkages between rural poverty and land degradation: some evidence from Africa. Agriculture, Ecosystems and Environment 82:355-370.

Barbier, E. B., and A. Markandya. 1990. The conditions for achieving environmentally sustainable development. European Economic Review 34:659-669.

Barrett, C. B., M. Bezuneh, and A. Aboud. 2001a. Income diversification, poverty traps and policy shocks in Coˆte d'Ivoire and Kenya. Food Policy 26:367-384.

Barrett, C. B., T. Reardon, and P. Webb. 2001b. Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics and policy implications. Food Policy 26: 315-331.

Bationo, A., editor. 2004. Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Academy Science Publishers, Nairobi.

Bationo, A., and A. Buerkert. 2001. Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. Nutrient Cycling in Agroecosystems 61:131-142.

Benhin, J., and R. Hassan. 2008. A dynamic analysis of trade and biodiversity loss in semi-arid Southern Africa: The role of grazing activities. International Journal of Ecological Economics and Statistics 11:31-48.

Berkhout, E. D., R. A. Schipper, H. Van Keulen, and O. Coulibaly. 2011. Heterogeneity in farmers' production decisions and its impact on soil nutrient use: Results and implications from northern Nigeria. Agricultural Systems 104:63-74.

Bhandari, B. S., and M. Grant. 2007. Analysis of livelihood security: A case study in the Kali-Khola watershed of Nepal. Journal of Environmental Management 85:17-26.
Bingham, G., R. Bishop, M. Brody, D. Bromley, E. Clark, W. Cooper, R. Costanza, T. Hale, G. Hayden, S. Kellert, R. Norgaard, B. Norton, J. Payne, C. Russell, and G. Suter. 1995. Issues in ecosystem valuation: Improving information for decision making. Ecological Economics 14:73-90.
Biondini, M., and P. Kandus. 2006. Transition matrix analysis of land-cover change in the Accretion area of the Lower Delta of the Parana River (Argentina) reveals two succession pathways Wetlands 26:981-991.
Bockstael, N. E., A. M. Freeman, R. J. Kopp, P. Portney, and V. K. Smith. 2000. On measuring economic values for nature. Environ. Sci. Technol. 32:1384.
Bonilla-Moheno, M., D. J. Redo, T. M. Aide, M. L. Clark, and H. R. Grau. 2013. Vegetation change and land tenure in Mexico: A country-wide analysis. Land Use Policy 30:355-364.
Boserup, E. 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure. Allen and Unwin, London.
Boserup, E. 1974. Environment, Population and Technology in Primitive Societies. Annales-Economies Societes Civilisations 29:538-552.
Boserup, E. 1989. Population, the status of women, and rural development. Population and Development Review 15:45-60.
Boserup, E. 1992. Resources, Environment and Population - Present Knowledge, Future-Options - Davis,K, Bernstam,M. European Journal of Population-Revue Europeenne De Demographie 8:389-391.
Bouma, J. 1997. The land use systems approach to planning sustainable land management at several scales. ITC Journal Enschede 3/4:237-242.
Brander, L., E. Gómez-Baggethun, B. Martín-López, and M. Verma. 2010. The economics of valuing ecosystem services and biodiversity. TEEB-The Economics of Ecosystems and Biodiversity.
Brown, D. R., E. C. Stephens, J. O. Ouma, F. M. Murithi, and C. B. Barrette. 2006. Livelihood strategies in the rural Kenyan highlands. Sustainable Livelihoods and Ecosystem Health: Informing Policy, Practice and Research. University of Guelph, Ontario.
Bulte, E. H., M. Joenje, and H. G. P. Jansen. 2000. Is there too much or too little natural forest in the Atlantic zone of Costa Rica? . Canadian Journal of Forest Resources 39:495-506.
Campbell, D. J., D. P. Lusch, T. Smucker, and E. E. Wangui. 2003. Root causes of land Use change in Loitoktok area, Kajiado District Kenya. Land Use Changeand Use, Impacts and Dynamics Project. Working Paper No. 9. International Livestock Research Institute, Nairobi.
Castella, J.-C. 2009. Assessing the role of learning devices and geovisualisation tools for collective action in natural resource management: Experiences from Vietnam. Journal of Environmental Management 90:1313-1319.
Castella, J.-C., S. Pheng Kam, D. Dinh Quang, P. H. Verburg, and C. Thai Hoanh. 2007. Combining top-down and bottom-up modelling approaches of land use/cover change to support public policies: Application to sustainable management of natural resources in northern Vietnam. Land Use Policy 24:531-545.
Cho, S.-H., S. G. Kim, and R. K. Roberts. 2011. Values of environmental landscape amenities during the 2000–2006 real estate boom and subsequent 2008 recession. Journal of Environmental Planning and Management 54:71-91.
CIA. 2012. CIA World Factbook: People and Society, Population Growth rate. Central Intelligence Agency, Washington, D.C.
Cihlar, J., and L. J. M. Jansen. 2001. From land cover to land use: A methodology for efficient land use mapping over large areas. The Professional Geographer 53:275-289.
Claessens, L., J. J. Stoorvogel, and J. M. Antle. 2008. Ex ante assessment of dual-purpose sweet potato in the crop-livestock system of western Kenya: A minimum-data approach. Agricultural Systems 99:13-22.

Clark, D. A., S. Brown, D. W. Kicklighter, J. Q. Chambers, J. R. Thomlinson, J. Ni, and E. A. Holland. 2001. Net primary production in tropical forests: An evaluation and synthesis of existing field data. Ecological Applications 11:371-384.
Clover, J. 2003. Food security in Sub-Saharan Africa. African Security Review 12:5-15.
Coelli, T. 2006. A guide to FRONTIER version 4.1: A computer program for stochastic frontier production and cost function estimation. Centre for Efficiency and Productivity Analysis. CEPA Working paper No.96/07. University of New England, Armidale.
Cohen, M. J., M. T. Brown, and K. D. Shepherd. 2006. Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. Agriculture, Ecosystems and Environment 114:249-269.
Cohen, M. J., K. D. Shepherd, and M. G. Walsh. 2005. Empirical reformulation of the universal soil loss equation for erosion risk assessment in a tropical watershed Geoderma. 124 235-252.
Collados, C., and T. P. Duane. 1999. Natural capital and quality of life: a model for evaluating the sustainability of alternative regional development paths. Ecological Economics 30:441-460.
Cowie, A. L., T. D. Penman, L. Gorissen, M. D. Winslow, J. Lehmann, T. D. Tyrrell, S. Twomlow, A. Wilkes, R. Lal, J. W. Jones, A. Paulsch, K. Kellner, and M. Akhtar-Schuster. 2011. Towards Sustainable Land Management in the Drylands: Scientific Connections in Monitoring and Assessing Dryland Degradation, Climate Change and Biodiversity. Land Degradation & Development 22:248-260.
Crowley, E., and S. Carter. 2000. Agrarian change and the changing relationships between toil and soil in Maragoli, western Kenya (1900–1994). Human Ecology 28:383-414.
Daily, G. C., S. Polasky, J. Goldstein, P. M. Kareiva, H. A. Mooney, L. Pejchar, T. H. Ricketts, J. Salzman, and R. Shallenberger. 2009. Ecosystem services in decision making: time to deliver. Frontiers in Ecology and the Environment 7:21-28.
Daily, G. C., T. Sderqvist, S. Aniyar, K. Arrow, and P. Dasgupta. 2000. The value of nature and the nature of value. Science 289:395.
Daly, H. E. 1994. Fostering environmentally sustainable development: four parting suggestions for the World Bank. Ecological Economics 10:183-187.
Dasgupta, P. 2001. On Population and Resources: Reply. Population and Development Review 27:748-754.
Davidson, R., and J. G. MacKinnon. 1993. Estimation and Inference in Econometrics. Oxford University Press, Oxford.
de Jager, A., I. Kariuku, F. M. Matiri, M. Odendo, and J. M. Wanyama. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) IV. Linking nutrient balances and economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment 71:81-92.
Debertin, D. L. 1986. Agricultural Production Economics. Macmillan Publishing, New York.
Dorward, A., and E. Chirwa. 2011. The Malawi agricultural input subsidy programme: 2005/06 to 2008/09. International Journal of Agricultural Sustainability 9:232-247.
Drechsel, P., L. Gyiele, D. Kunze, and O. Cofie. 2001. Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. Ecological Economics 38:251-258.
Dumanski, J. 1994. Proceedings of the International Workshop on Sustainable Land Management for the 21st Century: Workshop Summary. The Organising Committee, Agricultural Institute of Canada, Ottawa.
Dumanski, J., W. W. Pettapiece, and R. J. McGregor. 1998. Relevance of scale dependent approaches for integrating biophysical and socio-economic information and development of agroecological indicators. Nutrient Cycling in Agroecosystems 50:13-22.
Ellis, F. 1993. Peasant Economics: Farm Households and Agrarian Development. Second edition. Cambridge University Press, Cambridge.
Ellis, F. 1998. Household strategies and rural livelihood diversification. Journal of Development Studies 35:1-38.
Ellis, F. 2000. Rural livelihoods and diversity in developing countries. Oxford University Press, Oxford.

Engel, S., S. Pagiola, and S. Wunder. 2008. Designing payments for environmental services in theory and practice: An overview of the issues. Ecological Economics 65:663-674.
Eweg, H. P. A., R. Van Lammeren, H. Deurloo, and Z. Woldu. 1998. Analysing degradation and rehabilitation for sustainable land management in the highlands of Ethiopia. Land Degradation and Development 9:529-542.
FAOSTAT. 2012. Food and Agricultural Organization (FAO) Statistics Division. FAO, Rome.
Farley, J., A. Aquino, A. Daniels, A. Moulaert, D. Lee, and A. Krause. 2010. Global mechanisms for sustaining and enhancing PES schemes. Ecological Economics 69:2075-2084.
Fashing, P., A. Forrestel, C. Scully, and M. Cords. 2004. Long-term tree population dynamics and their implications for the conservation of the Kakamega Forest, Kenya. Biodiversity and Conservation 13:753-771.
Fernandes, L. A. O., and P. J. Woodhouse. 2008. Family farm sustainability in southern Brazil: An application of agri-environmental indicators. Ecological Economics 66:243-257.
Fisher, B., K. Turner, M. Zylstra, R. Brouwer, R. d. Groot, S. Farber, P. Ferraro, R. Green, D. Hadley, J. Harlow, P. Jefferiss, C. Kirkby, P. Morling, S. Mowatt, R. Naidoo, J. Paavola, B. Strassburg, D. Yu, and A. Balmford. 2008. Ecosystem services and economic theory: Integration for policy-relevant research. Ecological Applications 18:2050-2067.
Fisher, B., and K. R. Turner. 2008. Ecosystem services: Classification for valuation. Biological Conservation 141:1167-1169.
Foody, G. M. 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment 80:185- 201.
Frantzeskaki, N., D. Loorbach, and J. Kooiman. 2009. Transitions governance: Towards a new governance paradigm. Pages 1-16 13th Annual Conference of the International Research Society for Public Management (IRSPM XIII), Copenhagen Business School, Copenhagen, Denmark.
Freeman, A. M. 1991. Valuing environmental resources under alternative management regimes. Ecological Economics 3:247-256.
Garedew, E., M. Sandewall, U. Söderberg, and B. Campbell. 2009. Land-use and land-cover dynamics in the Central Rift Valley of Ethiopia. Environmental Management 44:683-694.
Geist, H. J., and E. F. Lambin. 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience 52:143-150.
Giller, K. E., P. Tittonell, M. C. Rufino, M. T. van Wijk, S. Zingore, P. Mapfumo, S. Adjei-Nsiah, M. Herrero, R. Chikowo, M. Corbeels, E. C. Rowe, F. Baijukya, A. Mwijage, J. Smith, E. Yeboah, W. J. van der Burg, O. M. Sanogo, M. Misiko, N. de Ridder, S. Karanja, C. Kaizzi, J. K'Ungu, M. Mwale, D. Nwaga, C. Pacini, and B. Vanlauwe. 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems 104:191-203.
Giller, K. E., E. Witter, M. Corbeels, and P. Tittonell. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114:23-34.
Glenday, J. 2006. Carbon storage and emissions offset potential in an East African tropical rainforest. Forest Ecology and Management 235:72-83.
Government of Kenya. 2004. State of the Enviroment Report: Vihiga District. National Environmental Management Authority (NEMA), Nairobi.
Government of Kenya. 2005. Vihiga District Strategic Plan 2005 - 2010 for Implementation of the National Population Policy for Sustainable Development. Page 55. National Coordination Agency for Population and Development, Nairobi.
Government of Kenya. 2009. Annual Report for Extension and Research Liaison and Technical Training (ERLTT) Department for Emuhaya District.*in* Extension and Research Liaison and Technical Training, editor. Ministry of Agriculture, Emuhaya.
Government of Kenya. 2010. Annual Agricultural Reports for Vihiga, Hamisi and Emuhaya Districts, Kenya. Ministry of Agriculture, Mbale.

Government of Kenya. 2005. The Forests Act, 2005 No. 7 of 2005.*in* Kenya Gazette Supplement Acts, editor. The Government Printer, Nairobi.
Government of Kenya. 2007. Sessional Paper No. 1 of 2007 on Forest Policy.*in* Ministry of Environment and Natural Resources, editor. The Government Printer, Nairobi.
Grepperud, S. 1996. Population pressure and land degradation: the case of Ethiopia. Environmental Economics and Management 30:18-33.
Grimble, R., and K. Wellard. 1997. Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. Agricultural Systems 55:173-193.
Gunderson, L. H., and C. S. Holling, editors. 2002. Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington DC.
Guthiga, P. M. 2007. Economic Assessment of Different Management Approaches of Kakamega Forest in Kenya: Cost-benefit and Local Community Satisfaction Analysis. Rheinische Friedrich-Wilhelms-Universität, Bonn.
Guto, S. N. 2011. Chakula bila kulima? Trade-offs concerning soil and water conservation in heterogenous smallholder farms of Central Kenya. Wageningen University, Wageningen.
Haab, T. C., and K. E. McConnell. 2003. Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation. Edward Elgar, Cheltenham.
Haines-Young, R., and M. Potschin. 2011. Common International Classification of Ecosystem Services (CICES): 2011 Update. Paper prepared for discussion at the expert meeting on ecosystem accounts organised by the UNSD, the EEA and the World Bank, London, December 2011. European Environment Agency, Copenhagen.
Hamilton, K., and J. A. Dixon. 2003. Measuring the wealth of nations. Environmental Monitoring and Assessment 86:75-89.
Hamilton, K., and G. Ruta. 2009. Wealth accounting, exhaustible resources and social welfare. Environmental and resource economics 42:53-64.
Hanley, N., and C. L. Spash. 1993. Cost-Benefit Analysis and the Environment. Edward Elgar Publishing Ltd, Cheltenham.
Hassan, R. M. 2003. Measuring asset values and flow benefits of non-traded products and ecosystems services of forest and woodland resources in South Africa. Environment, Development and Sustainability 5:403-418.
Hayami, Y., and V. W. Ruttan. 1985. Agricultural Development: An International Perspective. Johns Hopkins University Press, Baltimore.
Hein, L. 2011. Economic benefits generated by protected areas: the case of Hoge Veluwe Forest, the Netherlands. Ecology and Society 16:13.
Hein, L., and T. Fileccia. 2007. Assessment of the barriers and bottlenecks to scaling up Sustainable Land Management investments throughout Sub-Saharan Africa. Technical support Document 2007. FAO, Rome.
Hein, L., D. C. Miller, and R. de Groot. 2013. Payments for ecosystem services and the financing of global biodiversity conservation. Current Opinion in Environmental Sustainability 5:87–93.
Hein, L., and E. van Ierland. 2006. Efficient and sustainable management of complex forest ecosystems. Ecological Modelling 190:351–366.
Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57:209-228.
Hietel, E., R. Waldhardt, and A. Otte. 2007. Statistical modeling of land-cover changes based on key socio-economic indicators. Ecological Economics 62:496-507.
Holden, S., C. B. Barrett, and F. Hagos. 2006. Food-for-work for poverty reduction and the promotion of sustainable land use: can it work? Environment and Development Economics 11:15-38.
Holden, S., B. Shiferaw, and J. Pender. 2004. Non-farm income, household welfare, and sustainable land management in a less-favoured area in the Ethiopian highlands. Food Policy 29:369-392.
Hurni, H. 1999. Sustainable Management of Natural Resources in African and Asian Mountains. Ambio 28:382-389.

Hurni, H. 2000a. Assessing sustainable land management (SLM). Agriculture, Ecosystems and Environment 81:83-92.
Hurni, H. 2000b. Soil conservation policies and sustainable land management: A global overview. Pages 19-30 Soil and Water Conservation Policies and Programs: Successes and Failures. CRC Press, Boca Raton.
Hurni, H., K. Tato, and G. Zeleke. 2005. The Implications of Changes in Population, Land Use, and Land Management for Surface Runoff in the Upper Nile Basin Area of Ethiopia. Mountain Research and Development 25:147-154.
IIRR. 2000. Going to scale: can we bring more benefits to more people more quickly? International Institute for Rural Reconstruction, Silang.
ILRI. 2007. GIS Services by Geographic Locations: Kenya. International Livestock Research Institute (ILRI), Nairobi.
Jaetzold, R., H. Schmidt, B. Hornetz, and C. Shisanya. 2007. Farm Management Handbook of Kenya Vol II: Natural Conditions and Farm Management Information, Part B, Western Kenya. 2 edition. Ministry of Agriculture, Nairobi.
Jahnke, H. E. 1982. Livestock Production Systems and Livestock Development in Tropical Africa. Kieler Wissenschaftsverlag Vauk, Kiel.
Jama, B., J. Mutegi, and A. Njui. 2008. Potential of improved fallows to increase household and regional fuelwood supply: evidence from western Kenya. Agroforestry Systems 73:155-166.
Javdani, M. 2012. Malawi's agricultural input subsidy: study of a Green Revolution-style strategy for food security. International Journal of Agricultural Sustainability 10:150-163.
Jayne, T. S., D. Mather, and E. Mghenyi. 2010. Principal challenges confronting smallholder agriculture in Sub-Saharan Africa. World Development 38:1384-1398.
Jellema, A., D.-J. Stobbelaar, J. C. J. Groot, and W. A. H. Rossing. 2009. Landscape character assessment using region growing techniques in geographical information systems. Journal of Environmental Management 90:161-174.
Kamau, M. 2007. Farm household allocative efficiency: A multi-dimensional perspective on labour use in western Kenya. PhD thesis. Wageningen University, Wageningen.
Kashaigili, J. J., and A. M. Majaliwa. 2010. Integrated assessment of land use and cover changes in the Malagarasi river catchment in Tanzania. Physics and Chemistry of the Earth, Parts A/B/C 35:730-741.
Kemp, R. 1994. Technology and the transition to environmental sustainability: The problem of technological regime shifts. Futures 26:1023-1046.
Kemp, R., J. Rotmans, and D. Loorbach. 2007. Assessing the Dutch Energy Transition Policy: How Does it Deal with Dilemmas of Managing Transitions? Journal of Environmental Policy and Planning 9:315-331.
KFE. 2012. Kakamega Forest Ecosystem Management Plan 2010-2020. KFS and KWS, Kakamega.
Kimetu, M., J. Lehmann, S. Ngoze, D. N. Mugendi, J. Kinyangi, S. Riha, L. Verchot, W. Recha, and A. Pell. 2008. Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. Ecosystems 11:726-739.
King, D., M, and M. Mazzota, J. 2000. Ecosystem Valuation. U.S. Department of Agriculture, Natural Resources Conservation Service and National Oceanographic and Atmospheric Administration, Washington D.C.
Kline, J. D. 2003. Characterizing land use change in multidisciplinary landscape-level analyses. Agricultural and Resource Economics Review 32:103-115.
Kling, C. 1997. The gains from combining travel cost and contingent valuation data to value nonmarket goods. Land Economics 73:428.
KNBS. 2010. 2009 Kenya Population and Housing Census. Population Distribution by Administrative Units. Page 217. Kenya National Bureau of Statistics (KNBS), Nairobi.
KNBS. 2012. Consumer Price Index: Monthly Inflation. Government of Kenya, Nairobi.

Knowler, D. J. 2004. The economics of soil productivity: local, national and global perspectives. Land Degradation and Development 15:543-561.
Koomen, E., J. Stillwell, A. Bakema, and H. J. Scholten. 2008. Modelling land-use change: progress and applications. Springer, Dordrecht.
Kruseman, G., and J. Bade. 1998. Agrarian policies for sustainable land use: bio-economic modelling to assess the effectiveness of policy instruments. Agricultural Systems 58:465-481.
KWS. 2012. Kakamega Forest National Reserve: "Canopy of Natural Beauty". Kenya Wildlife Service, Nairobi.
Lambin, E. F. 2012. Global land availability: Malthus versus Ricardo. Global Food Security 1:83-87.
Lambin, E. F., H. J. Geist, and E. Lepers. 2003. Dynamics of land-use and land -cover change in tropical regions. Annual Review of Environment and Resources 28:205-241.
Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skånes, W. Steffen, G. D. Stone, U. Svedin, T. A. Veldkamp, C. Vogel, and J. Xu. 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11:261-269.
Lee, R. D. 1986. Malthus and Boserup: a dynamic synthesis. Pages 96-130 *in* D. Coleman and R. Schofield, editors. The State of Population Theory: Forward from Malthus. Basil Blackwell, Oxford.
Lefroy, R. D. B., H.-D. Bechstedt, and M. Rais. 2000. Indicators for sustainable land management based on farmer surveys in Vietnam, Indonesia, and Thailand. Agriculture, Ecosystems & Environment 81:137-146.
Lillesand, T. M., R. W. Kiefer, and J. W. Chipman. 2008. Remote Sensing and Image Interpretation. 5th edition edition. Wiley and Sons, New York.
List, J. A. 2004. Substitutability, experience, and the value disparity: evidence from the marketplace. Journal of Environmental Economics and Management 47:486-509.
Liu, Y. 2006. Model selection in stochastic frontier analysis: Maize production in Kenya. Michigan State University, East Lansing.
Lobell, D. B., M. B. Burke, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon, and R. L. Naylor. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science 319:607-610.
Long, H., G. Tang, X. Li, and G. K. Heilig. 2007. Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China. Journal of Environmental Management 83:351-364.
Longley, C., N. Mango, W. Nindo, and C. Mango. 2006. Conservation by Committee: The Catchment Approach to Soil and Water Conservation in Nyanza Province, Western Kenya. Pages 126-159 *in* R. Trip, editor. Sufficient Agriculture: Labour and Knowledge in Small-scale Farming. Earthscan, London.
Loorbach, D. 2007. Transition Management: New Mode of Governance for Sustainable Development. International Books, Utrecht.
Loorbach, D. 2010. Transition Management for Sustainable Development: A prescriptive, complexity-based governance framework. Governance 23:161-183.
Loorbach, D., and J. Rotmans. 2010. The practice of transition management: Examples and lessons from four distinct cases. Futures 42:237-246.
Lovett, J. C., and S. K. Wasser. 2008. Biogeography and Ecology of the Rain Forests of Eastern Africa. Cambridge University Press, Cambridge.
Lowdermilk, W. C. 1948. Conquest of the Land Through Seven Thousand Years. U. S. Department of Agriculture Washington, D.C.
MA. 2003. Millennium Ecosystem Assessment. A Framework for Assessment. Island Press, Washington DC.
MA. 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Mace, G. M., K. Norris, and A. H. Fitter. 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology and Evolution 27:19-26.
Maddala, G. S. 2001. Introduction to Econometrics. third edition. John Wiley and Sons, Chichester.
Malthus, T. R. 1809. An Essay on the Principle of Population, as it Affects the Future Improvement of Society. Roger Chew Weightman, Washington City.
Mansuri, G., and V. Rao. 2004. Community-Based and -Driven Development: A Critical Review. World Bank Res Obs 19:1-39.
Marenya, P. P., and C. B. Barrett. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. Food Policy 32:515-536.
Maxon, R. M. 2003. Going Their Separate Ways: Agrarian Transformation in Kenya, 1930-1950. Fairleigh Dickinson University Press, Granbury.
Mburu, J., and R. Birner. 2002. Analyzing the efficiency of collaborative wildlife management: The case of two wildlife sanctuaries in Kenya. International Journal of Organization Theory and Behavior 5:259-298.
Meadows, D. H., D. L. Meadows, J. Randers, and W. W. Behrens. 1972. The Limits to growth. A report for the Club of Rome's project on the predicament for mankind. Universe Books, New York.
MENR. 1994. Kenya Forestry Master Plan Development Programmes. Ministry of Environment and Natural Resources, Nairobi.
Mhango, J., and J. Dick. 2011. Analysis of fertilizer subsidy programs and ecosystem services in Malawi. Renewable Agriculture and Food Systems 26:200-207.
Miser, H. J., and E. S. Quade. 1997. Handbook of Systems Analysis: Craft Issues and Procedural Choices. Revised edition. John Wiley and Sons, Chichester.
Mitchell, R., and R. Carson. 1989. Using Surveys to Value Public Goods, Washington, D.C.
Mochebelele, M. T., and A. Winter-Nelson. 2000. Migrant Labor and Farm Technical Efficiency in Lesotho. World Development 28:143-153.
Mortimore, M., M. Ba, A. Mahamane, R. S. Rostom, P. S. del Pozo, and B. Turner. 2005. Changing systems and changing landscapes: Measuring and interpreting land use transformation in African drylands. Geografisk Tidsskrift, Danish Journal of Geography 105:101-118
Mortimore, M., and F. Harris. 2005. Do small farmers' achievements contradict the nutrient depletion scenarios for Africa? Land Use Policy 22:43-56.
Morton, D. C., R. S. DeFries, Y. E. Shimabukuro, L. O. Anderson, E. Arai, F. del Bon Espirito-Santo, R. Freitas, and J. Morisette. 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences 103:14637-14641.
Mose, L. O. 2007. Who gains, who loses? The impact of market liberalisation on rural households in northwestern Kenya. PhD thesis. Wageningen University, Wageningen.
Mugambi, D. 2007. Using travel cost method to estimate the recreational benefits of Kakamega forest, Kenya. Kenyatta University, Nairobi.
Müller, D., and J. Mburu. 2009. Forecasting hotspots of forest clearing in Kakamega Forest, Western Kenya. Forest Ecology and Management 257:968-977.
Mureithi, J. G., C. K. K. Gachene, F. N. Muyekho, M. Onyango, L. O. Mose, and O. Magenya, editors. 2002. Participatory Technology Development for Soil Management by Smallholders in Kenya. KARI, Nairobi.
Mureithi, J. G., E. M. Nyambati, M. Mutoko, W. Akuno, N. Kidula, and J. Wamuongo. 2006. Farmer field school methodology for information and technology transfer among smallholder farmers. The case of Soil Management Project in western Kenya. Pages 81-90 *in* Proceedings of the 18th International Symposium of the International Farming Systems Association: A Global Learning Opportunity, Rome.
Murillo-Luna, J. L., C. Garcés-Ayerbe, and P. Rivera-Torres. 2011. Barriers to the adoption of proactive environmental strategies. Journal of Cleaner Production 19:1417-1425.

Mutoko, M. C. 2012. Economic Efficiency and Environmental Conservation: Determinants and Gains in Degrading Smallholder Agro-Ecosystems. LAP Lambert Academic Publishing, Saarbrucken.
Mutoko, M. C., J. Benhin, C. N. Ritho, and O. L. E. Mbatia. 2008. Analysis of economic efficiency in smallholder maize production in northwestern Kenya. East African Agricultural and Forestry Journal 74:139-147.
Mutoko, M. C., L. Hein, and H. Bartholomeus. submitted. Integrated analysis of land use changes and their impacts on agrarian livelihoods in the western highlands of Kenya.
National Research Council. 2004. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. The National Academies Press, Washington D.C.
Ndufa, J. K., G. Cadisch, C. Poulton, Q. Noordin, and B. Vanlauwe. 2005. Integrated soil fertility management and poverty traps in Western Kenya. Pages 1-25 International Symposium on Improving Human Welfare and Environmental Conservation by Empowering Farmers to Combat Soil Fertility Degradation, Yaounde.
Ngoze, S., S. Riha, J. Lehmann, L. Verchot, J. Kinyangi, D. Mbugua, and A. Pell. 2008. Nutrient constraints to tropical agroecosystem productivity in long-term degrading soils. Global Change Biology 14:2810-2822.
Nkonya, E., P. Gicheru, J. Woelcke, B. Okoba, D. Kilambya, and L. N. Gachimbi. 2006. Out of site out of mind: Quantifying the long-term off-site economic impacts of land degradation in Kenya. American Agricultural Economics Association Annual Meeting, Long Beach, California.
Nkonya, E., J. Pender, C. K. Kayuki, E. Kato, S. Mugarura, H. Ssali, and J. Muwonge. 2009. Linkages between land management, land degradation and poverty in Sub-Saharan Africa: The case of Uganda. Research Report 159. International Food Policy Research Institute, Washington, D.C.
Norton-Griffiths, M., and C. Southey. 1995. The opportunity of biodiversity conservation in Kenya. Ecological Economics 12:125-139.
NTZDC. 2012. Nyayo Tea Zones Development Corporation. Nyayo Tea Zones Development Corporation, Nairobi.
Nyangena, W., and G. Köhlin. 2008. Estimating returns to soil and water conservation investments:An application to crop yield in Kenya. Discussion Paper, Gotenborgs Universitet.
Nyssen, J., J. Poesen, and J. Deckers. 2009. Land degradation and soil and water conservation in tropical highlands. Soil and Tillage Research 103:197-202.
Odendo, M., G. Obare, and B. Salasya. 2009. Factors responsible for differences in uptake of integrated soil fertility management practices amongst smallholders in western Kenya. African Journal of Agricultural Research 4:1303-1311.
Odendo, M., G. Obare, and B. Salasya. 2010. Farmers' perceptions and knowledge of soil fertility degradation in two contrasting sites in western Kenya. Land Degradation & Development 21:557-564.
Ojiem, J. O. 2006. Exploring socio-ecological niches for legumes in Western Kenya smallholder farming systems. PhD thesis. Wageningen University, Wageningen.
Ojiem, J. O., C. A. Palm, E. A. Okwuosa, and M. A. Mudeheri. 2004. Effect of combining organic and inorganic phosphorous sources on maize grain yield in a *humic*-Nitosol in Western Kenya.*in* A. J. Bationo, editor. Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Academy Science Publishers, Nairobi.
Ojiem, J. O., N. d. Ridder, B. Vanlauwe, and K. E. Giller. 2006. Socio-ecological niche: A conceptual framework for integration of legumes in smallholder farming systems. International Journal of Agricultural Sustainability 4:79-93.
Okoba, B. O., and J. De Graaff. 2005. Farmers' knowledge and perceptions of soil erosion and conservation measures in the Central Highlands, Kenya. Land Degradation and Development 16:475-487.
Oldeman, L. R. 1998. Soil degradation: A threat to food security? Report 98/01 International Soil Reference and Information Centre, Wageningen.

Olowa, O. W., and O. A. Olowa. 2010. Sources of technical efficiency among smallholder maize farmers in Osun State of Nigeria. Research Journal of Applied Sciences 5:115-122.
Omamo, S. W. 1998. Transaction costs and smallholder cropping choices: An application to Siaya District, Kenya. American Journal of Agricultural Economics 80:116-123.
Ouma, O. K., C. Stadel, and S. Eslamian. 2011. Perceptions of tourists on trail use and management implications for Kakamega Forest, Western Kenya. Journal of Geography and Regional Planning 4:243-250.
Oyake-Ombis, L. 2012. Managing Plastic Waste in Urban Kenya: Niche Innovations in Production and Recycling. Wageningen University, Wageningen.
Pacheco, P. 2006. Agricultural expansion and deforestation in lowland Bolivia: the import substitution versus the structural adjustment model. Land Use Policy 23:205-225.
Pagiola, S. 2007. Guidelines for "Pro-Poor" Payments for Environmental Services. Environment Department, World Bank, Washington D.C.
Pagiola, S. 2008. Payments for environmental services in Costa Rica. Ecological Economics 65:712-724.
Pagiola, S., A. Arcenas, and G. Platais. 2005a. Can Payments for Environmental Services help reduce poverty? An exploration of the issues and the evidence to date from Latin America. World Development 33:237-253.
Pagiola, S., A. Paola, J. Gobbi, C. de Haan, M. Ibrahim, E. Murgueitio, E. Ramírez, M. Rosales, and J. P. Ruíz. 2005b. Paying for Biodiversity Conservation Services: Experience in Colombia, Costa Rica, and Nicaragua. Mountain Research and Development 25:206-211.
Paré, S., U. Söderberg, M. Sandewall, and J. M. Ouadba. 2008. Land use analysis from spatial and field data capture in southern Burkina Faso, West Africa. Agriculture, Ecosystems and Environment 127:277-285.
Pearce, D. 1988. Economics, equity and sustainable development. Futures 20:598-605.
Pearce, D. 2007. Do we really care about Biodiversity? Environmental and resource economics 37:313-333.
Pearce, D., G. Atkinson, and S. Mourato. 2006. Cost-Benefit Analysis and the Environment: Recent Developments. Organisation for Economic Co-operation and Development (OECD) Publishing, Paris.
Pearce, D. W. 2001. The economic value of forest ecosystems. Ecosystem health 7:284-296.
Pearce, D. W., and R. K. Turner. 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf, Herfordshire.
Pender, J., E. Nkonya, P. Jagger, D. Sserunkuuma, and H. Ssali. 2006a. Strategies to Increase Agricultural Productivity and Reduce Land Degradation in Uganda:An Econometric Analysis. Pages 165-189 *in* J. Pender, F. Place, and S. Ehui, editors. Strategies for Sustainable Land Management in the East African Highlands. International Food Policy Research Institute, Washington, D.C.
Pender, J., F. Place, and S. Ehui, editors. 2006b. Strategies for Sustainable Land Management in the East African Highlands. International Food Policy Research Institute, Washington, D.C.
Pender, J. L. 1998. Population growth, agricultural intensification, induced innovation and natural resource sustainability: An application of neoclassical growth theory. Agricultural Economics 19:99-112.
Perman, R., Y. Ma, J. McGilvray, and M. S. Common. 2003. Natural Resource and Environmental Economics. 3 edition. Pearson Education, Addison Wesley.
Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science, New Series 267:1117-1123
Pistorius, T. 2012. From RED to REDD+: the evolution of a forest-based mitigation approach for developing countries. Current Opinion in Environmental Sustainability 4:638–645.
Place, F., S. Franzel, J. Dewolf, R. Rommelse, F. Kwesiga, A. Niang, and B. Jaba. 2002. Agro forestry for soil fertility replenishment: Evidence on adoption processes in Kenya and Zambia.*in* C. B. Barret,

F. Place, and A. A. Abdillah, editors. Understanding and Improving Current Practices. CABI, Wallingford.
Place, F., J. Njuki, F. Murithi, and F. Mugo. 2006. Agricultural Enterprise and Land Management in the Highlands of Kenya. Pages 191-215 *in* J. Pender, F. Place, and S. Ehui, editors. Strategies for Sustainable Land Management in the East African Highlands. International Food Policy Research Institute., Washington, D.C.
Pollock, C. 2009. Drivers for land use change: Timber, mutton or fuel? Debating the economics of land use and forestry. Pages 10-11 *in* G. E. Hemery, editor. Timber, mutton or fuel? Debating the economics of land use and forestry. CABI, Wallingford.
Pontius, R. G., and C. D. Lippitt. 2004. A method to distinguish real landscape change from map error during map comparison. Pages 1-9 Accuracy 2004 Symposium. Clark University, Worcester.
Pretty, J. N. 1999. Capital assets and natural resource improvements: linkages and new challenges. Pages 11-22 McDonald MA, Brown K (eds). Issues and Options in the Design of Soil and Water Conservation Projects. Centre for Environment and Society, University of Essex, Essex.
Reardon, T., C. Barrett, V. Kelly, and K. Savadogo. 1999. Policy Reforms and Sustainable Agricultural Intensification in Africa. Development Policy Review 17:375-395.
Reardon, T., and S. A. Vosti. 1995. Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. World Development 23:1495-1506.
Reed, M. S., and A. J. Dougill. 2010. Linking degradation assessment to sustainable land management: A decision support system for Kalahari pastoralists. Journal of Arid Environments 74:149-155.
Rembold, F., S. Carnicelli, M. Nori, and G. A. Ferrari. 2000. Use of aerial photographs, Landsat TM imagery and multidisciplinary field survey for land-cover change analysis in the lakes region (Ethiopia). International Journal of Applied Earth Observation and Geoinformation 2:181-189.
Righi, E., S. Dogliotti, F. M. Stefanini, and G. C. Pacini. 2011. Capturing farm diversity at regional level to up-scale farm level impact assessment of sustainable development options. Agriculture, Ecosystems & Environment 142:63-74.
Rip, A., and R. P. M. Kemp. 1998. Technological Change. Pages 327-399 *in* R. S and M. E.L, editors. Human Choice and Climate Change. Resources and Technology. Vol. II. Battelle Press, Columbus, Ohio.
Roose, E. 1996. Land husbandry: Components and strategy. FAO, Rome.
Rotmans, J. 2005. Societal Innovation: between dream and reality lies complexity. Page DRIFT Research Working Paper University of Maastricht - ICIS, Rotterdam.
Rotmans, J., R. Kemp, and M. Van Asselt. 2001. More evolution than revolution: transition management in public policy. Foresight - The journal of future studies, strategic thinking and policy 3:15-31.
Ruben, R., J. Pender, and A. Kuyvenhoven. 2007. Sustainable Poverty Reduction in Less-Favoured Areas: Problems, Options and Strategies. Pages 1-67 *in* R. Ruben, J. Pender, and A. Kuyvenhoven, editors. Sustainable Poverty Reduction in Less-Favoured Areas. CABI, Wallingford.
Ruttan, V. W., and C. Thirtle. 1989. Induced technical and institutional change in African agriculture. Journal of International Development 1:1-45.
Salasya, B. D. S. 2005. Crop production and soil nutrient management: An economic analysis of households in western and central Kenya. PhD thesis. Wageningen University, Wageningen.
Sardar, Z. 2010. The Namesake: Futures; futures studies; futurology; futuristic; foresight—What's in a name? Futures 42:177–184.
Sarkis, J., P. Gonzalez-Torre, and B. Adenso-Diaz. 2010. Stakeholder pressure and the adoption of environmental practices: The mediating effect of training. Journal of Operations Management 28:163-176.
Schmook, B., and C. Vance. 2009. Agricultural policy, market barriers, and deforestation: The case of Mexico's Southern Yucatán. World Development 37:1015-1025.
Schwilch, G., F. Bachmann, S. Valente, C. Coelho, J. Moreira, A. Laouina, M. Chaker, M. Aderghal, P. Santos, and M. S. Reed. 2012. A structured multi-stakeholder learning process for Sustainable Land Management. Journal of Environmental Management 107:52-63.

Schwilch, G., B. Bestelmeyer, S. Bunning, W. Critchley, J. Herrick, K. Kellner, H. P. Liniger, F. Nachtergaele, C. J. Ritsema, B. Schuster, R. Tabo, G. van Lynden, and M. Winslow. 2011. Experiences in Monitoring and Assessment of Sustainable Land Management. Land Degradation and Development 22:214-225.

Serneels, S., and E. F. Lambin. 2001. Proximate causes of land-use change in Narok District, Kenya: a spatial statistical model. Agriculture, Ecosystems and Environment 85:65-81.

Shepherd, K. D., and M. J. Soule. 1998. Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agriculture, Ecosystems and Environment 71:131-145.

Shiferaw, B., and S. T. Holden. 2000. Policy instruments for sustainable land management: the case of highland smallholders in Ethiopia. Agricultural Economics 22:217-232.

Shisanya, C. A., M. W. Mucheru, D. N. Mugendi, and J. B. Kung'u. 2009. Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya. Soil & Tillage Research 103:239-246.

Simbowo, H. 2009. National Accelerated Agricultural Inputs Access Programme (NAAIAP). Page 36 min. AIRC Video Unit, Nairobi.

Singh, I., L. Squire, and J. Strauss, editors. 1986. Agricultural Household Models- Extensions, Applications and Policy. The John Hopkins University Press, Baltimore.

Smale, M., and J. Olwande. 2011. Is older better? Maize hybrid change on household farms in Kenya. Tegemeo Institute of Agricultural Policy and Development, Nairobi.

Smyth, A. J., and J. Dumanski. 1995. A framework for evaluating sustainable land management. Canadian Journal of Soil Science 75:401-406.

Solano, C., H. León, E. Pérez, and M. Herrero. 2001. Characterising objective profiles of Costa Rican dairy farmers. Agricultural Systems 67:153-179.

Stanimirova, I., M. Daszykowski, and B. Walczak. 2007. Dealing with missing values and outliers in principal component analysis. Talanta 72:172-178.

Steiner, K., K. Herweg, and J. Dumanski. 2000. Practical and cost-effective indicators and procedures for monitoring the impacts of rural development projects on land quality and sustainable land management. Agriculture, Ecosystems and Environment 81:147-154.

Stoorvogel, J. J., J. M. Antle, C. C. Crissman, and W. Bowen. 2004. The tradeoff analysis model: integrated bio-physical and economic modeling of agricultural production systems. Agricultural Systems 80:43-66.

Tchale, H., and J. Sauer. 2007. The efficiency of maize farming in Malawi. A bootstrapped translog frontier. Cahiers d'économie et sociologie rurales 82-83:33-56.

TEEB. 2010a. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington D.C.

TEEB. 2010b. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. Progress Press, Malta.

Tiffen, M. 1993. Productivity and environmental conservation under rapid population growth: a case study of Machakos District. Journal of International Development 5:207-223.

Tiffen, M., and M. Mortimore. 1994. Malthus controverted: The role of capital and technology in growth and environment recovery in Kenya. World Development 22:997-1010.

Tiffen, M., M. Mortimore, and F. Gichuki. 1994. More People, Less Erosion: Environmental Recovery in Kenya. John Wiley and Sons, Chichester.

Tittonell, P., P. A. Leffelaar, B. Vanlauwe, M. T. van Wijk, and K. E. Giller. 2006. Exploring diversity of crop and soil management within smallholder African farms: A dynamic model for simulation of N balances and use efficiencies at field scale. Agricultural Systems 91:71-101.

Tittonell, P., A. Muriuki, K. D. Shepherd, D. Mugendi, K. C. Kaizzi, J. Okeyo, L. Verchot, R. Coe, and B. Vanlauwe. 2010. The diversity of rural livelihoods and their influence on soil fertility in

agricultural systems of East Africa - A typology of smallholder farms. Agricultural Systems 103:83-97.
Tittonell, P., B. Vanlauwe, N. de Ridder, and K. E. Giller. 2007. Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: Soil fertility gradients or management intensity gradients? Agricultural Systems 94:376-390.
Tittonell, P., B. Vanlauwe, P. A. Leffelaar, E. C. Rowe, and K. E. Giller. 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. Agriculture, Ecosystems and Environment 110:149-165.
Tittonell, P. A. 2007. Msimu wa Kupanda- Targeting resources within diverse, heterogeneous and dynamic farming systems of East Africa. PhD thesis. Wageningen University, Wageningen.
Todaro, M. P. 1989. Economic Development in the Third World. Longman Group, Addison-Wesley.
Todaro, M. P., and S. C. Smith. 2008. Economic Development. Longman Group, Addison-Wesley.
Tol, R. S. J. 2005. The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. Energy Policy 33:2064-2074.
Tsegaye, D., S. R. Moe, P. Vedeld, and E. Aynekulu. 2010. Land-use/cover dynamics in Northern Afar rangelands, Ethiopia. Agriculture, Ecosystems & Environment 139:174-180.
Turner, R. K., W. N. Adger, and R. Brouwer. 1998. Ecosystem services value, research needs, and policy relevance: a commentary. Ecological Economics 25:61-65.
Turner, R. K., J. Paavola, P. Cooper, S. Farber, V. Jessamy, and S. Georgiou. 2003. Valuing nature: lessons learned and future research directions. Ecological Economics 46:493-510.
UNESCO. 2011. World Network of Biosphere Reserves 2010: Sites for Sustainable Development. United Nations Educational, Scientific and Cultural Organisation.
United Nations. 2011. Department of Economic and Social Affairs, Population Division: World Population Prospects: The 2010 Revision. United Nations, New York.
United Nations. 2012. The Millennium Development Goals Report 2012. United Nations, New York.
van der Brugge, R., and R. van Raak. 2007. Facing the adaptive management challenge: insights from transition management. Ecology and Society 12:33.
van Kempen, L., R. Muradian, C. Sandóval, and J.-P. Castañeda. 2009. Too poor to be green consumers? A field experiment on revealed preferences for firewood in rural Guatemala. Ecological Economics 60:2160-2167.
Vanlauwe, B., P. Tittonell, and J. Mukalama. 2006. Within-farm soil fertility gradients affect response of maize to fertiliser application in western Kenya. Nutrient Cycling in Agroecosystems 76:171-182.
Veldkamp, A., and E. F. Lambin. 2001. Predicting land-use change. Agriculture, Ecosystems and Environment 85:1-6.
Verbeek, M. 2008. A Guide to Modern Econometrics. 3rd edition. John Wiley & Sons Ltd, Chichester.
Verburg, P. H., M. Bakker, K. P. Overmars, and I. Staritsky. 2008. Landscape level simulation of land use change. Wageningen University, Wageningen.
Walingo, M. K. 2009. The role of livestock projects in empowering women smallholder farmers for sustainable food security in rural Kenya. African Journal of Food Agriculture Nutrition and Development 9:1468-1483.
Walingo, M. K., E. T. Liwenga, R. Y. M. Kangalawe, N. F. Madulu, and R. Kabumbuli. 2009. Perceived impact of land use changes and livelihood diversification strategies of communities in the Lake Victoria Basin of Kenya. Journal of Agricultural Biotechnology and Sustainable Development 1:069-078.
Wang, H.-J., and P. Schmidt. 2002. One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. Journal of Productivity Analysis 18:129-144.
Wanyama, J. M., E. M. Nyambati, L. O. Mose, M. C. Mutoko, W. M. Wanyonyi, E. Wanjekeche, and S. C. Rono. 2010. Assessing Impact of soil management technologies on smallholder farmers' livelihoods in north western Kenya. African Journal of Agricultural Research 5:2899- 2908.
WCED. 1987. Our Common Future. Oxford University Press, Oxford.

World Bank. 2006a. Sustainable Land Management. Challenges, Opportunities, and Trade-offs. The World Bank, Washington, DC.
World Bank. 2006b. Where is the Wealth of the Nations? Measuring Capital for the 21st Century. The World Bank, Washington D.C.
World Bank. 2013. Data Indicators: Population growth. The World Bank, Washington D.C.
WRI. 2010. Kenya GIS Data: Population and Poverty. World Resources Institite, Washington, DC.
Wunder, S. 2006. Are direct payments for environmental services spelling doom for sustainable forest management in the tropics? Ecology and Society 11:23-44.
Wunder, S. 2007. The efficiency of Payments for Environmental Services in tropical conservation. Conservation Biology 21:48-58.
Wyman, M. S., and T. V. Stein. 2010. Modeling social and land-use/land-cover change data to assess drivers of smallholder deforestation in Belize. Applied Geography 30:329-342.
Yesuf, M., A. Mekonnen, M. Kassie, and J. Pender. 2005. Cost of Land Degradation in Ethiopia: A Critical Review of Past Studies. Environmental Economics Policy Forum in Ethiopia and International Food Policy Research Institute, Addis Ababa.
Zeleke, T. B., and B. C. Si. 2006. Characterizing scale-dependent spatial relationships between soil properties using multifractal techniques. Geoderma 134:440-452.

Appendices

Appendix A: Data collection tools

Appendix A1: Questionnaire for farming households

Sustainable Land Management: Fostering Scaling up of SLM Strategies in East African Highlands

Farm Household Questionnaire **Date**______________________

The information collected will be treated as ***confidential*** *and only be used for research purposes.*

SECTION A: GENERAL INFORMATION

1. District__________________ Site______________________
2. GPS of homestead: Latitude (N/S)_____________Longitude (W/E)___________ Altitude_____(M)
3. 3.1 Respondent's name___________________________________3.2 Age (Year born)__________
4. 4.1 Gender of Respondent: [1=Male; 2=Female]________4.2 Education(No. of years)_____________
5. Since when have you been actively engaged in farming? Year_______________
6. What are your main objectives for engaging in farming? _______[1=subsistence; 2=income generation; 3=both; 4= other specify_______________________________________]
7. What was the total acreage of your farm in 2009? 7.1 Owned land ____ (acres) 7.2 Hired land ____ (acres)
8. 8.1 Own farm was obtained farm in (year) _________ 8.2 Obtained through_______ [1= inheritance; 2=purchase; 3=settlement; 4= other __________________] 8.3 Obtained as: __________ [1= virgin land; 2=already cultivated]
9. How many livestock do you keep? (a) Cattle_________(b) Sheep_________(c) Goats___________
10. (d) Donkeys___________(f) Poultry_____________(g) Other, (indicate type)________________

SECTION B: FARM CHARACTERISTICS

1. Land parcels, their sizes and soil fertility rating (2008/09 cropping year).

1.1 Parcel no.	1.2 Acreage	1.3 Soil fertility rating **[1= Poor; 2=Good; 3=Very good]**	1.4 Ownership **[1=Owned with title; 2=Owned without title; 3 Communal; 4=Rented in; 5=other……………………]**
1			
2			
3			

2. Allocation of available land to various uses in the past growing season (2009)

Land use type	**Owned**	**Rented**					
		In			**Out**		
	Area *(acres)*	Area *(acres)*	Total rent paid (Ksh/year)	Source 1=in village, 2=outside village	Area *(acres)*	Rent received (Ksh/year)	Destination 1=within village, 2=outside village
Homestead							
Arable land							
Pasture/fodder							
Woodlot							
Wasteland							
Total area							

3. Which 4 main crops did you grow in your farm during the previous 2 years (2007 and2008)? [Annual production should be total for both long and short rains seasons]

	2007				2008		
3.1 Crop name	**3.2 Own land planted (acres)**	**3.3 Land rented in (acres)**	**3.4 Production (kg)**	**3.1 Crop name**	**3.2 Own land planted (acres)**	**3.3 Land rented in (acres)**	**3.4 Production (kg)**

4. Which 4 main crops did you cultivate on each of the land parcels in the last growing season (2009)?

[Combine production for both long and short rains seasons]

4.2 Crop name	**4.3 Own land planted (acres)**	**4.4 Land rented in (acres)**	**4.5 Manure [**Small Ox-cart = 300 kg; Big ox-cart = 500 kg; Wheel barrow = 50 kg]			**4.6 Fertiliser**		**4.7 Seed**				**4.8 Field pesticide**		**4.9 Storage pesticide**		**4.10 Labour (**Cost in Ksh)						**4.11 Production (kg)**
			Own (kg)	Bought		Amount (kg)	Value (Ksh)	Own saved (kg)	Gift seed (kg)	Bought		Litres/kg	Value (Ksh)	Amount (kg)	Value (Ksh)	Ploughing	Planting	Weeding	Chemical application	Harvesting/ picking	Threshing/s helling	
				Amount (kg)	Value (Ksh)					Amount (kg)	Value (Ksh)											

5. How many trees do you have on your farm? Estimated number__________________ Estimated total value (Ksh)__________________

7. Do you source for any products from the forest? Yes/No__________If yes, which key ones?

Forest product/benefit	**Number of times per month**	**Estimated value per unit/access (Ksh)**	**Trend in product availability** (1=increasing, 2=same, 3=decreasing)	**Main reason for the trend**

8. For each land parcel, provide a description of the soil characteristics and management measures you practise.

Parcel no.	**Distance to house** *one-way travel time in hours*	**Soils**				**Soil Conservation**				
		Colour: 1= black 2= brown 3= red 4= grey 5= yellow 6= other	**Texture:** 1=clay 2=loam 3=sand	**Fertility:** 1=good 2=medium 3=bad	**Slope:** 1=flat (<5%) 2=gentle (5-15%) 3=steep (>15%)	**Practices contour ploughing?** Yes/No	**Measures:** 1=terraces 2=trash lines 3=grass strips 4=cut-off drains 5=stone lines 6=Napier grass line 7=treelines 8=other:______	**Number** on farm	**Year** established	**Effectiveness rating:** 1=High 2=Medium 3=Low

9. How much labour and other inputs have been used to establish and maintain the soil conservation measures?

Parcel no.	**Measures:** 1=terraces 2=trash lines 3=grass strips 4=cut-off drains 5=stone lines 6=Napier grass line 7=tree lines 8=other:______	**Labour cost** (in Ksh per year)						**Other inputs used per year**						
		Own		**Hired / Exchanged/Received**				**Type:** 1=animal traction 2= Napier grass 3=manure 4=fertiliser 5=tree seeds 6= tree seedlings 7=stones 8= poles	**Own**		**Bought /Exchanged/Received**			
		Number of people	Value of labour (Ksh)	Number of people	Wage	Value of labour (Ksh)	Source 1=within village 2=outside village 3=other:		Quantity	Value (Ksh)	Quantity	Price	Value	Source 1=within village 2=outside village, 3=trader, 4=other:
Establishment cost														
Maintenance cost per year														

10. What is the history of the parcels with regard to the main crops grown during the last 3 years?

Parcel No.	**Cultivated since (year)**	**2007**		**2008**		**2009**		**If the crops are same for the 3 years then for how long has it been like this?**
		Main crops	**Input use** 0=none 1=fertiliser 2=manure 3=both	**Main crops**	**Input use** 0=none 1=fertiliser 2=manure 3=both	**Main crops**	**Input use** 0=none 1=fertiliser 2=manure 3=both	Since *fill year*
Total fertiliser used (in kg)								
Total manure used (in kg)								

11. Has soil quality in your farm increased, remained the same or decreased in the last ten years? ____________________. What was maize yield (in 90 kg bags per acre) (a) the first two years when you started to cultivate the farm?______Year________ and (b) in the last two years_______
12. What the main factors that influences your investment in better land management measures? ……………………………………………….

………

………

13. How has the occurrence of crop and animal diseases affected your farm production in the last ten years? ……………………………………………………..

………

………

14. Has rainfall been reliable in your area during the last ten years (Yes/No)? _____If NOT, how has it affected the land management practices on your farm?

………

………..

………..

………..

SECTION C: FARM OUTPUTS, UTILISATION AND ASSETS

1. How did you utilise the harvest from the main crops grown on your/rented farm last season?

Crop name	**Total output**	**Unit of measure**	**Utilisation**						
			Own consumption and stock	Exchange		Sale			
			Quantity	Quantity	Destination : 1= in village 2= outside village	Quantity	Price/unit	Total value	Destination 1=farm gate 2=village market, 3=middleman, 4=Urban market, 5=other:_____

2. How do you manage crop residues after harvesting?

Crop residue: 1= stovers 2= cobs 3=prunings 4=peelings 5=other___	**On the field**			**Carried away**			
	% Grazed on the field	% Burnt	% Left on the field	% Fed to animals in the farm	% Used as fuel by the household	% Used for compost making	% other use, ________

3. How many farm animals by type did you have at the start and end of 2009?

Animal type	**Stock at start of year**	**Total Value**	**Stock at end of year**	**Total Value**	**Main reason for the change in stock numbers**
Cows					
Calves					
Heifers					
Oxen					
Bulls					
Donkeys					
Sheep					
Goats					
Pigs					
Poultry					
Rabbits					
Bee (hives)					

4. How much labour input did you use in livestock management activities in 2009?

Animal type	Activity: 1=Grazing 2=Watering 3=Feeding 4=Treating/ Deworming	Dry season Labour use (days per month)					Wet season Labour use (days per month)				
		Own		**Hired**			**Own**		**Hired**		
		Total labour (days)	Total Value (Ksh)	Total labour (days)	Total Value (Ksh)	Source	Total labour (days)	Total Value (Ksh)	Total labour (days)	Total Value (Ksh)	Source
Cattle											
Sheep											
Goat											
Pigs											
Poultry											
Rabbits											

5. Apart from labour, what other inputs did you use in livestock keeping in 2009?

Animal type		Dry Season Input use (cost per month)						Wet season Input use (cost per month)				
	Type of input: 1=fodder 2=commercial feeds 3=mineral salts 4=vet. drugs 5=other_____	Amount (kg)	Cost	Total cost (Ksh)	**Source** 1=own farm, 2 = within village, 3=outside village, 4=trader 5=other	Transport cost (Ksh)	**Type of input**: 1=fodder 2=commercial feeds 3=mineral salts 4=vet. drugs 5=other_____	Amount (kg)	Cost	Total cost (Ksh)	**Source** 1=own farm, 2 = within village, 3=outside village, 4=trader, 5=other	Transport cost (Ksh)
Cattle												
Sheep												
Goats												
Pigs												
Poultry												
Rabbits												

6. What outputs did you get from livestock enterprises during the dry and wet seasons in the past one year?

Animal type	Dry Season								Wet season							
	Outputs 1= milk 2= meat 3= eggs 4= manure 5= hides and skins 6= honey 7= others:______								**Outputs** 1= milk 2= meat 3= eggs 4= manure 5= hides and skins 6= honey 7= others:______							
	Output type	Unit	Quantity	Price	Total Value	Destination (use codes)	Frequency (use codes)	Transport cost (Ksh)	Output type	Unit	Quantity	Price	Total Value	Destination (use codes)	Frequency (use codes)	Transport cost (Ksh)
Cattle																
Sheep																
Goat																
Pigs																
Poultry																
Rabbits																

Codes: Destination: 1=own farm, 2 = within village, 3=outside village, 4=trader, 5=other, specify___________
Frequency: 1= per day, 2= per week, 3= per month, 4= per year, 5= other, specify___________

SECTION D: HOUSEHOLD AND OTHER INCOME INFORMATION

Now I would like us to talk about your household's membership. There are often several persons in a household who have different capabilities and some may contribute to implementation of farming activities in various ways. For example, direct physical labour supply, provision of technical information and money from other sources used in farming and land management. How many people are in your household?

1. Household profile

Household characteristic	**Response**
Membership	Total: ________________________ Male: ________________________ Female: ________________________
Age bracket of household members	Above 18 years: _________________ Below 18 years: _________________
Education level of household members	None: __________________ Primary: __________________ Secondary: __________________ College: __________________ University: __________________
Residents in the household in 2009	Number: ____________________
Number of members who participated in farm activities in 2009 on:	Full time: ____________________ Part-time: ____________________

2. Apart from farming, are there other income activities that household members engaged in during the past one year? Yes/No______

3. If yes, did any of the household members perform **agricultural wage labour** outside the household in the past one year?

Number of persons engaged	Place: 1=within village 2=outside village	Number of months	Days per Month	Wage	
				Amount (Ksh)	Per: 1=day; 2=week 3=month; 4=year

4. Did any of the household members perform **non-agricultural wage labour** in the past one year?

Number of persons engaged	Place: 1=within village 2=outside village	Occupation 1= teacher; 2= nurse 3= guard; 4= driver 5= administrator 6= police; 7=clerical 8= other:_____	Number of months	Days per month	Wage	
					Amount (Ksh)	Per: 1=day; 2=week 3=month; 4=year

5. Did any of the household members have their **own business** in the past one year **(self-employed)**? Yes/No______

Self-employment income							
Number of persons involved	Place: 1=within village 2=outside village	Activity: 1=flour milling 2=shop keeping 3=bar/restaurant 4=bicycle transport 5=hawking 6=trading	7=wood processing 8=blacksmith 9=tailoring 10=brick making 11=brewing beer 12=other:___	Good time		Bad time	
				Gross income (Ksh)	Per: 1=day 2=week 3=month	Gross income (Ksh)	Per: 1=day 2=week 3=month

6. Did the household **receive** income from other sources in the past one year? Yes/No_______

Other income sources in 2009	Unit of measure	Quantity	Value (Ksh)	Times per Year	Total Amount	Source: 1=within village 2=outside village 3=trader 4=other, _____
Selling land						
Renting out houses						
Remittances from relatives						
Gifts from others (harambee)						
Gifts from projects						
Pensions						
Insurance receipts						
Dowry						
Dividend on shares						
Interest on savings						
Interest received on money which was lent out to others						
Other specify...................................						

7. Apart from land, what other assets do the farm household own?

Type of asset	**Quantity**	**Total value** (Ksh)	**Annual Maintenance cost (Ksh)**	**Whole Lifespan (years)**
Wheelbarrow				
Knapsack sprayer				
Car				
Motorcycle				
Bicycle				
Cart				
Irrigation pump				
Hoe				
Rake				
Stable for cattle				
Stable for sheep/goats				
Poultry house				
Well				
Television				
Radio				
Savings	Yes/No			
Shares	Yes/No			
Other				

8. Did you borrow money or inputs used in past seasons' farming activities? Yes/No______

9. If NOT, why? ……

10. If YES, what were the characteristics of the credit you accessed?

Type of credit provider: 1=commercial bank 2=microfinance 3=cooperative 4=trader /stockist 5=moneylender 6=friend/ relative 7=merry-go-rounds 8= other: ______	**Item of credit:** 1=cash 2=kind	**Location:** 1= within village, 2=outside village 3=other: ______	**Amount** (if in kind then estimate value) (Ksh)	**Borrowing conditions** Interest rate (%)	per: 1= day 2= week 3= month 4= year	Total amount (Ksh)

11. In your own view, how has the general status of land management/use (including forests) changed over the last 10 years? What are the main reasons for the change in land management?

General status of land management	**Main drivers of change**

12. How would you react to a Ksh 500 reduction in current fertiliser price (per 50 kg bag)?

Type of adjustment	Farmer's response : [1=increase; 2=remain same; 3=reduce]	Reason for response
Cultivated maize area		
Cultivated pasture/fodder area		
Cultivated vegetable area		
Fallow period		
Fertiliser use		
Manure use		
Compost use		
Family labour use		
Hired labour use		
Borrowed money		
Off- and non-farm wage labour		
Extraction of forest products		

[THANK THE RESPONDENT FOR THE TIME ALLOWED & INFORMATION PROVIDED. REMIND THE FARMER THAT THE INFORMATION WILL BE USED CONFIDENTIALLY & FOR RESEARCH PURPOSES ONLY]

Appendix A2: Questionnaire for the forest-adjacent households

Economic Valuation of Forest Services: Valuing the Non-Timber Benefits Provided by Kakamega Forest to Surrounding Households

Date____________________

1. District___________________ Village________________________
2. Homestead location: Latitude (N/S)____________________Longitude (W/E)_____________Altitude__________ (M)
3. Year of birth___________ Gender of Respondent: [1=Male; 2=Female]_________ Highest education level_________________________ Years of schooling________
4. Household head's main economic activity__________________ Average monthly income___________
5. Number of resident household members______ Average monthly household expenditure_______
6. When did you settle in this area? Year_________________
7. How many of each livestock type did you keep at your home during the last one year? Cattle_________ Sheep_________Goats_________Other (specify) __________
8. What is the approximate distance of the nearest edge of Kakamega forest from your home? ________ Km
9. What is the approximate distance of the nearest local market from your home? ________ Km
10. Do any of your household members directly source for some products from the forest? Yes/No [CIRCLE APPLICABLE]

11. If **YES**, which key non-timber products or benefits did your household obtain from the forest and at what frequency during the past one year?

Forest product/benefit	**HH member mostly involved** (use codes)	**Quantity obtained per trip**		**Time spent per trip (Hours)**	**Hired labour cost per trip (Ksh)**	**Trips per month**	**Months per year**
		Qnty	**Units** (use codes)				
1. Firewood							
2. Charcoal							
3. Pole wood							
4. Grazing pastures							
5. Thatching materials							
6. Medicinal extracts							
7. Cultural activities							
8. Other (specify)							

Household member codes: 1= HH head; 2= Spouse; 3= Children; 4= Hired worker; 5= Other (specify).......................
Quantity codes: 1= Kilogram; 2= Number; 3= Head lot; 4= Bundle; 5= Bale; 6= Bag; 7= Feet; 8= Other specify)....................

12. Do the harvested quantities indicated above apply to (1=all months of the year; 2=most months of the year; 3= few months of the year or 4=the most recent months? [CIRCLE]
13. Are you charged any fee to access these forest products/benefits? Yes/No
14. Did you pay and if **YES**, how much did you pay to be allowed to directly obtain each of the forest products/benefits?

Forest product/benefit	**Amount paid (Ksh)**	**Number of times paid past year**
1. Firewood		
2. Charcoal		
3. Pole wood		
4. Grazing pastures		
5. Thatching materials		
6. Medicinal extracts		
7. Cultural activities		
8. Other (specify)______		

15. How much time **(travelling + collection)** is normally spent to access each forest product or benefit during every visit?

Forest product/benefit	**Time spent per access (Hours)**		**Trend of product availability** (use codes)	**Main reasons**
	# People involved	**Hours taken**		
1. Firewood				
2. Charcoal				
3. Pole wood				
4. Grazing pastures				
5. Thatching materials				
6. Medicinal extracts				
7. Cultural activities				
8. Other (specify)				

Trend codes: 1=Increasing; 2=Constant; 3=Decreasing

16. From which **alternative sources** did you obtain any of the forest products/benefits and what price were you willing to pay for **one more** unit of each product during the past one year?

Forest product/benefit	**Alternative source** (use codes)	**Quantity obtained**		**Per** (1=day; 2= week; 3=month 4=year)	**Value of quantity obtained** (Ksh/unit)	**Time spent to obtain product** (Hours/trip)
		Qnty	**Units** (use codes)			
1. Firewood						
2. Charcoal						
3. Pole wood						
4. Grazing pastures						
5. Thatching materials						
6. Medicinal extracts						
7. Cultural activities						
8. Other (specify)						

Source codes: 1=Own farm; 2= Local market; 3= Neighbour; 4= other specify..
Quantity codes: 1= Kilogram; 2= Number; 3= Head lot; 4= Bundle; 5= Bale; 6= Bag; 7= Other (specify)..................

17. If you were **the seller**, how much would you be willing to accept for **one less** unit of each of the forest product or benefit?

Forest product/benefit	**Estimated value per unit/access (Ksh)**	**Reason for the value**
1. Firewood		
2. Charcoal		
3. Pole wood		
4. Pastures/Napier		
5. Thatching materials		
6. Medicinal extracts		
7. Cultural activities		
8. Other (specify)		

18. In your opinion, has the area covered by Kakamega forest 1=increased; 2=remained the same; 3=decreased in the past 10 years? [CIRCLE APPLICABLE]

19. If it has **decreased,** how has the decline in forest cover **affected your livelihood** and **the key strategies** taken by your household **to cope up?**

Impact of decline in forest cover		**Coping strategies** (use codes)		
	Impact Rank	**Strategy1**	**Strategy2**	**Strategy3**
Lack of fuel wood				
Lack of pastures				
Lack of medicinal herbs				
Lack of charcoal				
Lack of thatching grass				
Other (specify)				

Coping strategies
1= stop using fuel wood; 2= use less fuel wood; 3= use paraffin; 4= use energy-saving stoves/jikos; 5= buy fuel wood; 6= more time to collection; 7= planting own trees; 8=buy herbal medicine; 9= buy conventional medicine; 10= plant Napier grass; 10= buy Napier grass; 11= reduce livestock numbers; 12= use iron sheets; 13= other (specify) ______________________

20. In your own view, how has forest quality changed over the last 10 years?..
....
....

21. What are the main reasons responsible for the perceived changes in forest area and quality?

Reasons for area changes	**Reasons for quality changes**

22. Who is responsible for the management of forest in your area? 1=Kenya Forest Service; 2=Kenya Wildlife Service; 3=Local Community Groups; 4=Other (specify)__________ [CIRCLE APPLICABLE]
23. Is the conservation of this forest important to you? Yes/No
24. If **YES**, what are the specific aspects of forest conservation that are important to you? ....
....
25. If **NO,** why?..
....
26. What is your overall satisfaction with the way forest is managed in your area?
1=Very Dissatisfied; 2= Dissatisfied; 3=Neutral; 4= Satisfied; 5=Very Satisfied.
27. What are the reasons for your satisfaction rating above? [CIRCLE APPLICABLE]
1= Involves local community; 2=Strictly protects the forest from destruction;
3=Responsive when informed of destructive activities within the forest;
4=Allows local community to access products/benefits from the forest; 5= Other..............................
28. In your perspective as a resident, how would rate the following features of forest management in your area?

Management feature	**Ranking** 1=V. Poor; 2= Poor; 3=Neutral; 4= Good; 5=V. Good
Local community participation in decision-making	
Making of extraction rules, e.g. determination of access fee and permits	
Making of enforcement rules	
Preservation of certain unique areas of the forest	
Clarity of rules	
Directness of the rules i.e. are all rules of forest extraction clear to you?	
Enforcement of rules i.e. is there punishment if one disobeys the rules?	
Agreement with level of forest extraction allowed	
Promotion of environmental conservation programs	
School/church outreach activities	
Environmental enlightening programs, e.g. tree-planting days	
Provision of alternatives to forest extraction	
Promotion of energy-saving technologies, e.g. improved 'jikos'	
Provision of tree seedlings for farm forestry	
Promotion of alternative sources of income e.g. bee-keeping	
Provision of forest conservation incentives	
Provision of employment to the local people	
Share of park earnings with local community	
Prevention of wildlife damage to crops and livestock	
Resolution of conflicts	
Having mechanisms for conflict resolution, e.g. meetings	
Timely resolution of wildlife-human conflict	
Compensation given for crop or livestock damage	

29. What are your suggestions to enhance management of the forest in your area? ....
....
30. How can the benefits from this forest to the local people be improved? ....
....
....
31. What is the **average daily wage** rate for labour in **cropping activities** in this area? Ksh. ___________
32. What is the **average monthly wage rate** for **labour** in **livestock** activities in this area? Ksh. ___________
33. What is the **typical number of hours** worked **per day**? _______hours.

Appendix A3: Questionnaires for domestic and international visitors to Kakamega National Forest Reserve at Buyangu Park

Appendix A3 (i): Valuing Recreational Service Provided by Parks within Kakamega Forest

<u>Domestic Tourists</u> Date_________________

Dear respondent,
Kakamega forest forms a unique ecosystem that contains highly threatened biodiversity and is important in supporting local livelihoods in the surrounding area. Currently the forest is threatened by environmental degradation partly linked to increasing population around it. There is need to obtain a better insight in the various benefits the park provides including the contribution to tourism.

We kindly request you to answer the following questions that will enable us to get a better understanding of the value of the forest. The data of this questionnaire will be used for my PhD research at Wageningen University, the Netherlands.

Thank you so much for your co-operation.

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1. Where is the location of your home? District/County______________________
2. What is the approximate distance covered to reach this park?____________ km
3. How much time did you spent to travel to this park? ________hrs.
4. Did you enjoy the travel to the park / consider this to be part of the recreational experience? Yes/No [CIRCLE APPLICABLE]
5. Apart from visiting this park, what are your other reasons for the trip?
____
____
6. How many times have you visited this park during the past one year? ________and during the past 10 years?________________
7. How much entry fee are you charged in this park per visit? __________
8. How do you rate the entry charges at this park? 1= Cheap; 2= Reasonable; 3 =Expensive [CIRCLE APPLICABLE]

9. How much time do you intend to spent at this park during this visit? ________ hours.
10. What services did you pay for in the park and at what cost? [FILL IN TABLE]

Type of service	**Cost**	**Quality rating** (Poor/Fair/Good)
Guide		
Park information		
Camping		
Other (specify)________		

11. How much of each specific cost did you incur in travel expenses **within Kenya** on your trip to this park?

Type of cost	**Amount (indicate currency)**
Public transport	
Own expenses	
Car hire	
Flight	
Other (specify)____________	

12. On a scale of 1-5 [where: 1= Very poor; 2 = Poor; 3= Fair; 4 =Good; 5= Very good], how would you rate the quality of recreational experience at this park? [CIRCLE APPLICABLE].
13. How would you describe the overall environmental quality in this park? 1= Very Poor; 2 = Poor; 3= Fair; 4 =Good; 5= Very Good [CIRCLE APPLICABLE].
14. What are the main reasons for your answer above?

____

____

15. What are your suggestions to enhance recreational value of this forest?

____

____

16. In your view, how much **additional** demand from domestic tourists is there for improved recreational service of this forest? 1= None; 2= Low; 3= Moderate; 4= High; 5= Very High [CIRCLE].
17. How much **more** entry fee are you willing to pay for improved recreational service at this park? __

Appendix A3 (ii): Valuing Recreational Service Provided by Parks within Kakamega Forest

International Tourists Date_______________

Dear respondent,
Kakamega forest forms a unique ecosystem that contains highly threatened biodiversity and is important in supporting local livelihoods in the surrounding area. Currently the forest is threatened by environmental degradation partly linked to increasing population around it. There is need to obtain a better insight in the various benefits the park provides including the contribution to tourism.

We kindly request you to answer the following questions that will enable us to get a better understanding of the value of the forest. The data of this questionnaire will be used for my PhD research at Wageningen University, the Netherlands.

Thank you so much for your co-operation.

Morgan Mutoko, KARI Kitale, KENYA.
Mobile: +254 732 677 892, +254 721 593 111
E-mail: mmutoko@gmail.com; morgan.mutoko@wur.nl.

1. Where is the location of your home? City________________Country_____________
2. How much time did you spent to travel to this park? _________hrs.
3. Did you enjoy the travel to the park / consider this to be part of the recreational experience? Yes/No [CIRCLE APPLICABLE]
4. If **YES**, give some examples of recreational experience you had on the way to this park.

   ____

   ____
5. Apart from visiting this park, what are your other reasons for the trip?

____

____

6. How many times have you visited this park during the past one year? _________and during the past 10 years?_________________
7. How much park entry fee are you charged per visit? ___________
8. How do you rate the entry charges at this park? 1= Cheap; 2= Reasonable; 3 =Expensive [CIRCLE APPLICABLE]
9. What services did you pay for in the park and at what cost? [FILL IN TABLE]

Type of service	**Cost**	**Quality rating** (Poor/Fair/Good)
Guide		
Park information		
Camping		
Other (specify)_________		

10. How much of each specific cost did you incur in travel expenses **within Kenya** on your trip to this park?

Type of cost	**Amount (indicate currency)**
Public transport	
Own car fuel	
Own car repairs	
Car hire	
Driver hire	
Flight	
Other (specify)_____________	

11. On a scale of 1-5 [where: 1= Very poor; 2 = Poor; 3= Fair; 4 =Good; 5= Very good], how would you rate the quality of recreational experience at this park? [CIRCLE APPLICABLE].
12. How would you describe the overall environmental quality in this park? 1= Very Poor; 2 = Poor; 3= Fair; 4 =Good; 5= Very Good [CIRCLE APPLICABLE].
13. What are your suggestions to enhance recreational value of this forest?

____

____

14. In your view, how much **additional** demand from international tourists is there for improved recreational service of this forest? 1= None; 2= Low; 3= Moderate; 4= High; 5= Very High [CIRCLE APPLICABLE].
15. How much **more** entry fee are you willing to pay for improved recreational service at this park? _________
16. How much money did you spent on travelling expenses (including flight, visa, taxi costs) to Kenya? __________________ [SPECIFY CURRENCY]
17. How long is your total holiday stay in Kenya? _________days.
18. How many days have you stayed/ intend to spend visiting in Kakamega forest? _____ days.
19. Was touring Kakamega forest one of the motivations for you to come to Kenya? Yes/No [CIRCLE APPLICABLE].

20. Are there other alternative sites outside Kakamega forest that you might visit instead of this one? Yes/No [CIRCLE APPLICABLE].
21. During this trip, did you visit/do you intend to visit other locations apart from Kakamega forest? Yes/No [CIRCLE APPLICABLE].
22. If **YES**, fill in the table appropriately

Name of alternative site	**Travel distance to site** (Km)	**Time to site** (Hrs.)

23. How do you **rate recreational value** of Kakamega forest compared to that of other parks you have visited in Kenya? 1= Lower; 2=Same; 3= Higher [CIRCLE APPLICABLE].
24. How much expenses do you incur **daily during this trip** in Kenya

Item	**Average costs per day** (specify currency)	**Extra explanation**
Hotel in Nairobi		
Hotel in other parts of Kenya		
Meals & refreshments		
Souvenirs		
Transport		
Others....................................		

THANK YOU SO MUCH FOR YOUR TIME AND RESPONSES. THE INFORMATION YOU HAVE PROVIDED WILL BE TREATED CONFIDENTIALLY AND USED FOR RESEARCH PURPOSES ONLY.

Appendix A4: Questionnaire for key stakeholders

Name of organisation/area______________________**Respondent**__________________

1. How important is the promotion of sustainable land management in your organisation/area? Give examples..
....
....
2. What main programs/activities have you implemented that contribute to sustainable land management in this region during the past 10 years?..
....
....
3. What other organisations or local stakeholders have you actively involved during the implementation of such programs/activities?...
....
4. How did these organisations or local stakeholders collaborate with you?..
....
....
5. On a scale of 1-5, where 5 is the highest, how would rate the overall extent of stakeholder involvement in the implementation of the programs/activities mentioned above? ....
6. What synergies has the implementation of your programs/activities gained from the other stakeholders whom you collaborate with?...
....

7. How would you rate the overall success level (in %) of the programs/activities that promote sustainable land management implemented by your organisation/in your area?..
8. What are the key factors that influence the success of the SLM programs/activities?.......................................
....
....
9. In your opinion, what new strategies would guarantee successful implementation of programs/activities to ensure sustainable use of resources in this region?...
....
....
10. How can such new strategies be implemented differently at the local level to achieve sustainable use of resources in this region?...
....
....

THANK YOU SO MUCH FOR YOUR TIME AND RESPONSES. THE INFORMATION YOU HAVE PROVIDED WILL BE TREATED CONFIDENTIALLY AND USED FOR RESEARCH PURPOSES ONLY.

Appendix B1: Supplementary analyses

Table B-1: PostHoc test on mean differences of selected variables across farm types in Vihiga District

Dependent variable	(I) Base: Farm Type 1			
	(J) Farm Type	Mean difference (I-J)	Std. Error	Sig.
Total food crops output (kg)	Farm Type 2	(363.4)**	115.1	0.02
Total farmed area (ha)	Farm Type 4	(0.34)**	0.1	0.03
Fertiliser applied (kg)	Farm Type 2	(26.9)**	9.6	0.04
Annual income from farming (KES)	Farm Type 2	(22215)***	4916	0.00
	Farm Type 3	(16934)**	5466	0.02
	Farm Type 4	(29790)***	5376	0.00
Annual non-farm income (KES)	Farm Type 2	202791***	16210	0.00
	Farm Type 3	74445***	18021	0.00
	Farm Type 4	123197***	17725	0.00
	Farm Type 5	180488***	22061	0.00
Proportion of off-farm income in total income (%)	Farm Type 2	79.0***	2.1	0.00
	Farm Type 3	12.1***	2.3	0.00
	Farm Type 4	27.6***	2.3	0.00
	Farm Type 5	46.6***	2.8	0.00
Per capita daily income (KES/person)	Farm Type 2	45.9***	7.5	0.00
	Farm Type 5	42.6***	10.2	0.00
Farm area *per capita* (ha/person)	Farm Type 2	(0.065)***	0.02	0.00
	Farm Type 4	(0.068)***	0.02	0.00
Formal education (years)	Farm Type 2	3.0***	0.7	0.00
Household size (# members)	Farm Type 2	2.7***	0.6	0.00
	Farm Type 4	1.8**	0.6	0.04

Asterisks indicate significant mean differences: **p = 0.05, *** p = 0.01 levels.

Table B-2: Analysis of variance (ANOVA) on selected variables as explained by farm type classification in Vihiga District

Dependent variable	Source of Variation	Sum of Squares	D.F	Mean Square	F-statistic	Sig.
Efficiency in maize-bean production (%)	Between groups	4.5E+03	4	1.1E+03	1.88	0.12
	Within groups	1.4E+05	226	6.0E+02		
	Total	1.4E+05	230			
Total food crops production (kg)	Between groups	4.7E+06	4	1.2E+06	3.07	0.02
	Within groups	8.9E+07	231	3.8E+05		
	Total	9.4E+07	235			
Total area under farming activities (ha)	Between groups	4.1	4	1.0	3.12	0.02
	Within groups	7.6E+01	231	0.3		
	Total	8.0E+01	235			
Total labour cost (KES/ha)	Between groups	4.2E+08	4	1.1E+08	2.35	0.06
	Within groups	1.0E+10	228	4.5E+07		
	Total	1.1E+10	232			
Total amount of fertiliser applied (kg)	Between groups	2.9E+04	4	7.2E+03	2.69	0.03
	Within groups	6.1E+05	231	2.7E+03		
	Total	6.4E+05	235			
Total amount of manure used (kg)	Between groups	1.9E+07	4	4.7E+06	1.88	0.11
	Within groups	5.8E+08	231	2.5E+06		
	Total	6.0E+08	235			
Farm production orientation (% of produce sold)	Between groups	7.8E+03	4	2.0E+03	3.89	0.00
	Within groups	1.2E+05	229	5.0E+02		
	Total	1.2E+05	233			
Total annual income from farming (KES)	Between groups	2.4E+10	4	5.96E+09	8.51	0.00
	Within groups	1.6E+11	231	7.01E+08		
	Total	1.9E+11	235			
Total annual non-farm income (KES)	Between groups	1.4E+12	4	3.42E+11	44.93	0.00
	Within groups	1.8E+12	231	7.62E+09		
	Total	3.1E+12	235			
Off-farm income in total household income (%)	Between groups	2.3E+05	4	5.7E+04	460.91	0.00
	Within groups	2.8E+04	231	1.2E+02		
	Total	2.5E+05	235			
Per capita daily income (KES/person)	Between groups	8.9E+04	4	2.2E+04	13.62	0.00
	Within groups	3.8E+05	231	1.6E+03		
	Total	4.7E+05	235			
Farm available per family member (ha/person)	Between groups	0.2	4	0.0	5.13	0.00
	Within groups	1.8	231	0.0		
	Total	1.9	235			
SWC measures on the plot (#)	Between groups	9.0	4	2.3	1.22	0.30
	Within groups	3.6E+02	197	1.8		
	Total	3.7E+02	201			
Tropical livestock units (TLU) owned	Between groups	3.0E+01	4	7.5	3.78	0.01
	Within groups	4.6E+02	231	2.0		

Appendix B2: Validation points and histogram plots of the 2009 training areas used in ground-truth of remote sensing analysis

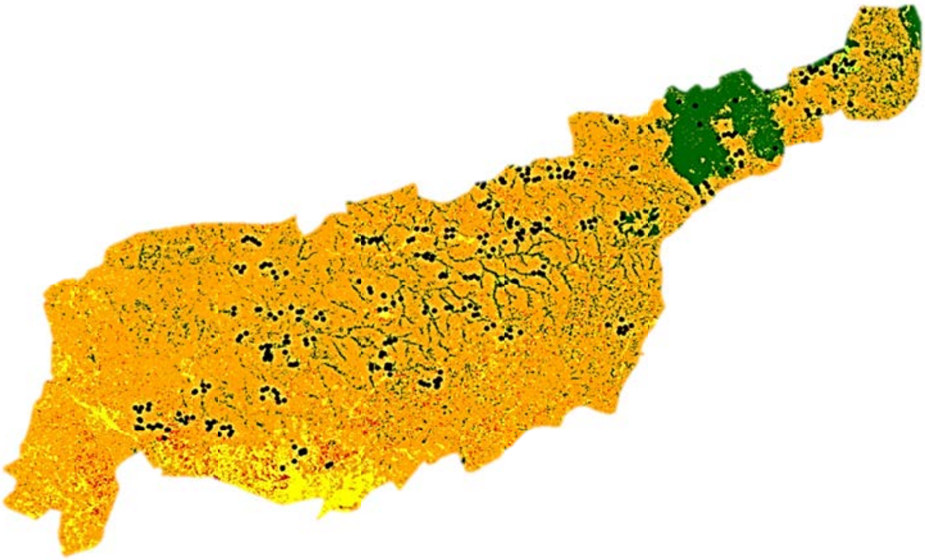

Figure B-1: Random validation points (dark dots) superimposed on the 2009 Landsat classified image

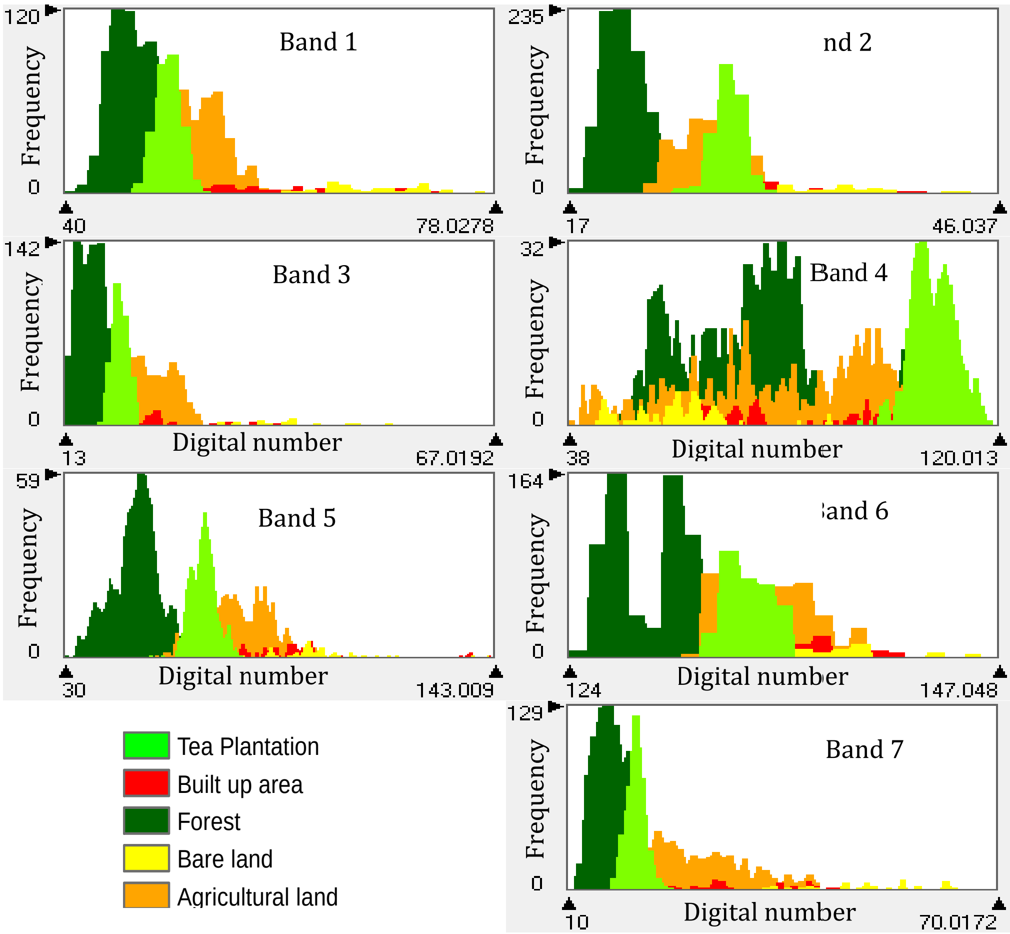

Figure B-2: Histogram plots of the 2009 training areas averaged per land-use/cover class showing some overlap between classes especially with spectral similarity because of the high spatial variation in the study area

Summary

Sustainable Land Management in Dynamic Agro-Ecosystems: An Integrated, Multi-Scale Socio-Ecological Analysis in Western Kenya Highlands

This study was motivated by the puzzlingly localised implementation of available Sustainable Land Management (SLM) practices despite the urgent need to reduce both land degradation and general poverty levels in the western highlands of Kenya. In this thesis therefore, I aimed to not only unravel reasons for the restricted geographical diffusion of SLM practices but also make concrete contributions to foster the promotion of SLM practices. The broad context of this research is that land degradation continues to affect rural livelihoods across sub-Saharan Africa (SSA). I describe the land degradation problem and review earlier empirical attempts to unravel the underlying drivers. I demonstrate that most of SSA countries still face further population growth in the coming decades and it is essential to increase food production in rural areas. Besides, ecosystem services provided by tropical forests are becoming scarcer due to continued deforestation as demand for forest benefits increases with growing population (Chapter 1). However, development programs to enhance land productivity have achieved only localised impacts. I then justify why the investigation focusses on Vihiga District, one of the most densely populated rural areas in SSA. In addition, I argue that promoting SLM practices requires a thorough understanding of land-use change drivers, processes and welfare effects. The challenge is that in most African countries reliable data for such investigations are scanty. Nevertheless, the application of SLM practices is essential to lessen the negative impacts of land degradation on rural welfare in SSA's agro-ecosystems. Moreover, there is need for comprehensive, integrated information in order to inform policy and implement better management systems to enhance agricultural productivity and supply of essential ecosystem services. Thus it is essential to explore the potential role that collaboration of diverse stakeholders could play in scaling-up of SLM technologies across multiple scales. I therefore formulate specific research objectives and questions, and design an integrated, multi-scale socio-ecological systems framework to address these issues. In addition, I present a detailed description of geophysical and socio-economic characteristics of the study area in the western highlands of Kenya. Generated study results are subsequently contained in empirical Chapters 2–5 and a synthesis of the key findings based on this study's scientific evidence are presented in Chapter 6.

In Chapter 2, I investigate at farming system level, households' responses to a changing agro-environment. The specific objective is to analyse farm diversity and resource use efficiency and their implications for promoting SLM practices in the western highlands of Kenya. I carried out an elaborate survey of 236 households, applied multivariate analyses to analyse farm efficiency and livelihood strategies. Results show major differences in responses to a changing agro-environment between five farm types in terms of resource endowment, income strategies and farm practices. Across farm types, efficiency was low (only 40% on average) indicating poor land productivity. Empirical findings show a lack of intensification in land use and that households are increasingly depending on off-farm income opportunities such as petty businesses, formal employment and to some extent remittances. I draw insights with practical implications on programs that aim to promote sustainable land management in SSA. I propose that successful implementation of such programs requires targeting areas

highly reliant on agriculture and within these areas focus on households mostly dependent on farming to sustain their welfare. I postulate that better targeting is likely to enhance the application of SLM practices, boost agricultural productivity and improve rural livelihoods. This is most important especially for agrarian livelihoods in the light of agro-based economies and prospects for an ever-increasing population growth in SSA.

Chapter 3 focusses on ecosystem analysis of Kakamega forest in relation to prospects for scaling-up SLM practices for natural resources. I adopt an ecosystem services approach to estimate local economic value of 10 ecosystem services provided by Kakamega rainforest and examine how the information can support sustainable forest management in Kenya as a whole. This is the only rainforest in Kenya. It has high biodiversity value and provides a classic case of conflict between conservation and exploitation goals given the dense population around it. I carried out elaborate surveys of 240 forest-adjacent households and 209 recreational visitors, to collect data used to estimate the economic value of 10 ecosystem services. I estimated the local economic value of key ecosystem services (excluding biodiversity value and CO_2 sequestration) at about US$ 8 million per year or around US$ 450 ha^{-1} yr^{-1}. The local economic benefits are considerably less than the forgone returns from agricultural activities if the forest were to be converted. Arguably, continued protection of this forest is justified because of the unknown value of its rich biodiversity and huge stored carbon in its system, which does not generate local economic benefits. This research found that the existing forest management system was less effective due to resource constraints and institutional weaknesses. These new results provide insights for the need to manage this forest for multiple uses. I recommend an integrated management strategy to balance local resource needs with biodiversity conservation. I suggest that improved stakeholder collaboration be facilitated within the transition management framework. Besides, carefully crafted Payment for Ecosystem Services mechanisms and broad environmental education programs can support sustainable forest conservation for this and other similar forest ecosystems in SSA.

I test an integrated approach to analyse land use dynamics and impacts on agrarian livelihoods in Chapter 4, by combining remote sensing images, an in-depth quantitative survey, stakeholder interviews and local statistics. I analyse land dynamics and agricultural production over a 25-year period at the district system level. Specifically, I examine how land use has changed in this period, the main drivers for land use change and the main effects of these changes on agricultural production. Study findings show that Vihiga District has undergone rapid land use change in the past 25 years. In particular, there has been a major conversion of forest and bare land to agricultural land use. Often, it is stated that increasing population pressure triggers agricultural intensification; however, we found little evidence of such a process in the study area. Results clearly show that productivity of tea and to a lesser extent, vegetables increased but the yields of maize and beans—the most common crops—oscillated around 1 ton ha^{-1}. As a result, *per capita* food crop production dropped by 28% during the past two decades. Empirical findings demonstrate that high and increasing population pressure on land does not necessarily lead to agricultural intensification. Therefore, there is a need to more explicitly consider off-farm income in rural development and land management policies and projects in similar agro-ecosystems of SSA.

Chapter 5 presents an integrated approach to assess prospects for a technological transition in the study area. I follow inter-disciplinary approaches to evaluate local potentials for wider promotion of SLM practices in the western highlands of Kenya. I assess conditions for initiating collaborative action towards improved agricultural productivity and sustainable

forest conservation, using an adapted multi-level framework. Findings from this study reveal that only 10% of farmers are properly implementing the available SLM practices. Agricultural productivity is low and there is high dependence on benefits extracted from the forest resource. A positive correlation (rho = 0.83) was found between stakeholder co-operation and the success level of past SLM projects. Results clearly show reasonable prospects such as some technology adoption activities and organisation of local actors that are necessary for triggering the transformation process to sustainable state of productivity. Nevertheless, technological transition could likely succeed if facilitated by enhanced stakeholder collaboration, a supportive policy environment and substantial resource mobilisation. I suggest the application of a context-specific transition management approach in this area in order to learn lessons on governance of transformative environmental programs for similar socio-ecological systems in SSA.

Based on synthesis of the key findings (presented in Chapter 6), I conclude that the difficulty of achieving wider geographical diffusion of SLM practices in the western highlands of Kenya can be attributed to four main reasons. First, there is a practical challenge to properly target the technologies to the right farming households in order to achieve the greatest impacts. Second, the rampant decrease in productive resources (land, capital and labour) for farm production coupled with low efficiencies in common farm enterprises has created an additional aspect of poverty traps—a 'maize-centred' poverty trap—making it difficult for a majority of farmers to invest meaningfully in SLM practices. Third, increasing pressure on land from population growth has failed to stimulate better land management practices and efficient resource use in agriculture possibly because the community attempts to make for the shortfall from off-farm activities or by accessing the almost free forest resources where available in the district. Finally, the low collaboration level among key stakeholders involved in promotion of various components of SLM practices indicates a thin spread of efforts on the ground and unexpectedly delays an accelerated technological transition process. Therefore, I recommend a paradigm shift to embrace a broader, integrated and multi-stakeholder approach to solving the problem of land degradation in the study area and other similar agro-ecosystems in SSA; an approach that equally promotes improved farm productivity and creates off-farm income opportunities.

Samenvatting

Duurzaam landbeheer in dynamische agro-ecosystemen: een geïntegreerde, meerschalige sociaalecologische analyse in de hooglanden van west Kenia

Deze studie wordt gemotiveerd door de verassende lokale implementatie van beschikbare duurzame landbeheer (SLM) praktijken, ondanks de dringende noodzaak om zowel landdegradatie als het algehele armoedeniveau te verminderen in de hooglanden van west Kenia. Daarom zijn in dit proefschrift niet alleen de oorzaken voor de beperkte geografische verspreiding van SLM praktijken ontrafeld, maar is tevens geprobeerd om een concrete bijdrage te leveren aan de bevordering van SLM praktijken. De brede context van dit onderzoek is dat landdegradatie het levensonderhoud in heel sub-Sahara Afrika (SSA) aantast. Wij beschrijven het landdegradatieprobleem en becommentariëren eerdere empirische pogingen om de onderliggende oorzaken te ontrafelen. We laten zien dat de bevolkingsgroei in de meeste SSA landen in de komende decennia het noodzakelijk maakt dat de voedselproductie in rurale gebieden stijgt. Bovendien worden ecosysteemdiensten uit tropische bossen schaarser als gevolg van ontbossing, veroorzaakt door de stijgende vraag naar bosproducten door de groeiende bevolking (Hoofdstuk 1). Ontwikkelingsprogramma's met het doel om de agrarische productiviteit te vermeerderen hebben echter alleen lokale effecten bewerkstelligd. Ons onderzoek richt zich op het Vihiga district, één van de dichtstbevolkte rurale gebieden in SSA. De bevordering van SLM praktijken vereist een grondige kennis van de oorzaken en gevolgen van landgebruiksveranderingen, van de onderliggende processen en van welzijnseffecten. Een onderzoeksuitdaging is dat data hierover schaars is in meeste SSA landen. Desondanks is de uitvoering van SLM praktijken hier essentieel voor het verminderen van negatieve gevolgen van landdegradatie op ruraal welzijn in agro-ecosystemen. Daarnaast is er behoefte aan uitgebreide, geïntegreerde informatie om beleid te informeren en betere management systemen te implementeren, waardoor de productiviteit van de landbouw en de levering van essentiële ecosysteemdiensten verbeterd. Het is van essentieel belang om te verkennen welke mogelijke rol de samenwerking van de verschillende belanghebbenden kan spelen bij opschaling van lokaal naar regionaal van SLM technologieën. Daarom hebben we specifieke onderzoeksdoelstellingen en vragen geformuleerd en ontwierpen we een kader van geïntegreerde, meerschalige sociaal-ecologische systemen om deze problemen te bestuderen en te begrijpen. Daarnaast beschrijven we indetailde geofysische en sociaal-economische kenmerken van de westelijke hooglanden van Kenia. De empirische onderzoeksresultaten worden vervolgens beschreven in hoofdstukken 2-5. Een synthese van de belangrijkste bevindingen op basis van ons wetenschappelijke onderzoek wordt gepresenteerd in hoofdstuk 6.

In hoofdstuk 2 onderzoeken we op landbouwsysteemniveau de reacties van huishoudens op een veranderende agrarische omgeving, en de praktische implicaties voor de bevordering van SLM praktijken. De specifieke doelstelling is het analyseren van landbouwdiversiteit, de efficiëntie van het gebruik van hulpbronnen en de implicaties hiervan voor het bevorderen van SLM praktijken in de hooglanden van West-Kenia. We hebben een uitgebreide enquête uitgevoerd bij 236 huishoudens. Op de resulterende data hebben we multivariate analyses toegepast om de landbouwefficiëntie en kostwinningstrategieën te analyseren. Grote verschillen in de reacties op de veranderende agrarische omgeving zijn gevonden tussen vijf verschillende productiesystemen. Deze hebbenbetrekking tot resource endowment, inkomensstrategieën en landbouwmethoden. Voor alle productiesystemen was de efficiëntie laag (gemiddeld maar 40%), wat een lage productiviteit van de landbouwgrond aangeeft. Onze bevindingen tonen een gebrek aan landgebruiksintensivering en een toenemende afhankelijkheid van huishoudens op inkomstenmogelijkheden van buiten de landbouw, zoals kleinschalige bedrijven, formele werkgelegenheid, en tot op zekere hoogte armoede- en productieterugval. Onze inzichten hebben praktische implicaties voor programma's die zich richten op het bevorderen van SLM in SSA. Wij stellen dat er voor een succesvolle uitvoering, dergelijke programma's zich moeten richten op gebieden die sterk afhankelijk zijn van landbouw. Binnen deze gebieden moet de focus liggen op huishoudens die afhankelijk zijn van landbouw voor hun welzijn. Wij stellen dat een gerichtere focus de uitvoering van SLM praktijken bevordert, de landbouwproductiviteit verhoogt en rurale kostwinning verbetert. Vooral voor agrarische kostwinning is dit erg belangrijk in het kader van agrarische economieën en de toenemende bevolkingsgroei in SSA.

Hoofdstuk 3 richt zich op een ecosysteemanalyse van het Kakamega bos in relatie tot de mogelijkheden om SLM praktijken op te schalen naar natuurlijke hulpbronnen. We passen een ecosysteemdiensten benadering toe om de lokale economische waarde van tien ecosysteemdiensten van het Kakamega regenwoud te schatten. We bestuderen hoe deze informatie duurzaam bosbeheer kan ondersteunen in heel Kenia. Het Kakamega bos is het enige regenwoud in Kenia. Het heeft een hoge biodiversiteitswaarde en kan worden beschouwd als een klassiek conflict tussen natuurbehoud en exploitatie doeleinden, teweeggebracht door de hoge bevolkingsdichtheid rondom het bos. We hebben uitgebreide enquête uitgevoerd bij 240 huishoudens rondom het bos en 209 recreanten, om data te verzamelen om de economische waarden van de verschillende ecosysteemdiensten te schatten. We schatten de lokale economische waarde van de belangrijkste ecosysteemdiensten (met uitzondering van biodiversiteit en CO_2-opslag) op ongeveer US$ 8 miljoen per jaar, of ongeveer US$ 450 per hectare en per jaar. Het lokale economische profijt is aanzienlijk lager dan de gederfde opbrengsten van agrarische activiteiten als dat bos zou zijn omgezet. De voortzetting van de bescherming van het bos wordt gerechtvaardigd door de onbekende waarde van de rijke biodiversiteit en de enorme hoeveelheid opgeslagen koolstof in het systeem, die geen lokaal economisch gewin genereren. Onze bevindingen wijzen uit dat het bestaande bosbeheersysteem minder effectief is door een gebrek aan middelen en institutioneletekortkomingen. Onze nieuwe resultaten geven inzicht in de noodzaak om multifunctioneel bosbeheer toe te passen. Wij bevelen een geïntegreerde beheerstrategie aan om een balans aan te brengen tussen de lokale behoefte aan natuurlijke hulpbronnen en het behoud van biodiversiteit. Wij stellen dat verbeterde samenwerking tussen belanghebbenden gefaciliteerd kan worden door het transitiemanagement framework. Bovendien kunnen zorgvuldige betalingen voor Ecosysteemdiensten mechanismes en breed opgezette milieueducatie programma's bijdragen aan duurzaam bosbeheer voor Kakamega en soortgelijke bosecosystemen in SSA.

In hoofdstuk 4 testen wij een geïntegreerde aanpak om landgebruik dynamiek en impacts op agrarische kostwinning te analyseren met een combinatie van remote sensing beelden, diepgaand kwantitatief surveyonderzoek, interviews met belanghebbenden en lokale statistieken. We analyseren landdynamiek en landbouwproductie over een tijdspanne van 25 jaar voor het Vihiga district. In het bijzonder, onderzoeken we hoe het landgebruik is veranderd in deze periode, de belangrijkste drivers voor verandering in landgebruik en de belangrijkste effecten van deze veranderingen op de landbouwproductie. De Het district heeft snelle landgebruiksveranderingen ondergaan in de afgelopen 25 jaar. Er is met name op grote schaal bos en braakliggend terrein omgezet naar landbouwgrond. Vaak wordt gesteld dat toenemende bevolkingsdruk de intensivering van landbouw veroorzaakt, maar wij hebben hiervoor weinig bewijs gevonden. Onze resultaten wijzen uit dat de productiviteit van thee en in mindere mate groenten toenam, maar dat de oogst van maïs en bonen – de meest verbouwde gewassen – rond 1 ton per hectare schommelde. Derhalve, is de *per capita* productie van voedingsgewassen met 28% gedaald over de afgelopen twee decennia. We tonen aan dat hoge en toenemende bevolkingsdruk niet noodzakelijkerwijs zal leiden tot intensivering van de landbouw. Daarom moeten inkomsten van buiten de landbouw nadrukkelijker worden meegenomen in rurale ontwikkeling en landbeheerbeleid en -projecten in soortgelijke agrarische ecosystemen in SSA.

In hoofdstuk 5 wordt een geïntegreerde aanpak gepresenteerd om een technologische transitie in het studiegebied te bewerkstelligen. We gebruiken een interdisciplinaire benadering om de lokale mogelijkheden voor een bredere bevordering van SLM praktijken in de westelijke hooglanden van Kenia te evalueren. We beoordelen door middel van een aangepast multi-level framework de voorwaarden voor het initiëren van gezamenlijke actie om gelijktijdig landbouwproductiviteit en duurzaam bosbeheer te bevorderen. Onze resultaten tonen aan dat slechts 10% van de boeren de beschikbare SLM praktijken naar behoren implementeert. De landbouwproductiviteit is laag en de afhankelijkheid van hulpbronnen uit het bos is hoog. Onze resultaten laten een positieve correlatie zien (rho = 0.83) tussen coöperatie van belanghebbenden en het succes van afgeronde SLM projecten. Om het transitieproces op gang te brengen en duurzame productie te bewerkstelligen, zijn positieve vooruitzichten, een zekere mate van technologieoverdracht en een goede organisatie van lokale actoren nodig. Een technologische transitie kan slagen als het wordt gefaciliteerd door verhoogde samenwerking tussen belanghebbende, een ondersteunende beleidsomgeving en een aanzienlijke mobilisatie van middelen. Wij stellen voor om een context-specifieke transitiemanagement aanpak toe te passen in dit gebied. De hierbij opgedane ervaring over governance van transformatieve milieuprogramma's kan worden gebruikt bij vergelijkbare sociaalecologische systemen in SSA.

Op basis van de synthese van de belangrijkste bevindingen (hoofdstuk 6), concluderen wij dat de beperkte geografische verspreiding van SLM praktijken in de westelijke hooglanden van Kenia toegeschreven kan worden aan vier oorzaken. Ten eerste bestaan er een praktische problemen om de juiste technologieën bij de juiste boerenhuishoudens te krijgen. Ten tweede is er een armoedeval ontstaan door een combinatie van de afname van productiemiddelen (land, kapitaal en arbeid) voor landbouw en de lage efficiëntie van een gemiddeld landbouwbedrijf. De 'maïs georiënteerde' armoedevalbelemmert de meerderheid van de boeren bij het investeren in SLM praktijken. Ten derde heeft de toegenomen druk van de groeiende bevolking niet geleid tot beter landbeheer en een efficiënter gebruik van beschikbare middelen. Mogelijk komt dit doordat de gemeenschap heeft geprobeerd hiervoor te compenseren met inkomsten van buiten de landbouw en door gebruik te maken van vrij toegankelijke hulpbronnen uit het bos. Ten slotte wijst de gebrekkige samenwerking tussen belanghebbenden, die betrokken waren bij de promotie van diverse onderdelen van SLM praktijken, erop dat er een dunne spreiding van inspanningen was in het veld. Dit heeft geleid tot onverwachte vertragingen van een versneld technologisch transitieproces. Wij adviseren een paradigmaverschuiving van naar een bredere, geïntegreerde, multi-stakeholder aanpak om landdegradatie problemen in het studiegebied en soortgelijke agrarische ecosystemen in SSA op te lossen. Zo'n aanpak moet zowel de landbouwproductiviteit verhogen als kansen voor inkomsten van buiten de landbouw bevorderen.

Muhtasari

Utunzaji Ardhi Endelevu kwa Mazingira Badilifu ya Kilimo: Uchanganuzi Jumuishi katika Nyanda za Juu, Magharibi mwa Kenya

Motisha ya utafiti huu ulitokana na tatizo la kutoenea kwa mbinu za utunzaji ardhi endelevu, licha ya hitaji la kupunguza kwa haraka uharibifu wa mazingira na viwango vya umaskini, katika nyanda za juu magharibi mwa Kenya. Kwa hivyo, lengo la tasnifu hii ni kung'amua vizuizi na pia kutoa mchango thabiti wa kueneza matumizi mapana ya mbinu hizo endelevu. Muktadha wa utafiti huu ni kuwa, mmomonyoko wa udongo na uharibifu wa mazingira unaendelea kuathiri maisha ya watu waishio vijijini kwenye nchi nyingi za Afrika, kusini mwa jangwa la Sahara. Nimeelezea tatizo la uharibifu wa mazingira na ili kuelewa visababishi vya tatizo hili, nimetathmini tafiti mbali mbali zilizokwishafanyika. Nimeonyesha kuwa nchi nyingi za Afrika bado zinakabiliwa na ongezeko kubwa la watu katika miongo ijayo na ni muhimu kuongeza uzalishaji wa chakula maeneo ya vijijini. Mbali na hilo, manufaa yatokanayo na misitu yanazidi kupungua kwa sababu ya ukataji miti unaoendelea na mahitaji yanayozidi kuongezeka kadri idadi ya watu inavyopanda (Sura ya 1). Bali mipango mingi ya maendeleo ya kilimo inayokusudia kuongeza tija imeonyesha mafanikio kwenye sehemu chache tu. Kwa hivyo, ninahalalisha sababu ya kufanya utafiti huu wilayani Vihiga; mojawapo ya wilaya yenye wingi wa wakaazi Afrika. Vilevile, ninatoa hoja kuwa ili kuwezesha usimamizi wa ardhi endelevu, tunahitaji kuelewa kwa kina mambo yanayosababisha mienendo ya matumizi ya ardhi, michakato na madhara yake kwenye ustawi wa jamii. Lakini changamoto kubwa inayokabili utafiti kama huu ni kuwa takwimu za uhakika ni chache katika nchi nyingi za Afrika. Hata hivyo, utunzaji wa ardhi endelevu ni muhimu ili kupunguza athari hasi za uharibifu wa ardhi katika kukidhi mahitaji ya maisha kwa wakaazi waishio vijijini katika nchi za Afrika. Mbali na hilo, kuna haja ya kuwa na taarifa jumuishi na za kina, ili kuwapasha habari watunga sera na kuwezesha utekelezaji wa mifumo yenye lengo la kuimarisha uzalishaji wa ardhi na utoaji wa manufaa yatokanayo na misitu. Hivyo basi, ni muhimu kuchunguza uwezekano wa kushirikisha wadau mbalimbali, ili kutathmini ni kwa namna gani tunaweza kuunda mifumo itakayowezesha kuenea kwa mbinu za kutunza ardhi endelevu katika ngazi mbambali. Ndio sababu nimebuni malengo na maswali ya utafiti huu na kutengeneza namna jumuishi, itakayoshirikisha mifumo ya kijamii na kiikolojia kushughulikia masuala hayo. Pamoja na hayo, nimetoa maelezo ya kina kuhusu sifa za kijografia, kijamii na kiuchumi katika maeneo ya utafiti, nyanda za juu magharibi mwa Kenya. Matokeo ya kitaalamu yamewakilishwa kwa kina kwenye Sura ya 2-5 na matokeo muhimu kutokana na ushahidi huo wa kisayansi yemejumuishwa katika Sura ya 6.

Katika Sura ya 2, kwa kuangalia mifumo ya kilimo, nimetafiti jinsi kaya zinavyokabiliana na mabadiliko kwenye mazingira ya kilimo. Lengo la utafiti huu ni kujua tofauti zilizopo baina ya kaya na matumizi ya rasilimali ikihusiana na inavyadhiri kuenea kwa utunzaji wa ardhi endelevu, kwenye maeneo ya miinuko ukanda wa magharibi mwa Kenya. Jumla ya kaya zipatazo 236 zilihusika kwenye hujaji. Nilitumia njia changanuzi ya rasilimali zilizopo, matumizi yake na jitihada mbali mbali za kumudu maisha, ili kujua ufanisi wa kilimo ikilinganishwa na jitihada mbadala za kumudu maisha katika ngazi ya kaya. Niligundua kuweko kwa tofauti kubwa kati ya aina tano za ukulima hasa uwepo wa rasilimali, mikakati ya kipato, na shughuli za kilimo kwa jumla. Karibu mashamba yote yameonyesha ufanisi mdogo (wastani wa asilimia 40 tu), ambayo inaonyesha uzalishaji mdogo kwa eneo. Matokeo haya yanadhihirisha kuwa hakuna jitihada za kutosha zinazoonyesha kujikita katika kuboresha kilimo na matumizi ya ardhi. Pia kaya nyingi sasa zinategemea shughuli nyingine kando na kilimo, kama vile biashara ndogo ndogo, ajira za kudumu na kwa kiasi fulani pesa kutoka kwa ndugu waishio nje ya kijiji. Nilitambua mambo mawili yenye umuhimu kwa utekelezaji wa miradi ya kuhamasisha juu ya utunzaji wa ardhi endelevu kwa nchi za Afrika. Kwa miradi hiyo kupata mafanikio makubwa, inastahili kutekelezwa ikilenga zaidi yale maeneo yanayotegemea sana kilimo. Halafu ndani ya maeneo hayo, kaya ambazo zinategemea kilimo zaidi ndizo zihusishwe kwa karibu katika utekelezaji wake. Nina uhakika ya kuwa kwa kulenga maeneo na kaya husika tutaimarisha utunzaji wa ardhi endelevu, uzalishaji kwa eneo na kuboresha hali ya maisha ya wanaotegemea kilimo na waishio vijijini. Hii ni muhimu sana hasa kwa familia zinazotegemea kilimo na itasaidia hasa katika kipindi cha ongezeko la watu barani Afrika.

Sura ya 3 inalenga uchanganuzi wa kiekologia katika msitu wa kipekee wa Kakamega na matarajio ya kuwezesha kuenea kwa utunzaji wa ardhi enedelevu kwa mali hii ya asili. Nimetumia utaratibu wa kukisia thamani ya uchumi wa ndani, kutokana na huduma 10 za kiekologia zinatolewa na msitu huu. Vilevile, nimechunguza kwa kina ni namna gani huu ufahamu unaweza kusaidia usimamizi wa misitu nchini Kenya. Huu ni msitu wa aina yake nchini Kenya. Una viumbe anuai wengi na kuna uwezekano wa mgongano kati ya malengo ya kuuhifadhi na mahitaji ya wananchi ambao idadi yao inaongezeka. Nilifanya utafiti uliohusisha hujaji ya kaya zipatazo 240 za wakaazi, wanaoishi karibu na msitu huu na watalii wapatao 209. Kupitia njia hii, nilikusanya takwimu ambazo zimesaidia kufanya makisio ya uchumi wa thamani ya huduma 10 za kiekologia. Nilikadiria thamani ya kiuchumi ya huduma muhimu kutokana na msitu huu (bila thamani ya bioanuwai na usafishaji wa hewa chafu ya kaboni), kama dola milioni 8 kwa mwaka au karibu dola zipatazo 450 kwa hectari kwa mwaka mmoja. Faida hizi za kiuchumi ziko chini ukilinganisha na faida yenye ingepatikana endapo sehemu ya msitu huu ungefanywa kuwa sehemu ya shughuli za kilimo. Huenda kuendeleza jitihada za kuulinda msitu ni muhimu tu kwa sababu ya thamani yenye haijulikani ya viumbe hai waliopo pamoja na uwezo wake mkubwa wa kuhifadhi kaboni. Lakini huduma hizi mbili muhimu hazitoi faida ya kuichumi kwa wakaazi wa eneo hili. Kupitia utafiti huu, niligundua kuwa mfumo wa sasa wa kusimamia msitu ni dhaifu kutokana na ukosefu wa rasilimali muhimu na udhaifu wa kitaasisi. Matokeo haya yanatoa mwanga kuwa kunahaja ya kusimamia hii rasilimali ya msitu ili kukidhi matumizi mbali mbali. Ninapendekeza usimamizi shirikishi wa msitu huu ili kusawazisha mahitaji ya rasilimali ya wenyeji wanaoishi karibu na jukumu la kuhifadhi bioanuwai. Kwa kuboresha ushirikiano baina ya wadau, mfumo wa usimamizi mzuri wa kipindi cha mpito unawetumika, pamoja na mipango mipana ya elimu ya mazingira na utaratibu wa kulipia huduma za mfumo wa ekolojia. Haya yakizingatiwa kwa njia hii, utunzaji endelevu wa misitu unaweza kufinikiwa hapa na kwingineko kwenye misitu kama huu barani Afrika.

Nimejaribu kutumia mkabala jumuishi kuchambua mienendo ya matumizi ya ardhi na athari zake kwa maisha ya wakulima katika Sura ya 4. Nimeoanisha picha za satelaiti, hujaji za kina za kaya, mahojiano na wadau na takwimu zilizopo kwenye ngazi mbali mbali nchini Kenya. Nimechanganua katika ngazi ya wilaya mienendo ya matumizi ya ardhi na uzalishaji wa kilimo kwa kipindi cha miaka 25. Hususan, nimeangalia ni kwa namna gani matumizi ya ardhi yamebadilika na kilichosababisha mabadiliko hayo pamoja na athari zake kwa kilimo na uzalishaji kwa ujumla. Niligundua kwamba mabadiliko makubwa ya matumizi ya ardhi yamefanyika wilayani Vihiga kwa kipindi cha miaka 25 iliyopita. Katika kipindi hicho, sehemu kubwa za msitu na ardhi iliyokuwa wazi ilibadilika na kuwa ya kilimo. Mara nyingi, inaelezwa kuwa ongezeko kubwa la watu linahamasisha matumizi ya ardhi kwa ufanisi, lakini dalili ya uhusiano huo haikuonekana katika eneo la utafiti. Matokeo ya utafiti huu yanaonyesha kuwa uzalishaji wa majani chai na kwa kiasi kidogo mazao ya mboga yaliongezeka, ila mavuno ya mahindi na maharagwe—mazao yanayokuzwa kwa kawaida—yaliegemea kwenye kiasi cha tani moja tu kwa hectari. Matokeo ya hali hii ni kwamba uzalishaji wa chakula ulishuka kwa asilimia 28 kwa kipindi cha miongo miwili iliyopita. Inaonekana kuwa, ongezeko na idadi kubwa ya watu kwa eneo sio lazima iongeze ufanisi katika uzalishaji wa kilimo. Kwa hiyo, kuna haja kubwa ya kuzingatia pia kipato kinachopatikana nje ya shughuli za kilimo, ili kufanikisha miradi ya maendeleo vijijini na sera zinazolenga utunzaji wa ardhi, kwenye maeneo mbali mbali yanayofana kimfumo wa kilimo na ikologia, barani Afrika.

Sura ya 5 inawakilisha mbinu mbadala, ya kuchangia matumaini mapya ya kufanikisha matumizi ya teknolojia kwenye eneo la utafiti. Nimefuata njia ya kuhusisha taaluma mbali mbali, ili kutathmini fursa zilizopo kwenye jamii za kuhamasisha kuenea kwa kasi utunzaji wa ardhi endelevu, magharibi mwa nchi ya Kenya. Ili kutathmini mazingira ambayo yanaweza kuboresha uzalishaji wa kilimo wenye tija na utunzaji wa misitu endelevu, nimetumia mfumo ambao utahusisha kuanzisha jitihada za pamoja, kwa ngazi mbali mbali. Utafiti huu umeonyesha kuwa ni asilimia 10 tu ya wakulima wote wanaotekeleza vizuri utunzaji wa ardhi endelevu eneo hili. Uzalishaji wa kilimo upo chini na kuna uharibifu unaotokana na kutegemea kwa kiwango kikubwa mafao yatokanayo na misitu. Nilipata uhusiano chanya (rho = 0.83) kati ya wadau kushirikiana na mafanikio ya miradi iliyohusu utunzaji wa ardhi endelevu iliyotekelezwa zamani. Nimegundua kuwa kuna matarajio ekevu, kama vile utekelezaji wa baadhi ya teknologia na kuhamasishwa kwa wadau mbali mbali, ambayo ni muhimu kwa kuleta msukumo na mabadiliko yatakayofikia hali endelevu ya uzalishaji na utunzaji wa aridhi. Hata hivyo, hatua hii itaweza kufikiwa kwa haraka na wepesi kama kutakuwa na ushirikiano mwema wa wadau, mazingira mazuri ya sera na upatikanaji wa rasilimali nyingi. Ninashauri kwamba, mfumo wa kusimamia mpito wa teknolojia unaozingatia hali halisi ya eneo hili la utafiti ufanyike, ili tujifunze usimamizi na utekelezaji wake kwa ajili ya kusaidia maeneo mengine kama haya barani Afrika.

Kulingana na ushahidi wa matokeo muhimu ya utafiti (yaliyowakilishwa katika Sura ya 6), ninahusisha ugumu uliopo wa kutoenea kwa kasi kwa teknolojia za utunzaji ardhi endelevu, katika nyanda za juu magharibi mwa Kenya, na sababu kuu nne. Kwanza, kuna changamoto ya kulenga vizuri teknolojia kwa kaya zenye mahitaji ili kuzikita na kutoa mafanikio makubwa. Pili, kupungua kwa kasi kwa rasilimali muhimu (ardhi, mitaji na nguvu kazi) za uzalishaji, pamoja na ufanisi mdogo katika shughuli za kilimo, umeongezea wimbi la umaskini—uliokikumba kilimo cha mahindi—ambao umewafanya wakulima wengi kushindwa kuwekeza kikamilifu katika utunzaji wa ardhi endelevu. Tatu, kuongezeka kwa idadi ya watu na mahitaji ya ardhi kumeshindwa kuchochea kilimo chenye ufanisi mkubwa, kwa sababu jamii inajaribu kuziba mwanya kutokana na mazao duni kwa kutegemea kipato nje ya kilimo au kutumia rasilimali za misitu ambazo zinapatikana bure. Mwisho, ushirikiano mdogo kati ya wadau katika ngazi zote, umechangia kutokuwepo kwa mshikamano wa kuleta msukumo wa kueneza teknolojia za utunzaji wa ardhi endelevu. Kwa hivyo, ninapendekeza mabadiliko ya mtazamo ili kuleta mtazamo mpana, wenye lengo na nia ya kuwahusisha na kuwaunganisha wadau mbali mbali, katika kutatua tatizo la uharibifu wa ardhi katika eneo la utafiti na sehemu zingine zenye mazingira yanayofanana kama haya katika nchi zingine za Afrika; jitihada ambazo zinahamasisha kilimo chenye tija pamoja na kuongeza fursa mbali mbali za kupata kipato nje ya kilimo.

Netherlands Research School for the
Socio-Economic and Natural Sciences of the Environment

C E R T I F I C A T E

The Netherlands Research School for the
Socio-Economic and Natural Sciences of the Environment
(SENSE), declares that

Morgan Chikamai Mutoko

born on 22 May 1977 in Lugari, Kenya

has successfully fulfilled all requirements of the
Educational Programme of SENSE.

Wageningen, 9 September 2013

the Chairman of the SENSE board

Prof. dr. Rik Leemans

the SENSE Director of Education

Dr. Ad van Dommelen

The SENSE Research School has been accredited by the Royal Netherlands Academy of Arts and Sciences (KNAW)

KONINKLIJKE NEDERLANDSE
AKADEMIE VAN WETENSCHAPPEN

The SENSE Research School declares that **Mr. Morgan Mutoko** has successfully fulfilled all requirements of the Educational PhD Programme of SENSE with a work load of 35 ECTS, including the following activities:

SENSE PhD Courses

- Environmental Research in Context
- Research Context Activity: Co- writing of publication on transdisciplinary effectiveness, entitled: *Integrated analysis of land use changes and their impacts on rural welfare in western highlands of Kenya*.
- Complex Dynamics in Human-Environment Systems

Other PhD and Advanced MSc Courses

- Advanced Econometrics
- Theories and Models in Environmental Economics
- Techniques for Writing and Presenting Scientific Papers

Management Skills Training

- Organisation of kick off workshop and local meetings with multiple stakeholders to foster promotion of Sustainable Land Management (SLM) practices in Western Kenya.

Oral Presentations

- *Soil Management and Technical Efficiency of Small scale Maize Farmers in North-western Kenya*. 11th KARI Biennial Scientific Conference, 10-14 November 2008, Nairobi, Kenya
- *Integrated analysis of landscape changes and livelihood effects in the western highlands of Kenya*. WOTRO Sustainable Land Management Project Workshop, 12-15 December 2011, Nairobi, Kenya
- *Agricultural intensification in Western Kenya: The role of farm diversity and resource use efficiency in the highland agro-ecosystems.* WOTRO Sustainable Land Management Project Workshop, 12-15 December 2011, Nairobi, Kenya

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About the Author

Morgan Chikamai Mutoko was born on the 22nd day of May 1977 in Mahanga Village, Lwandeti Location, Lugari District of Kenya. He entirely acquired his early education from local day-schools: Mahanga and Mayoyo Primary schools then Maturu Secondary School. After performing well in the Kenya Certificate of Secondary Education exams of 1995, he qualified for university admission. In 1997, he joined the University of Nairobi to pursue a Bachelor of Education (B.Ed) degree. Mutoko successfully completed his undergraduate studies and graduated in 2001 with a B.Ed (Hons) degree, Economics major and Geography minor.

The same year, he got a temporary job as a vacational employee with Kenya Agricultural Research Institute (KARI) and was posted to KARI Kitale station. Ten months later he was formally employed as an Assistant Research Officer, deployed in the Socio-Economics and Applied Statistics Research Program. Since then he has risen to the position of Research Officer 1 that he held at the time of writing this thesis.

In late 2005, he enrolled for a Collaborative Master's in Agricultural and Applied Economics (CMAAE) training program in the University of Nairobi, later specialising in Environment and Natural Resources Management at the University of Pretoria, South Africa. He successfully completed the CMAAE program and was awarded an MSc (Agricultural and Applied Economics) degree in 2008. In December 2008, he won a competitive PhD scholarship through a WOTRO-funded project to pursue further graduate studies at Wageningen University and Research Centre (WUR). On the 6th day of February 2009, Mutoko formally embarked on a sandwich PhD training program at WUR, under the supervision of the Environmental Systems Analysis group with local technical support provided by Kenyatta University. This thesis is the culmination of a 4-year period of rigorous training and supervised empirical research work.

Mutoko has special research interest in improvement of both rural livelihoods and environmental conservation, is an author of one book and (co-)author of several scientific publications (peer-reviewed conference papers and journal articles). He also 'randomly' teaches on various technical and general knowledge topics.

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