FARMER LIVELIHOODS STRATEGIES AND THE IMPACT OF AGROFORESTRY PRACTICES ON PARKLAND SYSTEMS IN KEDOUGOU SENEGAL

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ABSTRACT

FARMER LIVELIHOODS STRATEGIES AND THE IMPACT OF AGROFORESTRY PRACTICES ON PARKLAND SYSTEMS IN KEDOUGOU SENEGAL

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Farmers throughout West Africa have always faced adverse conditions and high vulnerability with regards to management of their agroecological systems, but climate change poses a new challenge to the sustainability of farming systems. Through field research conducted in the department of Kedougou in southwestern Senegal, I identified and analyzed livelihood strategies, and investigated the effects of climate change on farmer's management of their agroecological systems. Using the rural livelihood framework, I used focus group discussions to assess farmers' management approaches when facing climate related disturbances to agroecological systems. With the survey results, I used a regression model to analyze whether or not agroforestry has impacted farmer livelihood with regards to the valuation of on-farm activities through crop yields and livestock holdings. The lack of statistical significance from the regression model might point towards a lack of impact from agroforestry practices; however, the multiple co-benefits of agroforestry cannot be overlooked to reducing vulnerability. This study shows that West African farmers generally use approaches that enhance the resiliency of their agroecological systems to sustain their livelihoods when facing adverse environmental challenges, but that agroforestry has not shown to impact livelihoods in terms of production.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

AFS	Agroforestry Systems
ANACIM	National Agency for Civil Aviation and Meterology - *'Agence Nationale de l'Avion Civile et de la Météorologie'*
ANSD	National Agency for Statistics and Demographics - *'Agence Nationale de la Statistique et de la démographique'*
BCEAO	Central Bank of West African States – *'Banque Centrale des Etats de l'Afrique de l'Ouest'*
GHG	Greenhouse Gas
ICRAF	World Agroforestry Centre
NFTP	Non-Forest Timber Products
SD	System Dynamics
WFP	World Food Programme

CHAPTER 1. GENERAL INTRODUCTION

1.1. BACKGROUND AND RESEARCH CONTEXT

Climate change has emerged as a global environmental problem that has created many challenges for economic development. While climate change is a global problem affecting people from the international to local scale, rural farmers in developing countries face some of the greatest challenges to livelihood management due to climate change that will affect major aspects of everyday life. This is ever present across the Sudano-Sahelian and Guinean ecological zones in West Africa where contending with climate vulnerability and extreme weather events is the norm (Timberlake et al., 2010).

This study explores livelihood strategies and the impacts agroforestry has had on smallholder agroforestry systems in the region of Kedougou in southeastern Senegal. Going forward, it will be necessary for small-scale farmers to adapt to a changing climate to help reduce vulnerability to climate change while increasing food security and livelihood resiliency. Agroforestry as a cropping system has been proposed by many as a strategy to help decrease farmer vulnerability in the face of climate change (Mbow et al., 2014).

There is an ever-growing need to feed a larger population with the same amount of arable land while decreasing vulnerability and increasing food security. Local peoples whose livelihoods depend on subsistence farming face the challenge of altering their management practice through several pathways: land-use extension, intensification, diversification, or migration to meet their needs (Chidumayo & Marunda, 2010). With regards to farmers in West Africa, these four management responses lead to an adaptable and resilient livelihood strategy to continually meet the needs of a community in addition to other drivers of land-use change (Ros-Tonen et al., 2005).

To meet the future's growing needs, agriculture intensification, which is the increase of yields per area of cultivated land, is seen as an ideal response (Campbell et al., 2014; Petersen & Snapp, 2015). However, there is a need to increase yields without negatively impacting the environment; thus there is a need for sustainable intensification which is intensifying in an environmentally friendly way (Bommarco et al., 2013; Garnett et al., 2013). Agroforestry is seen as one pathway to sustainably intensify an agriculture system (Mbow et al., 2014). A more common response to growing settlements is land-use extension or extensification, which is the expansion of land to produce more goods or services (Kleemann et al., 2017). Lastly, diversification of production and livelihood outcomes is common and seen as integral management adaptation (Brookfield, 2001) while migration can be seen as a final effort to find other resources in the face of adversity (Tiffen et al., 1994).

1.2. RATIONALE AND RESEARCH OBJECTIVE

Kedougou is one of the most rural and impoverished regions in Senegal, making smallholder farmers more vulnerable to the effects of climate change (ANACIM et al., 2013). With over 70% of the population living in poverty, the majority of the population works in the agrarian sector in a subsistence capacity. Kedougou has a food insecure rate above the national average and one of the lowest diet diversities (WFP, 2014). Additionally, Kedougou has an increasing population due to a high birthrate (ANSD, 2015) and immigration from surrounding parts of West Africa due to a recent increase in interest of mineral extraction, predominantly gold (Diop, 2014).

Farmers in Kedougou will need to adapt or mitigate the negative effects of climate change to continue meeting the needs of their communities to thrive in the face of adverse conditions. Specifically, how farmers respond to system disturbance such as climate change has larger ramifications on regional and national level management policy and economic development goals through the effects of land-use change. Therefore, an analysis of farmer attitudes and responses to climate change is needed to assess the ability of communities to meet their livelihood needs.

In this research, I aim to explore how farmers in Kedougou manage, adapt, and respond to climate change in their livelihood strategies as well as the impacts of agroforestry on livelihoods. The major research question explored in this paper is:

-How are farmers actively adapting to the pressures of climate change to create a resilient agroecological system?

The two specific objectives of the study addressed in the following chapters are:

1. To conduct an analysis of agroforestry systems in the Kedougou region and assess how adaptive behavior affects management strategies regarding climate change
2. To determine how agroforestry has impacted farmer livelihoods through valuation of on farm activities

This study is laid out into five sections including the introduction (Chapter 1). Chapter 2 beings with a literature review of consisting of the definition and general principles of agroforestry followed by various focal points and subjects covered throughout the thesis. In chapter 3, a model derived from the rural livelihood framework is used to analyze farmer management strategies and how that relates to climate change. Chapter 4 uses a regression model to explore and analyze whether or not agroforestry practices have had an impact on the valuation of farm activities. Finally, chapter 5 provides a summary of the results and lessons learned during the research as well as discussing their implications, limits, and recommendations for future research.

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CHAPTER 2. LITERATURE REVIEW

2.1. DEFINITION OF AGROFORESTRY: PRACTICES AND SYSTEMS

2.1.1. Classification of Agroforestry Systems

Agroforestry systems have been developed in various forms throughout human history in both temperate and tropical regions. Agroforestry can generally be defined as the purposeful growing of trees and crops with some form of interaction to provide a combination of products or commodities with a vast array of ecological or environmental services. Essentially it is the culmination of perennial trees or shrubs grown on the same parcel of land as agricultural crops or animals in some form of spatial arrangement or temporal sequence. Several other terms for similar systems have been used. While the distinction can be considered hazy between agroforestry and other terms used in the literature such as community forestry, social forestry, and farm forestry, there is a distinct difference between these terms and agroforestry; additionally, these terms are used alongside such terms as permaculture, agroecology, and other integrated farming systems. While the first three directly involved trees, they focus on simply planting trees whereas agroforestry focuses on the interaction of crops, livestock and trees for multiple products and services. The latter are simply different types of agricultural systems; however, it is common for these terms are often used as synonyms or out of context (Nair, 2014).

Traditionally, indigenous forms of agroforestry systems incorporated a form of shifting cultivation also known as the swidden system which, defined by Raintree and Warner (1986), is 'the deliberate management of woody fallow vegetation as part of the rest cycle of fallow-based agricultural production.' Once the fallow cycle is completed, fields are then cleared usually by the use of fire. Afterwards, the fields are cultivated for a shorter period of time then again fallowed (Conklin, 1957); however, due to population and competing uses of land and labor these systems have generally undergone an intensification with a reduced period of fallow which now are categorized by a more scientific definition of AFS.

AFS throughout tropical Africa come in a wide variety of temporal scales and spatial forms that are dependent on environmental, climatic, economic, and socio-cultural niches. They can be as simple as solitary trees scattered throughout a landscape or be more organized in a specific spatial arrangement (Mbow et al., 2014). Okigbo and Greenland (1974) built off earlier work of classifications to devise a system of classification for farming systems throughout tropical Africa; however, this does not separate out monoculture, agroecology, pastoral, or agroforestry systems. It primarily relied upon fallow period, cropping period, and level of management.

From 1982 to 1987, the World Agroforestry Centre (ICRAF) conducted a global inventory of indigenous AFS. This information included the system's structure, function, and pros and cons. Nair (1987) proposed a classification scheme based on several criteria. This scheme was then modified by Sinclair (1999) in which the term system is defined by Spedding (1979) as: 'a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external stimuli: it is unaffected directly by its own outputs and has a specified boundary based on the inclusion of all significant feedbacks.' The generally accepted definition found in the agroforestry literature for 'farming systems' is 'a group of farms that are sufficiently similar to one another to be considered together for the purposes of improvement and the formulation of extension recommendations' (Simmonds, 1985). This is used primarily because it encompasses forest systems along with agricultural systems. The slightly modified hierarchical framework used in this paper that incorporates parts of both the AFS classification devised by Nair (1987) and the modified one by Sinclair (1999) is as follows:

1. Structure of the system and temporal scale
    a. Agrosilviculture (silvopastoral)
        i. Trees on Crop Land - 2
        ii. Crops on Tree land
            1. Plantation tree-crops - 2.i.1, 2.ii.3
            2. Plantation Forest/trees (cropping phase or orchard/tree garden) - 2.i
            3. Natural Forest/Tree Cover (forest garden, parkland, or cropping phase of shifting cultivation) – 2.i.2
    b. Silvopastoral
        i. Trees on Pasture/Rangeland – 2
        ii. Pasture on tree land
            1. Plantation Tree-crops - 2.i.1/2.ii.3
            2. Plantation Forest/trees – 2.i.1/2.ii.3
            3. Natural Forests/Tree Cover – 2.i.1/2.ii.3
    c. Trees and Animals (not pasture)
        i. Trees as Fodder (fodder banks) – 2.ii.5
        ii. Trees and bees
        iii. Trees and fish
    d. Forests/trees and people (sustainable multipurpose utilization)
        i. Fallow phase of shifting Cultivation (improved fallow)
        ii. Hunting/Collection
    e. Trees and perennial agricultural tree crops 2.i.1
2. Spatial arrangement
    a. Arrangement, density diversity
        i. Dispersed
            1. Regular
            2. Irregular
        ii. Zoned
            1. Boundaries (live fences, boundary planting, windbreaks/timber belts)
            2. Contours (terraces, bunds, barrier hedges)
            3. Rows (ally cropping, production hedges)
            4. Clumped
            5. Blocked (fodder banks, farm woodlands)
3. Location (distance from dwelling)
    a. Home garden
    b. Permanent field/Forest land/woodlands
4. Land type (altitude, slope, aspect, access to irrigation, and soil fertility)
5. Primary function
    a. Food, fodder, fuel, or income
    b. Protection or service function
6. Level of management
    a. Subsistence to commercial
    b. Household consumption to market-oriented

Figure 1: Agroforestry Classification (adapted from: Sinclair 1999)

P.K. Nair (2014) also devised a more simplified or streamlined subgrouping of systems which are as follows:

1. Multistrata Systems
    - Homegardens
    - Shaded perennials
    - Other multistrata agroforests
2. Tree intercropping
    - Alley cropping
    - Multipurpose trees on farmlands
3. Silvopasture (trees in support of crop production)
    - Grazing under scattered or planted trees
    - Tree-fodder systems (fodder banks)
4. Protective systems
    - Boundary planting, windbreaks, shelterbelts, soil conservation hedges
5. Agroforestry woodlots
    - Blocking planting of preferred tree species for specific purpose such as reclamation of salt-affect lands, eroded lands, acid soils, waterlogged soil, etc.

Figure 2: Agroforestry Classification (adapted from: Nair, 2014)

There is still a lack of consensus among the scientific community on how to classify agroforestry systems primarily due to the great diversity of management practices, spatial arrangements, temporal sequences, and ecological functions these systems have, and the variety of niches they fill depending on the climate, ecology, and culture of the area they are being cultivated in. Classification of temperate climate AFS are far less diverse and less complex than systems in the tropics. The five major agroforestry practices in the North America are alley cropping, forest farming, riparian buffer strips, silvopasture, and windbreaks (Nair, 2014). This paper will now focus on agroforestry systems and practices that occur throughout the entire tropics, but with a specific focus on West Africa.

2.1.2. Intercropping

Intercropping, the most widely researched topic in agroforestry, can take many forms, spatial arrangements, and temporal scales. A common intercropping practice is alley cropping which was developed by researchers as an alternative to the swidden systems. Alley cropping has the ability to achieve the same benefits of a natural fallow period in a decreased period of time.

Alley cropping is predominantly the planting of arable crops in between woody, fast-growing, leguminous species that have the ability to withstand repeated cutting to prevent shading of crops. Along with providing such benefits as nutrient recycling, weed suppression, and erosion control. The cuttings from the hedgerow can then be used for mulch, green manure, animal fodder, polewood, and fuelwood (Nair, 2014).

Pairing specific fertilizer trees with crops gives higher crop yields, increased nutrient cycling, increased soil organic matter, improvement in soil biological properties, and improvement in soil physical properties, along with carbon sequestration and climate mitigation (Sileshi et al., 2014).

Intercropping does have a high labor demand primarily associated with pruning which compounds the effect that if there is insufficient production of mulch or biomass, there is no added advantage to incorporating this practice concerning production and ecosystem services (Rao, Nair, & Ong, 1998). While there can be competition between trees and crops, it can be shown that the added benefits outweigh negatives through the amount of sequestered carbon and the enhanced stabilization of water-stable aggregates which in turn decreases erosion from water (Mutuo et al., 2005).

The most common form of intercropping throughout sub-Saharan Africa is known as the parkland system. This system can be found throughout all semi-arid Sub-Saharan African making it the predominate system found in West Africa (Boffa, 1999). Parklands are loosely defined as areas scattered with multipurpose mature trees in a landscape that is actively being cultivated or recently fallowed (Pullan, 1974). Common trees used in parkland systems are F*aidherbia albida, Parkia biglobosa*, and *Vitelleria paradoxa*. Parkland systems can be classified by the dominant species in the system. While they are usually dominated by one or two species, parklands have been observed to incorporate up to 40-50 species in turn helping to conserve genetic diversity. Common understory crops are maize, millet, cassava, sorghum, and cotton. Following the growing season, animals may also be released in the field to graze leftover crops and grasses (Boffa, 1999; Nair, 2014).

2.1.3. Taungya

Originally from Myanmar, taungya is considered a forestry system where the first 1-5 years act as an agroforestry system that eventually evolves into a plantation style or silviculture system. In taungya systems, farmers plant trees in a plantation style arrangement and then plant crops in between the trees each successive year until the trees eventually shade out the crops all while pruning the trees to maturity (Agyeman et al., 2003). In such places as Ghana, this system has been identified as a potential adaptation strategy for climate change that has the ability to improve food security and livelihoods along with sequestering carbon (Kalame et al., 2011). The primary purpose of taungya systems is to provide sustenance or income generation from farm related activities through the use of fruit producing trees or timber species as opposed to other forms of intercropping that might focus on environmental services (Sinclair, 1999).

2.1.4. Multistrata Systems

Considered a highly efficient land management system and also the most intensive and multispecies practice, multistrata systems are predominantly used throughout the humid and sub-humid tropics. The most common of these systems are homegardens, but multistrata systems can be considered any multistoried or multitier agroforestry system (Nair, 1987). The ICRAF global inventory of agroforestry identified several types of traditional land use that can all be considered ‘homegardens.’ The size of homegardens are small (<1 ha) with an intimate multistory combination of trees located close to homesteads with the use of shaded perennials with an over story of commercial tree crops or timber species managed intensively by family labor. Animals may or may not be incorporated into the system. These systems can be considered sustainable due to ecosystem services such as efficient nutrient cycling due their reliance on decomposition of organic material, lack of machinery used, and ability to sequester high levels of carbon (Nair, 2013). Homegardens incorporate food crops, fruits, and other forms of food. Common products from homegardens are tubers, leafy vegetables, fruits, vegetable crops, and medicinal plants (Fernandest & Nair, 1986).

2.1.5. Improved Fallow

Fallow is the resting of land from cropping often using natural vegetation to improve soil fertility and the use of animals to graze the land. Improved fallow is the deliberate use of fast growing trees to increase soil fertility rapidly. Improved fallow is conducted for a shorter period of time (2-3 years) and may contain woody species that have economic or forestry products (Nair, 2014). Studies have shown replenishment of soil fertility throughout numerous sub-Saharan countries using leguminous, fast-growing tree species; however, there have been very low adoption rates of this practice (Kaya, Hildebrand, & Nair, 2000). Improved fallows have good potential for ecological and economic benefits especially if trees species that produce such things as wood, gums, fruits, or fodder are used during the improved fallow (Boffa, 1999).

Improved fallow can also be paired with grazing systems where fertilizer trees may be used in the fallow cycle to improve soil properties, increase grass production for grazing, and provide leaf fodder for animals to eat (Sileshi et al., 2014). The use of fodder trees in improved fallow system has also shown to improve livestock productivity (Franzel et al., 2014).

2.1.6. Protective Agroforestry Systems

This practice uses trees or shrubs for their ecosystem-protection benefit. These include windbreaks, timber belts, shelter belts, soil conservation hedges, riparian buffers, and hedgerows. These systems, managed as part of a crop or livestock operation, are used to protect crops, trees, plant species, and animal species that are wind sensitive. Shelter belts and riparian buffers are used to prevent runoff, decrease non-point source pollution, stabilize stream banks, and provide a harvestable product. These systems are also used to prevent soil erosion of fields (Nair, 2013).

Stigter et al. (2002) analyzed 5 case studies from sub-Saharan Africa showing that shelter belts can greatly reduce soil degradation and desertification from wind erosion while protecting crops or trees inside the shelterbelt. The use of protective AFS is a financially accessible way for farmers to protect their crops and livelihoods and as a coping mechanism for climate variations (Lin, 2007).

2.1.7. Silvopasture

Silvopastoral systems incorporate trees and shrubs with livestock. There are two primary versions of silvopasture where animals are allowed to graze in open pastures or where fodder is grown in tree-fodder systems, and then brought to the animals. Intensive open grazing of free roaming animals is common throughout the sub-Saharan Africa especially in parkland systems. The use of silvopasture systems also provides desirable ecosystem services such as climate change mitigation, soil conservation, improved water quality, and providing shade for cattle (Nair, 2013).

Silvopastoral systems can be combined with many other AFS such as improved fallow, protective AFS, and intercropping to create a system that leads to increased livelihoods by increasing livestock productivity along with the added benefits of improved fallow, protective AFS, and intercropping (Franzel et al., 2014).

2.1.8. Tree Woodlots and Specialty Crops

These terms can denote any "non-conventional" land-use system; however, they are most commonly used to describe woodlots, boundary planting production for firewood, timber, poles, and fence posts, and the use of trees to reclaim degraded lands. This can also be used to describe the implementation of "fallow regeneration" which is used throughout various parts of sub-Saharan Africa (Nair, 2013).

Woodlots can be an independent system, but they can also be paired with other AFS such as intercropping, silvopasture, protective AFS, and improved fallow to create multiple synergies between all of the systems (Franzel et al., 2014). These systems can be integral to livelihood strategies for rural populations with regards to energy production (Kristoferson & Bokalders, 1986).

2.1.9. Predominant Agroforestry Systems in West Africa

Sub-Saharan Africa can be broken up into a few different types of ecological regions. The two most predominant systems in West Africa are the semi-arid climatic zone known as the Sahelo-Sudanian climatic zone and the sub-humid to semi-arid ecological zone known as the

Sudano-Guinean climatic zone (Kaufmann et al., 1985). Agroforestry systems in specific climatic zones tend to tailor towards the needs of the local populace; for example, trees being cultivated for fuelwood tend to be more common place in areas that have a lower density of trees. In the Sudano-Guinean climatic zone, the most common AFS are improved fallows in shifting cultivation, improvement to taungya, alley cropping, multilayered tree gardens, homegardens, woodlots, and multipurpose trees on crop lands (Nair, 1989). Additionally, combining livestock with trees is common in traditional and introduced agroforestry practices to intensify systems (Gambiza et al., 2010). Regardless, the use of trees, crops, and animals in agricultural systems can be seen as integral to livelihoods across various scales (Marunda & Bouda, 2010).

However, the predominant system used throughout West Africa is the agroforestry parkland system which is a variation on shifting cultivation (Boffa, 1999). In parkland systems, fallow lands and plots are used for livestock grazing and fuel wood production, incorporating silvopastoral systems and woodlots (Ohler, 1985). During the rainy season many farmers will graze their herds at a communal location away from fields being cultivated in fallow areas, and animals will then feed on crop residue and animal fodder from trees during the dry season (Houerou, 1989).

2.1.10. Parkland Systems

The dominant system across sub-humid West Africa, parkland systems, are landscapes in which mature trees occur scattered across cultivated or recently fallowed plots of land (Pullan, 1974). Nair (1987) classifies these systems in the general category of 'multipurpose trees on farmlands’. The production of livestock in these systems can be a major or secondary component, but the term ‘parkland’ can be interpreted widely (Boffa, 1999).

Parklands are heavily changed by anthropogenic selection where up to 75% of the trees can be cut down for annual crop cultivation. There is a definite bias towards comestible trees where as much as 50% of the trees can be one comestible species (Maranz, 2009). Parklands have always played an integral role to society throughout West Africa. Evidence has been found that parklands have been practiced for at least 1000 years and up to 3000 years (Ballouche & Neumann, 1995). There is a large diversity to how parklands are managed including various gendered and cultural contexts (Elias, 2015). A primary management component of parklands is natural regeneration of woody species through fallow or planting of seedlings which changes the composition and distribution of plant species (Gijsbers et al., 1994; Larwanou & Saadou, 2011).

Figure 3: Climatic zones of West Africa (Source: Jahnke, 1982)

2.2. FOCAL POINTS FOR THIS STUDY

Agroforestry, as a land management system, can be viewed as one piece of the puzzle to combatting climate change through the multiple synergies that it creates such as increasing food security, increasing ecosystem services, and mitigating climate change. These things are accomplished through management and livelihood strategies which are affected by multiple factors. The type of system being managed as well as factors that affect management all interplay with how AFS impacts food security, ecosystem services, and climate change mitigation. The following sections will touch on various topics that agroforestry impacts that has relevance to this study.

2.2.1. Role of Agroforestry in Land Management

Agroforestry is recognized as a sustainable land management practice that has the ability to increase and sustain agricultural production in land that has not been benefitted by the Green Revolution (Campbell et al., 2014; Ofori et al., 2014). AFS play an important role in creating a globalized food network that integrates significant co-benefits to populations, ecosystems, and biodiversity. While contributing to basic needs, AFS also contribute to ecosystem services which in turn contribute to many development goals on a national or local level (Pachauri, 2012; Steiner, 2012). The following section will discuss many of the ecosystem services that AFS provide.

2.2.2. Ecosystem Services

The Millennium Ecosystem Assessment has broadly defined ecosystems services as the benefits humans obtain from ecosystems. They are then grouped into four categories: provisioning services, regulating services, supporting services, and cultural services (Arico et al., 2005).

Provisioning services are defined as food, fuel wood, fiber, biochemical, and genetic resources received from a system. There are varying results between production of cereal crops and trees which is predominantly due to the competition between the trees and cereals. More shade tolerant crops such as legumes and tubers show greater potential for intercropping with trees. Increased tree management such as pruning can improve cereal yields along with rejuvenating older fruit trees (Bayala et al., 2014; Ræbild, 2012; Sanou et al., 2012). AFS possess the potential to increase the quantity as well as quality of fodder being consumed by livestock during the dry season (Hansen et al., 2008). AFS promote genetic diversity thus by increasing agriculture system resilience through the use of undomesticated trees and the introduction of exotic trees (Dawson et al., 2014; Boffa, 1999). Another way AFS provide provisioning services is through fuel wood or wood for construction (Franzel et al., 2014; Ohler, 1985) and through other forest products such as medicine, secondary forest products such as shea butter, and other secondary income generation (Faye, et al., 2010; Gakou, Force, & McLaughlin, 1994).

Regulating services are defined as climate, disease, and water regulation, as well as water purification. Trees have the ability to create microclimates for crops being grown around them by reducing average daily temperatures along with increasing the minimum air humidity and soil moisture (Lin, 2007, 2010; Lott et al., 2009; Ong et al., 2000). Infiltration of rainfall is also increased along with reduced soil temperature and lower rates of soil evaporation (Bayala et al., 2008; Samba et al., 2001). Another mechanism in which trees impact soil water dynamics is through hydraulic lift. Hydraulic lift is a process that redistributes water to the top soil making it more available for plants and preventing the top soil from drying out. Especially in sub-Saharan Africa, hydraulic lift plays a critical role in drought tolerance and soil moisture content (Bayala et al., 2008; Ong et al., 2014; Ong et al., 2002). Trees have the ability to capture nutrients that have leached below agronomic crops and would normally leach into bodies of water by recycling them through plant matter, keeping them stored in the plant-soil systems (Nair, 2013).

Supporting services are defined as soil formation, nutrient cycling, primary production, and provision of habitat. AFS build up soil fertility over time along with improving physical, biological, and chemical fertility characteristics of soil (Boffa, 1999; Chen et al., 2017; Zhang et al., 2007). AFS provide nitrogen fixation, enhanced nutrient cycling, and the capturing of deep nutrients as some added advantages to improve soil quality (Nair, 2014). Agroforestry species are also used as “fertilizer trees” if they are able to fixate nitrogen in soils. It once was generally assumed that nitrogen fixing trees increased crop yields; however, it is very difficult to quantify and to understand the actual benefits of such trees. Regardless, various woody species across West Africa have been shown to affect soil organic matter, pH, and available nutrients in soil (Bayala et al., 2005; Bernatchez et al., 2008). Perhaps more importantly, trees greatly increase the amount of biomass decomposition that occurs, improve soil through soil conservation by reducing erosions, and contribute significantly to higher soil microbiological activity. Another added benefit that trees provide is the increased amount of carbon in soil and an increase in stable carbon in deeper soil profiles (Deans et al., 1999; Lufafa et al., 2008; Nair, 2013).

Cultural services are nonmaterial services that are defined as recreational benefits such as ecotourism, aesthetics, inspiration, and education as well as religion, sense of place, and cultural heritage. These types of services are hard to quantify and value, and they are often intangible; however, they play an important role in smallholder livelihoods nonetheless. These services are often tightly bound with societal norms, human values, and communities (Arico et al., 2005). A community’s interactions with a landscape are driven in part by local perceptions and the dynamic interplay between productions and outcomes, creating a situation where trade-offs between various ecosystems services and how communities interact with them are necessary for assessing management goals and outcomes (Bennett, Peterson, & Gordon, 2009).

Sinare & Gordon (2015) conducted a review of ecosystem services for woody vegetation across West Africa, showing that there are multiple direct benefits to incomes and livelihoods with either positive or neutral indirect benefits to regulating services; however, they pointed out that these studies primarily show benefits at the individual tree or shrub scale. the relationships between various ecosystem services need to be taken into account to better understand the complexities of biodiversity, ecosystem services, and human well-being (Bennett et al., 2015).

2.2.3. Food Security

Food security is a major issue facing many communities throughout the world. Due to rising food prices, population growth, volatility in production, degradation of natural resources, urban migration, and economic and political instability, food insecurity is an ever growing problem (Beddington et al., 2012). All of these factors create an ever increasing demand to produce more food per parcel of land or to intensify production; however, a trajectory that leads to a path of environmentally sustainable agricultural intensification is needed to meet the global food demand (Tilman et al., 2011). Agroforestry is often considered as a way to sustainably intensify a system with the use of low external inputs and cost effective management strategies to increase food security. It can be shown that food security and environmental services are driving factors for adopting intensified AFS (Mbow et al., 2014).

Sustainable intensification is a concept where increased yields, better nutrition, and increased net incomes are produced from pre-existing agriculture land while decreasing the need of external inputs such as chemical pesticides, herbicides, and fertilizers, along with the additional benefits of climate change mitigation through carbon sequestration, reduced greenhouse gas emissions, and mitigation of other negative environmental impacts (Garnett et al., 2013; Lal et al., 2015). While other factors play into intensification, ecological intensification, which utilizes agricultural processes to intensify a system, is one pathway to increase food security. Agricultural practices such as agroforestry, integrated pest management, and conservation agriculture are just some of the pathways to intensification (The Montpellier Panel, 2013).

Incorporating trees into a system with low tree cover has been identified as a strategy to increase food production without increasing deforestation (Belem et al., 2011; Yin & Hyde, 2000) as well as contributing direct ecosystem service benefits and income to livelihoods (Sinare & Gordon, 2015a). Additionally, there are the added effects of enhanced soil fertility which can increase crop production. AFS directly affect livelihoods through such products as fuel wood, timber, fruits, and fodder. While some of these do not directly provide nutritional value, they have the ability to provide other services important for livelihoods (Bucagu et al., 2013). By diversifying marketable products, AFS are able to decrease food insecurity during times of extreme climate due to increased income from other sources (Faye et al., 2010; Petit, 2003; Ræbild, 2012; Thorlakson & Neufeldt, 2012).

Tree fruit and other edible products from AFS can be an important source of nutrients and vitamins with the added effect of providing sources of food during parts of the year food may be increasingly scarce as well as during periods of drought (Bayala et al., 2014). AFS can be valuable to particularly vulnerable groups by providing lipids, proteins, and micronutrients to help diversify and enhance diets as products become available throughout the year (Boffa, 1999)

2.2.4. Climate Change Adaptation and Mitigation

Studies have shown that AFS have the ability to store more carbon in soil compared to treeless systems (Nair, 2013; Nair et al., 2009; Pandey, 2002). While there is not a consensus to just how much agroforestry systems can sequester carbon, especially with the use of wood products from agroforestry systems, there is consensus that AFS do sequester more carbon than conventional land management practices. With a wide variety of systems being used through the tropics and sub-humid tropics, more research is required to quantify how much carbon AFS can sequester along with the role smallholder farmers play in climate mitigation (Mutuo et al., 2005). AFS systems have been shown to sequester more carbon than cropping/pasture systems in the humid tropics along with reducing emissions of nitrous oxide and carbon dioxide from soils, but this is greatly dependent on fallow length and tillage methods (Mutuo et al., 2005; Luedeling et al., 2011).

While AFS do have the ability to sequester carbon, systems such as the parkland system are not likely to be used in carbon sequestration projects unless the tree density is increased. Parkland systems do store significant amounts of carbon, but they do not meet the Kyoto Protocol definition of carbon sequestered as a result of newly implemented mitigation projects. While parkland systems do possess some potential, agroforestry practices such as live fencing or fodder banks possess a considerately greater potential for sequestering carbon (Dayamba et al., 2016; Nair et al., 2009; Takimoto et al., 2008; Tschakert et al., 2004).

Perhaps more relevant the carbon sequestration, AFS as a land use system possess a strong ability to meet mutual benefits between climate change adaptation, mitigation, and ecological conservation by efficiently using limited resources (Matocha et al., 2012) and increasing ecosystem resiliency (Lal et al., 2015). AFS efficiently use nutrients creating a more closed loop system that mitigates environmental disturbances. For example, AFS conserve soil and rainwater to be utilized more efficiently to increase productivity (Amuri, 2015). This increased in soil conservation and nutrient dynamics increases soil fertility which counter acts such things as droughts or soil acidity which may be exacerbated by climate change (Lungu, 2015).

Additionally, policy can be created to increase the adaptive capacity and resilience of AFS to mitigate climate change while meeting mutual benefits (Verchot et al., 2007). Climate change poses a threat to crop yields throughout Sudano-Guinean ecological zone making an already vulnerable population even more vulnerable, but the coupling of traditional agricultural techniques and agroforestry technologies has been shown to reduce the effects of climate change on crop yields along with increased carbon storage and a variety of increased environmental services (Bayala et al., 2014; Faye et al., 2010; Mbow et al., 2014).

2.2.5 Effects of Climate on Agroforestry Systems in West Africa

The vast majority of agriculture systems throughout Sub-Saharan Africa are dependent upon rainfall. Barrios et al. (2008) shows a direct link between increasing temperatures and decreasing precipitation to production shortages since the 1970s; however, the IPCC projects a temperature increase ranging from +1.8 °C to +4.7 °C in West Africa along with precipitation ranges varying from -9 % to +13 % (UNEP, 2007). As temperatures rise in both the Sudano-Sahelian and Guinean ecological zones, cereal grain yields will decrease; although, predictions of the severity are hard to quantify. Changes in rainfall will either aggravate or mitigate negative impacts of changing temperature (Roudier et al., 2011). Additionally, it has been shown in

Senegal that there is a strong correlation between rainfall and crop yields of the main crops of rice, maize, groundnut, sorghum, and millet (ANACIM, 2013).

Current losses of tree species throughout the Sudano-Sahelian and Guinean ecological zones can be attributed to a decline in rainfall (Maranz, 2009) where a decline in rainfall has a strong negative effect on crop yields (Lobell et al., 2011; Lobell & Field, 2007; Sultan et al., 2013). Gonzalez et al. (2012) states that human populations are a cause of tree loss throughout the Sudano-Sahelian and Guinean ecological zones too. However, it can be assumed that precipitation and temperature along with human disturbances directly lead to a decline of tree density throughout landscapes. This negative effect is compounded when broadened to a food security perspective in a local and global market context (Knox et al., 2012; Schlenker & Lobell, 2010).

2.2.6. Key Factors and Drivers for Choosing Agroforestry Systems

As part of a decentralized natural resources management plan, household decision making with regards to livelihood is key to how these natural resources are managed. Farmers throughout sub-Saharan Africa have always had to develop their livelihood strategies around great uncertainty, erratic climate, and changing policies at the local, national, or global level (Mertz et al., 2009). While climate certainly plays a role in influencing livelihood strategies, there are many other factors that influence coping and adaption strategies, even more so with poorer and more vulnerable communities (Elmqvist & Olsson, 2006).

Factors can be grouped into three main categories of socioeconomic, environmental, and mental processes that are all influenced by such things as an individual’s needs, knowledge set, and own perceptions and biases (Thangata & Alavalapati, 2003). This study sets out to primarily explore how various factors, especially climate, affect systems and land use change over time. The result of this change can be grouped into the three main categories of intensification, extensification, and diversification with each response being a product of constraint and incentives where households attempt to meet food and livelihood security objectives (Vosti & Reardon, 1997)

There are many examples throughout the literature that show farmers weighing different factors into what they decide to grow, where they decide to grow, and what specific species they decide to grow. They must use a mixture of indigenous knowledge, predetermined biases, and newer knowledge to decide which factors are most important to them. Local knowledge and decision-making can be very important for the future because research organizations and development organizations need to take into account the knowledge farmers already possess to maximize strategies and goals (Mccorkle, 1989). Factors can be categorized into two different temporal categories of event driven factors and more static factors where something such as an extreme event or decline in rainfall would be event driven, and population pressure on resources would be a static factor. It should also be taken into account that there will not be any one factor that solely drives responses or changes in land-use systems along with the fact that some factors will also be random (Reenberg, 2001).

It is difficult to satisfactorily choose an optimal management strategy to fulfill a specific measurable objective such as maximum yield or maximum income simply as a consequence of population size and need for food, but if specific priorities are looked at such as field size, soil type, and the divisions of inputs as more specific factors, broader insights and analyses of management strategies can be identified based on different objectives and rationalities for land use decisions (Reenberg & Paarup-laursen, 1997).

Farmers may use various factors such as biophysical, economic, climate, and risk in the management of agriculture systems. It is well documented that farmers use various soil indicators to choose cropping decisions as well as time scales (Assé & Lassoie, 2011; Badini & Dioni, 2004; Benjaminsen et al., 2010; Dawoe et al., 2012; Lal, 2013; Reenberg & Paarup-laursen, 1997; Rushemuka et al., 2014; Thangata & Hildebrand, 2012). Economic factors and risk also play a role when farmers decide on livelihood strategies and diversification of production (Caveness & Kurtz, 1993; Ghadim et al., 2005; Ghadim & Pannell, 1999; Marra et al., 2003; Orlove et al., 2010). Additionally, national agriculture policy has been shown to affect management strategies (Mortimore et al., 2005) as well as gender dynamics within a community (Gakou et al., 1994; Nyanga, 2012; Kiptot et al., 2014; Villamor et al., 2014). Lastly, climate in both the short and long term affects farmers decision-making for management strategies (Below et al., 2010; Elmqvist & Olsson, 2006; Lacy et al., 2006; Menapace et al., 2015; Nyong et al., 2007; Roncoli, 2006). Adversely, there is also strong evidence that climate change plays a small role in decision-making and that farmers are responding to more localized weather events (Mertz, 2009; Mertz et al., 2010). All of these drivers show that a multitude of experiences, cultural practices, and knowledge sets go into a complex process on deciding livelihood strategies and adaptability.

Farmers throughout sub-Saharan Africa have been coping and adapting to various climatic conditions for centuries. Chuku and Okoye (2009) note four available options for farmers to adapt: (i) income/asset management, (ii) government programs and insurance, (iii) farm production and practices, and (iv) technological developments. Farm level implementation of adaptation strategies have been researched, but it is difficult to separate the underlying drivers to these changes. Mertz et al. (2010) suggest that farmers respond more to a decline in yields as opposed to climate change, although those yield declines can be attributed to climate change. However, on farm activities such as agroforestry can be viewed as a primary way to adapt to climate change with added ecological co-benefits (Lasco et al., 2014; Mbow et al., 2014). Other common adaptation practices can be diversification of crops and crop varieties, changing times of planting and sowing, irrigation, extensification, and off farm income activities (Tambo & Abdoulaye, 2013). Weather forecasting, increasing training and extension services, and utilizing climate smart policy are seen as viable options to help farmers adapt to climate change (Juana et al., 2013; Mertz et al., 2011).

Coping mechanisms are another pathway to mitigating the impacts of climate change. Households have shown a large capacity to adapt to long term and short term climate variability (Goldman & Riosmena, 2013; Mortimore & Harris, 2005; Mortimore & Adams, 2001; Panda et al., 2013). Within agricultural systems, adaptation to agricultural practices and income diversification are a primary way households mitigate risk. A mixture of various on farm and off farm activities allows households to earn various income streams and food producing activities. Additionally, migration of younger household members, dry season income generating activities, and remittances are all examples of other coping mechanisms (Griep, 2005).

There are a wide variety of factors or drivers that drive land use change throughout Senegal and sub-Saharan Africa. Farmers take into account socio-economic, cultural, environmental, and political drivers into their decision-making. Trying to disaggregate primary drivers from underlying drivers is difficult if not nearly impossible, and it could be argued that all of these factors are driven by farmers' perceptions and biases toward these main categories of drivers. By better understanding the relevant and viable decisions by farmers, policy and institutional support can be increased to optimize agricultural systems (Hansen, 2002).

2.2.7. Rural Livelihood Framework

Decisions across spatial and temporal scales such as short-term and long-term household decisions more or less culminate into a larger framework that farmers use to manage agricultural systems. Research in this field has led to the development of the rural livelihood strategy framework (Berkes et al., 2003a, 2003b; Berkes & Folke, 1998; Scoones, 1998). This framework links socio-ecological concepts such as ecosystems, people and technology, local knowledge, property rights, interactions, and outcomes. A framework like this is important for assessing livelihood strategies in a specific context such as policy, historical, agroecological, or socio-economic settings (Scoones, 1998) providing a practical application to study the processes in which people achieve (or fail to achieve) sustainable livelihoods and creating a more exhaustive analysis of factors affecting populations in an international development context.

The social and ecological components of a system are both self-organizing and adaptive which essentially leads to the idea of adaptive management which parallels the accumulation of knowledge over generations in indigenous knowledge systems emphasizing flexibility (Holling, Berkes, & Folke, 1998). Both of these resource management types link to the idea of resiliency defined as: '*the ability of a system to maintain its structure and patterns of behavior in the face of disturbance.'* (Holling, 1973). This definition has evolved and has been expanded to social-ecological systems where resilience within adaptive management is needed for sustainable development (Walker et al., 2004).

2.3. GEOGRAPHY OF THE STUDY AREA: KEDOUGOU, SENEGAL

Senegal is a country of about 14 million people located on the Atlantic coast of the West Africa with the geographic coordinates of 14.00 N and 14.00 W. There are 11 regions in Senegal with Kedougou being the most southeastern region of Senegal bordering the countries of Mali and Guinea. Kedougou has 3 departments, 6 arrondissements, and 19 communes. The region in primarily of Pulaar and Malinke ethnicities with a large amount of smaller ethnic groups such as Bassari, Bedik, Jakhanke, Jalounke, and Tende. The majority of the population are subsistence agriculturists.

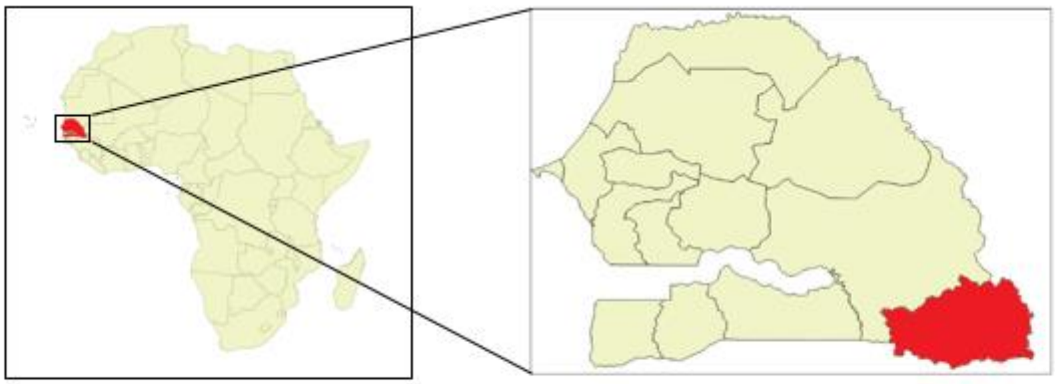

Figure 4: The Region of Kedougou in Senegal

2.3.1. Climate

Kedougou is in the Sudano-Guinean climatic zone which is a sub-humid climate with tropical characteristics such as having distinct rainy and dry seasons with the rainy season occurring from June to October, and the dry season occurring from November to May (Dansokho et al., 2012). Kedougou receives approximately 1200 mm of rain per year (ANACIM et al., 2013).

Total greenhouse gas (GHG) emissions for Senegal are 16.89 Mt CO_2, but approximately 10.59 Mt CO_2 is being sequestered by the forestry sector. The energy sector is approximately 49 percent of the total GHG emissions with a 0.4 metric tons per capita of CO_2 emission in 2009.

Agriculture makes up 37 percent of GHGs while waste and industrial process making up the remaining 14 percent of GHGs (UNEP, 2015).

2.3.2. Agroecological and Forestry Data

Kedougou is primarily classified as a Sudanese deciduous wooded savanna with more than 150 woody species having been identified. The landscape is not dominated by one specific species; however, frequent bush fires occur throughout the year (CSE, 2009; Giffard, 1974). While savannas are the predominant vegetation formations, several others do occur primarily as a function of geomorphology, soils, rainfall, fire, and grazing and shifting cultivation to a much lesser degree. To a lesser degree gallery forests occur throughout the landscape (CSE, 2011). Additionally, unique formations known as a grassy *bowal* are common through the region. A *bowal* is an outcrop of impermeable laterite clay that resists root growth or penetration ultimately creating a grassy meadow devoid of woody species (Stewart, 1987). Trends in land use change have remained relatively unchanged for the greater part of the last century with about 98 % in 2000 of the region still being covered by diverse natural vegetation types, with the exception coming from areas of fast growing mineral extraction and gallery forests being converted to agriculture lands (Tappan et al., 2004).

Over the past few decades, Kedougou has seen a marginal increase in wooded savannas with a marginal decline of gallery forests primarily due to human activities (Woomer et al., 2004). Over 90 % of the landscape has remained unchanged from 1986 to 2010 The greatest change in the landscape is primarily due to the exploration of mineral resources and the extraction of these minerals (Dansokho et al., 2012). The structure and diversity of native plant communities are driven primarily by precipitation, temperature, soil type, micro-topography, and fire disturbances (Abdoulaye & Fujiwara, 2007). It is common for villages to have a 'sacred forest' for socio-cultural reasons. These parcels of land remain relatively untouched, and they are areas that predominantly have higher biodiversity and density of tree species than surrounding areas (Dansokho et al., 2012).

Kedougou is home to Senegal's largest national park, the Niokolo-Koba National Park, which has 913,000 hectares of protected land with over 1,500 plants species, 80 mammal species, and 300 species of birds (Dupuy, 1971; Madsen et al., 1996). The park contains a majority of Senegal's gallery forests making it very important to sequestered carbon and the fight against desertification.

The majority of agricultural systems in Senegal are small holdings with a very low degree of mechanization, poor infrastructure, and high dependence on rain-fed crops (CSE, 2009; Diop, 2014). Overall there is a very low productivity in the agricultural sector coupled with high unemployment and poverty creating challenges. More recently, the government has undergone reforms in agriculture focusing on the promotion of crop diversification, agroforestry, soil restoration, and finance (MEDD, 2014). Forestry totaled 26.7 billion West African '*Communauté Financiére d'Afrique'* Franc (CFAF) in 2010 along with providing energy for 84 percent of households and increasing food security through fruits, leaves, roots, and game (UNEP, 2015). The 2016 exchange rate for CFA to USD was 593.01 francs to a dollar according to the BCEAO.

2.3.3. Socio-Economic Demographics and Indicators

As of 2013, Kedougou has a population of 151,000 with the growth rate increasing rapidly from 0.9 % between 1976-1988 to 3.5 % between 2002-2013 with 42 % of the population being 15 years old or younger. 25 % of the population lives in an urban environment predominantly located in the regional capital Kedougou. The region has a food insecure rate which indicates if a household experiences food insecure periods throughout the year of 33 %. Additionally, 79 % of households are living in a rural setting. The majority of the population is in the agricultural sector where rain fed subsistence agriculture is the primary livelihood strategy. Wood makes up 84.8 % of household energy consumption and charcoal is 11.6 % (ANSD, 2015; Diop, 2014).

89 % of households are considered very poor or poor by the WFP wealth index which measures wealth based on ownership of non-productive assets. Maize is the largest product crop from Kedougou; however, groundnuts and rice by a majority of households followed by sorghum and millet. Rice is the main staple consumed (80 % of households nationwide) where rice must be purchased to meet demand. Millet is another crop that is produced elsewhere but consumed in Kedougou (ANACIM et al., 2013). The 2016 Gross National Income (GNI) per capita was $950 USD where Kedougou is dominated by an informal economic sector.

2.3.4. Biophysical Indicators

The majority of soil classified in Kedougou is classified as a haplic lixisol. Soils in this area are predominately low fertility, high in aluminum and phosphates, and are very prone to erosion due to heavy rainfall especially after clearing of trees (Stancioff et al., 2013). Lixisols are soils that are leached acidic soils with a clay-enriched subsoil. Soils in this area are dominated by kaolinitic clay mineralogy with exceptions for areas dominated by montmorillonite mineralogy. The soil is red in color due to accumulation of iron oxides in the soil. A major constraint to soil conservation in Kedougou is seasonal flooding and erosion (Jones et al., 2013). All of these soils are found on top of lateritic and Precambrian bedrock (Tappan et al., 2004).

Soils in Kedougou are approximately made up on 10-30 % silt, 20-45 % clay, 10-45 % sand, and 10-40 % gravel content depending on where they are in Kedougou. The soils have a very low $CaCO_3$ content, and they are considered very acidic to acid soil. The cation exchange capacity is 4-20 cmol/kg, and a base saturation of < 20-50 % depending on terrain. The soils are either imperfectly to moderately well drained and have > 150 mm water storage capacity (Jones et al., 2013). These parameters were determined using the World Reference Base for Soil Resources adopted by the International Union of Soil Science in 1998, which created revisions on the United States Department of Agriculture soil taxonomy classification scheme. According to the United States Department of Agriculture's system for classification, Kedougou is dominated by alluvial or hydromorphic vertisols and lithosols (CSE, 2009)

2.3.5. Agroforestry Systems in Kedougou, Senegal

Kedougou is dominated by Agro-Sylvo-Pastoral systems that are predominantly classified as agroforestry parkland systems characterized by farmers growing crops on tree lands with a few exceptions of trees being grown on cropland. Farmers conduct a form of shifting cultivation where they will abandon a parcel of land once yields decrease and let it lay fallow for a period of time using the fallowed land as pasture land. Farmers in Kedougou are predominately subsistence agriculturist where most products from the systems are consumed or utilized at the household level; however, surpluses of cereal, grains, and fruits are sold in markets along with some farmers partaking in the production of charcoal, foraged fruits for market, production of bamboo fencing, and fire wood. Most farmers compliment on farm activities with dry season off farm activities to increase incomes. Agricultural is predominantly done by animal-drawn ploughs and by hand with very little inputs with a few exceptions of mechanization on a relatively minimal scale. Chemical inputs are used if a farmer has enough extra financial resources to purchase.

In addition to commercial products, endemic or naturalized fruit trees remain very important to the diets and economies of the local populace along with providing other forest or wood products and medicine or cultural services. Many of these species have been underutilized with regards to commercial value and represent an economic niche that agroforestry systems can help fill (Diedhiou, 2004). A brief list of common species found in Kedougou agroforestry systems are listed in **Table 1** below. Additionally, common forestry products, including fuel wood, timber, biochar, and *le crinting* (bamboo fencing), are produced by AFS. **Table 2** shows a list of significant species for forest products such as timber, fuel, and residual products. The importance of various shrubs and grasses for the co-benefit of ecosystem services has also been observed. Vetiver grass (*Chrysopogon zizanioides*) is widely used in riparian buffer zones and to help control erosion (Dansokho et al., 2012).

Table 1: Scientific names of important endemic or naturalized fruit trees (source: adapted from Diedhiou, 2004)

Scientific Name	**Common Name**
Detarium senegalense	*Detax*
Ficus spp.	Fig
Borassus aethiopum	Palm
Adansonia digitate	Baobab
Saba senegalensis	*Madd*
Parkia biglobosa	*Nere*
Vitellaria paradoxa	Shea, *Karite*
Cordyla pinnata	*dimb, nbimba, dimbe, dimbur*
Cola cordifolia	Cola Nut, *ntaba*
Cola netifolii	Cola Nut
Ziziphus mauritiana	Jujube
Anacardium occidentale	Cashew
Lannea spp.	

Table 2: Common trees used for forestry products (Dansokho et al., 2012)

Scientific Name	**Common Name**
Acacia spp.	
Prosopis spp.	Mesquite
Bombax costatum	*Garabou, laobe, kuyokuyo*
Hymenocardia acida	
Borassus akeassii/aethiopum	Palmyra palm
Combretum spp	
Arundinaria alpine; Oxytenanthera abyssinica	Bamboo

Table 3: List of common cereal grains and crops grown in agroforestry systems (Dansokho et al., 2012)

Scientific Name	**Common Name**
Sorghum bicolor	Sorghum
Zea mays	Maize
Pennisetum glaucum	Millet
Oryza glaberrima	Rice
Manihot esculenta	Manioc
Solanum tuberosum	Potatoes
Disoscorea spp.	Yams
Digitaria exilis	Fonio
Cucurbita spp	Squash

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CHAPTER 3. FARMER LIVELIHOOD STRATEGY, ATTITUDES, AND RESPONSES TO CLIMATE CHANGE IN AGROFORESTRY PARKLANDS IN KEDOUGOU SENEGAL

3.1. ABSTRACT

Farmers managing agroecological systems across sub-humid West Africa face a variety of challenges in meeting their needs to provide sustainable and resilient livelihoods for their communities. In the face of adverse conditions, farmers have successfully managed agroforestry parklands to create a long-term sustainable system. However, climate change presents a challenging and new disturbance to farmer livelihood strategies. Using a mixed-methods approached, I use the rural livelihood framework to analyze and assess farmers' livelihood strategies, attitudes, and responses to climate change. Through the use of semi-structured focus groups, the results showed that farmers are constantly changing management strategies through flexible and adaptable decision-making to mitigate negative disturbances. Through the accumulation of indigenous knowledge and adaptive management, West African farmers are keenly ready to handle challenges of managing agroecological systems under great vulnerability.

3.2. INTRODUCTION

Understanding decision-making factors for the management of agroforestry and agricultural systems is paramount to creating sustainable community based natural resource management strategies. Shifting from the 'technology-adoption' paradigm has been shown to create a more inclusive perspective looking at how farmers adapt. This shows how vulnerability interplays with decision-making allowing for an enhanced ability to capture complex interactions of farmer decision-making, especially regarding climate parameters, and how they interplay with farmer perceptions (Roncoli, 2006).

Various factors affecting decision-making and management strategies across West Africa have been well documented across the literature (Baker, 2000; Kristjanson et al., 2012; Mertz et al., 2011; Okike et al., 2017), but the role that climate narratives play into these factors is less documented (Mertz et al., 2010, 2009). These processes and strategies are a direct product of indigenous knowledge and perceptions and their direct interaction with the environment where local knowledge changes, adapts, and assimilates new ideas (Becker & Ghimire, 2003). Traditional forest management and conservation neglected the needs and interests of local peoples (Ros-Tonen et al., 2005). However, local knowledge has successfully been used to develop management strategies and identify conservation needs (Lykke, 2000).

The use of traditional subsistence farming knowledge and perspectives remains integral to developing more sustainable agricultural systems because it combines local knowledge with scientific findings and extension strategies to enact management interventions and move towards more sustainable land management, especially agroforestry (Isaac et al., 2009; Kristjanson et al., 2002; Rist & Daubouh-Guebas, 2006). Research on a local scale in Senegal is lacking linkages between farmers' indigenous knowledge of management strategies and climate change. Using both quantitative and qualitative methodologies and the integration of these two methodologies allows for a better understanding of the adaptation of farming systems to climate change (Kalaugher et al., 2013).

3.2.1. Livelihood Model for Rural Sahelian Communities

Theoretical frameworks for the linking of social and ecological systems place emphasis on human beings as the driving force behind management practices and land-use change in natural and managed lands where mechanisms exist to maintain system and societal resilience through adaptive behavior (Bebbington, 1999; Berkes et al., 2003; Berkes & Folke, 1998; Scoones, 1998). Using a model derived from the livelihood framework for the linkages between rural Sahelian communities and ecological systems (**Figure 5**) created by M. J. Mortimore & Adams (2001), I propose to analyze the variable properties *diversity*, *flexibility*, and *adaptability*, and the linkages between theses variable properties and the system constraints, rainfall and bioproductivity, in the context of climate change and agroecological management to assess resiliency of farming systems.

Within the model, diversity refers to the resources and options available to a household with these resources being natural, economic, technical, or social. The active decisions a household makes about its resources in the short term is flexibility. More specifically within flexibility, this paper refers to (i) the use of biodiversity, (ii) use of economic plants, and (iii) choice of livelihood strategy within agricultural systems. Adaptability refers to longer term decision-making that affects inter-year adjustments and responses to the constraints. This can be viewed as a sequential element or a culmination of the flexibility decisions to reflect understanding of longer term and larger scale management. This change is a constant and continuous changing patchwork of the relationship between people and the environment to manage variation and adapt to changing conditions.

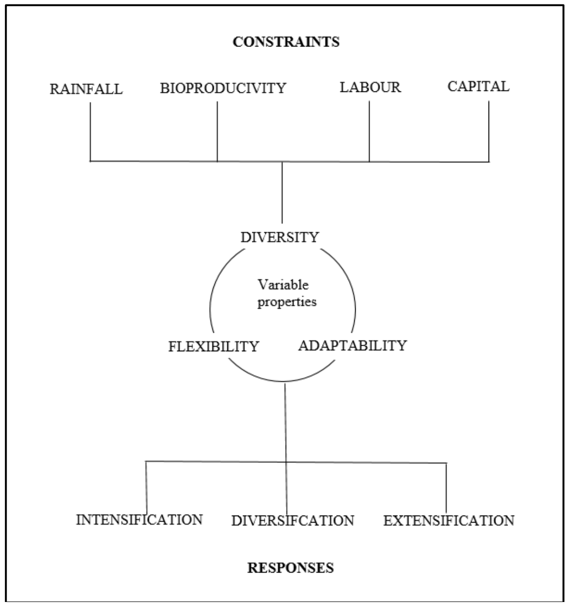


Figure 5: Sahelian model derived from Rural Livelihood Framework (Modified from: Mortimore & Adams, 1999)

The objective of this study was to conduct an analysis of agroforestry systems in the Kedougou region of Senegal fully characterizing major cropping systems used, key factors affecting agroforestry systems, how farmer attitude affects these factors in a climate context under the model listed above, and how the management of constant variation leads to system responses and adaptation. The premise of the study was that these factors are critical to natural resource management and adaptations and culminate in a resilient agroecological system. Characterizing and identifying these factors such as (1) the use of biological resources; (2) soil fertility management; and (3) livelihood management can lead to insights for both community stakeholders and relevant members of the extension, development, and policy community. I will show how farmers use gradual sequential change to mitigate high vulnerability and variability within agricultural systems in response to disturbances to agroecological systems such as climate change. This study will add to a body of literature regarding the understanding of community based natural resource management across a longitudinal scale that more properly characterizes and diagnoses land use change and the decision behind it to create resiliency.

3.3. MATERIALS AND METHODS

3.3.1. Study Area

The study area is located in the region of Kedougou (**Figure 5**) in the southeastern part of Senegal. Twelve villages were randomly selected from a survey of villages and coordinates provided by ANSD. All villages were located within the administrative district of Kedougou spanning four communes (**Table 4**). Kedougou has a population of 151,000 where 79% live in a rural setting and the poverty rate is of 71.3% which is far above the national average of 46.7%. The food insecure rate or rate at which a household experiences food insecurity throughout the year for the region is 33% of households. The majority of the population works in the agricultural sector with many of those being subsistence farmers, and 69% of the agricultural products from the region are cereal grains grown in rain fed agricultural systems (ANSD, 2015; Diop, 2014). Kedougou has some of the higher forest cover in Senegal, but bush fires are common and are seen as a threat to forest cover throughout the region of Kedougou (CSE, 2011).

Table 4: Communes and Villages included in the study

Commune	**Bandafassi**	**Dindefelo**	**Tomboronkoto**	**Dimboli**
Village	Sinthiouroudji	Thiangue	Niemenike	Kafory
	Syllacounda Diakha	Dar Salam	Mako	Bambaya
	Bandafassi			Woulaba
	Thiabedji			
	Niangue			

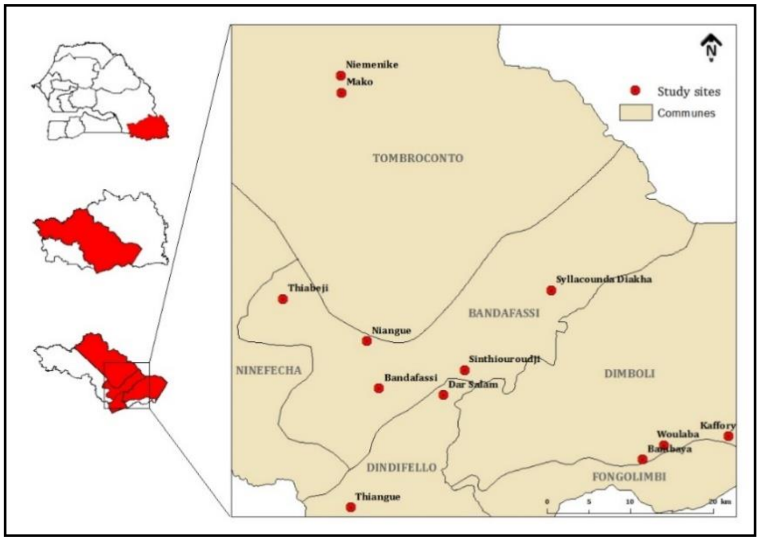


Figure 6: Area of Study

3.3.2. Methodologies

This study takes a mixed-methods approach to analyze the research question of how adaptive behavior affects management strategies regarding climate change. It combines data collected by various governmental agencies or international research organizations, in-depth interviews, in field observations, and focus groups. The in-depth semi-structured interviews of key stakeholders (**Table 5**) were conducted with relevant stakeholders in the government and non-governmental organizations (NGOs).

3.3.3. Data Analysis

Analysis was done using participant response matrices to identify patterns within agricultural, social, and resource organizations across households participating in focus groups (Wolcott, 1994). Answers and language from different respondents describing various components of local agroecological systems were analyzed to identify similar patterns among farmer knowledge, attitudes, and practices (Murray-Prior, 1998) using a mixture of categories, theory, and evidence for analysis derived from Crang (1997). A listing method was used to identify common parkland tree species and an indices of use of tree species similar to that as used in Lykke (2000).

3.3.4. Data Collection

Field work was conducted over a series of 5 months from May to September 2016. This time was selected to coincide with the beginning and middle of the rainy season to increase accuracy of personal observations from the field since farmers would be actively cultivating. The climate data was collected from the Senegalese government agencies.

3.3.5. Focus Groups

A total of three focus groups were conducted in each of the twelve villages. The focus group structure was created using Stack (2009) and Laws et al. (2003). The focus groups continually built off of the previous focus groups in a linear fashion introducing climate narratives later on to avoid biases in answers. All focus groups were conducted in local languages through a translator trained by USAID/Feed the Future in stakeholder engagement and lasted between 1-2 hours followed by field observations with focus group participants. A total of 175 participants took part in the focus groups where 30% partook in all of the focus groups and 55% partook in at least two focus groups.

3.3.6. In-Depth Stakeholder Interviews

Semi-structured in-depth interviews were conducted with key stakeholders within the agriculture sector of Kedougou. The purpose of these interviews was to get the unique perspective and insights of people who play an integral role within the agriculture sector of Kedougou.

Table 5: Institutions and functions of key stakeholders

Institution	Function
Eaux et Forets	Government agency charged with protection and management of forests, fauna, reforestation, soil conservation, and public education;
Kedougou Bureau de l'Agriculture	Implementation of food and agriculture policies, extension services, pest control programs, and research and training in crop production;
Trees for the Future	International NGO working to alleviate poverty through agriculture development;
Peace Corps Senegal	Grass roots development organization in agriculture, health, and economics;
Universite Cheikh Anta Diop de Dakar l'Insitut des Science de l'Environnement	The Institute for Environmental Sciences at the University Cheikh Anta Diop in Dakar. Conducts research in all fields pertaining to environmental sciences throughout all regions of Senegal;
Centre de Suivi Ecologique	Center specializing in environmental monitoring and sustainable management of natural resources to provide information to the local and national government, private sector, civil society, and research and development institutions

3.3.7. Personal Observations and Field Observations

In additional to the focus groups and in depth interviews, personal observations of agricultural systems from focus group participants were conducted allowing for some follow up questions about their systems and to clarify discrepancy that seemed to occur. A total of 35 farms were observed following the focus groups using a human geography participant observation methodology derived from Cook (1997).

3.4. DISCUSSION AND RESULTS

To begin understanding responses within agricultural systems under the Sahelian social organizational model (**Figure 4**), it is necessary to do a characterization of agroecological systems present in the region starting with predominant types of agricultural practices, spatial organizations, species diversity within systems, and temporal scales (e.g. diversity of resources) followed by determinants for crop and tree choice as well as determinants for the incorporation of trees on farms (e.g. flexibility). This is followed lastly by using local indigenous knowledge to analyze long-term responses and management strategies of farmers (e.g. adaptability) that all culminate in one of the three categorical responses.

3.4.1. Common Agroforestry Practices

The vast majority of agricultural systems in Kedougou are agroforestry systems (Dansokho et al., 2012; Diedhiou, 2004; FAO & CSE, 2007). As represented in **Table 3**, farmers reported the use of four main agroforestry practices, which are parklands, hedgerows, plantations, and the taungya system. Parklands are the predominant system in which 99% of responders reported that they practiced parkland systems. It has been well documented that parklands are the predominate system used across west Africa (e.g. Assé & Lassoie, 2011; Boffa, 1999; Tappan & Mcgahuey, 2007).

Taungya was the second most common practice in which 66.3% of farmers reported the use of the taungya practice while attempting to establish a plantation for fruit and wood production. Farmers establish mango or cashew orchards while rotating corn, sorghum, rice, millet, and peanuts between the rows of trees for subsequent years until the trees reached maturity shading out the cereal grains. In this study, hedgerows are defined as various practices such a live fencing, wind breaks, erosion control, and field demarcation lines depending on the farmers' individual needs. 27.7% of farmers practiced one of these various types of hedgerows.

Only 11% of farmers responded with just practicing plantation style arrangement without planting annual crops in between rows of trees. It was noted that all of the responders that listed this were from villages that were heavily involved in artisanal gold mining. The farmers in these villages cited that agricultural production was viewed as a secondary source of income with the primary source being the extraction and production of gold. However, these farmers did show interest in establishing fruit orchards as a long-term financial investment for their families knowing that gold is a nonrenewable resource. Farmers that practiced simple plantations primarily used the fallowed land and forests to collect forest products such as fruit, bamboo, and pole wood to be sold in market, used for construction, or transformed into charcoal for sale to supplement incomes during times of the year without mining.

Table 6: Common agroforestry practices used in Kedougou

Agroforestry Practice	Description of Practice	Number of Respondents (n=101)	Percentage
Parkland	Landscapes in which mature trees occur scattered across cultivated or recently fallowed plots of land (source: Boffa, 1999)	100	99%
Taungya	Plantation style arrangement with crops grown between trees for each successive year until trees shade out crops (source: Agyeman et al., 2003)	67	66.3%
Hedgerow	Use of trees to for boundary planting and to protect from wind, erosion, and animals (source: Nair, 2014)	28	27.7%
Plantation	Single species stands of forestry and fruit species (source: Nair, 2014)	11	10.9%

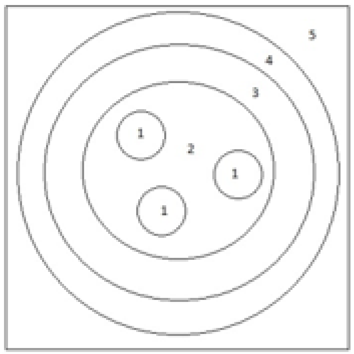
During field observations, there was a relationship between the distance of farming fields from the household compound or village and its level of management. Fields closer to villages had lower tree density to allow for greater cereal grain cultivation along with a greater duration of years under cultivation before beginning the fallow cycle. These fields were also more likely to have chemical inputs be used on them along with an increased amount of years between fallow periods. Fields farther from village centers usually had a higher density of trees along with longer fallow times. Farmers showed a strong preference toward intensifying fields closer to the village or homesteads.

The majority of farmers incorporated more than one of these practices onto the same plot. To a much smaller scale, riparian buffer zones, windbreaks, and hedgerows to control for erosion were observed. Farmers with fields adjacent to rivers would leave a row of tree species when converting the forest to farmland along the banks of the river forming a riparian buffer zone. All fields that had fully functioning windbreaks were in villages that had been or were currently active intervention sites for government or NGO extension services.

Farmers show a diverse use of various agroforestry practices to mitigate climate risk through buffering its negative impacts through such things as increased soil moisture and relative humidity. Additionally, a diversity of activities in an agroecological system generates production from a variety activities increasing the availability of food or resources throughout the year. By utilizing various practices, the impacts from reductions in production from specific on farm activities can be dampened by concurrent production from other on farm activities. The use of various agroforestry practices has a large effect across the spatial and temporal management of resources and agroecological systems.

3.4.2. Spatial Organizations of Systems

The spatial and temporal scales of a physical settlement in relation to agricultural systems requires a distinct land use observation. Settlements are a major ecological disturbance across natural landscapes that have effects on biological resources available, use of biological resources, and livelihood strategies (Duvall, 2006). Two different types of spatial arrangement of villages and farms were observed which impacted the structure of agricultural system temporally and spatially. These arrangements largely fell along ethnic lines, but this was not the case in every village.



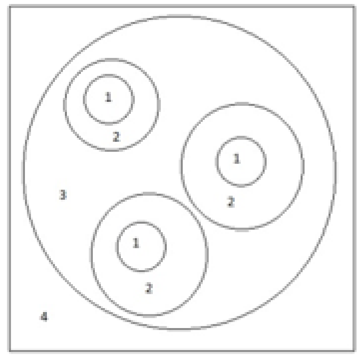


Figure 7a: Spatial Arrangement I **Figure 7b**: Spatial Arrangement 2

The main differences between the two spatial arrangements is that the first spatial arrangement (**Figure 7a)** has the majority population living closely together with the fields completely surrounding the village while the second type of spatial arrangement (**Figure 7b)** has highly intensified fields in between family compounds. The villages with the fields in between cited protection of field crops from animals as the main rationale. It was cited that it was easier to build a fence around that area then around fields farther away from the village to keep animals out. Spatial arrangement I is similar to other systems describe in Assé & Lassoie (2011), Duvall (2006), and Mortimore & Adams (1999), while spatial arrangement II is similar to a system described in Brookfield (2001).

Fields within the village in spatial arrangement II are usually cultivated on a longer cycle of consecutive years with a higher reliance on chemical inputs such as fertilizers or pesticide to mitigate decline yields. In both spatial organizations I and II forests that are not actively being cultivated still provide various forest products for households such as fuel wood, food, medicine, construction material, and marketable goods such as charcoal or bamboo. The option remains to expand the area under cultivation if needed. Additionally, fallowed fields were actively used in gathering various native fruits and other wood products such medicine, firewood, or construction materials.

About half of the villages delineated land between pasture and cropland on a temporal scale. These villages usually would delineate one side of the village in which all of the fields are being fallowed as pasture land while they actively cultivate fields on the opposite side of the village eventually switching between these plots once yields begin to decrease. Farmers cited that it was easier to protect their crops from animals, the animals actively provided manure to increase soil fertility of the fallowed areas, and animal fodder was more readily accessible in the fallowed area.

Settlements within Kedougou are inherently a distinct type of land use within spatial and temporal scales that have direct effects on biological resource use, fertility management, and livelihood management fitting into the theoretical framework for Sahelian societies. The spatiality of settlements can be seen as an adaptive and flexible variable leading to one of the three model responses in the framework. Spatial organization of settlements impacts both the intensity of cultivation and land use type where farmers weigh the cost-benefit of plot proximity, water sources, and resource availability within agroecological systems.

3.4.3. Common Agroforestry Species

Diversifying with the use of different tree species effectively mitigates negative impacts of the rainfall and bioproductivity constraints by diversifying productions throughout the year. Diversifying wood and non-wood forest products augments household nutrition, availability of resources, and can increase incomes (Faye et al., 2010; Maranz et al., 2004; Petit, 2003; Ræbild, 2012). For example, dry season activities may consist of gathering fruits from *Vitellaria* *paradoxa* and *Parkia biglobosa* to process into shea oil and '*nere*' respectively. These can serve as nutritional or income sources during the beginning of the rainy season before crops have matured (**Figure 8**) Common species used in various agroforestry systems in the region were identified along with what farmers use them for and the level at which they are used to measure the use of biological diversity. A scale of 1-3 is used to denote the level of use of each species where one denotes common use and three denotes sparse use by using the listing method from trees cited in focus groups.

Source of revenue Activities	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Agricultural crops					■	■	■	■	■	■		
Home/Market Gardens	■	■									■	■
Animal Husbandry	■	■	■	■	■	■	■	■	■	■	■	■
Timber Products	■	■	■	■	■	■	■	■	■	■	■	■
Adasonia digitatas				■	■							
Vitellaria paradoxa (Shea)					■	■						
Saba Senegalensis						■	■	■				
Parkia biglobosa			■	■								
Gold Mining/Panning	■	■	■	■	■						■	■

Figure 8: Calendar of various income or food producing activities in Kedougou (Adapted from: CSE, 2011a)

3.4.3.1. Parkland Species

This paper defines parkland specie as endemic or naturalized tree species being used in agricultural systems. The trees listed in the table below were identified by farmers as trees that they commonly use in their parkland systems. The trees and uses in listed in **Table 7** are similar to other species recorded across the literature (e.g. Gueye et al., 2014; Sinare & Gordon, 2015).

Table 7: Endemic species used in parkland systems (1=frequent; 2=occasional; 3=rare)

Species	Level of use	Common uses
Vitellaria paradoxa	1	Food, butter, oil, medicine
Parkia biglobosa **	1	Food, medicine
Adansonia digitata	1	Food, forest products, medicine
Saba senegalensis	1	Food, medicine
Tamarind indica **	1	Food, green manure, nitrogen fixation
Acacia spp.**	1	Protection, green manure, nitrogen fixation
Ziziphus mauritiana	1	Food, nitrogen fixation
Bombax costatum	2	Wood, forest products
Ceiba spp.	2	Wood, forest products
Cordyla pinnata	1	Food, firewood
Lannea spp.	2	Food, firewood
Ficus spp.	3	Food, medicine
Khaya senegalensis	1	Firewood, construction wood
Detarium microcarpum	1	Food, forest products
Detarium senegalense	1	Food, forest products
Pterocarpus erinaceus	3	Wood, medicine
Borassum aethiopium	1	Food, wood, palm wine
Elaeis guineensis	2	Oil, palm wine, wood
Raphia sudanica	1	Food, oil, palm wine, construction wood
Bambusa spp.	1	Construction wood
Piliostigma reticulatum **	1	Firewood
Piliostigma thonningii **	1	Firewood

**Denotes trees that fixate nitrogen

Vitellaria paradoxa and *Parkia biglobosa* were the two most commonly listed species. 75 % of the trees listed provide provision services that increase the nutrition or the income of households. The majority of the species utilized provide multipurpose products such as food, marketable value-added products, and forestry products such as firewood consumed by households. While the vast amount of products is consumed at the household level, a smaller proportion of these products are used as on farm and off farm income generation.

3.4.3.2. Cultivated Species

Along with leaving endemic or naturalized species *in-situ* in their systems farmers also actively propagate species that mainly have nutritional or economic benefits that have primarily been introduced by extension services, the colonial system, or NGOs. Many of these species are actively extended by governmental and non-governmental organizations throughout Senegal in efforts to increase food security and stop deforestation.

Table 8: Common cultivated and extended species used in agroforestry systems

Species	Level of use	Use
Mangifera indica	1	Food, market product
Anacardium occidentale	1	Food, market product
Citrus spp.	1	Food, market product
Acacia spp.	1	Live fencing, green manure
Psidium guajava	2	Food, market product
Eucalyptus camaldulensis	2	Windbreak, wood
Senna spp.	2	Windbreak, pole wood
Leucaena leucocephala	3	Windbreak, green manure, pole wood
Bauhinia ruscefens	2	Live Fencing, green manure
Jatropha curcas	1	Live fencing, demarcation, medicine, oil
Tamarind indica	2	Food, green manure
Azerondacta indica	1	Wind break, pesticides, oil

All of the villages had a mixture of parkland species and cultivated species throughout farming landscapes. Farmers put an emphasis on the importance of having parkland trees in their systems along with having cultivated species to increase nutrition, products, and income. Land tenure and increased production were stressed as the factors behind the preference.

A stark difference between the two types of species is farmers very rarely actively cultivate native or endemic tree species as opposed to the species listed in **Table 8**. Farmers noted that they do not actively cultivate endemic species because they are plentiful in the forests.

Management of such trees is limited to natural regeneration, collection of forest products, and minor pruning and tree selection when occurring *in-situ* on farms.

3.4.3.3. Homegarden Species

While not all households practiced homegardens, the practice was common throughout all of the focus groups. These small intensified areas were cultivated not only during the rainy season but during the dry season with a direct focus on food production, such as leaves and vegetables for household consumption, using an intimate multistory combination of trees and crops. Homegardens are primarily managed by women in the household and occur within the homestead or immediately adjacent to the homestead.

Table 9: Common species used in homegarden systems

Common Homegarden Species	Level of use	Use
Jatropha curcas	1	Live Fence, demarcation, medicine, oil
Moringa oleifera	1	Food
Carica papya	1	Food
Musa spp.	2	Food
Psidium guajava	2	Food
Punica granatum	3	Food

*Amaranths and leafy vegetables are an integral component of homegarden understories

Farmers have shown great diversity of using various tree species to provide a multitude of provisioning and protective services to not only increase food security but also mitigate the negative impacts of rainfall or bioproductivity. Using a large number of trees on farms shows the flexibility of farmers to use biodiversity and economic plants to increase food security (Agbola et al., 2008; Reardon et al., 1992) The management of endemic and non-endemic tree species on farms shows diversity and flexibility within livelihood strategies with large impacts on land-use options and resource management across agricultural landscapes.

3.4.4. Fallow Trends

Soil is a major management component for all agroecological systems. Flexibility within decision-making with regards to soil management on a year to year basis culminates into adaptability by impacting not only soil fertility but also the biodiversity, bioproductivity, and general livelihood strategies.

Farmers in the region of Kedougou still practice a form of shifting cultivation. Once cereal grain productions begin to decline (usually 3-5 years) per plot of land, farmers then fallow the plot to allow vegetation naturally regenerated to ameliorate topsoil and soil health. When the fallow cycle has been completed, naturally regenerated mature trees are selected to be cut down or coppiced. The plot of land is then burned. Farmers cited that the burned trees provide fertilizer for the soil. **Table 10** shows the average fallow cycle per cultivated plot as well as factors leading to a decline in fallow cycles.

Table 10: Amount of years in fallow cycle per village (Average fallow = 4 years)

Village	Fallow	Reasons for reduction in fallow cycle
Woulaba	5-7 years	
Syllacounda Diakha	1-2 years	Population pressure and land availability
Dar Salam	5-7 years	
Thiangue	5 years	
Bambaya	4-5 years	
Thiabedji	4-5 years	Population pressure and land availability
Niangue	3-5 years	Decreased land availability due to encroachment of nationally protected lands
Kafory	3-4 years	Population pressure and land availability
Indara/Bandafassi	4-5 years	
Sinthiouroudji	None	Reduction in available land due to lack of land tenure and encroachment of surrounding communities
Niemenike/Touba Diakha	4-5 years	
Mako	3-5 years	Land availability

Farmers were asked questions about the mechanism behind fallow and soil regeneration. When asked, farmers responded that the decomposition of biomass from trees, predominantly leaves, woody material, and roots, along with burning woody debris are the two main ways soil health is increased by fallow. Farmers put a large emphasis on the decomposition of leaves being the primary mechanism for soil regeneration with burning woody debris during field preparation being the second most important mechanism for soil regeneration. There was a lack of understanding about the nitrogen fixation; however, farmers cited nitrogen-fixing trees as trees that can be attributed to faster soil health regeneration

Reduction of available land and increasing populations were the main stresses on land availability because the constraint bioproductivity does not have the ability to increase, resulting in either intensification or extensification of fields. This has created pressure to feed a growing population with a similar amount of land, leading to a reduction in fallow cycles to produce higher production from the same plot of land. Households would apply chemical inputs to plots of land if the financial means were available to increase production. Due to various stresses and pressures, farmers are being forced to adapt to changing conditions to maintain an equilibrium, showing a level of resilience.

3.4.5. Determinants for Crop and Tree Choices

A primary component of the flexibility and adaptability of farmers is the management of soil fertility. A few different factors have been identified as the key determinants for choosing what farmers decide to grow on various temporal and spatial scales within the given constraints. Focus group responses ranked soil type, quality, and texture as the primary determinants for crop choice across spatial and temporal scales. Farmers demonstrated a vast amount of knowledge and understanding of soil quality. For example, they could clearly understand the difference between sand, silt, and clay, and had the ability to determine soil texture using the hand method. This conforms to similar soil classification systems and perceptions impacting management strategies (e.g. Assé & Lassoie, 2011; Badini & Dioni, 2004; Dawoe et al., 2012). Farmers regularly noted that various crops perform better under various soil textures and organic matter.

Higher clay soils are reserved exclusively for rice production due to its seasonal flooding ability. Millet and peanuts are cultivated primarily in sandier soils with higher gravel content while corn is cultivated in soil with a higher silt fraction or soils resembling loam. Farmers primarily grow corn or millet immediately following the fallow and then switch to peanuts after yields begin to decrease. After peanuts, they will then try to get at least another season or two of corn or millet again before letting the field go to fallow and switching their place of cultivation. Farmers cited soil type as a determinant to specific tree species too with an understanding that specific trees increase organic matter at a higher rate. Norgrove & Hauser (2016), Rushemuka et al, (2014), Assé & Lassoie, (2011), and Dawoe et al., (2012) found similar findings regarding farmer knowledge of soil and crop choice.

Farmers reported a preference for cultivating cereal grains over tree products due to the ability of long-term food storage to increase food security. Cereal grains can be stored until prices increase during the lean season coinciding with the beginning of the subsequent rainy season. Due to lack of transportation and available markets, farmers reported that it is difficult to consume larges amount of fruit before spoilage.

Responses on crop and tree determinants show flexibility on a year to year basis with the management of resources and soil fertility. Farmers make adaptive decisions about planting choices on a yearly basis based on soil quality. While these determinants show flexibility on an annual basis, these determinants also have ramifications on the management of trees on farms, in turn affecting both the diversity of resources and adaptive management.

3.4.6. Factors Driving use of Trees on Farms

The culmination of shorter-term decisions sequentially equates to longer-term management strategies. Within the model, farmers must manage trees and crops on different temporal scales while navigating the pros and cons of various livelihood strategies. During the open-ended discussions, farmers discussed positive and negative drivers or factors that affect the use of trees within their agricultural systems. These discussions were approached with the understanding that trees are managed as long-term and permanent structures in agricultural landscapes where I sought to understand the underlying drivers for the inclusion of both parkland species utilized following a fallow cycle and trees purposefully planted on farms. These decisions can be seen as the adaptability of farmers using both diversity and flexibility properties. These factors tend to be a culmination of shorter-term decisions that impact adaptability and long-term management creating feedback loops for soil fertility management, food security, and ecosystem services as well as mitigating risk.

Table 11: Factors contributing to the use of trees on farms

Factors that increase the use of trees on farms	Number of Responses (n=101)	Percentage of Responders
Cultural/Religious Importance	10	10%
Forest Products (fruit, leaves, medicine, wood)	69	68%
Microclimates (Increased shade, cooler temperatures)	37	37%
Increased rainfall and water retention	9	9%
Protective services (windbreaks, live fences, shelterbelts)	23	23%
Products for Market/Income Generation	12	12%
Increased soil health	22	22%
Increased production of green manure	5	5%
Prevent Desertification	2	2%
Long term food security and income investment	2	2%
Aesthetics	2	2%
Increased land tenure and land ownership rights	7	7%
Increased production of animal fodder	7	7%
Reduction in pest pressure	1	1%

By far the key positive driving factor for the incorporation of agroforestry cropping systems are yields that provide direct provisioning for the household. There is a primary focus on products that either provide direct nutrition to the household through fruit or leaves along with medicine and wood for construction or fuel. The data shows that environmental factors are by far the main driving force behind farmers' decision-making practices in Kedougou. From the 101 responses, over 85% can be considered environmental factors; however, it is difficult to separate these factors from other underlying drivers that influence all decision-making of farmers. The larger share of factors focused on provisioning services, but there was also emphasis on supporting and regulating services. However, there is a religious and cultural importance tied to the use of trees on farms (Brun, 2017; Duvall, 2006).

Table 12: Factors that contribute to a decreased use of trees on farms

Factors that decrease the use of trees on farms	Number of responses (n=101)	Percentage of Responders
Clear trees for extensification*	13	13%
Termites*	6	6%
Past failures/biases	1	1%
Lack of information/training/ignorance*	11	11%
Lack of water or protection or materials*	9	9%
Fire	1	1%
Lack of Market Access	10	10%

The key negative driver for a decrease in use of trees is also directly related to providing provisions for the household. One topic that came up during every focus group was the debate between needing trees due to their direct benefits for nutrition, household consumption, market value, and environmental services versus the need for more space to cultivate cereal grains which make up the bulk part of a household's diet. Farmers definitely understood the beneficial side of trees; however, there was an underlying driver that too many trees took up space that could be used for growing cereal grains which farmers viewed as more beneficial to feeding their families and increasing food security. They discussed that some trees are good because they create microclimates that increase yields of cereals grains; however, an overabundance of trees will shade crops out. There seems to be either a lack of knowledge or another underlying driver as to why farmers do not practice more aggressive pruning techniques to reduce shading in their fields. Instead farmers often decide to cut the tree down and burn it.

Debate occurred between long-term spatial and temporal management of trees on farms with the production of cereal grains in the short term. In the short term, farmers responded to large changes in constraints to primarily increase production through extensifying cereal grain production by the clearing of more land or intensifying cereal grain production by cultivating a specific plot for a longer period of time where chemical inputs may be applied to mitigate declining annual yields.

3.4.7. Farmer Attitudes Towards Model Constraints

Within the model, climate change can be viewed as a disturbance to the overall system impacting the variable properties and constraints, changing system outcomes or responses to create a feedback that then affects the variable properties and constraints again (Berkes & Folke, 1998). Farmers provided a vast wealth of knowledge on how they use trees to buffer and adapt to high variation in climatic conditions. However, it appears that climate change narratives are a secondary factor with regards to the long-term management of mature trees across agricultural landscapes. While trees are viewed as a buffer to climate variation, long-term management strategies appear to be affected by other factors such as food security, biophysical indicators, and population pressures.

Farmers noted how they viewed changes in precipitation and temperature over the past 10 years as well how they view the impacts on three components within their agricultural systems. Farmers cited a strong correlation with tree density and precipitation patterns with a high density of trees corresponding with high annual precipitation. Respondents generally saw an increase in precipitation as a positive effect on production for all components of their agricultural systems while an increase in temperature as a negative effect. Adapting to climate change is viewed under the notion of flexibility which fosters continuous adjustments to agroecological systems (McIntosh, 2000).

3.4.8. Responses to Model Variable Properties

Farmers must manage framework constraints while managing diversity of resources within a system through flexible decisions in the short-term and long-term adaptable decision-making. The three responses observed throughout this study were intensification through reduction of fallow cycles or chemical inputs, extensification cited as a response to lower than expected yields on an annual basis, or diversification through the use of biological and technical resources. Diversification appears to be a constant throughout farm management across the region to mitigate all types of risk, socio-economic or biophysical.

Respondents cited extensification of cereal grain production was the primary response to changes in the constraints (rainfall and bioproductivity) as a means to increase agricultural production on a year to year scale. Farmers will simply expand the range of fields surrounding village to increase the area under cultivation. This can mean an expansion of agricultural lands onto lands not ideally suited for cultivation. This response causes a reduction in forest lands by the clearing of trees off existing forested lands. Another for extensification is that trees may be cleared off of existing agricultural lands. Another common response is to intensify fields by continuing to cultivate plots sequentially for a longer period of time.

Farmers noted costs and benefits to allocating areas across plots of land to the management of mature trees with a decrease in area for cereal grain cultivation. Cereal grain production provides household food in a rapid time period that is easily stored for long periods of time as where trees are a long-term investment until the trees have reached maturity. A farmer would have the ability to cultivate a cereal grain for multiple rainy seasons on the same piece of land that a tree would be taking up as it matures so while a tree might provide sustainable resources, resources from cultivating a cereal grain would be seen within the first year as opposed to a multi-year time scale.

Farmers do use agroforestry practices and trees on farms as ways to reduce agricultural risk and climate variation along with added benefits such as nutrient cycling, reduced soil temperatures, increased humidity, increased water retention, increased income generations, and livestock benefits. It remains to be seen whether or not climate impacts the density of mature trees on farms. Regardless, farmers do see trees as a way to mitigate reduction in precipitation and increases in annual temperature.

Outside of the model used, farmers view governmental and non-governmental extension services as a key technical resource when facing adverse conditions. Additionally, the use of religion and prayer was strongly emphasized as a way to mitigate negative effects of climate change. Farmers stressed a strong spiritual connection to trees and the use of trees in agricultural landscapes believing that trees provide secure sources of nutrition and income while adding co-benefits of soil regeneration and beneficial conditions for cereal grain production.

3.4.9. Flexible and Adaptive Management Strategies

All management decision-making towards model constraints, variables, and responses create a resilient livelihood strategy used by farmers. With a mixture of the accumulation of local indigenous knowledge and adaptive management, farmers are acutely prepared to manage agroecological systems with resilience. The combination of using a diverse set of resources (biological, technical, and cultural) and the flexibility of decision-making around soil fertility management, agroforestry practice use, and farm spatial scales on an annual basis accumulates into longer term adaptive measures; however, these adaptive measures may only go so far in mitigating the negative effects of climate change.

3.5. CONCLUSION

The model to analyze the social organization of Sahelian households and livelihood strategies used in this study offers various insights in indigenous knowledge and household decision-making with regards to climate change and agroecological system management to maintain a resilient equilibrium. A key insight is that farmers readily perceive changes in climate (actual or not) and incorporate this knowledge into the long-term management of agricultural systems. A second insight is that farmers possess a fairly strong knowledge of ecological principles directly related to the management of soil, food production, and management of forests and forestry products. Lastly, farmers use trees to adapt and cope by reducing vulnerability to variations in climate, but also strongly depend on extensification.

There is a primary focus on production of provisioning services from agroforestry systems. Primarily products such as food, fuel wood, timber, and medicine are consumed at the household level with excess being sold at market. This can be seen in the factors listed for reasons to incorporate trees on farm, and within the specific species farmers choose to cultivate. This makes plausible sense since the vast majority of farmers in the region are subsistence farmers. The next tier of factors listed for adoption albeit do not directly provide food for the farmers except money being made from products sold can be understood to also increase yields. Farmers put a great importance on microclimates and soil health which have the beneficial effect of increasing crop yields, which in turn would increase food security through better nutrition and a greater disposable income.

While climate change does play a role in farmer and household decision making, there is a lack of evidence that climate change narratives are a primary driver to farmer adaptation. Farmers continue to adapt and respond to all factors that affect farming systems. Farmers in West Africa have and will continue to practice agriculture in agroecological systems under high variability and volatility. The livelihood model developed for Sahelian communities allowed for an analysis of how farmers adapt by flexible management decisions on a year to year time scale. It was shown in the focus groups that farmers have a vast wealth of knowledge of ecosystem services provided by trees on farms along with using them as an adaptation strategy to ever changing climate variations along with increasing extreme weather events. Farmers have shown resilience in adapting to climate variation across temporal scales through traditional knowledge of farming systems.

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CHAPTER 4. IMPACTS OF AGRFORESTRY PRACTICES AND TREE DENSITY ON FARM VALUATION: THE CASE OF KEDOUGOU SENEGAL

4.1 ABSTRACT

Rural subsistence households face a variety of environmental pressures that increase vulnerability. Agroforestry and biodiversity are seen as two practices that can reduce sensitivity to risk thus by decreasing vulnerability. There was a strong correlation between crop production and farm size ($R^2 = 0.89$) where livestock was a significant proportion of the total farm valuation. Using a regression model, the effect of agroforestry practices and tree diversity on the valuation of crop yields and livestock holdings was analyzed. There was a lack of significance between means except for the types of agroforestry practices had an effect on the valuation of crop yields and livestock holdings together. Even though agroforestry practices and tree diversity were shown to have a small effect on farm valuation the multiple co-benefits cannot be overlooked when assessing their impact on reducing vulnerability. The lack of significance is probably due to a small sample size and lack of a multi-year data set.

4.2 INTRODUCTION

Food security is defined as when '*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preference for an active and healthy live*' (FAO, 1996). Food security is a direct outcome of the status of a food system with a food system being a range of activities from consumption to production of food (Ericksen et al., 2009). To completely understand and study food systems, a broadening of the definition to fully encompass the economic, social, and environmental drivers that affect food security, food, management, and livelihood strategies is needed as well as their outcomes. A broader definition of food systems includes the interactions between biogeophysical and human environments, the activities themselves, and the outcomes of the activities with feedback mechanisms (Berkes et al., 2003; Ericksen, 2008). The production of food, food security, and food systems can all be directly linked to vulnerability for subsistence farming systems through both natural capital and financial capital.

While there is not agreement on a perfect method of assessing vulnerability especially within subsistence farmers, farm productivity, household wealth, and diversification of activities have all been used to develop vulnerability indices (Evangelista et al., 2015; Hoogeveen et al., 2004). Regardless, the incorporation of agroforestry practices has been shown to rapidly increase agricultural output (Yin & Hyde, 2000) while creating systems that can be sustained long-term (Mbow et al., 2014). The FAO views augmentation to traditional production systems through agroforestry as a viable option for agricultural development in rural areas (El-Hadji et al, 2001).

Agroforestry has added advantages as compared to other adjustments to agricultural lands. Practices such as chemical fertilizers, pesticides, or extension of improved seed varieties may lead to a decrease in soil organic matter (Maeder et al, 2002), increased crop vulnerability to pests and diseases (Matson et al., 1997), and a decrease in overall environmental productivity (Aktar et al., 2009). Whereas the increase of tree cover through agroforestry practices can increase hydraulic lift (Ong et al., 2014), reduce wind velocity (Stigter et al., 2002), increase soil carbon (Chen et al., 2017), and decrease pests or diseases (Gadanakis et al., 2015). By looking at the relationship between the valuation of crop yields, valuation of livestock holdings (i.e. the amount of livestock per household converted to a monetary value), agroforestry practices, and tree diversity, I aim to assess if there are beneficial effects to crop yields on farms that practice different agroforestry practices and have different amounts of tree diversity. The main objective of this study is to determine if agroforestry practices can reduce sensitivity to risk in turn reducing vulnerability by looking at crop yields and livestock valuation as proxies for productivity and capital. Evangelista et al., (2015) defines sensitivity as the degree to which a system is affected and by increasing plant diversity, number of livestock, types of land-use, and agricultural yields. An increase in any of these factors decreases the sensitivity or the degree by which a household experiences vulnerability.

In this study, I examined agricultural yields and valuation of livestock holdings as a function of both agroforestry practices and tree diversity on farms. This approach examines how various agroforestry practices and tree diversity occurring as a result of different management styles affect valuation of crop yields and valuation of livestock holdings. Agroforestry practices and tree diversity were chosen because increased biodiversity (i.e. multiple tree species) in an agroecological system increases overall ecosystem health (Peterson, Allen, & Holling, 1998), and agroforestry practices increase both ecosystem services and primary productivity (P K R Nair, 1998).

4.3 MATERIALS AND METHODOLOGIES

4.3.1 Study Area

Kedougou, Senegal is the most rural and food insecure region of Senegal. The population relies primarily upon rain fed agriculture with a large dependency on parkland agroforestry species to increase incomes and nutrition (ANSD, 2015; Gueye et al., 2014). The rainy season normally last from May to late October with about 1200 mm of water per year (Dansokho et al., 2012).

The main crops cultivated are peanuts, rice, maize, cassava, *fonio*, and potatoes with parklands being dominated by mangos, cashews, shea trees, locust bean, and palm trees (Wood

& Mendelsohn, 2014). Maize is the dominant cash crop in Kedougou; however, by household consumption groundnuts and rice are important followed by sorghum and millet (ANACIM et al., 2013). Additionally, this region of the country produces a large amount of charcoal and wild fruits (IREF, 2015), but wood is used for the majority of energy production followed by propane and charcoal (ANSD, 2015). Average farm size was determined to be 2.27 hectares where 89 % of households are considered very poor or poor by the WFP wealth index which measures wealth based on ownership of non-productive assets.

4.3.2. Survey Method

53 households were surveyed across 12 randomly selected villages. The data was collected using translators whom had been trained to engage stakeholders and community groups. All values were calculated in 2016 FCFA currency rates. Households were 36 % Mande speakers and 64 % Pulaar speakers. Average farm size was 2.27 hectares, and maize, peanuts, and rice were the predominant grains cultivated. All households cultivate subsistence agroforestry systems while using surrounding forests for additional wood and NTFPs to augment household diets and income. The majority of households view soil health and rainfall as the main determinants for production.

4.3.3. Conceptual Method

Two separate multi-linear regression models were conducted with the two response variables being crop valuation and the sum of crop valuation and livestock holdings respectively. Crop valuation was used to evaluate annual production of a farm while the sum of both crop valuation and livestock holdings served as proxy for a household’s yearly capital. These independent variables were used to assess farm productivity from two separate concepts. Agroforestry practice and crop diversity were the dependent variables for both models.

The model takes form as: $\ln Y_i = \alpha + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i$

where Y is crop valuation and livestock holdings, α is a constant, x_1 is categorical variable for agroforestry practices, x_2 is the categorical variable for tree diversity, β_1 and β_2 are intercepts, ε_i are independently distributed error terms where *i* represents each household. Crop yields were determined by multiplying size of farms by average regional yields per hectare, and the multiplied by median market pricing for 2016. Valuation of livestock were determined by multiplying herd size by median market prices for 2016. Pricing was determined by surveying local market vendors.

4.4. RESULTS

4.4.1. Trends in Senegal's Agricultural Sector

Senegal's agricultural sector has remained fairly stagnate in terms of production and acreage for the latter part of the 20th century. **Figure 8** show trends in production, area under cultivation, and yields over a 49-year period. The majority of these have remained relatively stable with the exception being increases in maize and paddy rice production without a comparable increase in area under cultivation which can be viewed in both the production and yields charts. Annual decreases especially in the 1970s are due to major droughts (ANACIM et al., 2013).

Trends in market pricing for cereal grains has also remained fairly constant over a similar time period (Kelly et al., 1996). Even though cereal grain production has remained fairly constant, total area under agroforestry practices has more than doubled through the extension of agroforestry practices from governmental and non-governmental extension services (CSE, 2009).

4.4.2. Description of Agroforestry Practices in Southeastern Senegal

Senegal promoted monoculture production of cereal grains and cash crops such as cotton starting from the colonial era through independence. More recently, Senegal has undertaken agricultural and land-tenure reforms decentralizing land rights and forest management (MEDD, 2014). The state has shifted focus on the promotion of diversification of food crops as well as the development of more intensive agro-sylvo-pastoral systems as well as the promotion of agroforestry to meet the needs of the households specifically in a rural context. Senegal has begun more specific promotion of practices depending on the type of landscape and environmental conditions such as the exploitation of Non-Timber Forest Products (NTFP) and paddy rice cultivation in southern Senegal (FAO & CSE, 2007) to decrease dependence on imports (El-Hadji et al., 2001). This is especially important to the region of Kedougou due to historically lower yields per unit area of cereal grains compared to national averages (ANACIM et al., 2013).

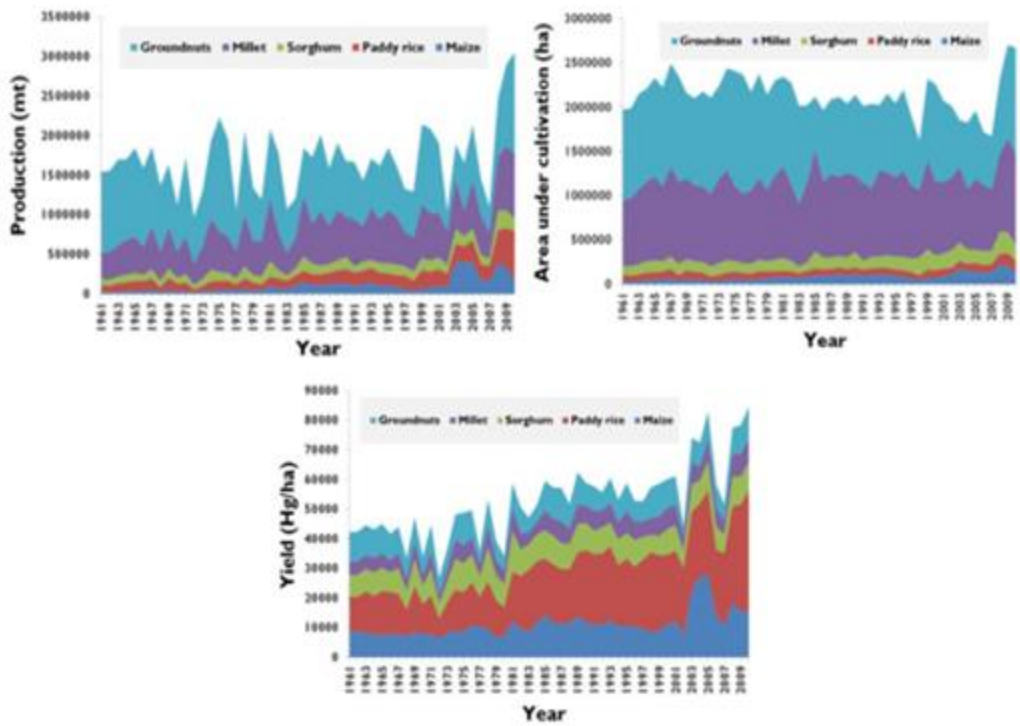


Figure 9: Trends in cereal grain production (left); area under cultivation in hectares (right); yields in hectogram per hectare (bottom) between 1961 and 2010 (Source: ANACIM et al. 2013)

Agricultural systems in Kedougou are predominantly rain fed parkland agroforestry systems intermixed with various agroforestry practices such as hedgerows and taungya. Hedgerows are a practice of using trees to establish a row of trees to protect fields from wind damage, erosion, floods, or animals often called windbreaks, shelterbelts, or live fences. Taungya is the practice of growing agricultural crops in between trees during the early stages of establishing forestry species for timber or NFTPs (P.K.R. Nair, 2014).

Table 13 shows the amount of additional hectares and linear kilometers of taungya and hedgerows over the years 2012, 2014, and 2015. The region of Kedougou Senegal poses an interesting opportunity to examine the impact of specific agroforestry practices on agricultural production. I aim to analyze how agroforestry practices and tree diversity have an effect on farm productivity and household wealth through valuating crop production and livestock holdings.

Table 13: Yearly increases in agroforestry practices in Kedougou (Source: IREF, 2013, 2014, 2015)

Year	**Plantation (ha)**	**Hedgerow (linear km)**
2012	72.59	44.9
2014	150.56	95.964
2015	130	88.35

4.4.3. The Effect of Farm Size on Yields

Figure 10 shows the average amount of crop yields cited per village as well as the average value of livestock holdings per village. This figure shows that livestock holdings make up a majority of capital possessed by each household whereas the value of the crop yields is predominantly smaller. Livestock is the predominant way to store wealth across West Africa (Kamuanga et al., 2008).

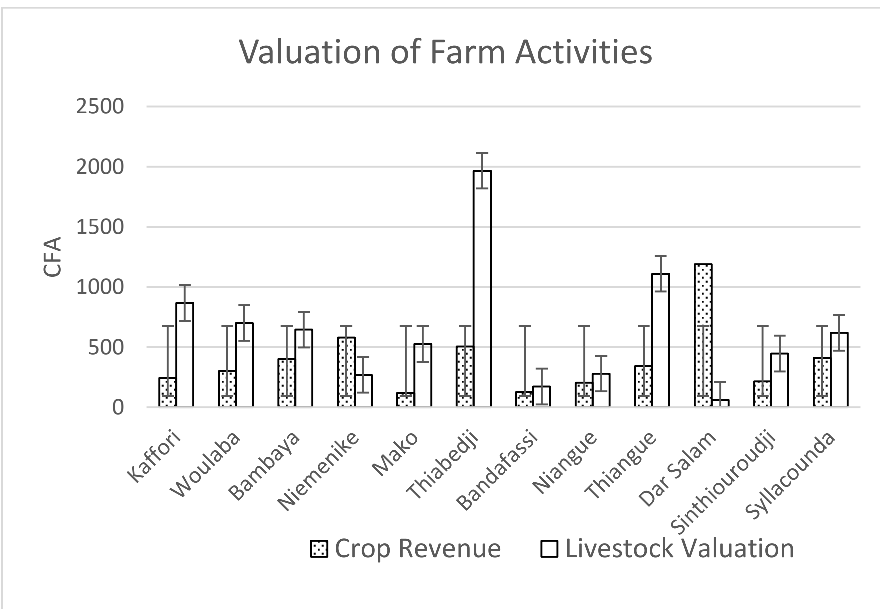


Figure 10: Total Valuation of Crop Yield and Valuation of Livestock Holdings by Village

Figure 11 shows that as farm size increases so does valuation of crop yields per farm. The R^2 value of 0.89 shows that there is a strong correlation between farm size and crop valuation. Area under cultivation is an accurate predictor to yields of cereal grains especially on farms with a low level of mechanization. As area under cultivation increases so does the amount of yields.

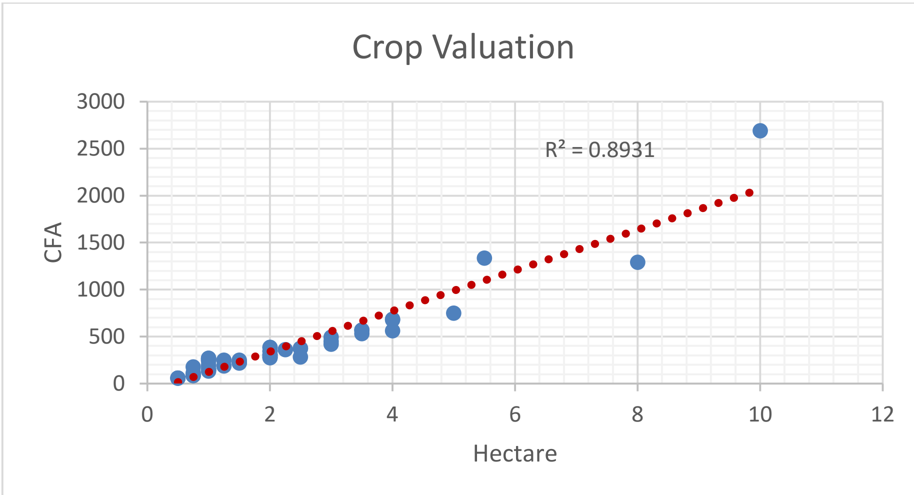


Figure 11: Correlation between crop valuation and farm size

4.4.4. Effect of Choice of Agroforestry Practice on Farm Valuation

An analysis of agroforestry practice difference on crop valuation showed no overall statistical significance (F = 0.76, p = 0.5218). Looking at pairwise comparisons for agroforestry practice on solely crop valuation showed no significant difference between means. However, livestock valuation with crop revenue showed a statistical significance (F = 2.37, p = 0.0827) using an alpha value of $\alpha = 0.10$.

A closer look at pairwise comparisons for crop and livestock together showed there is a statistical difference between farms that practiced parklands alone, farms that practiced either taungya or hedgerows with parklands, and farms that practice all three congruously. Farms that practice all three forms of agroforestry has the highest valuation of crop yields and livestock holdings. Farms that practices either taungya or hedgerows in conjunction with parklands had the next highest valuation of crops yields and livestock holdings where farms that only practiced parklands had the lowest amount of crop yields and livestock holdings.

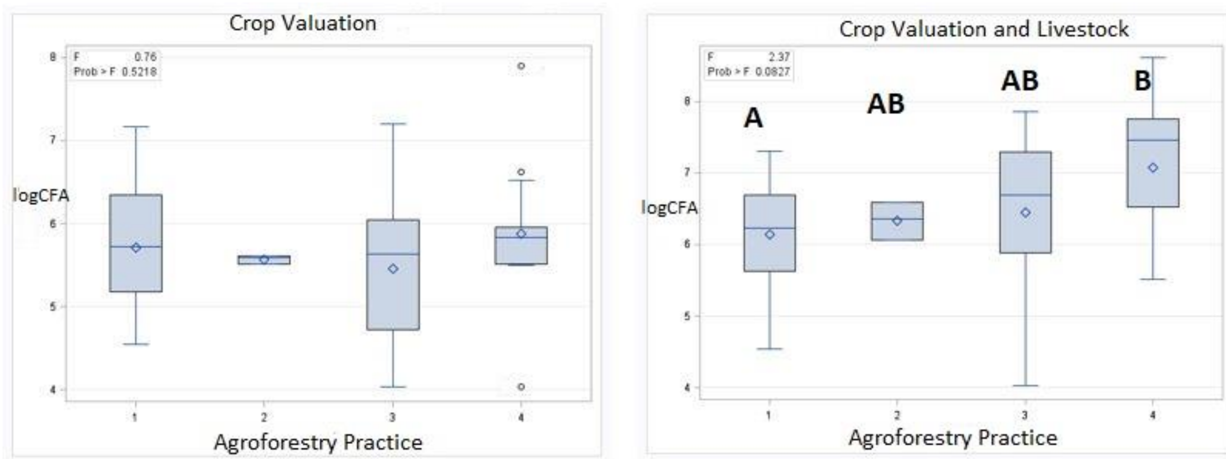


Figure 12: Effect of agroforestry practice on valuation of crop yields (left); Effect of agroforestry practice on valuation of crop yields with livestock holdings (right);
1 = Parkland; 2 = Parkland + Taungya; 3 = Parkland + Hedgerow; 4 = Parkland + Taungya + Hedgerow

4.4.5. Effect of Tree Diversity on Farm Valuation

Looking at the number of tree species per farm also showed no statistical significance for crop valuation ($F = 0.45$, $p = 0.6415$) as well as valuation of livestock holdings and crop valuation together ($F = 1.16$, $p = 0.3233$). This goes to suggest that the diversity of trees on farms does not dictate the amount of crop yields or livestock holdings. Additionally, there does not seem to be any increase or decrease trends for farm valuation with changes to tree diversity. Finally, an analyses of interaction between the two variables showed there was no significant interaction between them.

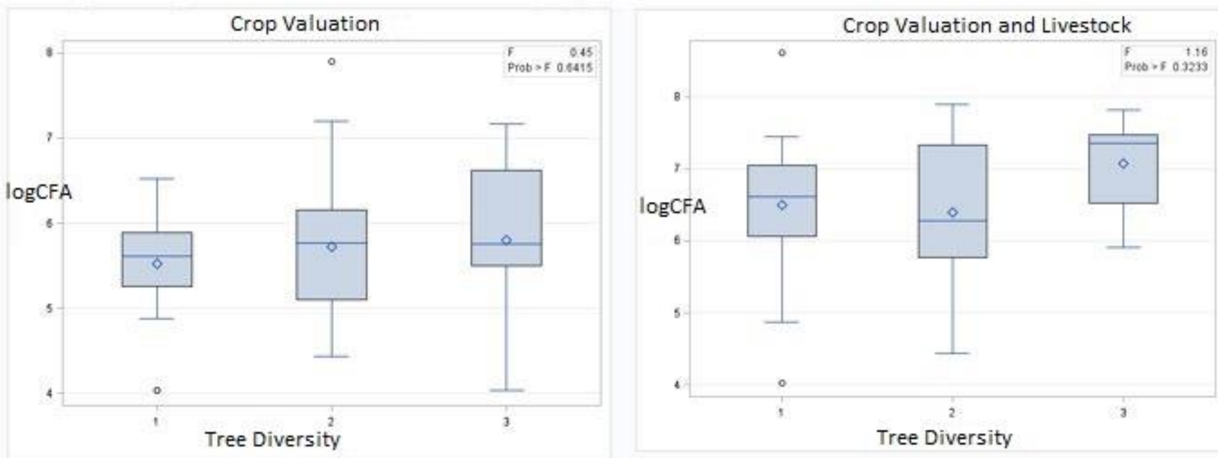


Figure 13: Effect of tree species diversity on valuation of crop yields (left); Effect of tree species diversity valuation of crop yields and livestock holdings (right);
1 = 1-5 tree species; 2 = 6-10 tree species; 3 = ≥11 tree species, *No statistical significance

4.4.6. Analysis of Deviation from Mean by Agroforestry Practice

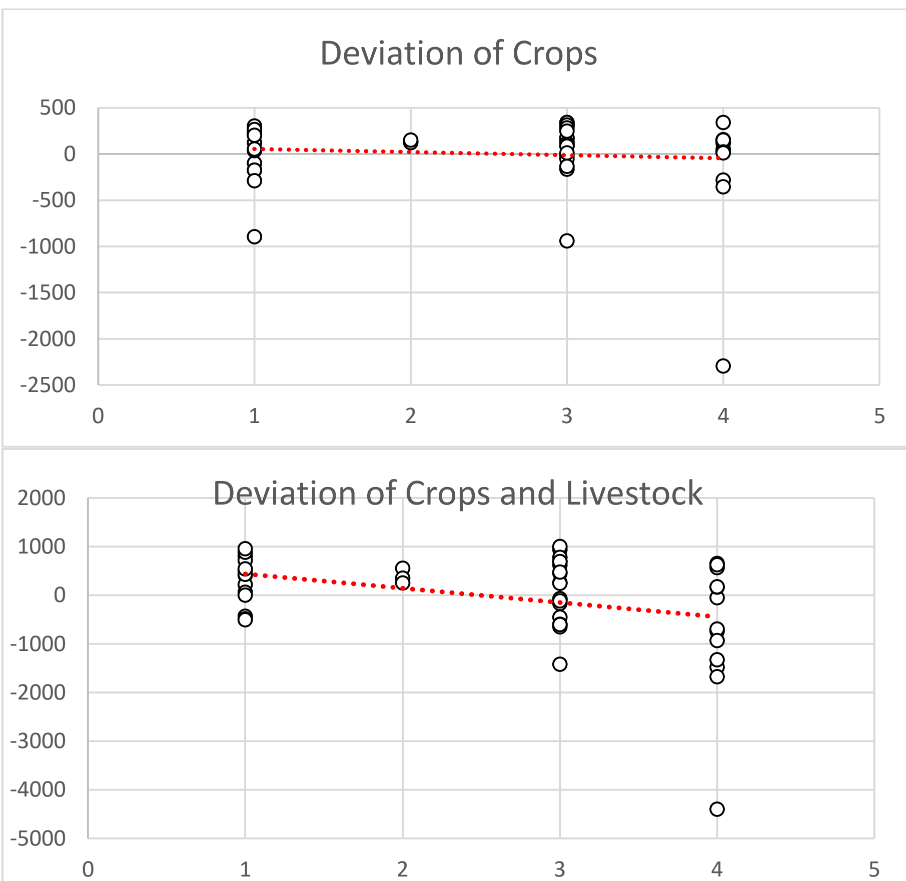
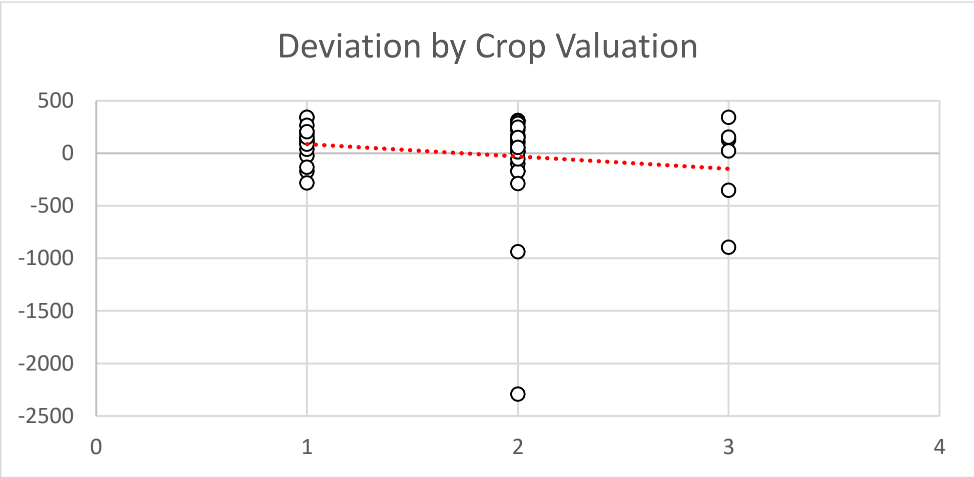


Figure 14: Analysis of deviation from mean for valuation crop yields (above); analysis of deviation from mean for valuation of crop yields and livestock (below), by agroforestry practice; 1 = Parkland; 2 = Parkland + Taungya; 3 = Parkland + Hedgerow; 4 = Parkland + Taungya + Hedgerow

Figure 14 shows that for both the valuation of crops and livestock there is a negative correlation for deviation from the mean of each respectively. A negative correlation signifies that the incorporation of agroforestry practices is correlated to a stronger valuation of farm activities. The correlation for the deviation for crop yields alone is weaker than with the valuation of both crop yields and livestock holdings together; however, both of them of a negative trend.

4.4.7. Analysis of Deviation from Mean by Tree Diversity



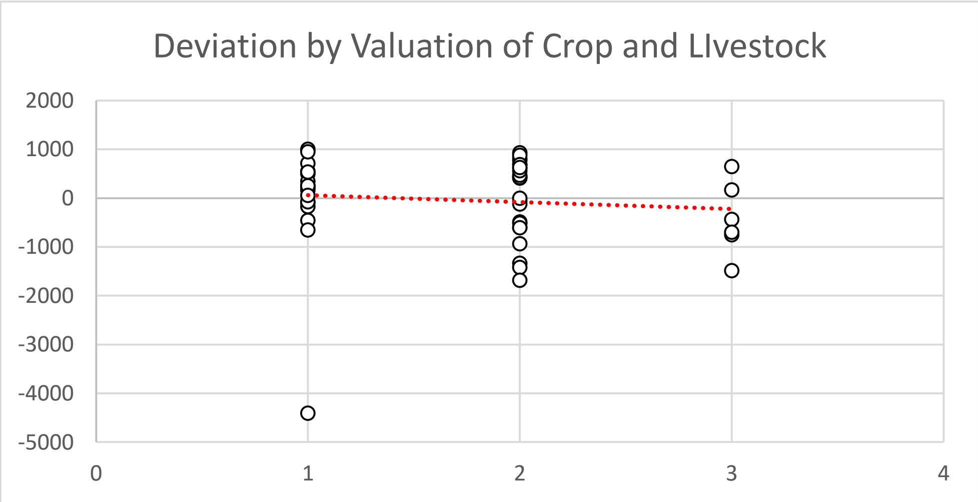


Figure 15: Analysis of deviation from mean by valuation crop yields (above); analysis of deviation from mean by valuation of crop yields and livestock (below), by tree diversity; 1 = 1-5 tree species; 2 = 6-10 tree species; 3 = ≥11 tree species

Figure 15 shows that there is a negative correlation for both the valuation of crop yields and the valuation of crop yields and livestock together with added diversity on farms. The more tree diversity on farms has a higher correlation with regards to deviation from the mean. Valuation of crop yields has a stronger correlation with tree diversity than valuation of both crop yields and livestock holdings together.

4.5 DISCUSSION

4.5.1. Agroforestry Practice

The lack of significance with agroforestry practices and crop valuation (**Figure 12**) may lie in the idea that agroforestry is viewed as having a positive net effect over the long-term. There has been a recent increase in area under agroforestry in Kedougou; however, there is an inherent time lag within the establishment of agroforestry benefits. Additionally, giving up arable land to production of trees instead of crops could be another reason to why the incorporation of trees on farms showed no positive effect on crop yields. While overall productivity may increase in the long-term, crop yields may decrease due to less land available for cultivation.

Individual tree-crop interactions such as maize and *Gliricidum sepium* have been studied at length (Odhiambo et al., 2001; Smethurst et al., 2017) so another reason for the lack of significance could be competition between crops and the trees intercropped or a lack of fertilizer trees properly suited for this specific environment. The problem could also lie within specific aboveground or belowground competition such as a less than optimal planting arrangement, root competition, nutrient competition, shading, or competition for water. To increase efficiency within an agroforestry system, proper tree selection is needed to fit specific biological niches and decrease competition between species (Schroth, 1995).

A significance between the type of agroforestry practice and total farm valuation (i.e. crop yields and livestock holdings) may be linked to traditional management of fallow lands and livestock. Hedgerows and other agroforestry practices provide protection and increased weight gain for livestock (He et al., 2017) while creating and increasing a significant fodder source through leaves, pods, and fruits (Franzel et al., 2014). Another possible reason is that households with higher capital i.e. larger livestock holdings are more likely to adopt agroforestry practices (Caveness & Kurtz, 1993) so the significance between the means could a product of households already possessing larger wealth in livestock may be more likely to adopt agroforestry practices.

4.5.2. Tree Diversity

Tree diversification has shown to increase soil health (Abdoulaye & Fujiwara, 2007) as well as diversifying household nutrition, livelihoods, and income streams (Diedhiou, 2004; Maranz et al., 2004; Ordonez et al., 2014). An increased number of species also reduces stress from disease and pests (Way & Heong, 1994) as well as generally increasing a household's resiliency to adverse conditions (Bayala et al., 2014). However, the link between tree diversity and crop yields is not as strongly established. While there is a strong link between biodiversity and food security (Thrupp, 2010), this might not readily translate into increased yields which the lack of significance in this study would support.

There could be a variety of reasons for the lack of significance with one reason being the shading of crops caused by trees. A higher amount of tree diversity within a farm could be correlated to higher shading of crops. Over shading of crops especially within parklands (J.

Bayala et al., 2008) can cause a decrease in crop yields even with the added benefits of intercropping. Without a proper pruning and spacing, trees will shade out crops reducing yields (Chauhan et al., 2013). Tree-crop competition between roots (Stigter et al., 2002), tree spacing, and competition for nutrients (Rao et al., 1998) also lead to a lack of significance. While an increase in tree diversity may intuitively lead to increases in valuation of livestock holdings through a diversity across seasons in fodder for animals (Gachuiri et al., 2017; Petit, 2003), a lack of ability to buy feed in times of shortages may play into this (Dawson, Carsan, et al., 2014).

4.5.3. Linking Agroforestry, Tree Diversity, and Vulnerability

At a national policy level, increased yields may be the goal to feed an ever growing population, but being able to feed that population sustainably under adverse conditions through resilient systems is also necessary. Agroforestry and trees are one piece of the puzzle to decrease vulnerability (Nguyen, Hoang, & Öborn, 2013). While the incorporation of agroforestry practices and tree diversity on farms may have not shown a statistical significance with regards to differences in farm valuation, the other benefits provided by these two factors cannot be overlooked. As well as the contribution to species diversity to improving household diets. (Ng'endo et al., 2015)

Figure 14 and **15** strengthen the argument that while there was not an overall significance to either agroforestry practices and tree diversity on farm valuation there is still a beneficial effect cause by both agroforestry practices and tree diversity. The incorporation of more agroforestry practices and higher tree diversity are both correlated with a larger departure from the mean regarding higher valuation of farm activities.

Regardless of impacts on valuation of farm activities, an increase in diversification of practices has shown a strong correlation to decrease the vulnerability through decreasing sensitivity of the system (Reidsma & Ewert, 2008; Thorlakson & Neufeldt, 2012). Trees on farms have the added benefit of increasing ecosystem services by not only increasing provisioning services (Kuyah et al., 2016) but increasing regulating services (Bayala et al., 2014) and secondary services (Lott et al., 2009; Ong et al., 2000). So while statistical significance and an increase in valuation was not observed, the added co-benefits of agroforestry cannot be overlooked when creating sustainable food systems in a rural developmental context. Research looking at yields and farm valuation over a multiple year period is needed to assess the true efficacy of agroforestry on food systems in Kedougou.

4.5.4. Limitations

The overall lack of significance could be a results of a small sample size or a lag time between agroforestry practice implementation and maturation of trees. Additionally, an analysis of practices on forest products both timber and NTFPs is necessary to understand the larger picture of how agroforestry can affect farm yields and valuation. Going forward, data collected on a multi-year time scale may show a correlation between an increase in agroforestry practices in Kedougou and increased yields. A lack of maturity of trees within practices could be main cause of lack of significance within farm valuation.

4.6. CONCLUSION

National agricultural policy in Senegal has shifted towards a more decentralized governance with a focus on sustainable practices such as agroforestry. While this study suggests that there is a low correlation between overall valuation of farm production with both agroforestry practices and tree diversity on farms, an increase in such practices can have an overall positive affect on other factors not quantifiable in a monetary value.

Even with a lack of statistical significance between crop yields and livestock holdings with agroforestry practice and tree diversity, except for the effect of agroforestry practice on the valuation of both crop yields and livestock holdings, agroforestry practices and tree diversity can still be considered to decrease vulnerability of farmers through a decreased in sensitivity to risk. Additionally, multiple co-benefits such as increased environmental services lead to a more stable and sustainable environment to produce food.

Agroforestry can be viewed as just one piece of the puzzle to the issue of low yields across rural areas in the developing world. It remains to be seen whether agroforestry practices in the Kedougou region will translate to increases of agricultural crops, but agroforestry will continue to contribute to the livelihoods of rural farmers in Kedougou through boosting multiple ecosystem services.

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CHAPTER 5. GENERAL CONCLUSIONS

5.1. DISCUSSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The objective of this research was to assess farmer attitude, responses, and livelihood strategies and agroforestry's impact on farmer livelihood in agroforestry parklands in Kedougou, Senegal. There is currently a growing body of literature around indigenous knowledge and adaptive behavior regarding livelihood strategies and resilience (Engle, de Bremond, Malone, & Moss, 2014; Gbedomon et al., 2016; Isaac et al., 2009; Mahoo et al., 2015; Merritt, Patch, Reddy, Rout, & Syme, 2014; Ozesmi & Ozesmi, 2004; Rushemuka et al., 2014; Tremblay, 2016). By incorporating the resiliency of local knowledge with scientific knowledge, policy-makers and decision-makers will be better suited to confront the ever growing challenge of climate change (Nyong et al., 2007). The chapter assessing farmer livelihood strategies, attitudes, and responses regarding climate change adds to this body of literature. These findings strengthen the arguments that human managed systems may achieve a resilient equilibrium (Mortimore, 2010; Petra Tschakert & Dietrich, 2010; Vanlauwe et al., 2014). The chapter showed through adaptive management and the accumulation of knowledge, farmers used the vast amount of options available to them to mitigate any negative risks or disturbances. Specifically, farmers used a wealth of diverse technical, biological, and cultural resources, diversification of activities, management of soil, and the management of agricultural systems spatially and temporally, as well as flexible decisions across annual and great time scales.

The results from the regression model showed that agroforestry has had little to no impact on production from a monetary stand point. However, there was significance with regard to the management of livestock across practices. The more agroforestry practices incorporated was correlated to a higher valuation of livestock holdings and crop yields. Regardless, the multiple co-benefits provided to farmers by agroforestry cannot be overlooked such as increased regulating and secondary ecosystem services.

Based on these results, I conclude that West African farmers have developed a resilient agricultural systems using flexible and adaptive management to achieve their current goals and partially mitigate the negative effects of climate change while trying to meet the needs of the future using agroforestry. Going forward, there needs to be more targeted research looking at the correct scale of such research to best aid in local, regional, and national level policy discussions. Lastly, research needs to be conducted on how responses to livelihood strategies affect various biophysical indicators over time such as tree density, nutrient dynamics, soil fertility, yields, and nutrition as well as land-use change. With further research, stakeholders will be able to aid communities in developing sustainable practices and management plans using scientific evidence and local knowledge to face future challenges.

5.2. LIMITATIONS

This research has some limitations presented as follows:

(I). One of the first biggest limitations is the use of focus groups as a primary data source due to the inherent human bias within answers. Although methods were used to avoid this, due to societal norms there is a chance of a gender bias to the data. Women were present and participated in all of the focus groups; however, due to societal norms, there still could be an inherent gender bias

(II). The survey results used in the regression model had a relatively small sample size potentially leading to lack of significance in the results

(III). The lack of repeated data on an annual time scale for the region of Kedougou also makes it difficult for agroforestry practices and tree diversity to show an impact on production on farms (IV). An analysis of labor as well as dry season and off-farm activities would also provide a more insightful analysis of agroforestry systems in the region

5.3. IMPLICATIONS AND A GLOBAL CONTEXT

This study was conducted at a time and context where developing countries are beginning to emerge while still having to mitigate and combat climate change affecting both local and national level policy concerning natural resource management and the decentralization of forest and agricultural management. As Senegal continues to decentralize forest management, agricultural management, and land-tenure policy (Faye, 2008; MEDD, 2014), the incorporation of traditional knowledge as well as farmer representation will be integral in developing sustainable management policies. These policies will affect not only the lives of rural communities, but surrounding urban centers as Senegal continues to emerge on the international stage.

I addressed how farmers in Kedougou incorporated a complex, flexible, and multifaceted decision-making process with the available resources to carve out a livelihood strategy that mitigates some risks to meet local needs. Farmers have shown great ingeniousness in adverse conditions, and this will continue to happen to partially mitigate the negative impacts of climate change. Stakeholders in the area need to incorporate this knowledge and skills at local, regional, and national scale to best impact and create “climate smart” solutions to problems facing farmers in the area. Local farmers need a seat at the table when implementing forest and agricultural activities to build a resilient global management system.

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