Assessing the link between rural food security and rangeland woody biomass in Limpopo.

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DECLARATION

I declare that this dissertation is my own, unaided work, unless otherwise noted within the text. It is being submitted for the Degree of Master of Science at the school of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg.

This work has not been submitted for any previous degree or examination.

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ABSTRACT

People living in rural areas are directly dependent on the local natural resources. The continued unsustainable use of natural resources leads to woodland degradation, through changes in vegetation structure. If the integrity of a rangeland is compromised, then so would the quality and quantity of provision of ecosystem services such as wild fruits, firewood and medicinal plants that rural households rely on. This in turn threatens the food security of rural communities.

Changes in woody biomass and vertical vegetation structure is a consequence of resource extraction in human utilised landscapes. This study aims to enhance the understanding of the role that above ground woody biomass plays in rural South Africa, focusing specifically on the impact that the state of the woody biomass has on surrounding communities' food security.

The study site was four villages in the Lowveld of Limpopo province: Mafarana, Ga-Selwana, Vyeboom and Ka-Ndengeza. The research assessed woody biomass and vertical vegetation structures, as a proxy for provisioning ecosystem services. I used LiDAR (Light Imaging Detection and Ranging) to measure vegetation structure and estimate biomass in the communal rangelands of these four rural villages. The average rangeland canopy cover and average rangeland biomass of the four case study villages was not influenced by the village settlement areas (size of the village). At the rangeland-scale across the four villages, anthropogenic influences on biomass and vegetation structure were evident. This is particularly true for the biomass in Ka-Ndengeza and Ga-Selwana villages where the spatial trajectory of biomass increased with increasing distance from the village settlement as well as the nearest road. High levels of anthropogenic disturbance were evident in Mafarana's rangeland, where the biomass gradient was bimodal (had two maximum points), and levels of human disturbance was evident at increased distances from the village settlement and the nearest road.

Having explored the impacts that rural households have on the biomass of their communal rangeland, this study then aimed to explore the cost associated with collecting firewood. The access to fruiting trees was explored as 97-100% of all households were reported to use this resource. Based on the examination of the cost pathways on a finer scale, slope and shrub cover only factor in at the end of a pathway. Moreover, the least cost pathways value is that they show that accessing a resource is not uniform, as multiple factors influence this access. This study found that, the cost to access a natural resource does not increase with increasing distance

from the village settlement as described in the “Central Place Theory” and Piosphere Theory and that there are multiple factors influencing accessibility. This research highlighted the impact that human utilisation can have on woody resources and vegetation structure in communal rangelands.

After establishing the effect of resource extraction on vegetation structure, the study goes further to explore the links between rangeland integrity and food security. This was done with household interviews that were conducted with the person responsible for household tasks, across the four case study villages in Limpopo, South Africa. The household survey consisted of 28 questions, divided into five categories. The first two sections focused on collecting information regarding the household characteristics, income and expenditure. The following section focused on the use of the suite of local natural resources. The questionnaire also focused on describing the source of the fuelwood used within the household, whether the fuelwood was purchased or collected, species preference as well as perceived declines or increases in fuelwood availability. The questionnaire also explored food security and nutrition, food shortages and the diet of interviewed households.

The most commonly utilised resources were firewood, wild vegetables and wild fruit which were used across all four study villages. This study found that virtually all the households, across all four villages used firewood, wild fruit and wild vegetables. Despite this that some households are clearly more vulnerable to food insecurity than others. Ga-Selwana was the only village that had no households that experienced hunger all the time. Mafarana and Vyboom had the highest proportion of households that did not experience any food shortages in the last year. The results from this study suggest that improved food security might be associated with a healthier state of the communal woodlands, but more detailed analysis of where the relationship exists needs to be explored.

This study found that the resource use and the associated disturbance gradients are settlement specific, which highlights the value of settlement specific studies that incorporate local information is. It is expected that the disturbance gradients evident in this study will begin to diminish and merge around the settlements as the future vegetation structure becomes more homogeneous. The intensive use of nature resources evident in this study suggest impending, if not already occurring, sustainability issues. Repeated data collection is required to assess and monitor the changes in woodland structure and biomass as well as change in patterns of rangeland use as natural resources decrease.

For my mom and dad, Joanne and Graham, who taught me that anything was possible if you set your mind to it, and the love to see it through with me.

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"Today is your day! Your mountain is waiting. So, get on your way!"

- **Dr. Seuss**

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"If you want a happy ending, that depends, of course, on where you stop your story."

- **Orson Welles**

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3D	Three Dimensional
AGWB	Above Ground Woody Biomass
CC	Canopy Cover
CHM	Canopy Height Model
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
FS	Food Security
GCSRI	Global Change and Sustainability Research Institute
H	Mean Top-of-Canopy Height
ha	Hectares
HREC	Human Research Ethics Committee
K2C	Kruger to Canyons Biosphere Reserve
LiDAR	Light Detection and Ranging
MAP	Mean Annual Precipitation
p.a	Per Annum
SCD	Size Class Distribution
SES	Social Ecological Systems
SL	Sustainable Livelihoods
SLA	Sustainable Livelihoods Approach
Voxel	Volumetric Pixels

CHAPTER 1: INTRODUCTION

1.1. Rationale

People living in rural areas in developing countries such as South Africa, are directly dependent on their local natural resources, which form part of their livelihood strategies (Shackleton and Shackleton, 2004b). High population densities in developing countries in combination with the unsustainable harvesting of natural resources can lead to the continued impoverishment of rural settlements, through woodland degradation and changes in vegetation structure which dramatically impact the quality and integrity of communal rangelands. If the integrity of a rangeland is compromised, then so would the quality and quantity of provisioning ecosystem services such as wild fruits, firewood and medicinal plants that rural households rely on. The changes in vegetation structure and functioning can result in the long-term degradation of woodlands near human settlements (Neke *et al.* 2006; Wessels *et al.* 2013).

In South Africa, 80% of all rural households use biomass or fuelwood as their primary energy source (IEA, 2010). Even though approximately 54% of these rural households are connected to the electricity grid (Madubansi and Shackleton, 2007; Wessels *et al.* 2013). The continued use of biomass as an energy source appears to be driven by the costs of using electricity and the associated appliances. Shackleton and Shackleton, (2004a) found that nationally, rural households use approximately 4.5 to 6.7 million tonnes of fuelwood per year. The continued use of this quantity of fuelwood is unsustainable, and can exacerbate poverty in rural communities, by reducing the availability of natural wild food products which communities rely on in times of need. Households rely on natural resources due to the high cost of purchasing a stove and additional electricity (Wessels *et al.* 2013). The continued use of fuelwood, despite the degradation it causes, highlights the value that natural resources play in rural households. The sustainability of communal woodlands is essential to alleviate poverty, food and energy insecurity. If harvested within sustainable limits, fuelwood can continue to supplement rural household's energy requirements (Williams and Shackleton, 2002; Ghilardi *et al.* 2009; Mograbi *et al*. 2016; Twine and Holdo, 2016). Sustainability can only be achieved, when the long-term supply exceeds demand (Banks *et al.* 1996; Wessels *et al.* 2013). Within this context, 90% of current fuelwood demands in South Africa are no longer met (Madubansi and Shackleton, 2007) due to the long-term impacts that over harvesting is having on vegetation structure.

Specific changes in vegetation structure, such as increased presence of shrubs, which is seen as bush encroachment, coppicing or changes in tree-grass ratios all impact the quality and integrity of communal rangelands (Neke *et al*. 2006; Fisher *et al.* 2015; Mograbi *et al*. 2016). Changes in the quality and quantity of provisioning ecosystem services such as wild fruits, firewood and medicinal plants (Shackleton and Shackleton, 2004a; Shackleton and Shackleton, 2012) threatens the food security of rural communities. Natural resources provide these communities with subsistence through their direct use value, income-generation and cash saving opportunities (Shackleton and Shackleton, 2004a). The use of natural resources, during times of vulnerability, provides households with a safety net and represents their level of resilience in changing environmental conditions (Shackleton and Shackleton, 2004b). Natural resources are also important as they meet the communities spiritual and cultural needs. Large trees are often valued for their spiritual significance (Cocks and Wiersum, 2003). The reliance on natural resources is evident in the changes seen in communal rangelands, which have impacts years after harvesting has occurred.

The changes in woody biomass present in rural communal rangelands found in the former homelands are due to fuelwood extraction and the dependence of these communities on natural resources (Hunter *et al*. 2007; Wessels *et al*. 2013). The Promotion of Bantu Self-Government Act of 1959, resulted in the forced resettlement of indigenous people into 'homelands' during the Apartheid era. The more recent influxes of refugees from neighbouring states, has led to an increase in human densities in these areas (Thornton, 2002). High human densities, unemployment and widespread poverty are the legacy left behind from the Apartheid system (Twine, 2005). Fuelwood is a cheap or free energy source in areas experiencing widespread poverty and so today (2016), fuelwood remains the dominant energy source for these households. As mentioned, this resource base is under increasing pressure from harvesting, especially, in these densely-populated areas (Matsika *et al.,* 2012a). The strong dependence of rural communities on these communal woodlands has raised not only concerns surrounding their sustainability, but also the important implications for the environment. High dependence on natural resources can also affect a community's energy and food security, if overharvested.

Past research has been conducted on the impact that fuelwood extraction has on vegetation structure in communal areas (Neke *et al*. 2006; Matsika, 2012; Fisher, 2013; Mograbi *et al*. 2015), the value that non-timber natural resources have on rural household's livelihoods (Shackleton and Shackleton, 2000; Shackleton and Shackleton, 2004), as well as the importance of non-timber forest products in aiding poverty alleviation (Shackleton *et al.* 2007). Research has also shown how socio-economic factors influence vegetation changes observed in communal areas (Twine, 2005)., few studies have linked fuelwood extraction and the state of these areas to food security in rural communal woodlands or rangelands. The value of this study will be that it sheds light on the link between natural resource use and the state of communal woodlands, which will explain the impact that this has on a community's food security.

This study aimed to enhance the understanding of the role that above ground woody biomass plays in rural South Africa, focusing specifically on the impact that the state of the woody biomass has on surrounding community's food security. This was achieved by investigating the relationship between fuelwood use, the state of the above ground woody vegetation and household food security along a rainfall gradient in the communal lands of Limpopo Province.

1.2. Literature review

1.2.1. Drivers of savanna structure

Savannas are heterogeneous, complex adaptive systems characterized by the dynamic co-dominance of trees and grasses (Scholes and Walker, 1993). A distinguishing feature of these systems is the spatially and temporal variability of a generally continuous grass layer and discontinuous tree layer, which results in a mosaic of vegetation patches (Scholes and Archer 1997; Bond, 2008).

Savanna systems occur within a range of bioclimatic conditions. Different processes that determine their structure will vary in between regions (Sankaran *et al.* 2005). The spatial and temporal variability of trees and grasses results in savannas ranging from open grasslands interspersed with large trees to dense woodlands (Scholes and Walker, 1993)., the vegetation structure and composition of savannas appears to be controlled by several factors, such as, climate and geology; at medium scales, it is controlled by topography, soil type, organisms and precipitation. It is also influenced by disturbance events such as fire, herbivory and human activities at finer scales (Pickett *et al.* 2003; Sankaran *et al.* 2005; Sankaran *et al.* 2008; Gillson, 2004, Levick and Rogers, 2011).

Savannas are highly variable systems in their natural state and this variability becomes more evident under the influence of human land use. Ultimately, understanding the dynamics of tree-grass interactions within savannas systems is dependent on the scale at which these processes are being studied and measured. This understanding has a profound impact on the sustainability of these systems, especially in the face of the continuously growing human population.

1.2.2. People in savannas

In South Africa, savannas contain 96% of the wooded land in the country, and 25% of this is communal land (Shackleton *et al.* 2007). Due to the abundance and extent of vegetation, as well as wild fauna found within savannas, people have inhabited these areas for millions of years and have had a significant impact on the vegetation structure (Twine *et al.* 2003). In conjunction with environmental factors, human disturbances are largely responsible because African savanna landscapes have developed and shaped over time (Scholes and Walker, 1993). Consequently, human activities in savannas are classified as disturbance events, similar to fire and herbivory, because of the impacts and disturbances human activities have on the landscape (Twine, 2005). Human disturbances in savannas occur simultaneously at different intensities as well as at different spatial and temporal scales (Giannecchini *et al.* 2007). Harvesting pressure, the methods used, and the extent of harvesting vary from place to place in savannas as society is heterogeneous (Dovie, 2003).

Harvesting of trees for the use of firewood has occurred throughout savannas for millennia as it is a cheap or 'free' resource (Shackleton and Shackleton, 2004). The fact that the use of firewood saves households the cost of purchasing electricity is one of the main reasons that households still use firewood as their primary energy source today (Shackleton and Shackleton, 2004). The continued dependence on fuelwood will result in long-term impacts on vegetation structure and functioning at both a local and national levels. Regardless of the local traditions and societal control mechanisms surrounding firewood harvesting, households often harvest live wood stems, especially if the deadwood stocks are insufficient to meet local demands (Shackleton, 1993). In some cases, 90% of household firewood stocks are made up of harvested live wood (Shackleton, 1993).

A study conducted in Bushbuckridge, South Africa found that fuelwood harvesting around two villages caused a decline in the total wood stock in both communal woodlands, despite different population densities in each village (Matsika *et al.* 2012). The village with the higher population density, lost desirable species and experienced overall changes in the woodland structure (Matsika *et al.* 2012). There was also a change in the species diversity of the commonly harvested firewood species. The authors suggested, that the absence of similar negative impacts in the other village was likely attributed to the lower population density and fuelwood extraction pressure, associated with the presence of more sustainable harvesting regimes (Masika *et al.* 2012). The authors concluded that overall the woodlands surrounding these two villages was degraded, highlighting the direct relationship between fuelwood harvesting and rural villages population densities. Households have preferences for the size and species they harvest (Luoga *et al.* 2000; Neke, 2006). Over time this can lead to substantial changes in the size class distribution of trees and the mortality of certain species. The mortality of certain species affects the structural diversity of a landscape (Shackleton *et al.* 1994). Higgins (1999) found that mean stem height of plants generally decreases with an increase in proximity to villages. Similarly, other studies also found disturbance gradients around rural settlements (Banks *et al.* 1996; Fisher *et al.* 2012; Wessels *et al.* 2013; Mograbi *et al.* 2015), but they seem to disappear around villages that share easily accessible rangelands, because of high levels of resource use (Fisher *et al.* 2012).

Increasing disturbance events, of any nature, appears to affect many woody species negatively (Saunders, 2015). Some ruderals species have been found to increase in abundance under high disturbance, while others have become locally extinct (Shackleton *et al*. 1994). The increased demand for firewood has also resulted in the harvesting of ecologically important trees such as Marula (*Sclerocarya birrea*) and Jackal Berry (*Diosyros mespiliformis*) as well as the harvesting of trees <3 m in height which exacerbates coppicing (Twine, 2005; Kirkland *et al.* 2007; Mograbi *et al*. 2015). Although, coppicing results in thick stands of small stemmed trees that yield woodier biomass than few larger trees, due to size specific growth rates. The productivity of coppiced plants and the ecosystems in which they are found changes (Caspersen *et al.* 2011) due to the loss of seed-producing plants and can decrease future woodland persistence.

Coppicing is one of the ways in which a woody plant can survive a disturbance event. Coppicing occurs when a woody plant resprouts after incurring damage to its stem, this results in the persistence of a plant rather than replacement (Neke, 2006). A plants ability to coppice after a human disturbance, is dependent on the plants age, size, stump height, the type and severity of the disturbance as well as percentage of the stem removed (Luoga *et al.* 2004; Guerro-Campo *et al.* 2005). Therefore, it is essential to understand the dynamic relationship between savanna vegetation and human use.

1.2.3. Socio-ecological systems and sustainable rural livelihoods

Ecosystems provide a range of benefits to people, known as ecosystem services (Millennium Ecosystem Assessment, 2005). Ecosystem services are benefits that people obtain directly from an ecosystem. These include "*provisioning services"* such as food, water, timber, and fibre; "*regulating services"* that affect climate, floods, disease, wastes, and water quality; "*cultural services"* that provide recreational, aesthetic, and spiritual benefits and "*supporting services"* such as soil formation, photosynthesis, and nutrient cycling" (Millennium Ecosystem Assessment, 2005). Humans are directly dependent on the sustainability and flow of ecosystem services. "*Provisioning ecosystem services"*, which is the focus of this study, are tangible products or raw materials that people harvest directly from their surrounding environment (Millennium Ecosystem Assessment, 2005).

The interaction between people and the environment is complex and adaptive (Fisher *et al*. 2012). This interaction is described by the concept of socio-ecological systems (SES) (Halliday and Glaser, 2011). SES are used to explain the relationship between people and their surrounding environment. When analysing SES, it is important to consider the four sub-units making up SES which are, resource system, resource units, users and governance system (Ostrom, 2009) (Figure 1.1). A variety of second level variables also influence the sustainability or resilience of a system, including the size of the resource system, predictability of the resource system, number of users, leadership, history of use and the importance of resources to the users (Ostrom, 2009; Fisher, 2013).

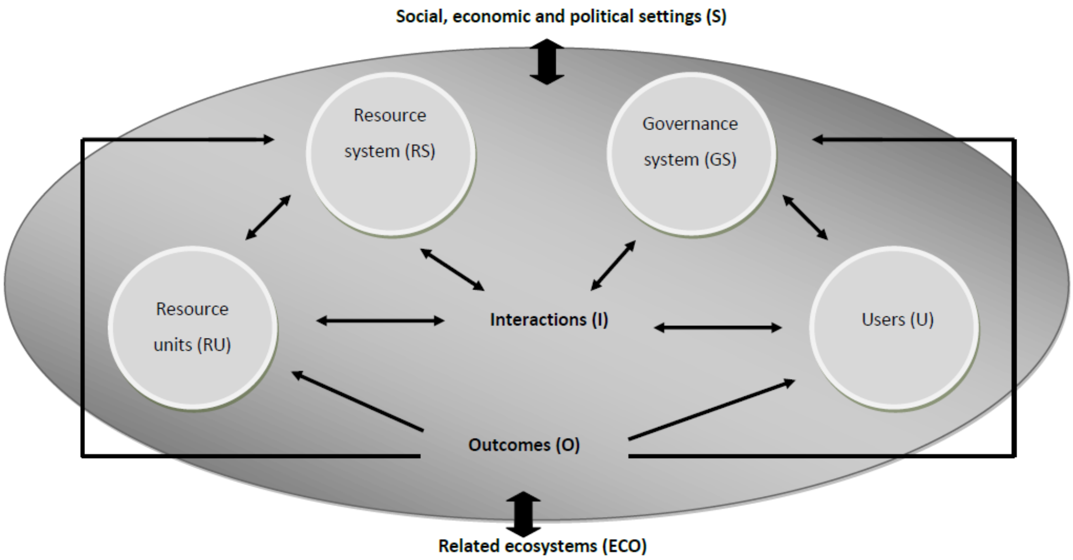

Figure 1.1 The subcomponents making up and used to analyse socio-ecological systems (Ostrom, 2009).

A SES, often refers to people living in rural areas and the natural resources on which they depend, such as the rural areas in South Africa (Giannecchini *et al.* 2007). Communal lands in South Africa support a large proportion of the rural population, often those living below the poverty line. Studies have shown that communal lands and natural resources have a significant impact on rural people's livelihoods and household's incomes (Shackleton *et al.* 2000). Livelihood encompasses various methods of supporting and sustaining life by meeting individual and community needs (Dovie *et al*. 2005; Scoones, 2009). , a households' livelihood is only sustainable when it can absorb and recover from stresses and shocks or alternatively maintain or enhance its assets without diminishing its natural resource base (Scoones, 2009).

To achieve a sustainable livelihood (SL), households or communities need to rely on different livelihood strategies. This requires an integrated understanding in which the environment and its suite of resources are viewed in conjunction with anthropogenic processes. An ecosystem cannot be viewed as sustainable if the economic and social systems that influence it are unsustainable. If an ecosystem is not sustainable then economic and social sustainability cannot be guaranteed.

Livelihood perspectives have influenced thinking and practice throughout the developing world by investigating a conceptual understanding of poverty and its causes (Carney, 1999; Scoones, 2009). SL thinking is centred around the objectives, scope and priorities for development and sustainability from the perspective of the poor, as well as looking at how different people in different areas live (Carney, 1999; Scoones, 2009). This method of thinking explores the complex interactions and activities of how people make a living and highlights the diversity of livelihood strategies (Scoones, 2009). By understanding the relationship of these interactions and activities, it is possible to gain a better insight into rural communities and households abilities to cope, adapt, improve, diversify and transform their livelihood strategies under differing circumstances (Scoones, 2009).

The SL approach (SLA) does not belong to a specific discipline, which allows research and work to be done across a variety of fields as well allowing both outsiders and local people to be involved in the learning and development process (Scoones, 2009). Examining livelihood at an individual level can be aggregated to analysing livelihood strategies at a household, village or even district level (Scoones, 2009). The SLA explores the relationship between three livelihood components: capital assets, transforming strategies and livelihood outcomes (Figure 1.2). The different livelihood assets that a household or individual has access to, is termed capital assets (Carney, 2003). These include: Human capital which includes health, nutrition, work, education etc.); Social capital (neighbours, leadership, networks and connections etc.); Natural capital (land, biodiversity, environmental services, wildlife, wild foods etc.); Physical capital (infrastructure, tools and technology) and lastly Financial capital (savings, credit, wages, pension remittance etc.). Livelihood components have to be dynamic, in order for a household to achieve a desired outcomes or goal (Serrat, 2010).

Capital assets are based on the activities and choices made by individuals to sustain their livelihood, which is described as livelihood strategies (Serrat, 2010). Livelihood strategies may include the use of the natural-resource base, migration and remittances, non-natural resource based off farming activities, pensions and grants, intensification versus diversification, as well as short term versus long term outcomes (Carney, 2003). These assets and the utilisation of livelihood strategies contribute to livelihood outcomes such as financial stability, food security, well-being, more sustainable use of natural resources and reduced vulnerability. In addition, capital assets, transforming strategies and livelihood outcomes influence and are influenced by the vulnerability of the environmental context in which they occur (Carney, 2003). This includes shocks, seasonality and critical trends with the environment and the components of the SL framework. The seasonality, aspects of the components of the SL framework are also influenced by anthropogenic processes and structures.

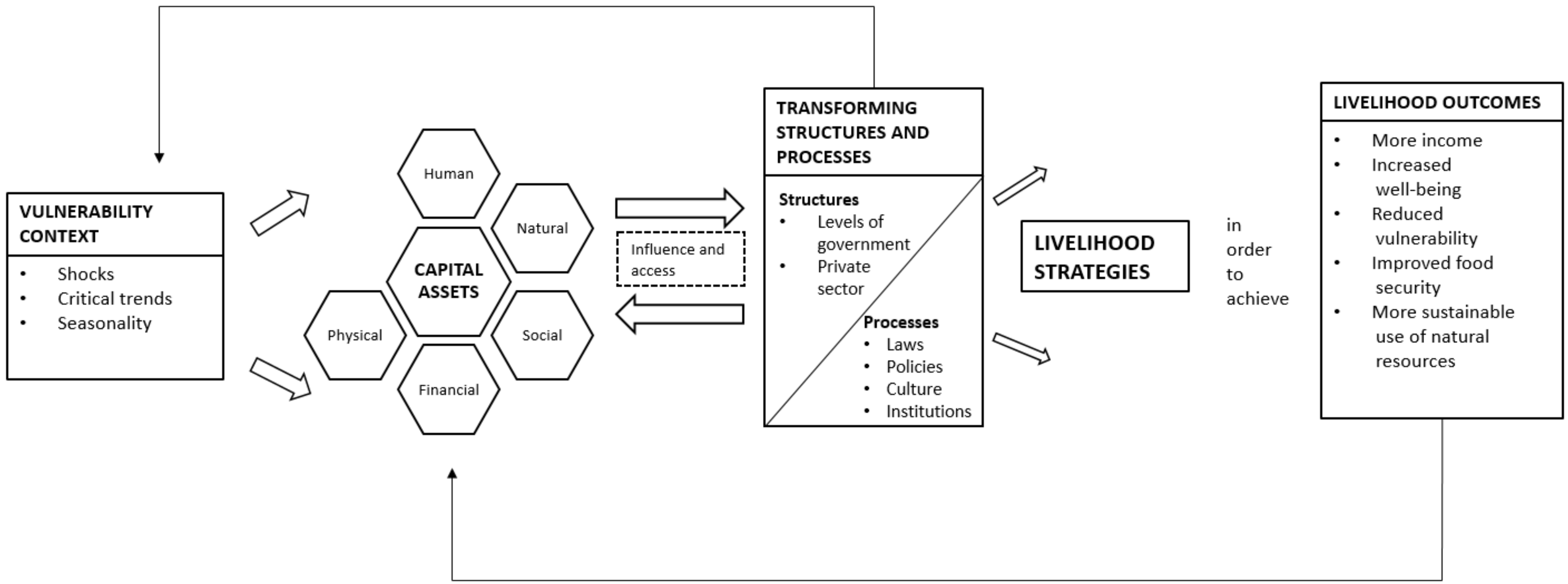

Figure 1.2. Graphical represenatation of the SLA showing the links between capital assests, transforming structures and livelihood outcomes. These are all influenced by a vulnerability context as well as anthropogenic processeses and structures (adapted from : Carney, 2003; Serrat, 2010).

1.2.4. Household livelihood strategies

In most developing countries around the world, including rural South Africa, the reliance on natural resources forms the foundations of people's livelihood strategies (Shackleton and Shackleton, 2004b). This is a result of under-developed economies. People living in rural areas have limited or no access to basic utilities, forcing them in many cases to rely partly or solely on their surrounding natural resources. In these areas, fuelwood and food, is collected from the communal woodlands or agricultural fields around the villages. This has led to the formation of a process known as diversification of livelihood strategies, which occurs in the response to food insecurity (Dovie *et al.* 2005).

People living in rural areas tend to exhibit a diverse range of livelihood strategies based on assets (Shackleton *et al*. 2000). Most rural households in Southern Africa have a range of activities and incomes (Shackleton *et al.* 2000). How vulnerable or robust an individual or household is to changes in their internal and external environment, depends on their ability to access their assets or draw on different livelihood activities when necessary (Shackleton *et al.* 2000). These different livelihood strategies can enhance or supplement a household's income, as well as their food security.

The use and sale of natural resources often enables a household to be more resilient. These natural resources can act as a safety net when other livelihood strategies fail (Shackleton and Shackleton, 2004). Previous research suggests that rural households use natural environmental resources quite extensively and that there is a substantial suite of natural resources used by these households (Pollard *et al.* 1998; Cavendish, 2000; Twine, 2005; Dovie *et al.* 2006). Natural resources are also important in the provision of ecosystem services; such as wild fruits, firewood and medicinal plants (Shackleton and Shackleton, 2004a). Research has also shown that natural resource use plays a very important role in the economy of rural households (Cavendish, 2000; Twine *et al.* 2003; Twine, 2005; Ragie, 2015).

Natural resource use contributes to a household's livelihood in three ways. Firstly, by alleviating financial stress and generating supplementary incomes as these products can be sold locally or at markets (Shackleton, 2004b). For example, woman often make Marula beer, wooden utensils, grass brooms or brushes that they can then sell for additional income (Shackleton and Shackleton, 2004b). Secondly, households can save costs through the direct use of natural resources. Shackleton and Shackleton (2004b) indicated that in the Ntubeni area, the annual, gross, direct-use value of natural resources can be as high as R 12 000.00 p.a, varying between villages. Lastly, the use of natural resources directly contributes to individuals or households provisioning of needs. This is evident in the consumption of Mopane worms as a supplement protein source or the collection of bush meat (Hunter *et al.* 2011). In some cases, the value of harvesting natural resources is often similar or higher than other livelihood activities or government grants (Shackleton *et al.* 2000).

1.2.5. Value of natural resources to rural households

The value that natural resources play in rural households in comparison to other economic activities, aside from the renewability, is their natural occurrences in savanna landscapes. The fact that they often fall under communal tenure makes them a free resource which makes the use of natural resources more appealing than socio-economic activities. This results in a large suite of resources being freely available to the households located in these landscapes (Cavendish, 2000). The majority of savannas and forests are located in remote areas. The communities living around these areas are characterised by high unemployment, poverty and have limited livelihood opportunities available to them (Shackleton *et al.* 2000; Dovie *et al.* 2005). This is evident in the former homelands established under the Apartheid government that implemented the forced relocation of people of colour. The land tenure in these homelands was communal and communities were allocated land by the government for agriculture, grazing purposes and had open access to the surrounding woodlands (Shackleton and Shackleton, 2002; Thornton, 2002; Kaschula *et al*. 2005). The impact that these homelands had on rural households is echoed in post-democratic South Africa, where households still maintain many of the characteristics and structures imposed during the Apartheid era. The reliance on natural resources by households in these areas is exacerbated by an under developed infrastructure, unemployment, poor education, high levels of migrant labour as well as limited agriculture activities due to the aridity of the region (Shackleton and Shackleton, 2000; Shackleton *et al.* 2005; Giannecchini *et al.* 2007). Despite this, these communal woodlands or rangelands are still utilised for wide variety of natural resources to the surrounding communities (Twine, *et al*. 2003; Twine, 2005).

The free availability of natural resources as previously mentioned, benefits the surrounding households as they can significantly reduce their cash expenditure, which is an essential part of their livelihood strategies (Shackleton *et al.* 2000). For example, fuelwood, craft materials, food, medicinal plants and timber sold or used for the construction of fences or kraals (Twine, 2003). Some of these resources are collected daily such as fuelwood, while others are collected when needed. In South Africa, Shackleton *et al.* (1999) found that communities in three villages in Bushbuckridge were regularly using between 18 and 27 wild natural resources from their surrounding communal areas, including firewood, wild vegetables, wild fruit, thatching grass etc. The extent of these natural resources extended across a range between 100 - 300 different species, excluding the use of medicinal plants. In South Africa, natural resources contribute between 15 - 30% of people's livelihood strategies (Shackleton *et al.* 2007). Ashley and La Franchi (1997), found that wild food products harvested from surrounding natural resources in Caprivi, Namibia, provided up to 50% of a household's food subsistence during winter months. The use of natural food resources influences a household's resilience and sustainability when facing food scarcity (Kaschula *et al*. 2005).

1.2.6. Rural communities' food security

Food security can be defined as a household's access to safe and nutritious food at all times, and is one of the challenges facing most of Africa (Bonti-Ankomah, 2001; Kirkland *et al.,* 2011). Households experience food insecurity when they are unable to absorb, reduce or mitigate the impact of a decline in food availability, access, and/or consumption (Misselhorn, 2005; Webb *et al.* 2006). The socio-economic conditions within a household as well as external political, socio-economic and environmental stressors influence's a households food security or insecurity (Bonti-Ankomah, 2001; Kirkland *et al.* 2011; Boelee, 2011). Access to food at a household level, not only depends on the availability of food, but also on purchasing power (Bonti-Ankomah, 2001). If a household is not able to grow or purchase enough food and social grants or income is stunted or absent, then a household will be food insecure.

For many years, food security has been measured through objective (consumption) and subjective (self-reported behaviours) indicators. Allowing for assessment and monitoring of food security at national, regional, community, household and individual levels (Kirkland *et al.* 2011). Measuring food security is difficult, as there is no standard methodology (Kirkland *et al*. 2011). Food security is most commonly experienced at a household level (Maxwell, 1996; Kirkland *et al*. 2011), and is not static; it can be permanent, temporary or cyclic, which makes it even harder to quantify (Frankenberger,1992; Hendricks, 2015).

Assessing a household's experience of food shortages or hunger, coping strategies and dietary diversity are all factors which influence a household's food security. These factors compound the complex nature of assessing food security, and often need to be explored during a food security study. Food security also varies within social circles, such as between different cultures, villages or even age groups, which also compounds the complexity of measuring food security and substantial literature has been undertaken around this (Corbett, 1988; Maxwell, 1996; Misselhorn, 2005; Webb *et al.* 2006, Kirkland *et al*. 2011).

Research conducted on food security, strategies to obtain food security, and the conditions faced, found that there are important differences within and between households and communities (Bob, 2002). The relationship between these factors results in some households being more vulnerable to food insecurity than others. Food security in rural households or communities needs to be assessed in conjunction with historic economic inequalities, and local livelihood strategies, which are aimed at ensuring household survival (Bob, 2002). This is supported by May *et al*. (1995), who found that rural households engage in a wide variety of activities to generate livelihoods, which enable them to achieve food security. It is therefore, necessary to have a holistic profile of vulnerable households when looking at their food security.

It is estimated that approximately 39% of the South African population is vulnerable to food scarcity and are food insecure (Bonti-Ankomah, 2001). People in rural communities often turn to their surrounding natural resources to supplement their income or their food supplies when faced with these vulnerabilities. The availability of natural resources such as wild foods (e.g. bush meat, edible insects, wild fruits and vegetables), and fuelwood plays a crucial role in buffering households from food or income shortages (Shackleton and Shackleton, 2004; Hunter *et al*. 2007; Kashula 2008; McGarry and Shackleton, 2009). Hunter *et al.* (2007) found that *guxe* (a local wild vegetable) and Marula fruits are important sources of food and incomes among rural households in South Africa. Wild leafy greens such as *guxe* or *mohoro* are often cooked as a relish and eaten with maize meal (Hunter *et al*. 2007). Marula fruits are eaten raw and the Marula nuts are eaten raw or cooked together with *guxe* or *mohoro*. Shackleton *et al*. (1998) found that residents of Bushbuckridge regard *guxe* as being commonly available and drought resistant which makes it an ideal stable food., Reid and Vogel (2006) found in their research that woman in rural KwaZulu-Natal, use local grasses, reeds and beads to make craft, booms or mats to generate additional income and decrease their vulnerability to crop failure.

Natural resources have an integral role to play in rural people’s livelihoods and their survival. This highlights the importance of understanding the effects that human land use has on the stability and sustainability of these natural resources, as this can aid in poverty alleviation.

1.2.7. Rural household use of above ground woody biomass for fuelwood

Historically, cultural values, traditional taboos and regulations enforced by the village chiefs, resulted in a resource management process which prevented the harvesting of live wood from culturally important, medicinal, or fruiting trees (Twine, 2005; Kirkland *et al.* 2007) people instead harvested fuelwood from dead twigs, dead stems or branches. In theory, these traditional resource management structures are still in place. With the increase in human population and the resultant demand for fuelwood and timber, in rural communities, traditional management is often contravened, and enforcement has weakened due to the decrease in dead wood availability (Giannecchini, 2001; Twine, 2005; Kirkland *et al*. 2007). The absence or weakening of traditional resource management systems in these communal areas, makes them vulnerable to resource exploitation (Neke *et al.* 2006). and an increase in the live harvesting of trees (Kirkland *et al*. 2007; Matsika *et al.* 2013), bush encroachment, coppicing, and harvesting of trees smaller than 3 m high (Fisher *et al*. 2012; Mograbi *et al*. 2015). The effects of human disturbances within communal woodlands are seen in distinct changes in species composition and vegetation structure (Shackleton *et al.* 1994). These changes often decrease with increasing distance from communities (Shackleton *et al.* 1994). This suggests that the vegetation patterns in these communal areas is related to harvesting and continued use of the natural resources (Wessels *et al.* 2013). Wessels *et al.* (2013) found that biomass increases with distance from a settlement, which was linked to the self-collection of fuelwood (Fisher *et al*., 2012; Mograbi *et al*. 2015)

The intense persistence of human disturbance and harvesting, results in a decrease of woody biomass, species richness and woody plant density in conjunction with changes to the overall vegetation structure including decreasing height classes and basal stem areas (Neke *et al.* 2006). Fisher *et al*. (2012), found that due to heavy utilisation, the disturbance and woody biomass gradients may have coalesced and could disappear over time. Another study found that if the quality and density of fuelwood decreases and becomes too low to make harvesting worthwhile, then fuelwood collecting preferences my change (Shackleton, 1993). A communal rangeland study, conducted by Fisher *et al.* (2012), found that high levels of resource harvesting reduced the structural diversity of rangelands, by changing the amplitude of height class distributions. Matsika *et al.* (2012) found that a 40% reduction in biomass results in a degraded woodland and causes a shift in species composition. Fisher *et al.* (2012), found that under extreme conditions, reduction in distance gradients, which is seen as a warning of severe woodland degradation. As fuelwood of households' preferred species and stem size is no longer sufficient in terms of quality and quantity, households may begin to harvest trees with a smaller stem diameter. This has huge implications for the recruitment of the plants, as they are then unable to reach reproductive maturity before they are harvested, this then renders adult trees "functionally juvenile" (Twine, 2005). To ensure the continued supply of resources, as well as their sustainability in the future, it is becoming increasingly important to quantify the biomass within these communal areas and determine the long-term effects that continued harvesting has on the biomass.

1.2.8. Measuring vegetation structure and quantifying vegetation biomass

Biodiversity comprises of the structure, composition and function of living organisms within a system (Noss, 1990). Historically, biodiversity research has focussed on compositional diversity, even though it is structural diversity that gives rise to landscape heterogeneity. Vegetation structure is defined as the spatial and temporal organisations of aboveground vertical and horizontal components that determine the position, extent, quantity and type of vegetation (Lefsky *et al.* 2002). It is the composition and diversity of vegetation structure that provides information about the functioning of the vegetation (Lefsky *et al.* 2002). For example, Shackleton (2000) found that there was significantly less herbaceous cover and lower vegetation height in communal lands, in comparison to protected areas (such as national parks or private game reserves), yet the communal lands also had significantly higher species richness. Structural complexity has been linked with, the productivity of a landscape (Aguiar and Sala, 1999; Ishii *et al.* 2004), inhabitability and species richness of a landscape (Halaj *et al.* 2000), the regulation of edge effects (Harper *et al.* 2005), as well as ecosystem health and integrity (Manning *et al.* 2006).

The importance of vertical complexity in a landscape, is often over looked when looking at structural diversity (Mograbi *et al*. 2015)., vertical complexity has relevance to ecosystem function, as canopy height is related to biomass and productivity (Lefsky *et al.* 2002), biodiversity (Herremans, 1995; Halaj *et al.* 2000; Lumsden and Bennett, 2005) and contributes to structural heterogeneity (Hall *et al.* 2011). To understand the state of an area, the biomass needs to be assessed which can only be achieved through vegetation structural information derived from vegetation structure studies (Hall *et al.* 2011).

By studying an area's woody biomass and vegetation structure it is possible to quantify the ecosystem services an area may provide, such as fuelwood, wild fruits and vegetables (Colgan *et al.* 2013)., repeated biomass measurements over time can show the estimated growth rate of trees which can aid in the understanding of an areas thresholds for change (Colgan *et al.* 2013). Traditional vegetation sampling methods are often reliant on manual non-destructive field-based sampling of structural characteristics, such as stem diameter, tree height, literature reviews and map interpretation (Xie *et al,* 2008; Colgan *et al*. 2013). This data is then used to create allometric equations to estimate a tree- or an area's biomass. These methods are beneficial as they often generate highly accurate measurements (Mabowe, 2006)., most of these methods have been created and carried out in forest ecosystems and very few have been applied in savanna systems. field-based methods are not effective for vegetation sampling, as they are labour intensive; time consuming, with large quantities of data that needs to be logged and often expensive. They also cannot be applied to areas larger than 5 ha (Fisher *et al*. 2013), additional vegetation sampling methods are required for larger areas.

In the past, remote sensing techniques have been utilised in an effort to assess the impact of anthropogenic activities on vegetation structure through mapping vegetation types, land use and land cover (Fisher *et al*. 2014)., remote sensing data often matches poorly with small-scale field measurements due to discrepancies between spatial resolution of images and field data (Baldeck *et al.* 2014). Remote sensing techniques have limitations for ecological applications as the sensitivity and accuracy decreases with increasing above ground biomass (Lefsky *et al.* 2002). They also poorly represent spatial patterns as they produce two dimensional images which cannot accurately represent the three-dimensional nature of a system, such as a forests canopy (Lefsky *et al.* 2002).

Active remote sensing methods such as LiDAR (Light Imaging Detection and Ranging) offers an alternative method that incorporates the 3D structure of vegetation while also increasing the accuracy of biophysical measurements. LiDAR is a more robust method for measuring vegetation structure., because of the linear relationship between LiDAR measured height and field-measured height. which allows for the creation of canopy height models (CHM) based on the laser's ability to penetrate through vegetation (Wehr and Lohr, 1999; Donoghue and Watt, 2006; Wessels *et al.* 2011). LiDAR directly measures the vertical distribution of vegetation canopies and sub-canopies that provide high-resolution canopy maps. It provides highly accurate estimates of vegetation height, cover and canopy structure (Lefsky *et al.*2002). LiDAR has been used in forest systems to measure fuel loads and structural attributes, such as, tree height, biomass and canopy cover (Lefsky *et al.* 1999; Lefsky *et al.* 2002). Although LiDAR cannot directly measure all the attributes of vegetation structure, these can be derived from other measurements such as canopy height (*Fisher et al*. 2013). Alternative uses of LiDAR include estimating carbon storage and mapping topographic features (Lefsky *et al.* 2002; Colgan *et al*. 2012).

LiDAR uses active sensors that emit laser pulses that measure the distance between the laser and the target surface (Wehr and Lohr, 1999). Multiple return LiDAR systems are often used to map vegetation structure, which allows for multiple readings to be recorded based on the number of objects the laser intercepts on its pathway down to the surface. For example, the first return pulse would give the top of a vegetation canopy while the last return pulse would more often than not be the ground (Lefsky *et al.* 2002) (Figure 1.3).

The use of LiDAR makes it possible to study the effect of land use on biodiversity by quantifying 3D woody vegetation structure and structural patterns across the landscape (Lefsky *et al.* 2002a; Turner *et al.* 2003).

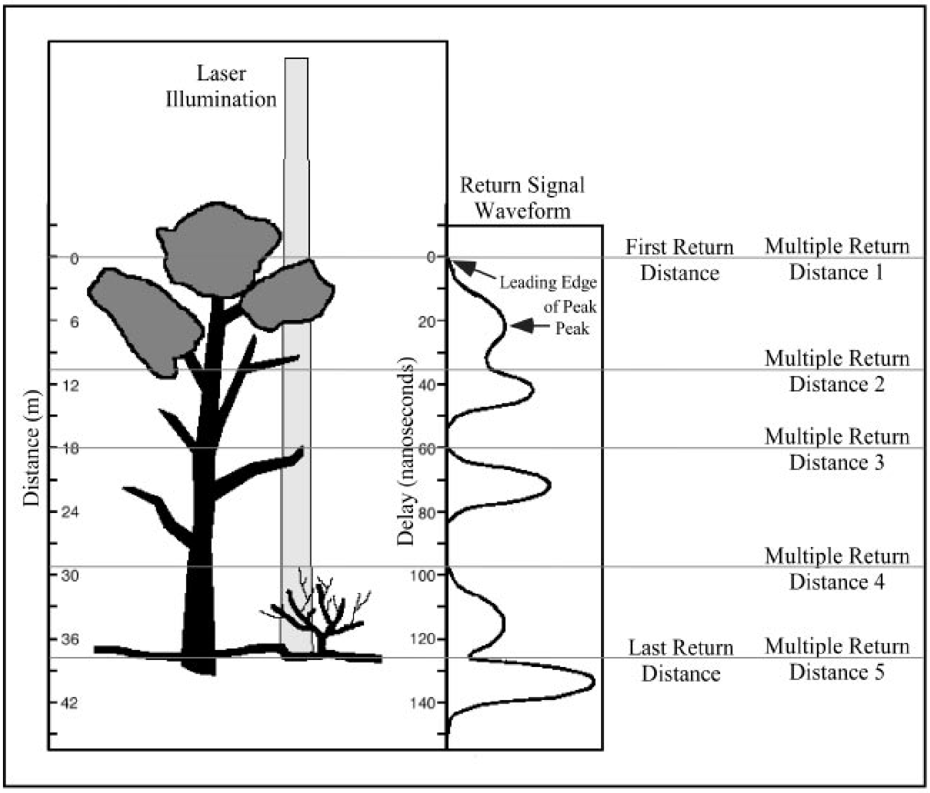

Figure 1.3. LiDAR measurements of vegetation (Lefsky *et al*. 2002).

1.3. Aims and Objectives

1.3.1. Aim of study

The aim of this research is to enhance the understanding of the role that above ground woody biomass plays in rural South Africa, focusing specifically on the impact that the state of the woody biomass has on surrounding communities' food security. The broad objectives of this study are divided into two categories:

1.3.2. Objective 1: Investigate the impact of human land use on above ground woody biomass in communal woodlands

a. How does the state of the communal woodlands vary between villages?
b. How does above ground woody biomass vary spatially in the selected study villages communal woodlands?
    - How does the above ground woody biomass found in Bushbuckridge communal woodlands compare to those found in Limpopo communal woodlands?
c. How do biomass gradients vary between communal areas in Limpopo?
d. How does above ground woody vegetation structure change with increasing distance from human settlements?
e. How does a household's access to natural resources vary spatially, in the selected study villages communal woodlands?

1.3.3. Objective 2: Investigate the link between state of surrounding local woodlands and communities' food security

a. How does the use of natural resources in the communal woodlands vary across the selected study villages?
    - What quantity of these resources is being used annually?
b. How has the availability of natural resources changed over the past five years across the selected villages?
c. Do the perceptions of resource availability by household members influence rural consumption?
d. How does the state of the surrounding woodlands influence the local community's food security?
    - How does food security vary across the selected study villages?
    - What is the relationship between food security and state of environment?
    - What is the relationship between household use of natural resources and food security?

1.4. Study Area

1.4.1. History of Limpopo, South Africa

This research was conducted in rural villages located in Limpopo Province, South Africa. Limpopo is one of South Africa's poorest and most rural province, with 78.9% of the inhabitants living below the poverty line (Hall *et al*. 2012; StatsSA, 2012)., the livelihoods of these inhabitants are closely linked to land use, for both agriculture and resource harvesting

(Hall *et al*. 2012). The land of South Africa, and particularly Limpopo, has a long history of over-grazing from white-owned cattle farms during 1913-1940 (Pollard *et al*. 2011). This trend continued and was further exacerbated by the start of Apartheid in 1948. The Promotion of Bantu Self-Government Act of 1959, resulted in the forced relocation of black South Africans to designated 'homelands (Pollard *et al*. 2011). Under the Apartheid government, the communal farms and lands of Limpopo were divided into three *Bantustan* homelands: *Gazankulu*, *Lebowa* and *Venda* (Thornton, 2002; Thornton, 2003; Hall *et al*. 2012). The relocation of black people into the *Bantustan* homelands contributed to the huge population densities seen today and placed a massive increase in pressure on natural resources (Thornton, 2002). Today, 74.4% of the households in Limpopo are in communal lands governed by traditional authorities, in comparison to the rest of the country (27.1%) (Statistics South Africa, 2012).

1.4.2. Socio-economic context: Case study villages

Four case-study villages were selected in Limpopo, South Africa namely Vyeboom, Mafarana, Ga-Selwana and Ka-Ndengeza, (Figure 1.4) The settlement patterns within Limpopo represent semi-rural and rural communities, typical of those found within north-eastern South Africa (Hunter *et al*. 2007). The villages are distributed throughout the landscape and are surrounded by communal rangelands. These communal rangelands are used for the collection and use of natural resources, such as firewood, wild fruit, vegetables, building materials, traditional medicine as well as grazing for livestock (Hunter *et al*. 2007). A typical village comprises of multiple homesteads which are made up of multiple dwellings, sometimes with livestock enclosures and often small-scale agricultural fields or orchards of fruit, vegetables and other crops (particularly maize) (Hunter *et al*. 2007). Although these areas fall under state control, which is responsible for service delivery, they are also managed by traditional authorities who are responsible for mediating disputes, regulating the use of land and natural resources and homestead allocation. These traditional authorities are chief-based and exist within the greater South African political infrastructure with individual headmen from each community reporting to an appointed tribal authority. The land tenure in these villages is communal and controlled by headmen or chiefs who section the land into residential, arable and communal areas for grazing of livestock and the collection of timber and non-timber (Shackleton and Shackleton, 2000).

The population of these areas ranges from 150 637 people living in the Ba-Phalaborwa Municipality and 516 031 people living in the Makhado Municipality, with an intermediate population in the Greater Tzaneen Municipality and the Greater Giyani Municipality (StatsSA 2016). The socio-economic conditions of these villages are characterised by poor economic and infrastructure development with densely populated human settlements ranging from 20 persons/km^2 in Ba-Phalaborwa Local Municipality to 120 persons/km^2 in the Greater Tzaneel Local Municipality (StatsSA, 2016). The local districts where the selected case-study villages are located are characterised by widespread poverty, where unemployment rates range from 36.7% to 47% (StatsSA, 2016). Village residents rely heavily on communal rangelands for their livelihood. Due to shortages of land and widespread poverty, many village residents must rely on money received from migrant household members and / or government social grants to survive (Twine *et al*. 2003).

The case study villages were selected to represent a range of socio-economic and environmental contexts within the communal areas of Limpopo. Overall village population, density, number of household and average household size were extracted from the Census 2011 survey (StatsSA, 2016). Measurements of the spatial extent of each of the villages were carried out using the 2014 orthophotos in ArcGIS 10.4. The village settlement area, for this study is defined as the total area of the residential area and the village commons (woodlands and rangelands) (Table 1.1).

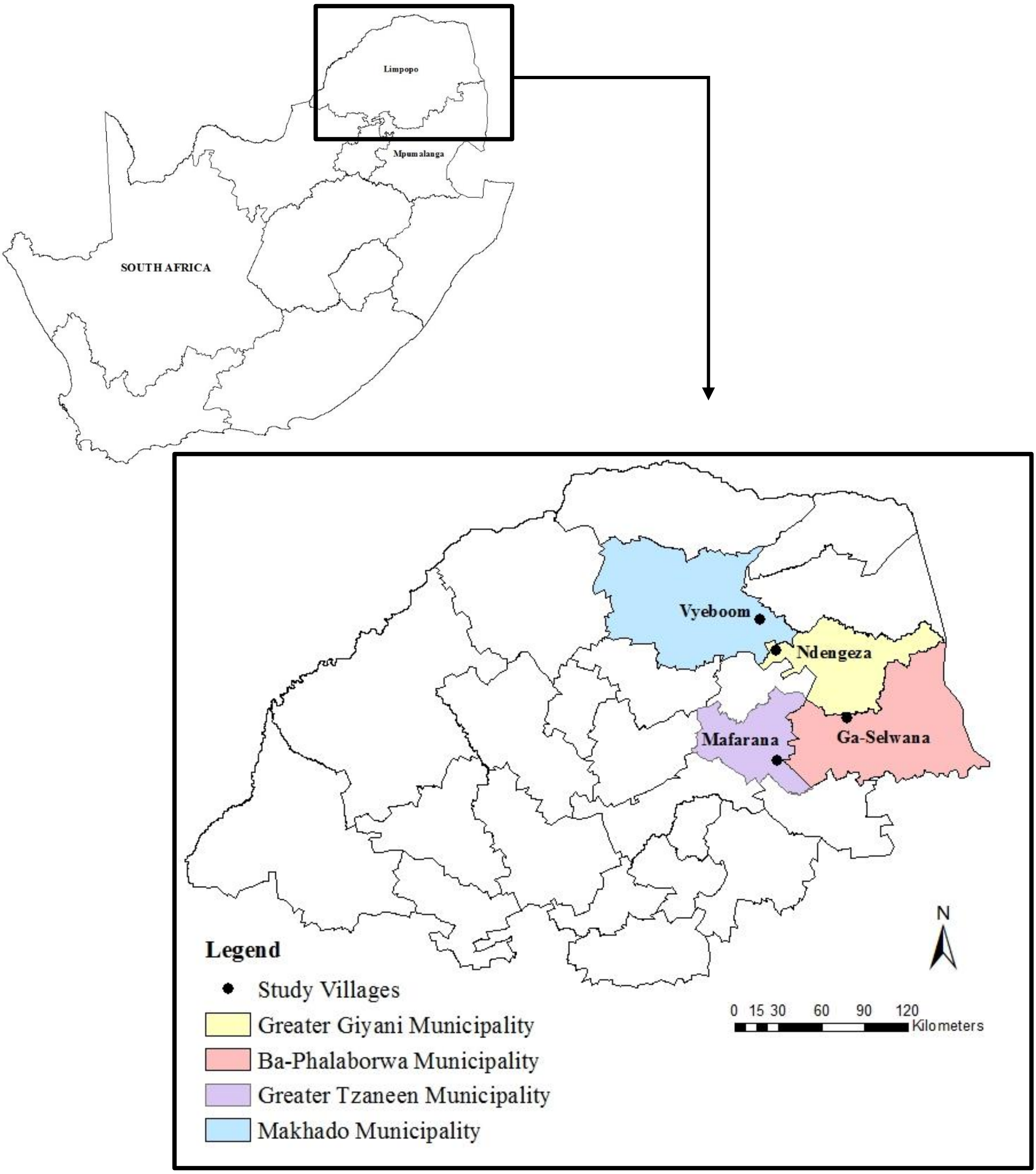

Figure 1.4. Locations of the four selected villages, Vyeboom, Mafarana, Ga-Selwana and Ka-Ndengeza, Limpopo Province, South Africa. Coloured polygons represent the Local Municipalities of the selected study villages.

Table 1.1. Spatial extent and socio-economic characteristics of the four Limpopo Case Study Villages (Stats SA, 2016).

	Villages			
	Vyeboom	Ga-Selwana	Ka-Ndengeza	Mafarana
Total Population	5 026	5 263	4 637	2 554
Population Density (persons/km^2)	824	1 131	769	1266
Number of households	1 271	1 350	1 331	698
Average Household size	3.9	3.9	3.5	3.7
Village settlement area (ha)*	5 212	8 474	5 624	1 961
Total Woodland area (ha)*	4449	7 838	5 212	1 817
Woodland availability (Hectares of communal woodland/ Number of households) *	3.5	5.8	3.9	2.6
Woodland extraction pressure (Households/ hectare of communal woodland) *	0.29	0.17	0.25	0.38

*Calculated from the orthophotos and LiDAR data for each of the case study villages in ArcGIS 10.4

1.4.3. Biophysical characteristics of case study villages

The vegetation found in Ga-Selwana is broadly classified as Tsendze Mopaneveld, dominated by thornless, broad-leafed, deciduous tree species such as mutlistemmed *Colophospermun mopane, Senegalia nigrescens* and *Combretum apiculatum* (Mucina and Rutherford, 2010). The terrain is comprised of slightly undulating plains with an average altitude of between 300-550 m. Potassium-poor, quartz-feldspar rocks of the Goudplaats Gneiss Basement underlie the soil in three quarters of the area, while the north-eastern quarter is underlain by clayey soils. The climate of the area is characterised by summer rainfall and very dry winters, with a Mean Annual Precipitation (MAP) of approximately 450-650 mm (Mucina and Rutherford, 2010).

The vegetation found in Vyeboom, Mafarana and Ka-Ndengeza is broadly classified as Granite Lowveld, dominated by *Terminalia sericea*, *Combretum zeyheri* and *C. apiculatum* trees in the deep sandy uplands, while the lowlands are dominated by *Senegalia nigrescens*, *Dicrostachys cinerea* and *Grewia bicolor*. This vegetation consists of tall shrub lands with few trees as well as dense thicket to open savanna in the bottomlands. The soils are underlain by the Swazian Goudplaats Gneiss, Makhutswi Gneiss, Nelspruit Suite and Mpuluzi Granite. The area is characterised by summer rainfall and dry winters, with a MAP of 450mm in the east to 900 m in the west (Mucina and Rutherford, 2010).

1.5. Structure of Dissertation

Chapter 1 introduces the dissertation, establishing the rational for the study, a literature review as well as the research aims and objectives. In Chapter 2, the impact that anthropogenic land use of four rural villages has on the surrounding communal rangelands was investigated. This was done by looking at the influence that human utilisation of communal rangelands has on above ground woody biomass and vertical vegetation structure. In Chapter 3, the focus was on household use of natural resources and food security, through the exploration of household interviews. Chapter 4, provides a synthesis of the study and linking the state of communal woodlands to household food security.

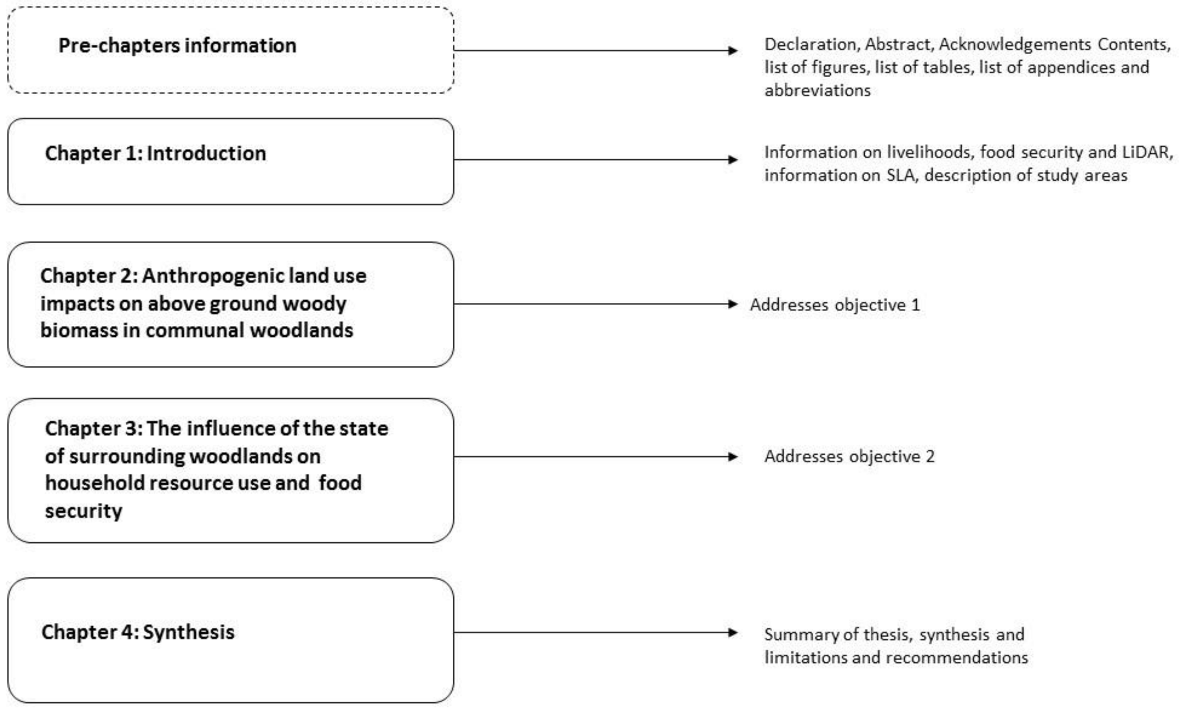

Figure 1.5. The structure of this dissertation with the names of chapters and the details of the subject matter that is discussed in each chapter.

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CHAPTER 2: ANTHROPOGENIC LAND USE IMPACTS ON ABOVE GROUND WOODY BIOMASS IN COMMUNAL WOODLANDS

2.1. Introduction

2.1.1. Understanding natural resource use

Savannas are extensive, socioeconomically important ecosystems made up of trees and grasses (Belsky *et al*. 1993; Belsky, 1994; Scholes and Archer, 1997; Manning *et al*. 2006; Treydte *et al*. 2009; Ward, 2009). Savannas are important because they supply grazing and agricultural land, fuelwood, timber and other non-timber resources which plays a vital role in supporting rural communities who depend on these resources for their survival (Neke *et al.* 2006; Riginos and Grace, 2009). The use of natural resources in savannas acts as a buffer against external shocks experienced in rural households (Dovie *et al*. 2002; Shackleton *et al.* 2007), such as the death of the households' breadwinner. Natural resources are especially important to households in rural areas, where work is hard to obtain, population densities are high and where HIV/AIDS infection rates are high (Shackleton and Shackleton, 2004). This is evidenced by past research conducted in Kruger to Canyons Biosphere Reserve (K2C) which showed that over a 13-year period, the settlement areas of rural villages in the K2C had increased by 39.7% (more than 180 km^2) (Coetzer *et al.* 2010). This research found that not only have the settlement areas increased, but that the individual settlements have become denser, suggesting a more intensive utilisation of the settlement space by the growing local population (Coetzer *et al.* 2010). This coincided with increases of more than 6.8% in human-impacted vegetation (Coetzer *et al.* 2010). All the factors mentioned above alter the income potential of a household (Hunter *et al.* 2011). Although people realise the negative effects that resource harvesting has on the natural resource base (Shackleton *et al.* 2007), the direct value that resources contributed to a household is significant as no other option exists for households in rural communities. Natural resource use acts as a buffer against poverty (Twine *et al.* 2003b). For example, in rural villages where electricity is available, 90% of households will still use firewood as their primary energy source due to the cost of electricity and the high cost of purchasing a stove (Twine *et al.* 2003a; Wessels *et al.* 2013). Natural resources are seen as a key "common property resource", as they are generally gathered from communal lands surrounding villages. The use of these resources is not monitored effectively (Kirkland *et al.* 2007). Based on trends seen elsewhere is South Africa (Matsika *et al*. 2012a), it is highly unlikely that in the future there will be a substantial decline in the use of natural resources.

Natural resource use in savannas changes the vegetation structure and functioning of the woody vegetation (Freitag-Ronaldson and Foxcroft, 2003). the relationship between humans and savannas is complex. The way in which people use savannas is dependent on national and local governance, socio-economics as well as individual and or group behaviour (Scholes, 2009). Resource use is not evenly distributed throughout a landscape and usage patterns are settlement specific (Giannecchini *et al*. 2007; Fisher *et al.* 2012), and often reflect village level characteristics (Twine *et al*. 2003; Twine, 2005, Kirkland *et al.* 2007). Not only has the distance from settlement increased for fuelwood collection, so has the time taken to collect fuelwood, which has increased from 239 minutes per trip in 1992 to 268 minutes per trip in 2002 (Madubansi and Shackleton, 2007). Matiska *et al.* (2013) found that in Bushbuckridge, households were spending between 180 - 240 minutes per trip, collecting firewood (Matsika *et al*. 2013).

Such changes can explain large increases in biomass seen beyond 1 km from settlements in 2008, as households have started switching to purchasing fuelwood from vendors who collect firewood using vehicles rather than collecting it themselves (Giannecchini *et al*. 2007; Wessels *et al.* 2013). It is essential that there is an understanding of the local interactions between natural resource use, socioeconomic factors and the structure of theses ecosystems to ensure their long-term sustainability. By examining the patterns of resource extraction in communal rangelands further insight into the factors driving the use and extraction of resources can be understood, while also identifying the heavily utilised areas. Although the use of natural resources increases human well-being in the short term, in the long term the over use of resources has been at the cost of ecosystem degradation and future generations' well-being (MA, 2005; Mograbi *et al*. 2015). Natural resource use improves human well-being, but it can have detrimental impacts on the environment, whether or not, it is used as a desperate coping strategy. The growing human population and expansion of rural settlements and the over use of natural resources is having a contaminant effect on the surrounding natural environment. This impact is seen radiating outwards from a village and is evident by small 'hotspots' of biomass change through the communal rangelands (Fisher *et al*. 2012).

2.1.2. Understanding access to natural resources

Access to natural resources could lead to the unsustainable use of resources, especially in rural areas (Norfolk, 2004). Many rural African households have come to rely on a wide range of income generating activities, for example the collection of firewood via trucks for sale purposes. Some of these activities are acknowledged to be socially or environmentally detrimental (Lee *et al.* 2009). The livelihoods of rural people without access, or with very limited access to natural resources, are vulnerable because they have difficulty in obtaining food, accumulating other assets, and recuperating after natural or socio-economic shocks or misfortunes (Baumann, 2002).

Access to natural resources is a central criterion to assuring sustainable rural livelihoods (Lee e*t al.* 2009). Natural resources become natural "assets" when access to these resources are assured, either through asset ownership or other forms of secure access and control (Lee *et al.* 2009). Natural capital or natural assets are often considered one of the five forms of capital assets (Carney, 1998). The five categories of assets (Figure 2.1) are key factors that influence livelihood strategies and opportunities used by individuals and households (Lee *et al.* 2009). The ability to access various combinations of natural capital or natural assets helps determine how a household's livelihood may be vulnerable or robust (Shackleton and Shackleton, 2000). For example, a larger asset base may mean that households are less constrained by choices between livelihood strategies, this means that they can easily substitute one form of capital for another (Lee *et al.* 2009) this helps reduce their level of vulnerability.

It is important to note that access to natural resources, in and of itself, is not enough to ensure sustainable livelihood, food security or generate sustainable household incomes and lift the poor out of poverty (de Janvry *et al.* 2001, Lee *et al*. 2009). As previously mentioned natural resources can contribute up to 30% of a household's livelihood stream (Bonti-Ankomah, 2001; Dovie *et al*. 2005). The factors limiting access to natural resources will fluctuate between any given situation and between households. Despite this, access to natural resources contribute significantly to mitigating the impacts of poverty and improving human well-being, in conjunction with other forms of capital assets (mentioned above) can help improve a households' livelihood security.

It is widely understood that there is a difference between production-based food availability and a household's access to food (Sen, 1981; Kirkland *et al.* 2011). There is a difference between the physical availability of natural resources and the access that households may or may not have to these resources (Lee *et al*. 2009). Essentially, it is the access to a resource that determines utilisation rather than the overall supply or availability of a resource.

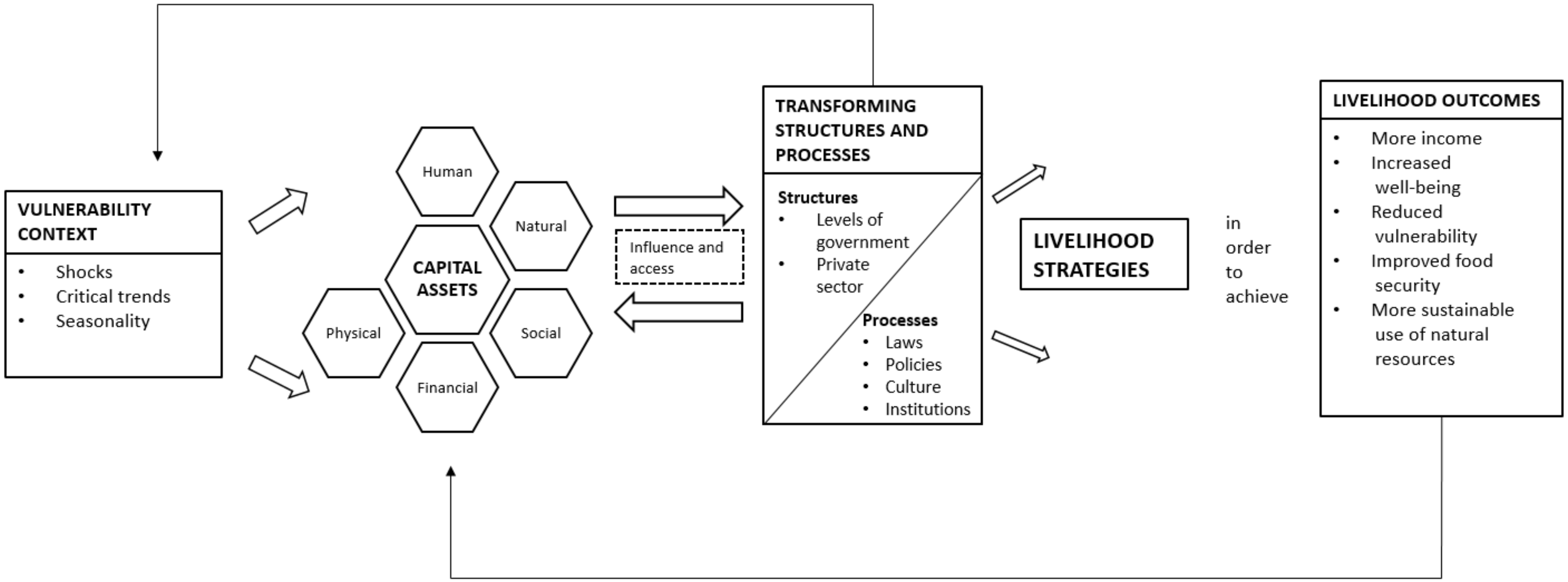


Figure 2.1. Graphical represenatation of the Sustainable Livelihoods framework showing the links between capital assests, transforming structures and livelihood outcomes. These are all influenced by a vulnerability context as well as anthropogenic processeses and structures (adapted from : Serrat, 2010 and Carney, 2003). (Figure appears in CHAPTER 1: INTRODUCTION, Section1.2.3, Replicated for ease of reading)

2.1.3. Access to natural resources

Not all woodland resources are exploited equally, as households prefer certain resources for specific tasks. (Top *et al*. 2006). The likelihood of a woody plant being used is not only determined by preference, its accessibility (determined by location) and availability (determined by local custom and laws) also plays a role (Top *et al*. 2006). Understanding the access to and use of natural resources is important in rural landscapes, where livelihood strategies are linked to access of lands (Cousins, 1999; Shackleton *et al.* 2001; Dovie *et al.* 2005). One of the aims of this study, is to highlight how the use of communal woodlands and their associated impacts vary between villages. Just as communities and households can be differentiated based on their social and economic status, so too can their access to and use of natural resources be differentiated (Kepe, 2002).

As discussed (Chapter 1), past research has showed a general pattern of depletion of resources close to villages and roads, with higher biomass and canopy cover further away from anthropogenic impacts (Wessels *et al.* 2011; Fisher *et al.* 2012; Wessels *et al.* 2013; Mograbi *et al.* 2015). This suggests that disturbance to a landscape by human utilisation, increases with increasing distance from human activities (Coetzer *et al*. 2010). This has previously been defined in the "Central Place Theory", which describes villages or settlements as central points with an associated sphere of influence. This influence radiates outwards from the settlement and is directly proportional to the size of a settlement (Christaller, 1993). This theory is also based on the notion, that the range an individual will travel, to obtain a certain resource or resources is related to the importance of that resource to that individual at a given time. This "Central Place Theory"' is limited, as it assumes that resources firstly, are distributed evenly across a landscape and secondly, that resource use is homogenous through a landscape. So, the "Central Place Theory" is not an appropriate theory to apply in cultural landscapes (Farina, 2000). An extension of the "Central Place Theory" is the idea of disturbance gradients, which depict high to low human disturbance radiating outwards from a village or road and resembles a piosphere (Shackleton *et al*. 1994).

Disturbance gradients have been seen before in research conducted in Bushbuckridge (Shackleton *et al.* 1999; Shackleton and Shackleton, 2000; Shackleton *et al.* 2002; Twine, 2005; Fisher *et al.* 2012; Matsika *et al*. 2012a; Mograbi *et al.* 2015). The piosphere method again assumes that disturbance occurs in a radial pattern outward from a village or road, linearly in all directions (Adler and Hall, 2005), and assumes homogeneity of resources. It does not consider communal land boundaries or the social processes that drive resource use (Adler and Hall, 2005). Shackleton *et al*. (1994) suggests that the mechanism for the pattern of resource use is based on the fact that people use resources that are closer to the village and more easily accessible. The gradient of disturbance around a village is not linear, as the areas where people harvest resources from is not only determined by accessibility but also by the availability, the patchiness of biophysical characteristics, conflicts and socio-political aspects (Mograbi *et al.* 2016).

Evidence suggests that the extraction and utilization of natural resources is related to the economic cost of collection and resource availability (Dewees, 1989; MacDonald *et al*. 2001; Hegan *et al.* 2004; Pattanayak *et al*. 2004). Often the collection cost is determined by the distances travelled to a resource, the difficulty of extraction and the resource quality. The changes in resources consumption patterns can be predicted, as cost collection increases as supply decreases. If it is assumed that resource collection is a function of the distance travelled to collect it (MacDonald *et al.* 2001; Hegan *et al.* 2004), then by assessing the cost of choosing the most cost-effective path, it is possible to predict the likelihood of a resource being chosen over other alternatives. It is also possible, that aboveground vegetation that is heavily impacted by resource collection as it has the highest cost associated to the harvester. This may be a function of slope, the distance travelled to the site of the resource, the accessibility of the resource (access roads, pathways, bush encroachment), the load carried back to the homestead, the quality and quantities of a resource (MacDonald *et al* 1998, Hegan *et al* 2004, Pattanayek *et al* 2004). Exploring the cost associated with collecting a given resource. May be a more effective way to describe patterns of resource use, than the “Central Place Theory” and the Piosphere Theory, as cost can be determined through several combined limiting factors.

2.1.4. Impacts of non-timber forest products use on the ecosystem

Larger single standing trees are of importance to savannas systems, as they play a key role in maintaining the functioning and the structural diversity of these ecosystems (Manning *et al.* 2006; Treydte *et al.* 2009). Trees protect the soil surface in two main ways: namely the litter layer and the leaf canopy (Sanchez *et al*. 1997). Large trees also provide shade, reduce evapo-transpiration of the below-canopy herbaceous layer, and increase local nutrients which are accumulated close to root systems (Belsky *et al.* 1993; Belsky, 1994; Manning *et al*. 2006). The quality of the vegetation, shade and micro-habitats associated with large trees, attract different fauna and increase the local biodiversity of savannas (Belsky *et al.* 1993; Belsky, 1994; Manning *et al*. 2006). These factors highlight the important role that trees play in maintaining structural integrity, diversity, ecosystem functioning in savannas.

Large trees are also socio-economically important as, they provide fruit which can be harvested for direct use and sold for additional income (Shackleton *et al.* 2003; Luoga *et al.* 2005; Kirkland *et al*. 2007). Measuring large trees in communal areas can serve as a proxy for cultural ecosystem services as they are often valued for their cultural significance (Shackleton *et al*. 2003; Luoga *et al*. 2005; Kirkland *et al*. 2007; Mograbi, 2014). For example, in South Africa, there are certain species that are conserved in communal areas area (Wessels *et al.* 2011) and it is considered taboo to harvest wood from these trees, namely: Jackal Berry (*Diospyros mespiliformis),* Marula *(Sclerocarya birrea)* and Monkey Orange (*Strychnos* species) (Madubansi and Shackleton, 2007; Mograbi, 2014). Any changes to the number and/or height of these fruiting trees might be an indicator of fuelwood scarcity, as people are prepared to violate local taboos and harvest live wood. This was observed in Mafarana communal rangelands during this study, where people were seen harvesting live wood. Additionally, in Mafarana, many fruiting trees had their branches removed.

Savannas are also prone to bush encroachment of woody species which can result in the suppression of herbs and palatable grasses for grazing (Archer *et al.* 2001; Meik *et al*. 2002; Ward, 2005). Bush encroachment in savannas is controlled and maintained by dynamics such as fire, rain and harvesting, if there is an increase or decrease in either one of these controlling factors, it can alter the structure and functioning of savannas (Staver *et al*. 2011). Bush encroachment in savannas is often attributed to overgrazing, over harvesting and unsuitable fire regimes (Oba *et al*. 2000). Bush encroachment is exacerbated by continued harvesting of woody vegetation by humans (Rietkerk and van de Koppel, 1997). Intensive harvesting of natural resources that change the structure of savannas, threatens to alter communal rangelands into homogenous, functionally inferior landscapes (Mograbi *et al.* 2015). It is essential to conserve large trees, to maintain and ensure the sustainability of savannas.

Woody biomass estimates can be used to quantify a provisioning ecosystem service such as fuelwood. The distribution of biomass depicts the spatial pattern of topo-edaphic and climate gradients as well as responses to disturbances (De Castro *et al.* 1998; Frolking *et al*. 2009). Due to the vast number of people that reside and depend on savanna ecosystems in

South Africa, the rate of harvesting of woody biomass is high, which can have detrimental effects on the ecosystem over time. For example, an increase in shrub stem density can be seen as bush encroachment, which results in a decrease in palatable grass species. This reduction in palatable grass species reduces cattle grazing which influences the soil nutrient content of the landscape, as cattle defecation increases the soil nutrients (Moleele *et al.* 2002). Moreover, bush encroachment can change the behaviour of ungulates who will then tend to avoid densely vegetated areas, creating a domino effect on the ecosystem's vegetation (Riginos and Grace, 2008). Bush thickening can be exacerbated by continued wood harvesting and coppicing shoots in communal rangelands. Desertification the opposite of bush thickening, is also detrimental for ecosystem functioning (Mograbi, 2014), as bare patches of land increase surface-water run-off, decreased infiltration, an overall loss of soil nutrients and soil erosion (Rietkerk and van de Koppel, 1997).

The impact of humans on the landscape is evident in post-Apartheid South Africa, where traditional authorities' control over natural resource use within communal rangelands has deteriorated (Kaschula *et al.* 2005; Twine 2005). This is exacerbated by the fact that households are often disinclined to limit their personal consumption when, due to diminished resource control other households have unrestricted access the natural resources in their rangelands (Scholes, 2009). The change in rural villages culture, expanding homesteads, poverty and a high reliance on natural resources, coupled with non-village residents using vehicles to collect large amounts of fuelwood for commercial purposes, has added to the increased demand and subsequent decline in natural resources in rural villages (Twine, 2005). This is evident by the increases in the distance households are prepared to walk to collect fuelwood. It was 100 m in the 1980's and in the 1990's had increased to 1000 m (Giannecchini *et al.* 2007).

A trend in decreasing land cover has already been observed in the greater Kruger to Canyons (K2C) Biosphere Reserve (Coetzer *et al.* 2010; Coetzer *et al.* 2013). A communal rangeland study conducted by Fisher *et al*. (2012) found that areas where high wood harvesting occurred, that the structural diversity of the area was reduced, through changing height class distributions. Past research on human-impacted vegetation surrounding rural settlements, has shown that there has been a decrease in human-impacted vegetation with increasing distance from villages (Coetzer *et al.* 2010; Coetzer *et al.* 2013; Mograbi *et al*. 2015). Under extreme circumstances, disturbance gradients decline in highly utilised areas and this is a warning of severe woodland degradation (Fisher *et al.* 2012).

2.1.5. Detection of natural resource use patterns

Acknowledging that anthropogenic drivers are important in communal savannas is essential. It is imperative that the degree of woody biomass utilisation is known to ensure the sustainability of resource harvesting and the resilience of the ecosystem (Mograbi, 2014). Wood harvesting not only changes woody biomass but also the vertical structure of vegetation, which in turn impacts the overall functioning of savannas. The vertical complexity of vegetation is important and vital to an ecosystem’s functioning, as canopy height is related to biomass and productivity (Lefsky *et al*. 2002), biodiversity (Halaj *et al.* 2000; Lumsden and Bennet, 2005) and contributes to structural integrity and heterogeneity (Hall *et al*. 2011). Communal rangelands are an example of where trade-offs occur between human requirements and ecosystem services. When woody biomass extraction, like fuelwood harvesting, occurs beyond sustainable limits, it threatens the provision of other ecosystem services (Mograbi, 2014).

Biomass estimates are often complex, due to the variable species richness, composition and structural complexity (Mograbi *et al*. 2015). Biomass quantification (% canopy cover) does not provide information on where in the vertical canopy the biomass is concentrated (Mograbi *et al*. 2015). It is key that the right scientific methods are applied to estimate biomass and determine the ecosystems vertical structure and functioning. Monitoring changes in woody vegetation structure can be equated with monitoring the sustainability of rural wood-use (Mograbi *et al*. 2015). The value of this research, is that it will provide a baseline for future assessment of natural resources in the area.

Historically, ecologists tend to use used field-based methods to measure vegetation structure, for example sampling vegetation using transects or plots on the ground (Fisher *et al.* 2015). While these studies are effective at measuring a relatively large number of trees, they often can only be applied at smaller scales (<5 ha) (Higgins *et al*. 1999; Shackleton, 2000; Witkowski and O'Connor, 1996). Due to the heterogeneity and patchy nature of savannas, it is necessary to use alternative methods that adequately measure vegetation structure. This is especially relevant when measuring vegetation on a larger scale, to ensure that the heterogeneity at varying scales is recorded.

The use of Light Detection and Ranging (LiDAR) application in biomass studies has increased in recent years as it aided in improving the accuracy of landscape-scale biomass estimation methods (Colgan *et al.* 2013). As LiDAR extends spatial analysis into the third dimension, by providing an opportunity to analyse the structure of an ecosystem (Lefsky *et al*. 2002). LiDAR sensors directly measure the 3-D distribution of plant canopies as well as canopy topography. LiDAR datasets are often large and simplified into summary statistics, often including canopy cover (Lefsky *et al.* 2002a; Anderson *et al.* 2006; Meyer *et al.* 2013). These, do not express savanna heterogeneity in an ecologically meaningful context (Fisher *et al.* 2011; Wessels *et al.* 2011; Fisher *et al.* 2014). LiDAR data allows for the analysis of vertical information which opens a suite of possibilities for further analysis. often LiDAR application in savannas makes use of voxels (volumetric pixels) which are a 2-D summary of the 3-D point cloud by binning LiDAR laser returns into aggregated 1 m height classes (Weishampel *et al*. 2000). The analysis of this data produces high resolution maps and highly accurate estimates of vegetation height, cover and canopy structure, which can then be used to generate above ground biomass estimates. This information is useful in analysing savannas where the main concerns are focused around unsustainable resource use which can lead to desertification or bush encroachment, which is a 3-D problem.

LiDAR, which in summary is based on accurate measurement of the return trip distance of emitted laser pulses, is now widely used in terrestrial environments to assess woody vegetation structure and map landscape topography (e.g. Lefsky *et al.* 2002). Vertical subcanopy structure of vegetation canopies, cannot be derived from traditional 2-D remote sensing methods and top of canopy cover is a poor predictor of subcanopy cover (Fisher *et al*. 2015), 3-D field-based efforts are impractical at landscape scales such as those being carried out in this dissertation. The use of LiDAR is a valuable tool which allows for repeat estimations and monitoring of biomass, in conjunction with providing subcanopy information on large scale geographic areas coupled with fine-scale detail (Goatley and Bellwood, 2011; Mograbi, 2015). LiDAR has also been applied successfully to assess fine scale vegetation trends over the communal rangelands (Fisher *et al.* 2011; Wessels *et al.* 2011) and to provide baseline biomass data for fuelwood supply-demand models (Wessels *et al*. 2013). The areas being studied in this thesis are savannas, due to the large areas being analysed, LiDAR was used to determine the structure of these areas. The overarching aim of this study was to investigate how biomass varies spatially and how the biomass gradients vary in four communal woodlands.

This study also aimed to explore how the human-impacted vegetation patterns affected rural households' access to natural resources. Lastly, patterns seen elsewhere in South Africa, such as Bushbuckridge, need to be explored in other areas, such as this study in Limpopo, to see if human-impacted vegetation structure is settlement specific or if generalisations can be made across South African savannas.

2.2. Methods

2.2.1. Study Site

For information on the biophysical characteristics and livelihoods of the people in the study villages please see Chapter1, Section 1.4 of this dissertation.

2.2.2. Vegetation structure data acquisition

Vegetation structure was measured using a small footprint discrete return LiDAR instrument of the four selected study villages communal rangelands: Vyeboom, Mafarana, Ga-Selwana and Ka-Ndengeza, Limpopo Province, South Africa. Airborne LiDAR data was collected at the end of the growing season on the 26th and 27th July 2014 by African Consulting Surveyors CC, for 22 000 ha that spans the rangelands of the four study villages. This thesis is a subset of the LiDAR data collected and focused on the communal rangelands of the four villages, to determine the biomass of surrounding communal rangelands where the villagers harvest natural resources. A Robinson R44 helicopter was used to collect the LiDAR data. The LiDAR data was captured using a RIEGL LMS-Q560 (Hug *et al*. 2004). The operational parameters and key features (Table 2.1) of the RIEGL LMS-Q560 can be altered and configured to cover a wide field of applications (Hug *et al*. 2004). Such as the "range", which can be defined based on the desired needs of the user and can be determined during post-processing, which improves the collected data's accuracy (Hug *et al*. 2004). By altering the range of the LiDAR system, more detailed analysis can be performed on the distributed vertical structures (Hug *et al*. 2004). This was particularly valuable for this study, as one of the aims was to assess the vertical sub-canopy characteristics of communal rangelands. The features of the RIEGL LMS-Q560 in the LiteMapper-560 LiDAR were ideal for application to this study as it allowed for vegetation parameters to be derived such as tree/vegetation height, vertical canopy expanse and density, which aids in the facilitation of more accurate biomass and other vegetation descriptors (Hug *et al*. 2004). The LiDAR sensor used was flown over the study sites at approximately 650 m above ground level.

Table 2.1. The key features of the RIEGL LMS-Q560 instrument used in the LiteMapper-5600 LiDAR system (Hug *et al.* 2004).

LiDAR Features	**RIEGL LMS-Q560 application**
Measurement range (target size in excess of laser footprint, normal incidence, visibility ≥ 10 km, PRR < 40kHz, ρ gives reflectivity of diffusely reflecting target)	≥ 850 m at ρ = 0.2, ≥ 1500 m at ρ = 0.8
Measurement accuracy (standard deviation, plus distance depending error ≤ 20)	± 20 mm
Scan speed	5 – 160line scans per second
Scan angle accuracy	0.0025 degrees
Number of Lasers	Dual

When using a LiDAR system, it is essential to understand the measurement principle of different vegetation targets being analysed. The time taken for a discrete return can be taken (such as the first and last return intervals), or a complete waveform of the returned signal can be measured (Figure 2.1). The first LiDAR pulse return, typically indicates the top of canopy, or the sole return in the case of a ground hit, while the last return is often associated with the ground, unless dense vegetation hindered signal penetration to the ground level (Asner *et al.* 2007; Colgan *et al*. 2012). Algorithms, based on between-return vertical angles, are used in pre-processing steps to classify ground versus non-ground returns. The product of the LiDAR data is a high resolution 3-D point cloud (Figure 2.2), from which Volumetric pixels (Voxels) can be derived (Figure 2.4) (Weishampel *et al.* 2000; Asner *et al.* 2007;) from which the vegetation structure and biomass estimates of the communal rangelands could be computed.

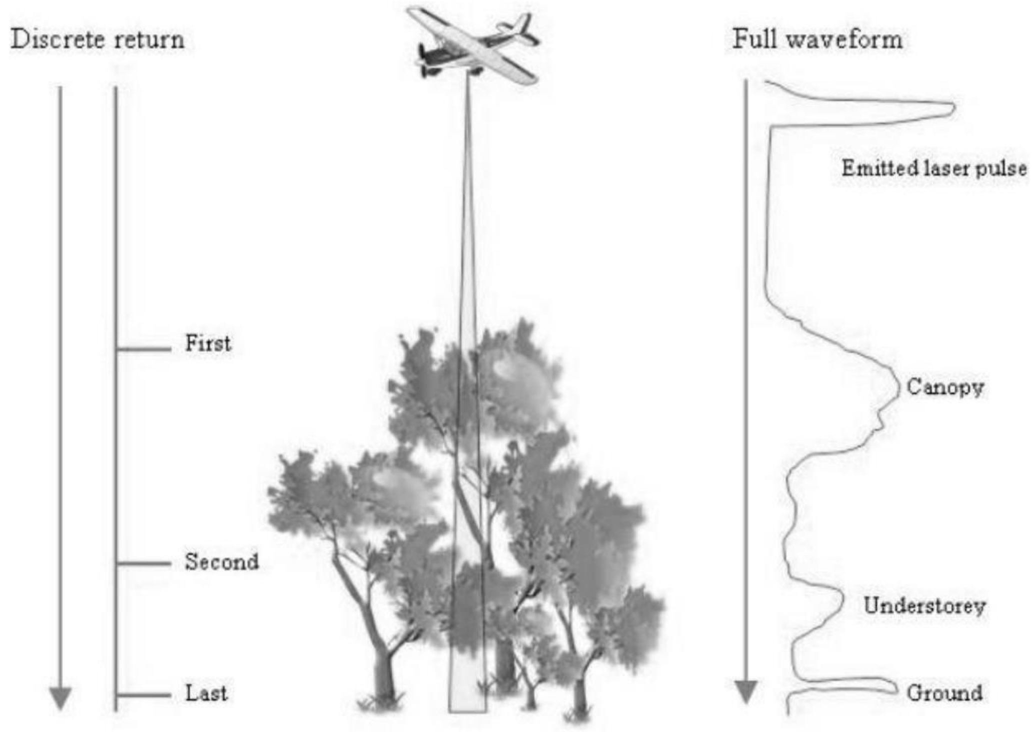


Figure 2.2. Discrete and full waveform LiDAR sensor returning laser pulses off different vegetation height within the canopy (from: Miura, 2010).

Voxels were created from binned data over 5 m x 5 m x 1 m (Figure 2.5). The position of each voxel was determined by the centre of the voxel in relation to the ground (Mograbi *et al*. 2015). The use of voxels incorporates the decrease in sensitivity of local variations in leaf and branch characteristics, as the frequency of LiDAR hits through a vegetation canopy it will be affected by leaf presence and orientation of the leaves and branches. Reporting the number of LiDAR returns as a percentage in a complete normalised vertical column of voxels removes the variation in LiDAR returns due to canopy variation (Lefsky *et al*. 2002; Asner *et al.* 2008; Popescu and Zhao, 2008; Colgan *et al*. 2012). To ensure that local variations in leaf and branch characteristics did not affect the LiDAR data, all the LiDAR data, for all sites, was collected during the same month in winter, 2014. The LiDAR data (points) of each voxel were normalised in relation to all the LiDAR points in a complete vertical column and is pressed as a percentage (Fisher *et al*. 2014). The voxel data is used to determine the subcanopy structure and characteristics of an area, as the resulting vertical profile is an indication of the mean density of vegetation at a particular height (Fisher *et al*. 2014; Mograbi *et al*. 2015;). The voxel data were stacked into ecological relevant vertical height classes and are listed in order from shrubs to tall trees (Table 2.2; Figure 2.4). The exclusion of data below 1.5 m was done to account for the possibility of ground or grass being misclassified as above ground woody vegetation (Colgan *et al.* 2012) and that woody cover can be underestimated below 1.5 m (Wessels *et al.* 2011).

Table 2.2. Ecological height classes of above ground woody vegetation according to which the LiDAR estimates of canopy height in the voxel bins were classified (Adapted from Wessels *et al.* 2010).

Description		**Functional Significance**
1.5 – 3 m	Small Shrubs and bushes	• Often controlled and influenced by fire (Govender *et al.* 2006) and frost (Whitecross *et al.* 2012) • Are heavily browsed by small-to medium-size herbivores (Birkett and Stevens-Wood, 2005; Scholes and Walker, 1993; Witkowski, 1983). • Coppice and encroached woody vegetation, used as live fuelwood production
3 – 6 m	Low Trees	• In conservation areas are targeted by mega herbivores (Owen-Smith, 1988; Asner and Levick, 2012; Levick and Asner, 2013) • Used as live fuelwood production and less influenced by fire (Wessels *et al.* 2010)
6 – 10 m	Trees	• Less influenced by fire and herbivory (Wessels *et al.* 2010), • Contribute to structural diversity and to ecosystem function (Fisher *et al.* 2006). Great use to people for non-timber products (Wessels *et al.* 2010)
10 – 30 m	Tall Trees	• Fire and herbivory have little influence (Wessels *et al.* 2010). • Seen as keystone structures' (Tews *et al.* 2004; Mograbi, 2014), • Often culturally important trees conserved in the rangelands (Wessels *et al.* 2011; Mograbi, 2014)

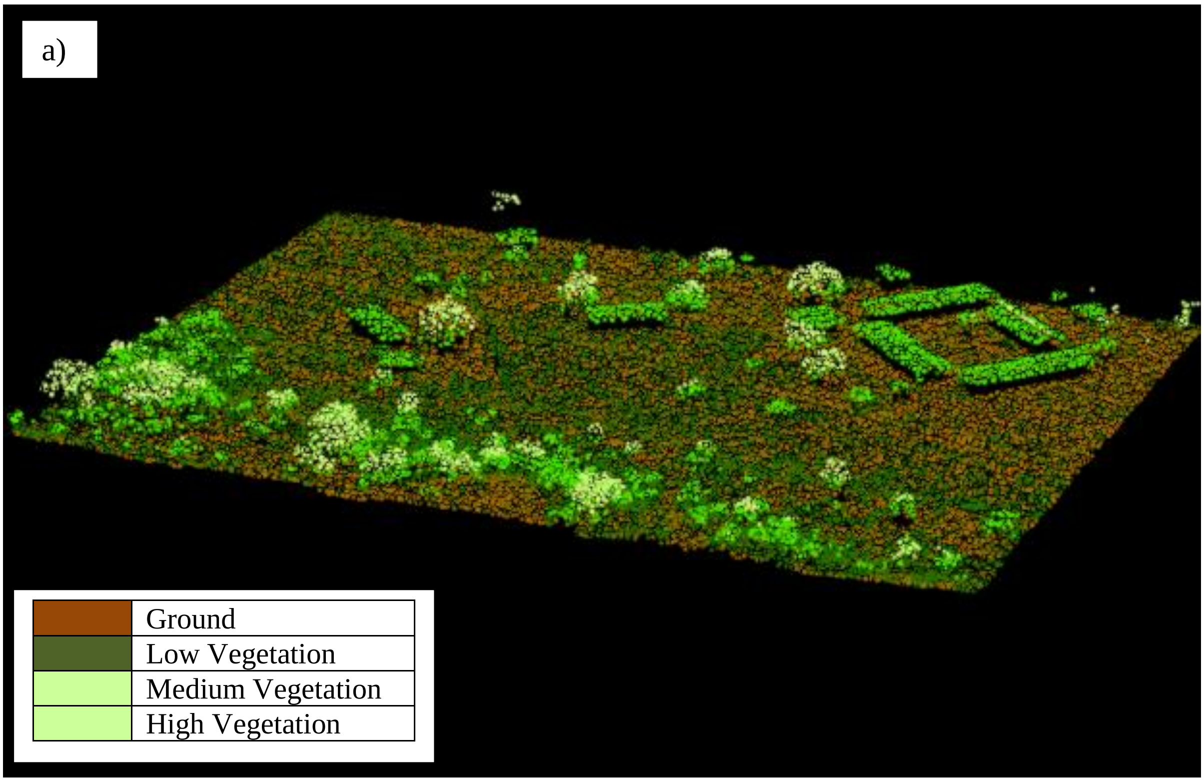


Figure 2.3. A portion of Ka-Ndengeza's villages in Limpopo, South Africa showing a.) a 3-D view of Ka-Ndengeza's LAS Dataset collected from the LiDAR data and b.) a true colour image of the same corresponding area showing the trees, houses and homestead boundaries.

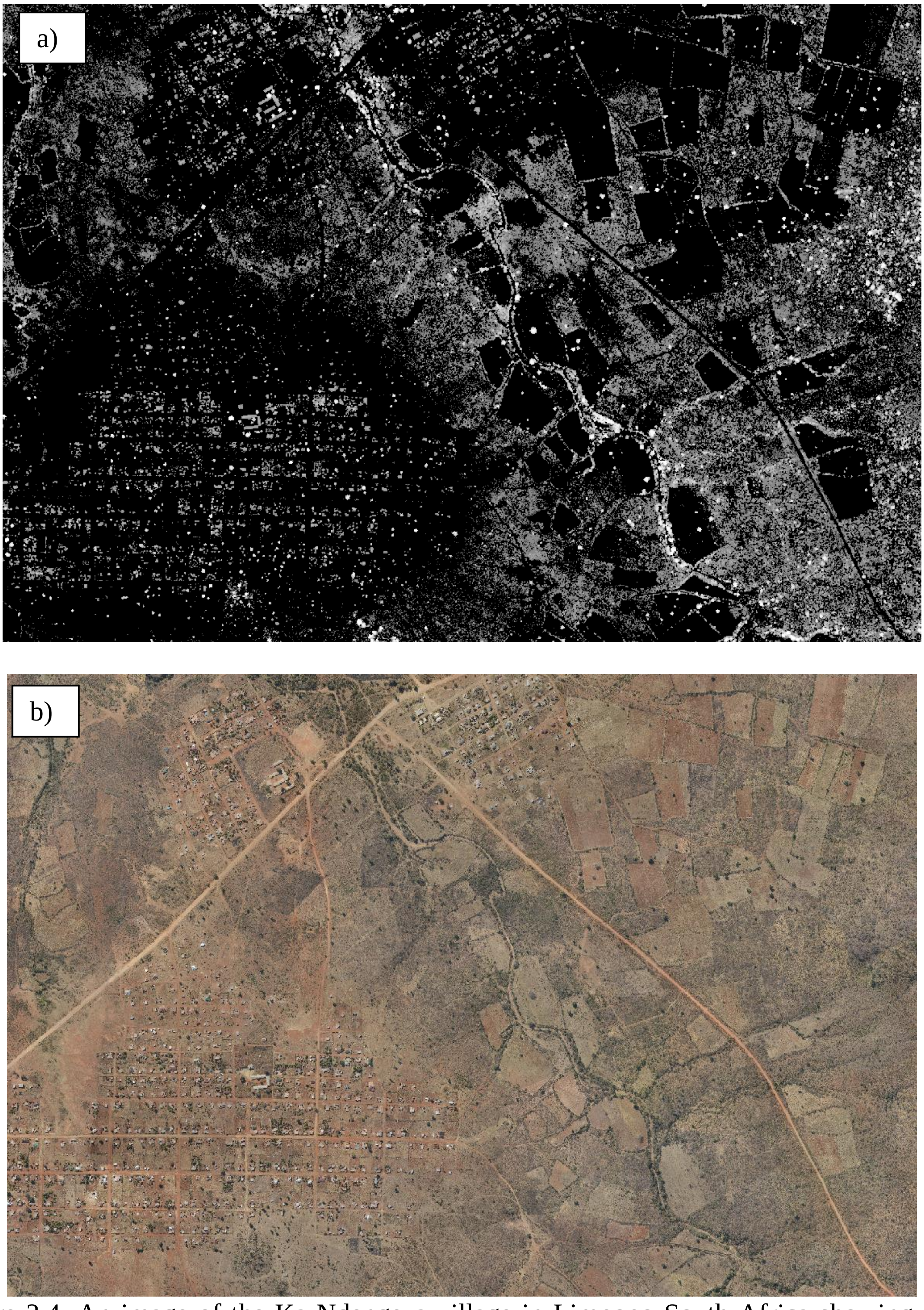
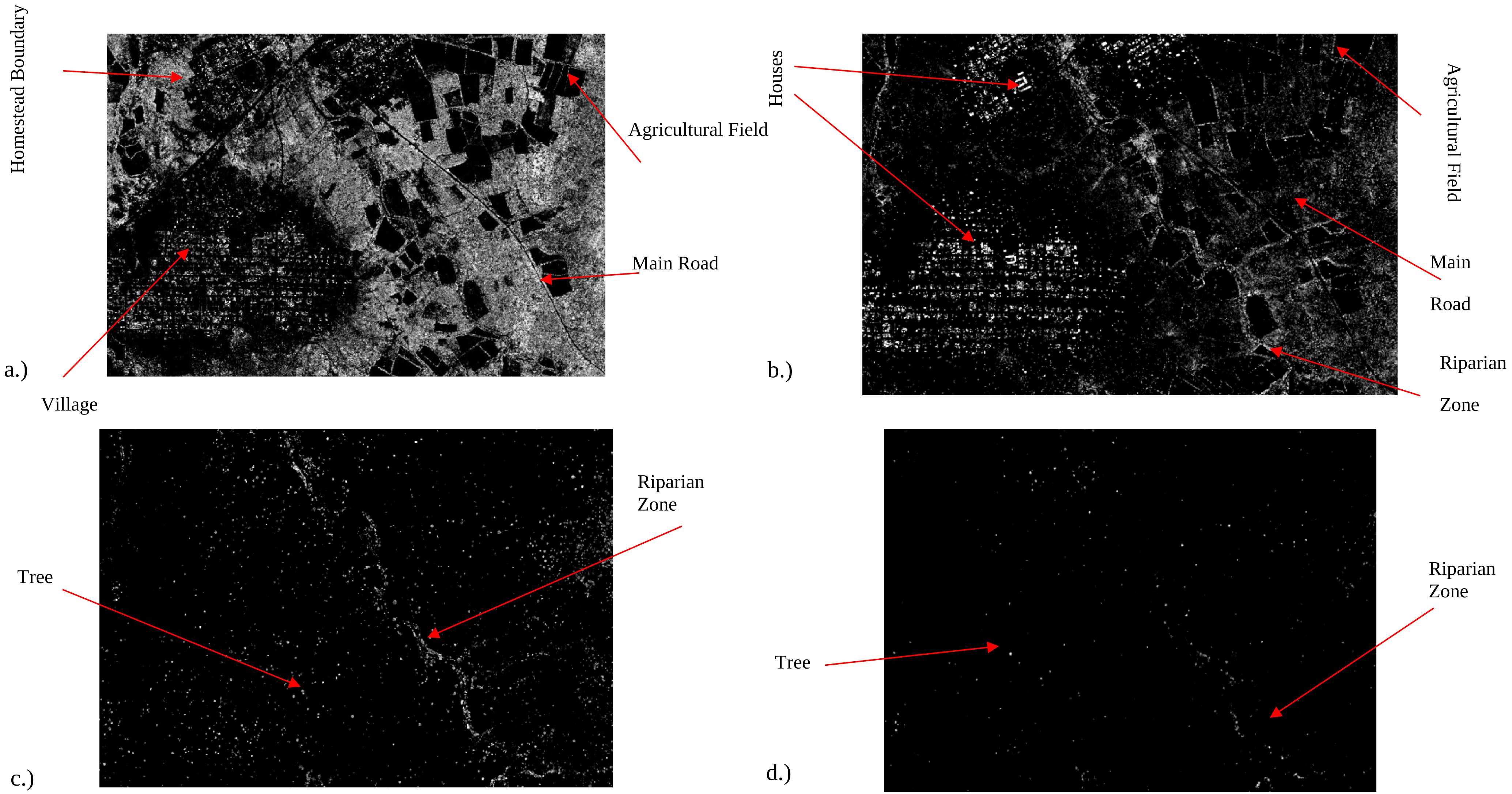


Figure 2.4. An image of the Ka-Ndengeza village in Limpopo South Africa showing an a) overhead view of canopy height model masked at a height between 1.5-30 m with a spot radius of 10 cm (refer to Section 2.2.3) and b) a true colour image of the same corresponding area showing the trees, houses, homestead boundaries, riperian zone, agricultural fields and main roads.


Homestead Boundary
Agricultural Field
Main Road
a.)
Village
Houses
Agricultural Field
Main
Road
Riparian
Zone
b.)
Riparian
Zone
Tree
c.)
Riparian
Zone
Tree
d.)

e) 

Figure 2.5. LiDAR data sliced images binned into a.) 1.5-3 m, b.) 3.1-6 m, c.) 6.1-10 m d) 10.1 - 30 m height classes to create the subcanopy canopy cover voxels with a e.) a true colour image of the same corresponding area showing the trees, houses, homestead boundaries, riparian zone, agricultural fields and main roads.

2.2.3. Vegetation structure parameter extraction

The LiDAR dataset used were analysed using the LASTools (Isenburg, 2015) extension in ArcGIS 10.4 to create Digital Surface Models (DSM) and Digital Elevation Models (DEM). These models were derived through linear interpolation of the first and ground returns, respectively using lasheight and lasground. The LiDAR data was then height-normalised, using the DEM as a reference, with a maximum height cut-off of 30 m, so that radio masts, birds or other noise would not be counted as vegetation. The result is a canopy height model (CHM), in raster format. The rasterization process relies on a manual estimate of the pixel size, using point spacing information, which in this case was 25 x 25 m, because of variable point spacing, not all pixels receive a CHM value. Empty pixels were present, known as "pits" which could hamper the subsequent analysis such as biomass. One method to reduce the number of pits, is to replace each LiDAR return point with a circle with a radius of 10 centimetres (referred to as "spot spacing"), in this case lasthin was used which ensured fewer empty pixels (Khosravipour *et al.* 2014).

After this was preformed, there were no more empty pixels from point spacing errors, there were "pits" as some of the laser pulses penetrated deep into the canopy before producing a first return (Chang *et al.* 2016), when multiple flight lines are combined some laser pulses may have an unobstructed view of the ground without hitting any branches (Khosravipour *et al.* 2014; Chang *et al.* 2016;). The result is a CHM pit-free raster, derived from height normalised LAS files (Method by Khosravipour *et al.* 2013) and represented the highest point value in each pixel. The difference between a raw CHM and a pit-free CHM is shown below (Figure 2.5).

The CHM showed canopy metrics in tiled raster's, such as maximum and maximum vegetation height. By using lascanopy, average standard deviation of above ground vegetation, percentiles (5, 25, 50, 75, 95), vegetation density and percent canopy cover were extracted from the voxel data. Both CHM and voxels measurements described above, are useful for identifying differences in woody vegetation, with voxel measurements representing complexity within the canopy that CHM measurements would omit (Fisher *et al*. 2014).

a)

b)

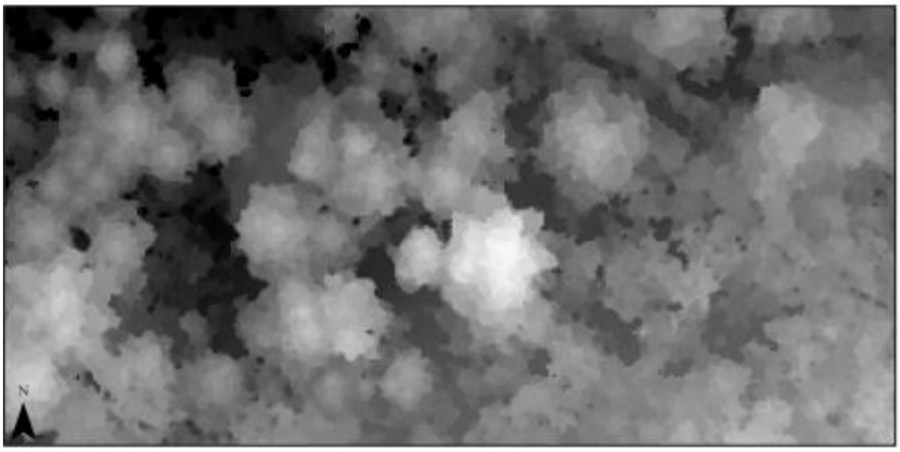


Figure 2.6. The a) standard DSM versus b) a pit-free DSM of high density LiDAR data (adapted from Khosravipour *et al.* 2014).

2.2.4. *Aboveground woody biomass modelling*

Destructive methods of biomass sampling involve the harvesting and weighing of plant biomass (Colgan *et al.* 2013). Although destructive methods are often the most accurate form of measurement, several issues arise when directly measuring biomass at large scales, such as harvesting and manoeuvring large trees. Thus, a variety of allometric equations have been generated by measuring trees stem diameter (D), tree height (H) and wood specific gravity (ƿ) for a small number of trees (Colgan *et al.* 2013). The measured trees are then harvested and weighed, and then a statistical regression is created to relate the actual tree mass to the inventory data (D, H and ƿ). This results in a non-destructive biomass estimation of other trees in the future.

Allometric equations have been developed specific to South African trees by Nickless *et al.* (2011) and by Jenkins *et al.* (2003), which uses only stem diameter as a predictor value for biomass estimation (Colgan *et al.* 2013). These species-specific equations have a limited range, as Colgan *et al.* (2013) found. Often tree specific equations have been generated from a small sample size, which can result in errors in biomass estimations (Colgan *et al.* 2013). Another type of error can arise based on how well the sample area represents the spatial variation of trees in an area, which is determined by environmental gradients such as topography, soil and climate.

Generic equations are more commonly used in estimating above ground woody biomass, as they are based on hundreds of trees that span a variety of species, geographic regions and environmental conditions, such as those developed for tropical forests (Colgan *et al*. 2013). Past research conducted by Chave *et al.* (2004) and Colgan *et al.* (2013) stress that the selection of allometry is the most common source of errors in biomass estimates, as even field-allometry had 16% Residual Standard Error (RSE). These errors often compound with averaging (Mograbi *et al*. 2015). Although Colgan *et al.*'s (2013) plot-averaged LiDAR-derived biomass estimates had 9% more relative error (which is the difference between predicted and measured biomass) than field-harvested biomass, the bias (mean error) was only -3% (compared to Nickless *et al.* (2011) allometry with 15% more relative error and 50% bias) (Colgan *et al.* 2013). These equations are not always accurate enough at regional or landscape levels, and the use of LiDAR is valuable as it has been used to capture the variability of environmental factors that can aid in the upscaling of biomass estimates to larger spatial and temporal scales (Asner, 2009; Colgan *et al*. 2013).

LiDAR derived measurements of above ground woody vegetation can be used to estimate LiDAR-based allometry and infer biomass by measuring vegetation height at high resolutions (e.g. <1 m) and then correlating it back to field measured biomass (Lefsky *et al.* 2002; Chave *et al.* 2005; Popescu, 2007; Colgan *et al.* 2012; Colgan *et al.* 2013; Wessels *et al.* 2013; Mograbi *et al.* 2015). These assessments have contributed to determining the link between LiDAR-derived biomass estimates and plot level field allometry as detailed above and determining the most appropriate equation for LiDAR-derived biomass calculations (Drake *et al.* 2002, Lefsky *et al.* 2002, Asner *et al.* 2012b; Colgan *et al.* 2013; Mograbi *et al.* 2015;).

Recent research conducted in Bushbuckridge, Mpumalanga, explored the correlation between plot-level field biomass and LiDAR derived biomass for 25 x 25 m grid cells that corresponded to 25 x 25 m field plots (Mograbi *et al.* 2015). They found that the use of LiDAR derived metrics, were an excellent practical means of mapping woodlands in communally-utilised areas (Mograbi *et al.* 2015). Because land-scale properties (geology and elevation) influence on woody biomass, different LiDAR-derived biomass equations exist for areas with different underlying geology, such as granite or gabbro substrates in savanna landscapes. The biomass equation used a Bushbuckridge study was a granite equation (Mograbi *et al.* 2015), and the underlying geology of the study areas in Limpopo was also granite.

One of the aims of this study was to compare the biomass of communal rangelands from Bushbuckridge to those found in this study. Two villages in Bushbuckridge, Mpumalanga, of high and low extractive pressures, with the same geology were compared with two villages or similar extractive pressure and geology. Extractive pressure was determined as number of people and households relative to the corresponding rangeland area: high (9.2 people ha^{-1}); intermediate (1.8 people ha^{-1}) and low (0.21 people ha^{-1}) (Fisher *et al.* 2012; Table 2.3). Although each rangeland is used by its corresponding settlements, the use of these rangelands is not exclusive to these villages as foreigners (both local and cross-border immigrants) are known to harvest from these areas (Twine 2005). To ensure standardisation of methods and to reduce the possibility of errors, 25 x 25 m pixel grid cells were applied to all analyses in this study and the same granite savanna allomerty was used in this dissertation as used in Mograbi *et al*. (2015). The importance of equation type is associated with previous research, that found that the general, H x CC metric accounted for 75% of biomass variances and minimised residual error of the mean biomass by 48% (Wessels, 2012; Wessels *et al*. 2013) when applied to sites underlain with granite substrates.

For this study, biomass was calculated using the LiDAR-derived metric of H x CC (Colgan *et al.* 2012; Mograbi *et al.* 2015), where H is mean top-of-canopy height where the mean pixel height for values greater than 1.5 m and CC is the proportion of canopy cover per grid where the proportion of pixels greater than 1.5 m in height (Colgan *et al*. 2013; Mograbi *et al.* 2015). The resultant vegetation height map was the primary input to the above ground woody biomass (AGWB) estimation.

2.2.5. Data extraction and analysis

In order to relate the above ground woody biomass of the communal rangelands and the presence of biomass gradients around communal rangelands to environmental and anthropogenic variables, the LiDAR data selected in this study was based on whether the data was available and whether the data had featured in previous studies on woody biomass and vegetation structure in the regional communal rangeland context (Shackleton and Scholes, 2011; Wessels *et al.* 2011; Fisher *et al.* 2012; Wessels *et al.* 2013). Consequently, the above ground woody biomass was assessed in 200 m distance bands radiating outwards from a village to determine the presence of disturbance gradients, as well as resource collection and use from non-village residents. Distance gradients from the nearest road were included and assessed, due to the increasing use of vehicular transport in the rangelands (Twine *et al.* 2003a; Twine 2005b, Smit and Asner, 2012). As roads provide easy access to communal rangelands, it was assumed that this could have an impact on the patterns of resource use and influence biomass. The impact of fire on fuel load was excluded from this study as low fuel loads from intensive grazing maintain low grass fuel loads and, less intense fires (Archibald *et al.* 2009). Distances walked to collect natural resources have increased over the years, which has resulted in the development of gradients of wood resource availability around settlements (Twine, 2005; Giannecchini *et al*. 2007; Wessels *et al*. 2013). Like Mograbi *et al.* (2015), distance classes were created as buffer zones, radiating out from the edge of the settlement areas and roads, in increments of 200 m.

In each of the four case study villages, features of the settlements such as roads, villages and rangeland area were manually digitized in ArcMap^{TM} V10.4 (ESRI ®2014-2016) using the orthophotos of the village study area (Appendix 1-4). The resultant data from the biomass and voxel maps were exported using the zonal statistics tool in ArcMap^{TM} V10.4 (ESRI ®2014-2015) and imported into excel for further analysis. The zonal statistics tool exports several basic statistics (e.g. max, min, mean, standard deviation and sum) of the pixel within a selected "zone" (e.g. 200 m buffer zones). In order to assess the relationship between above ground woody cover and average biomass ANOVA tests were performed on the average communal rangeland biomass in comparison to village settlement areas. Regression analyses were used to assess the relationship between above ground woody biomass gradients and distance to the nearest village settlement and road.

2.2.6. Assessing households access to natural resources

After exploring the patterns of human-impacted vegetation in the communal woodlands, the aim was then to explore the link between the accessibility of resources and household resource use. This was because the research and findings in this study raised more questions regarding the patterns driving the resource use observed in the four villages (Discussed in Chapter 3). To assess the accessibility of households to natural resources, access was defined as the least amount of energy required to collect any given resource (least cost path). This was achieved by creating a least cost path map in ArcGIS 10.4. The least cost path maps were created using a distance analysis tool that compares the least cost path between specified locations to determine the most cost-effective route between a source and destination. Cost can be a function of time, distance or another criterion that can be defined by the user, based on the desired outcome of the cost analysis (Briney, 2014).

In this study, slope and canopy cover of small shrubs were used as proxies to identify the least cost path associated with a given resource. A path was deemed undesirable if it had a slope > 10 % (Lee *et al*. 2009) due to the energy exerted to walk uphill, and a canopy cover > 50 % of small shrubs (at a height of 1.5 - 3 m), due to the amount of energy required to cut through this vegetation to make an access path. The slope and canopy cover of shrubs was reclassified and assigned weighted values (1 – 10). The value applied to small shrubs was higher than that applied to slope as the area is relatively flat. For example, a low canopy cover of shrubs was weighted as 1, while a high canopy cover of shrubs was weighted as 10. The proportion of slope and shrub layer was assigned a ratio of 30:70 since the area was relatively flat.

In this study, distance travelled to collect certain resources was not explored, as this data was not collected during the household interviews, distance to collect a resource was not used in determining the least cost path. Information regarding the common resources utilised by households was collected (Chapter 3). The accessibility of households to fruiting trees (classified as trees between 6 – 10 m, Table 2.2) was explored. Only access to fruiting trees was explored as wild fruits are used by 97 – 100 % of households (Chapter 3).

Past research has found that vegetation changes are most related to ease of accessibility within the landscape (Luoga *et al.* 2002). Wessels *et al.* (2013) found that the maximum distance people are willing to travel to collect resources is approximately 1.5 km. Giannecchini *et al*. (2007) found that there has been an increase in the distance walked to collect fuelwood observed by over a 10-year period. Subsequently a study conducted by Mograbi *et al*. (2015) found that vegetation harvesting occurred up to 2.6 km away from a settlement boundary in Bushbuckridge. In this study, the distance that people were willing to walk to collect a natural resource was assumed to be 3000 m, to account for any variations previously observed in other research. The proxies used to calculate the access of household's to fruiting trees was derived from the Canopy height metrics (detailed in Section 2.2.2 above).

The Cost Distance Tool calculates the least cumulative cost distance from or to the least cost source over a cost surface. This is created in ArcGIS by radiating out from the source (in this case the village settlement), determining the cost of each cell by identifying the neighbour cell with the lowest accumulated cost and adding its cost to the total cost of the cell. Simultaneously, a separate grid, called a *backlink raster* defines the neighbour that is the next cell on the least accumulative path, which encodes the direction from each cell to its lowest cost neighbour. The least cost pathway then takes a desired destination (in this case shrubs and trees) and finds the corresponding cell in the backlink raster, then traces a path from the destination back to the source by following the direction of each cell to the lowest cost neighbour (ArcGIS, 2014). A detailed description of the workflow used to calculate the least cost pathway associated with firewood (Figure 2.7) is shown below.

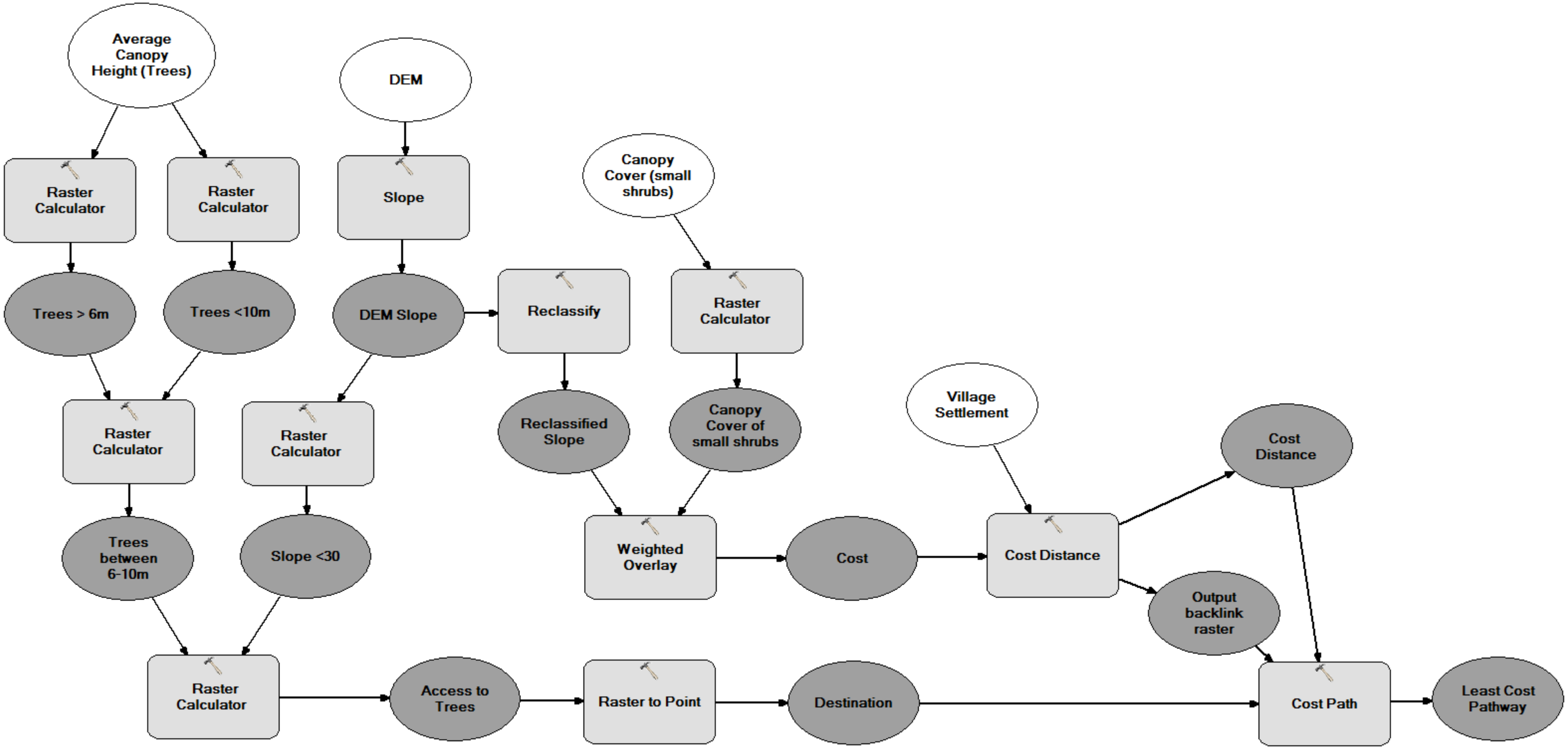


Figure 2.7. Least cost pathway work flow, detailing the processes of CH metrics analysis, to form a least cost pathway map of households' access to fruiting trees in the surrounding communal rangelands. Slope and canopy cover of small shrubs were used as proxies for cost, both proxies were derived from the canopy height metrics Chapter 2 Section 2.2.3) and computed in ArcGIS 10.4. White circles refer to an input layer, light grey squares refer to a tool used, and dark grey circles refers to and output layer.

2.3. Results

2.3.1. Communal rangeland above ground woody cover and biomass

The average canopy cover and average biomass of the four village rangelands were compared with the villages' area, defined as the spatial extent of the residential area and the village commons such as the woodlands and rangelands (Figure 2.8). Mafarana and Ga-Selwana had similar settlement areas, 21.43 km^2 and 21.96 km ^{2} respectively. In comparison to the other villages Ga-Selwana had the largest average rangeland canopy cover. While Mafarana had the lowest average rangeland canopy cover. Vyeboom and Ka-Ndengeza had a similar average rangeland canopy cover with 52.12% and 56.24% respectively. There was no statistically significant difference between average canopy cover and settlement area ($F_{(1,2)}$=0.028, p=0.88). Vyeboom and Ga-Selwana had similar average rangeland biomass per hectare, with 7.40 Mg/ha and 7.31 Mg/ha respectively. While, Ka-Ndengeza had the highest average rangeland biomass (9.82 Mg/ha). There was no statistically significant difference between average rangeland biomass and settlement area ($F_{(1,2)}$=5.553, p=0.15).

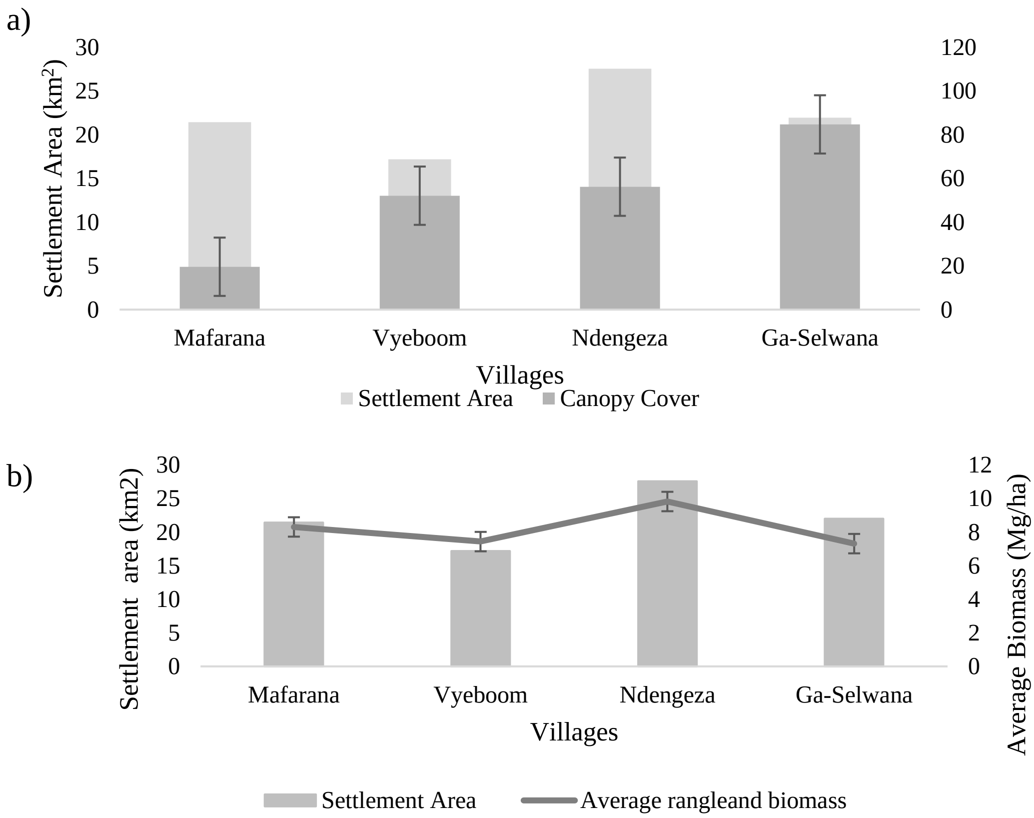


Figure 2.8 a) Average communal rangeland above ground woody canopy cover and b) Average communal rangeland above ground woody biomass of the four case study villages in Limpopo, South Africa in comparison to settlement area.

The average rangeland biomass for the four villages was then compared with two villages from Bushbuckridge in a study conducted by Mograbi *et al.* (2015), looking at human-mediated bush encroachment in communal rangelands. This comparison was done to see how biomass patterns vary depending on geographical location. The average rangeland biomass between Bushbuckridge (Mpumalanga) were significantly higher than those in Limpopo ($p<0.05$), even though the geology of the rangelands were the same (Table 2.3).

Table 2.2. Biomass (Mg/ha) (mean ± SD) for two Mpumalanga Bushbuckridge villages, collected in 2012 and for two Limpopo villages collected in 2014, including geology, rainfall and land use.

	Kildare, Ireagh and Lillydale, Bushbuckridge	**Agincourt, Bushbuckridge**	**Mafarana**	**Ga-Selwana**
Geology	Granite	Granite	Granite	Granite
Rainfall	Semi-mesic	Mesic	Mesic	Semi-Mesic
Wood extractive pressure	High	Low	High	Low
Biomass	45.4±28.4 (2012)	32.5±17.6 (2012)	8.3±14.1 (2014)	7.3±9.8 (2014)

2.3.2. Communal rangeland Above ground woody biomass gradients

The rangeland biomass trends were analysed relative to the increasing distance from the village settlements and from the closest road. In Vyeboom, the within village biomass is similar to the biomass between 0-200 m buffer from the village (Figure 2.9b). Overall, there is a gradual increase in biomass between 0-2200 m from the village, where after it starts to decrease quite rapidly. Conversely, the biomass from the nearest road gradually increases with increasing distance. There was a noticeable difference in the biomass values between 2400 – 3000 m from the nearest road in comparison to the same distance increment from the village (Figure 2.9b). Although, there is no significant relationship between biomass and increasing distance from the village ($R^2=0.3185$, $p=0.52$) there is a strong significant relationship between biomass and increasing distance from the nearest road in Vyeboom ($R^2=0.90243$, $p<0.01$).

In Ka-Ndengeza, there was a steep increase in average biomass between 0-1200 m from the village settlement (Figure 2.9c). The biomass then plateaus between 1200 m and 2600 m after which it begins to increase again. A strong significant relationship exists between biomass and increasing distance from the nearest settlement in Ka-Ndengeza (R^2=0.71095, p<0.01). The biomass gradients from the nearest road in Ka-Ndengeza follow the same trend as the biomass gradient from the village settlement. After 2600 m from the nearest road the biomass decreases in comparison to the increase at this increment from the village settlement (Figure 2.9c c)., Between 0 - 200 m from the nearest road, the biomass is three times that of the biomass near the village at the same distance increment. While between 200 – 600 m from the nearest road, the biomass is double that of the biomass near the village at the same distance increment. Despite this, there is no significant relationship between biomass and increasing distance from the nearest road (R^2=0.14083, p=0.16). Ka-Ndengeza had the lowest within village biomass in comparison to the other villages (4.42 Mg/ha).

Ga-Selwana showed the most constant biomass gradient with an overall gradual increase in biomass with increasing distance from the village settlement (Figure2.9d). With only one noticeable peak in biomass between 100 – 1200 m from the settlement. The biomass gradient from the nearest road in Ga-Selwana followed the same overall trend of increasing biomass with increasing distance (Figure 2.9d). With only one clear peak in biomass between 1400 -1600 m from the nearest road. Biomass gradients, from the settlement and the nearest road were similar. There was only a significant relationship between biomass and increasing distance from the settlement (R^2=0.34583, p=0.02), in comparison to biomass and increasing distance from the nearest road (R^2=0.11282, p=0.22).

Mafarana had a very irregular biomass gradient with many peaks and dips throughout the biomass gradient with increasing distance from the settlement (Figure 2.9d a). The biomass gradient from the nearest road was also irregular in comparison to the other villages. Between 0 – 800 m, 1400 – 1600 m and 2400 – 3000 m from the nearest road. The biomass values were higher than those for the same distance increments from the village settlement (Figure 2.9d a). There was no significant relationship between biomass as increasing distance from the nearest settlement or the nearest road (R^2=0.00545, p=0.79). Mafarana had the highest within village biomass in comparison to the other villages at 9.77 Mg/ha.

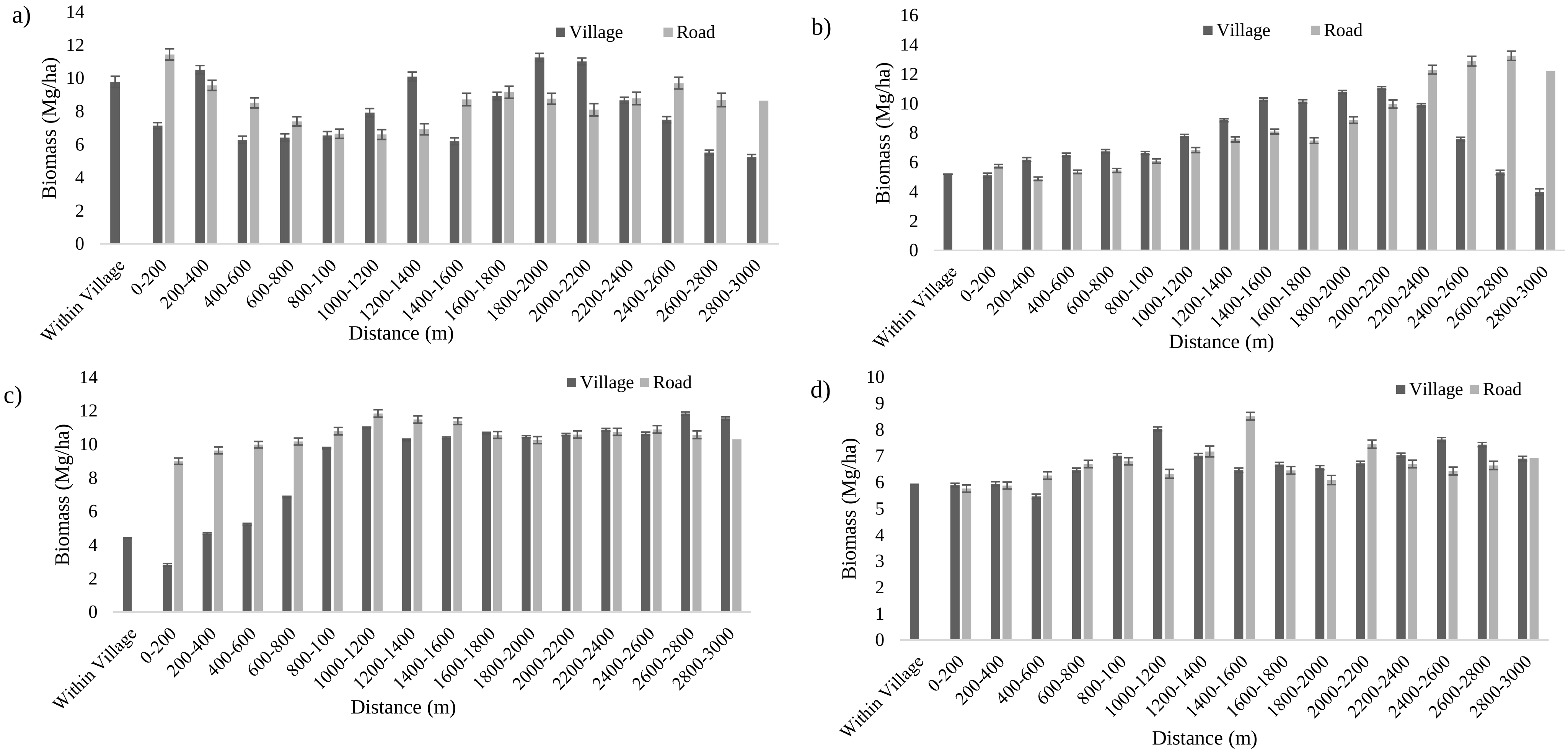


Figure 2.9. Biomass (Mg/ha) for the villages of a) Mafarana, b) Vyeboom, c) Ka-Ka-Ndengeza and d) Ga-Selwana, along a distance gradient from the closest settlements and road in each village in 200 m increments, Limpopo Province, South Africa

2.3.3. *Communal rangeland above ground vegetation structure dynamics*

In Vyeboom, there was a similar proportion of small shrubs (bushes) and shrubs at all distance increments from the village settlement and many tall trees at 2900 m from the village settlement (Figure 2.10b). There was a strong relationship between the canopy cover of small shrubs (bushes) (R^2=0.89671, p<0.01), low trees (R^2=0.96796, p<0.01) and tall trees (R^2=0.90414, p=0.03) with increasing distances from the village settlement. While there was no significant relationship between the canopy cover of low trees and distances from the settlement (R^2=0.00318, p=0.84). In Ka-Ndengeza and Ga-Selwana there was a gradual and increase in sub-canopy structures with increasing distance from the village settlements (Figure 2.10c and Figure 2.10d). There was a significant relationship between all four sub-canopy structures distances from the village settlement in Ka-Ndengeza (p<0.01). In Ga-Selwana there was only a significant relationship between the percent canopy cover of shrubs (R^2=0.54938, p<0.01), and low trees (R^2=0.53000, p<0.01) and distance from settlements in comparison to the percent canopy cover of trees (R^2=0.16949, p=0.12) and tall trees (R^2=0.10008, p=0.25) (p>0.05). In Mafarana there was no obvious pattern in the sub-canopy structures at different distance increments from the village settlement (Figure 2.10c). Tall trees were more prevalent between 0 - 1300 m from the village settlement than between 1300 - 2900 m from the village settlement (Figure 2.10c). The percent canopy cover of the small shrubs (bushes) layer was higher further way from the village settlement than closer to the village settlement (Figure 2.10c). There was no significant relationship between the percent canopy cover of small shrubs and low trees with increasing distance from the village settlement (R^2=0.00545, p<0.01). Yet, there was no significant relationship between trees and tall trees with increasing distance from the village settlement (R^2= 0.0008, p>0.05).

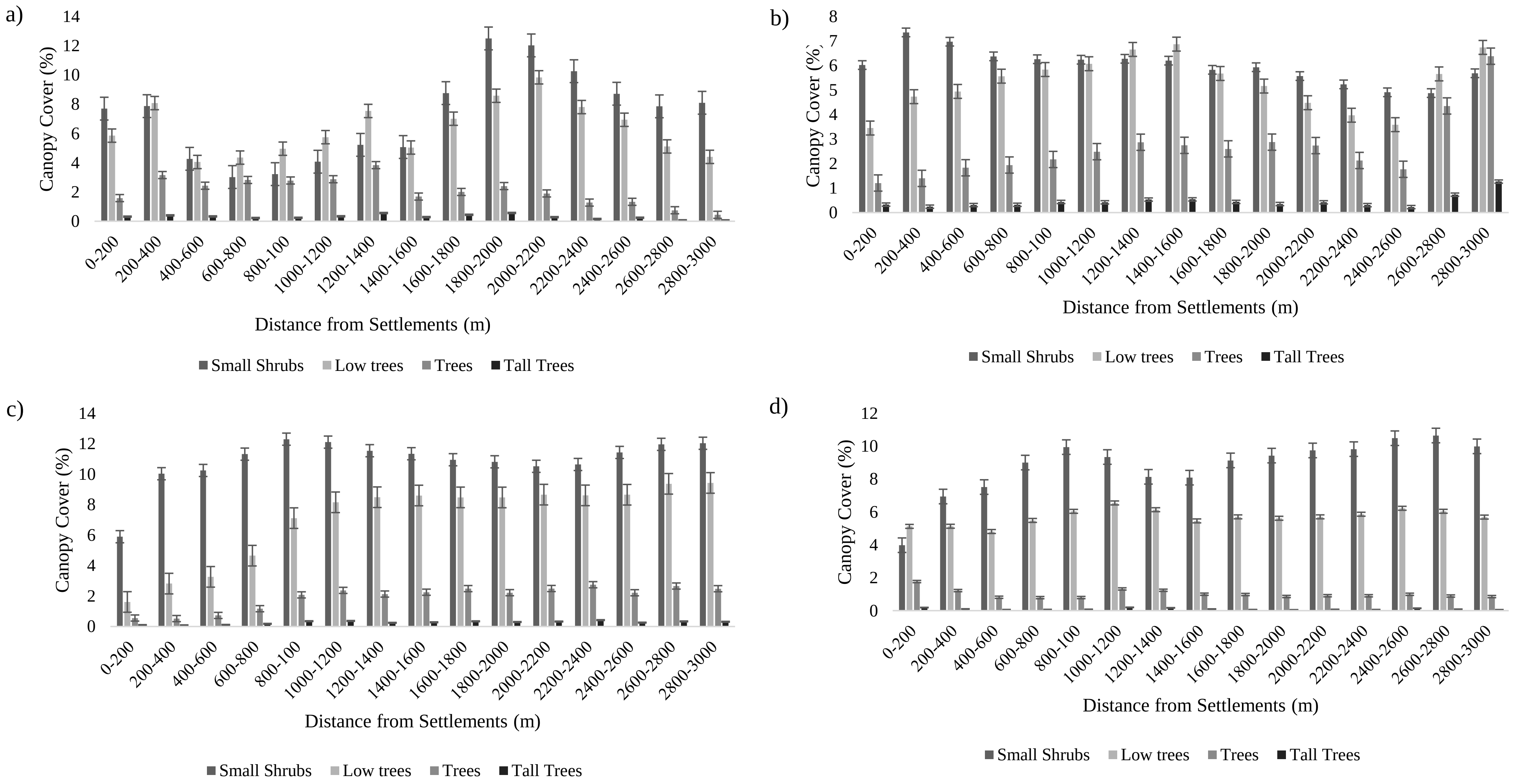


Figure 2.10. Size class distributions (SCD) of percent canopy cover in a) Mafarana, b) Vyeboom, c) Ka-Ka-Ndengeza and d) Ga-Selwana along a distance gradient from the closest settlements in 200 m increments in Limpopo, South Africa.

In Vyeboom, between 0–1200 m from the nearest road there were a large proportion of small shrubs (bushes) in comparison to the other sub-canopy structures (Figure 2.11b)., between 1200-2000 m from the nearest road the proportion of small shrubs (bushes) and shrubs is similar and plateaus, where after 2200 m low trees have the highest canopy cover and gradually increases while the canopy cover of small shrubs (bushes) decreases (Figure 2.10b). The canopy cover of tall trees gradually increases with increasing distance from the nearest road and trees remained relatively constant throughout all distance increments. There was no significant relationship between the canopy cover of small shrubs (R^2=0.00318) and tall trees (R^2=0.2904) increasing distance from the nearest road ($p>0.05$), while there was a strong significant relationship between low trees (R^2=0.89671), trees (R^2=0.96764) and with increasing distance ($p>0.01$).

In Ka-Ndengeza, the canopy cover of small shrubs (bushes) is almost double that of the shrubs between 0-400 m from the nearest road (Figure 2.11c). There is an overall increase in the canopy cover of small shrubs (bushes) and shrubs between 0–1200 m from the nearest road, after which they then begin to gradually decrease (Figure 2.11c). Despite this, there is only a significant relationship between canopy cover of small shrubs (bushes) (R^2=0.62178, $p<0.01$) in comparison to low trees (R^2=0.04222, $p>0.05$). Canopy cover of trees follows the same trend as the small shrubs sub-canopy layer, while the canopy cover of tall trees remains consistence through all distance increments from the nearest road. Subsequently, there is a moderately significant relationship between the canopy cover of trees (R^2=0.47966) and tall trees (R^2=0.42986) with increasing distance from the nearest road ($p<0.01$).

In Mafarana, the canopy cover of shrubs is higher than the canopy cover of small shrubs (bushes) between 0–600 m from the nearest road. Between 600-2400 m from the nearest road the canopy cover of small shrubs (bushes) and shrubs is similar (Figure 2.11a). The canopy cover of trees decreases between 0 – 1200 m from the nearest road and then rapidly increases between 1200–2000 m from the nearest road, after which it gradually decreases again. The canopy cover of tall trees is constant throughout the distance increments from the nearest road with a peak in canopy cover between 1600–1800 m from the nearest road (Figure 2.11a). There was no significant relationship between any of the subcanopy structures canopy cover in Mafarana with increasing distance from the nearest road ($p>0.05$).

In Ga-Selwana, the canopy cover of small shrubs (bushes) between 0 - 800m and 2200 – 3000 m from the nearest road increases gradually, the canopy cover also plateaus between

800 – 1600 m and between 1800-2200 m (Figure 2.11d). The canopy cover of shrubs gradually increases with increasing distance from the nearest road with a few dips at 100-1200 m and 1600 – 200 m. There is a significant relationship between the canopy cover of small shrubs (bushes) (R^2=0.54968) and low trees (R^2=0.53829) with increasing distance from the nearest road ($p<0.01$). The canopy cover of trees increases between 0 – 1600 m, and then gradually decrease again with a peak at 2000 - 2200 m. The canopy cover of tall trees is very low at all distance increments and there is a peak at 1400 – 1600 m from the nearest road (Figure 2.11d). There is no significant relationship between the canopy cover of trees (R^2=0.16982) and tall trees (R^2=0.10284) with increasing distance from the nearest road ($p>0.05$). The canopy cover of tall trees is the lowest in Ga-Selwana in comparison to the canopy cover of tall trees in the other villages.

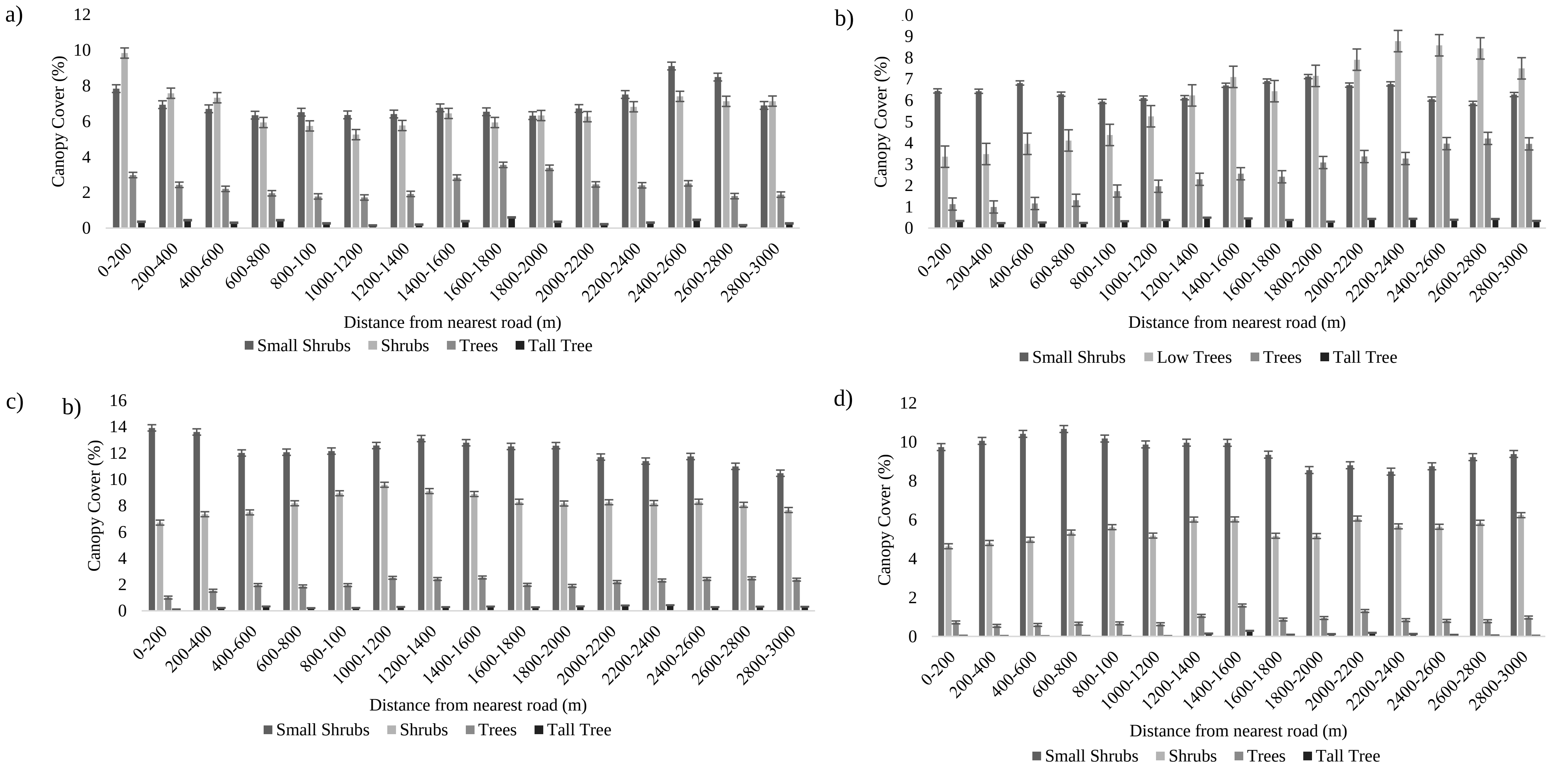
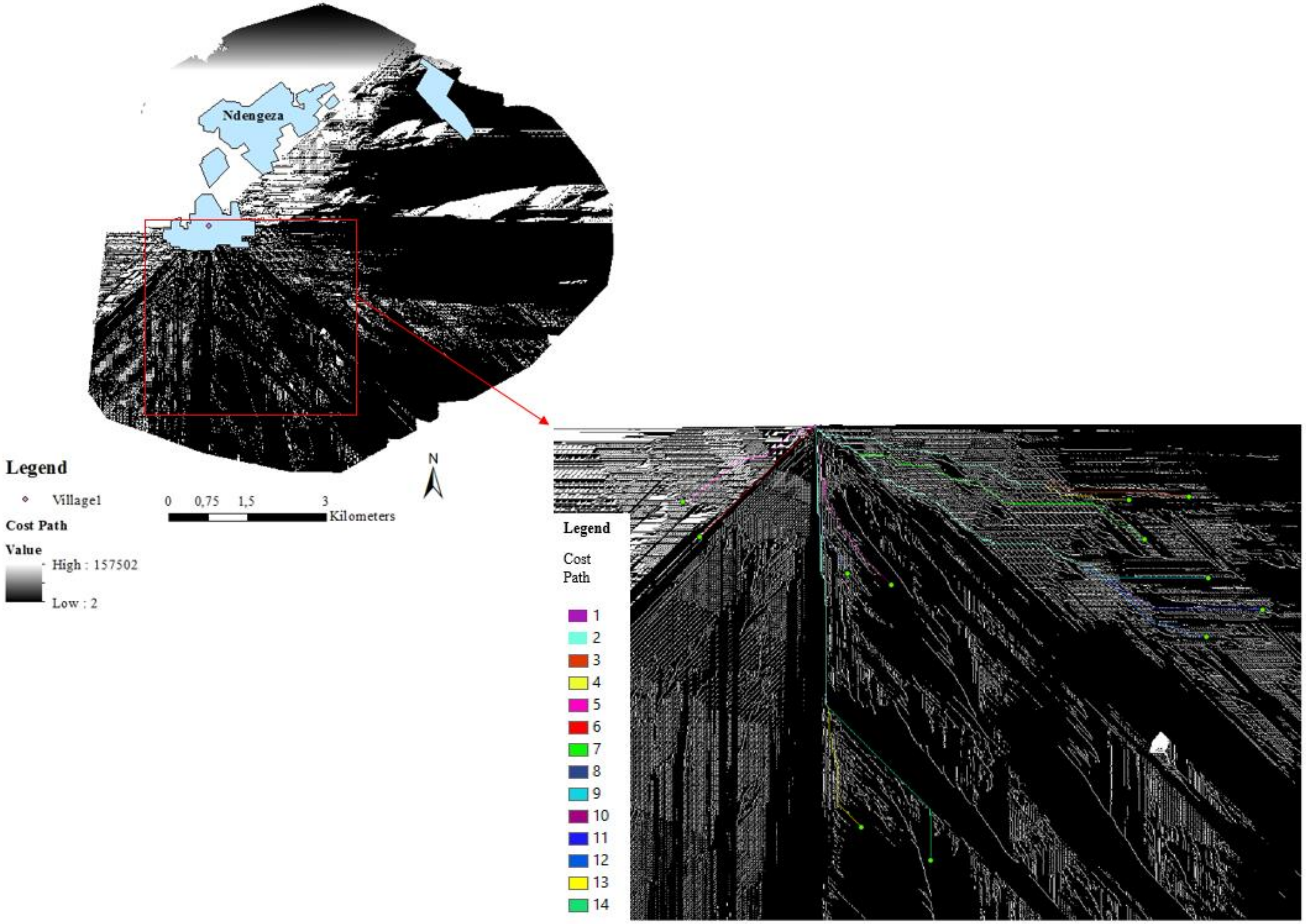


Figure 2.11. Size class distributions (SCD) of percent canopy cover in a) Mafarana, b) Vyeboom, c) Ka-Ka-Ndengeza and d) Ga-Selwana along a distance gradient from the nearest road in 200 m increments in Limpopo Province, South Africa.

2.3.4. *Villages access to natural resources*

The cost maps were generated for the cost associated with collecting fruit from trees (between 6 - 10 m, detailed in Section 2.2.6) with the starting point as the centre of the village settlements which were polygons. Initial analyses using all available trees as possible path end points, resulted in either a failed algorithm, or maps with so many overlapping paths that it was not possible to interpret them in terms of landscape features. As a remedial measure, a cost path map was generated using 12 separate randomly selected trees (which met the criteria, 6 – 10m, detailed in section 2.2.6) each in a separate distance band (1 tree from each of the 200 m distance bands). From this map, it is evident that the linear lines present on the cost maps describe an individual pathway to a given resource. This based on Figure 2.12 shows that the cost associated with the purple pathway is lower than the cost associated with the green pathway. The pathways overlap the further away from the village a person gets. This shows that one pathway can be followed to a point and then change to access a resource as per Figure 2.12. It can then be concluded that there are numerous pathways to a given resource depending on where in the landscape an individual is starting from and ending. The least cost pathways associated with the 12 trees make sense when the cost pathways are overlaid on orthophotos of the communal rangeland. Based on the analyses of the least cost pathways, in conjunction with the orthophotos, it appears that slope and shrub cover only play a role in the cost associated with collecting a given resource at the end of that pathway, close to the destination. This is because the cost paths follow contours or pathways that have already been previously established in the rangeland. Consequently, slope and shrub cover only factor in the cost at the end of a given pathway.

a.)



b)

Figure 2.12. a) The cumulative cost surface for the access of households in Ka-Ndengeza to firewood (classified as shrubs, based on the voxel data collected in Chapter 2 Section 2.2.3, Table 2.2) in the surrounding communal rangeland and b) Least Cost Pathways associated with 12 randomly selected trees.

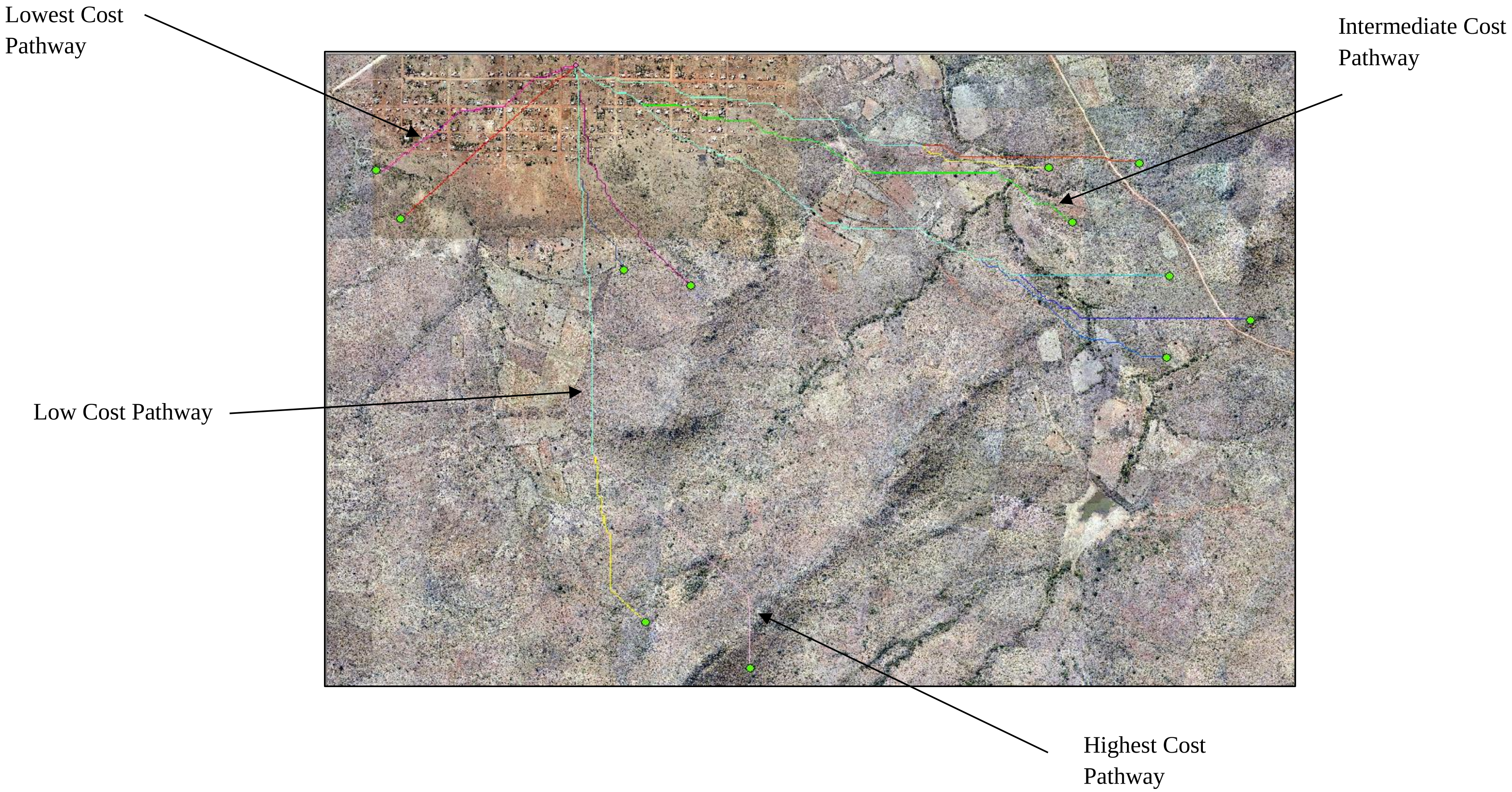


Figure 2.13. Least Cost Pathways associated with 12 randomly selected trees (classified as shrubs, based on the voxel data collected in Chapter 2 Section 2.2.3, Table 2.2in the surrounding communal rangeland overlaid an orthophoto of the Ka-Ndengeza village, Limpopo, South Africa. Slope and canopy cover of small shrubs were used as proxies to identify the least cost path associated with a given resource. Proxies were derived from the Canopy height metrics (detailed in Chapter 2) and were computed in ArcGIS 10.4. A high cost is equivalent to a slope >10% and canopy cover of shrubs >50%.

2.4. Discussion

Biomass disturbance gradients generally occur with increasing distance from human impacts. The study of these gradients is used to describe the relationship and interaction between people and their surrounding environment (Carleton and Taylor, 1982; Ratcliffe, 1984; Belsky, 1987; McDonnel and Pickett, 1990, Mograbi *et al*. 2015). Research conducted in Bushbuckridge South Africa found disturbance gradients relative to distance from the nearest settlement resulted in a change in the community composition, woody size structure and biomass (Shackleton *et al.* 1994; Higgins *et al.* 1999; Shackleton and Scholes 2011; Matsika *et al.* 2012, Fisher *et al*. 2014, Mograbi *et al*, 2015). Fisher *et al*. (2012), found that in highly utilised rangelands a decrease in disturbance gradients could be a precursor to degradation.

When the average rangeland biomass from the Limpopo villages was compared with those in Bushbuckridge South Africa, the average rangelands biomass between Bushbuckridge (Mpumalanga) were significantly higher than those in Limpopo, even though the geology of the rangelands was the same (Table 2.3). The variations in the average rangeland biomass could be explained by the rainfall, as Limpopo receives less rain annually than Bushbuckridge. These variations could also be due to the time of year the data was collected as the Bushbuckridge data was collected in April 2012 while the Limpopo data was collected in July 2014, which could account for the lower biomass readings in the Limpopo villages. The intensity of wood extractive pressure also appears to influence the biomass of the rangeland, seen in Table 2.3. Although there is a more noticeable difference in biomass and intensity of use in the Bushbuckridge villages in comparison to the villages in Limpopo. A more comparative analysis needs to be explored on data from each area, collected at the same time of year for a more accurate comparison of the biomass between the two areas.

2.4.1. State of the communal woodlands

In this study, the average rangeland canopy cover and average rangeland biomass of the four case study villages was not influenced by the village settlement size, defined as number of residents (Figure 2.8). At the rangeland-scale, across the four villages, anthropogenic influences on biomass and vegetation structure were evident. This was particularly true for the biomass in Ka-Ndengeza and Ga-Selwana where the trajectory of biomass increased with increased distance from the settlements and the nearest road (Figure 2.9). The similar biomass gradients found at both Ka-Ndengeza and Ga-Selwana village settlements, may be attributed to their location, as they are both located along a main road and have a secondary road transecting the middle of the rangelands. These roads allow village residents easy access to their respective rangelands (Appendix 1 – Appendix 4). Previous research has found that disturbance gradients typically appear with increasing distance from villages (McDonnell and Picket, 1990; Fisher *et al.* 2012, Wessels, 2013; Mograbi *et al.* 2015). Twine (2005) found that village residents are increasingly using vehicles to collect and transport natural resources. This use of vehicles could similarly explain the biomass patterns observed in Ka-Ndengeza and Ga-Selwana. These biomass patterns indirectly depict the resource use patterns of these two villages.

High levels of anthropogenic disturbance were evident in Mafarana's rangeland, where the biomass gradient was bimodal, it had two maximum points, and human disturbance was evident at increased distance from the settlement and the nearest road seen in Figure 2.9. The percent canopy cover in Mafarana for the subcanopy categories was also bimodal and showed high levels of human disturbance at increased distance from the settlement (Figure 2.10). This could be attributed to the fact that Mafarana's village and communal rangelands are surrounded by main roads, theR529 and R36. These main roads make access to these rangelands a lot easier, especially considering that vehicles are increasingly being used to transport larger amounts of wood from more distant locations (Twine *et al.* 2003). There is also the presence of woodland degradation which could also been an indication of disturbance gradients (Coetzer *et al.* 2010). When the percent canopy cover of the subcanopy categories was explored at increasing distance from the nearest road, the gradient was more consistent, indicating that the road access was not a large factor influencing Mafarana's rangeland vegetation structure. Nevertheless, the disturbance present in Mafarana's rangeland could be attributed to the proximity of Ka-Ngolombe village to Mafarana. When villages are near one another, their collection base may overlap (Saunders, 2015). This can lead to accelerated extraction pressures placed on the overlapping areas and high levels of disturbance are seen (Fisher *et al*. 2012). Village residents in Mafarana verbally mentioned, that the communal rangelands of the adjacent villages do not overlap, but this does not mean that the collection base of adjacent communal lands are clearly defined. Furthermore, unclear boundaries between villages adds confusion to natural resource management (Kirkland *et al*. 2007) and can exacerbate woodland degradation through poor rangeland management.

Village boundaries are constantly shifting and so conflict often arises over boundary demarcation of villages woodland resource use areas (Nemarundwe, 2004). In the former homelands, under the Apartheid regime, village communal land boundaries were demarcated by the government. When a new village was established, during land reallocation and forced removals (Kirkland *et al*. 2007), this was done without the participation of local residents. Today, in some instances, people lay claims to land falling under two adjacent villages, while retaining allegiance to only one headman or chief (Kirkland *et al.* 2007). These blurring lines makes resource management difficult and it has been documented that community members take advantage of this by extending their access rights to woodland resources (Nemarundwe, 2004). For example, Lynam *et al.* (1996) found that in a rural village in Zimbabwe Africa, on average, 86% of households in their study area harvested resources from common property resources outside their own village boundaries. They concluded that resource constraints were often overcome by the "spill over" use of neighbouring villages' resources (Lynam *et al.* 1996). Twine *et al*. (2003b) also found that resource harvesting by village "outsiders" or neighbouring village residents has increased in South Africa, this has raised concerns among the village residents and traditional authorities over the declining resources due to over use. Research conducted in Zimbabwe, found that national policies around natural resource use does little to ensure the sustainable harvesting at a local level (McGregor, 1995). This has been extrapolated to South Africa, where the national policies promote sustainable resource use, yet resource use in communal areas is likely unsustainable (Shackleton and Shackleton 2000).

During this study it was observed that there were very different approaches and enforcement to resource harvesting in the case study villages. As mention previously, Vyeboom had the highest canopy cover of tall trees and high trees in comparison to all the other villages (Figure 2.10b), while Mafarana had almost no tall trees within 1.5 km of the village (Figure 2.10a). The high canopy cover evident in Vyeboom could be attributed to the fact that large fruiting trees are normally conserved by villagers as they are a major non-timber resource (Shackleton *et al.* 2003; Kirkland *et al.* 2007). In some villages, tall trees are protected in communal rangelands and special permission is needed to cut them down (Twine, 2005). Some resource collection activities are deemed illegal by the traditional authorities, such as the cutting down of live trees or the theft of wood harvested by others (Kirkland *et al*. 2007). Evidence of this was seen in Ga-Selwana, where if any villagers were seen cutting down large trees or found with / harvesting live wood they were fined R500 and their wood was confiscated by the village head-men. Despite the taboo on live wood harvesting (Kirkland *et al.* 2007), and the restrictions established by the local traditional authorities, villagers admit that they do cut down large trees such as Marulas (*Sclerocarya birrea*). They also admitted that they do harvest live wood, as they feel they have no alternative due to the price of electricity and fuelwood shortages (Kirkland *et al.* 2007). This was further mentioned during household interviews (Discussed in Chapter 3). This conclusion was based on the respondents' answers during household interviews (Chapter 3) claiming that they engaged in cutting down of live trees, or who have reported witnessing others doing so, coupled with my own observations in the field, where I found piles of live wood cuttings hidden behind shrubs and off the access roads. This live wood harvesting has also been seen in other research where Kirkland *et al*. (2007), also found that village residents in Limpopo admitted to "stealing" fuelwood and/or devising strategies to avoid being caught by the authorities (e.g., hiding harvested wood for later pickup).

In Ka-Ndengeza by contrast to Vyeboom and Ga-Selwana the sub-canopy structure of the rangeland was dominated by a very high shrub layer and diminishing low tree cover (Figure 2.10c). This could be attributed to the fact that fuelwood and fencing poles are harvested from trees predominantly under 3 m (Twine, 2005; Neke *et al.* 2006), thereby resulting in future losses in vegetation between 1 - 3 m. The high canopy cover of the shrub layer observed in Ga-Selwana is indicative of either coppicing or bush encroachment (Neke, 2005), as over harvesting can exacerbate bush encroachment as many of the harvested savanna species have strong regenerative responses (Kaschula *et al.* 2005a; Neke *et al.* 2006). The over harvesting of coppice regrowth can prevent trees from reaching sexual maturity, which in turn results in a lack of juvenile recruitment and limited regeneration ability (Fisher *et al*. 2012). The unsustainable harvesting of natural resources will lead to overall woodland degradation (Banks *et al*. 1996), which highlights the value of assessing and monitoring the impact that road access and village location can have on, resources use and vegetation structure.

2.4.2. Ecosystem response to disturbance

A crucial aspect when looking at sustainability is the concept of ecosystem renewal and response to any forms of disturbance. This is referred to as resilience (Fisher *et al.* 2006). Resilience is defined as "the capacity to absorb disturbance and reorganise while undergoing change to still retain essentially the same function, structure, identity and feedbacks" (Walker *et al.* 2004; Fisher *et al.* 2006). An example of this is that within a resilient system, the system would be able to cope with woody biomass extraction while still maintaining its functions. Savanna ecosystems are one of the most ecologically resilient systems as they are particularly vulnerable to disturbance events (Whitfield and Reed, 2012). As a complex system, savanna ecosystems are capable of reorganising after disturbances (Mograbi, 2014). Frequent disturbances in an ecosystem, whether natural (e.g. droughts, floods) or anthropogenic (e.g. overharvesting), are exacerbated by the socioeconomic status (e.g. poverty, population growth) of the communities who rely on the ecosystem (Mograbi, 2014) can all become mutually reinforcing (Barrett *et al.* 2011; Mograbi *et al*. 2015), when combined. These disturbances can result in the changes in the vegetation structure and functioning and change the state of the ecosystem (Cumming, 2011) (Figure 2.14). Under extreme circumstances, disturbance gradients decline in highly utilised areas and this is a warning of severe woodland degradation (Fisher *et al*. 2012). This was evident in the villages in Limpopo which were dominated by a dense shrub layer with very few tall trees located close to the village settlements. This indicates that the level of human disturbance, in the form of over harvesting, is much closer to the village settlements rather than further away due to the ease of access to natural resources around the villages., the visible state change of the vegetation near the village settlements is likely to be attributed to overharvesting than to natural disturbance events.

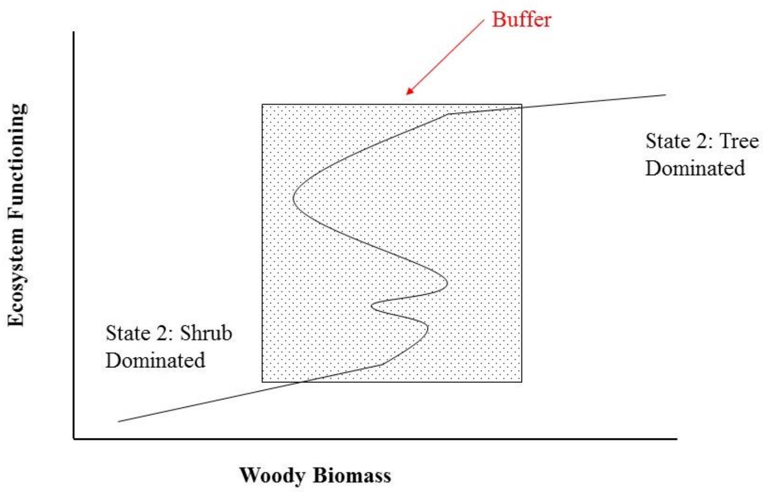


Figure 2.14. Conceptual diagram depicting the buffering capacity of a system. For a system to change state, it must exceed the loss of woody biomass and the buffering capacity (Adapted from Cumming, 2011 and Mograbi, 2014).

The impact that human utilisation has on surrounding communal woodlands is evident in the varying vertical vegetation structure of the four case study villages' communal rangelands. The long-term impact of this utilisation in these villages rangelands requires further research. The diminishing cover of low trees could be a result of a shift in resource collection strategies due to low resource supply.

When examining the fuelwood context in Limpopo and throughout Africa, the responses to fuelwood shortages have included:

- Households change the size class of stems that are collected for fuelwood (Luoga *et al.* 2000; Matsika *et al.* 2012);
- Household members may switch from their preferred fuelwood species to less preferable species (Luoga *et al.* 2000; Madubansi and Shackleton, 2007). This was verbally mentioned in the four case study villages;
- Households may increase the number of collection trips made (Dovie *et al.* 2004; Matsika *et al.* 2013);
- Households may also spend more time collecting fuelwood (Dovie *et al.* 2004; Matsika *et al.* 2013);
- Households may also travel further in the rangelands or elsewhere to collect firewood (Giannecchini *et al.* 2007);
- Households may make use of wheelbarrows and vehicles to collect more wood per trip (Twine, 2005; Madubansi and Shackleton, 2007);
- Households or communities may develop fuelwood markets (Madubansi and Shackleton, 2007; Twine *et al.* 2003); and
- Households may also collect resources from neighbouring private land (Matsika *et al.* 2012).

The continued high reliance on natural resources, especially fuelwood (Twine *et al.* 2003), highlights the need for continuous monitoring of this resource base, to assess and ensure future sustainability and provide solutions if resources use is unsustainable. As the removal of live wood, or the harvesting of different size classes can in the long run result in an ecosystem state change. A state change is more likely if large ecologically important trees are being removed and their successive plants being harvested due to shortages. Based on the vegetation trends seen in this study, as well as the household interview data, the households in Limpopo's first response to fuelwood shortages is to switch from their preferred species, many village residents also hire trucks so that they can collect more wood per trip and can also travel further.

2.4.3. Household access to natural resources

As previously mentioned, the impacts that humans have on their surrounding landscape has been well documented (Twine 2005; Giannecchini *et al.* 2007; Coetzer *et al.* 2010; Fisher *et al.* 2012; Coetzer *et al.* 2013; Coetzer *et al.* 2014; Mograbi *et al.* 2015). The most common theory regarding the patterns of this disturbance is referred to as “The Central Place Theory”, although it has its limitations (Christaller, 1993). An extension of the “Central Place Theory” is the idea of disturbance gradients, which depicts high to low human disturbance radiating outwards from a village or road and resembles a piosphere (Shackleton *et al*. 1994). The data explored in this thesis found that patterns of disturbance gradients do exist around the village settlements in Limpopo, considering that much research has been applied to disturbance gradients around villages elsewhere in South Africa (Shackleton *et al.* 1999, Shackleton and Shackleton, 2000; Shackleton *et al.* 2002; Twine, 2005; Fisher *et al.* 2011; Matsika *et al*. 2012; Mograbi *et al.* 2015), the findings in this thesis are not novel. To take the Central Place Theory a step further, the access of household to natural resources was explored. It was hypothesised that these disturbance gradients may be influenced by more than just the locality of households to a certain resource, such as gradient or vegetation cover. The cumulative cost surface maps generated for the four villages in Limpopo showed that the cost to access a natural resource was not uniform, nor did the cost to access a natural resource increase with increasing distance from the village settlement. When examined on a smaller scale the cost associated with a given pathway is easy to explain based on the landscape features and vegetation. Although the least cost pathway is a possible extension of the “Central Place Theory”, it is hard to apply to such large areas. The proxies used to generate these cost surface maps needs to be refined further and other proxies such as riparian vegetation and rivers may need to be included in the cost pathway maps. Which could then explain further the cost associated with accessing a given resource.

2.5. Conclusions

This research has highlighted the impact that human utilisation can have on woody resources and vegetation structure in communal rangelands. This has been explored in other research (Louga *et al.* 2002; Wessels *et al*. 2010; Fisher *et al*. 2012; Wessels *et al*. 2013; Mograbi *et al*. 2015). This research has also demonstrated the impact that village location and access to roads can have on resource harvesting, and the associated impacts on vegetation structure. Based on the results it can then be concluded that there are numerous pathways to a given resource depending on where in the landscape an individual is starting from and ending., there were too many trees that met the criteria (fruiting trees) which resulted in the cost maps being hard to interpret over a large scale such as a village rangeland. As the distance from the nearest roads and the distance from settlements to a given resources affects how people make complex trade-offs in their decision-making (Giannecchini *et al.* 2007).”

Resource use and the associated disturbance gradients are settlement specific and highlights the value of settlement specific studies that incorporate local information, as broad-scale studies often neglect fine-scale variation (Giannecchini *et al*. 2007). It is evident that the current resource use in these villages is unsustainable and is having a huge impact on the vegetation structure and AGWB in the surrounding communal rangelands. With the ever-increasing demand placed on these natural resources and more people collecting fuelwood with vehicles (Twine, 2005), it is expected that the disturbance gradients evident here will begin to diminish and merge around the settlements as the future vegetation structure becomes more homogeneous (Fisher *et al*. 2012; Mograbi, 2014). The intensive use of natural resources evident in this study suggest impending, if not already occurring, sustainability issues. Repeated data collection is required to assess and monitor the changes in woodland structure and biomass as well as change in patterns of rangeland use as natural resources decrease.

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CHAPTER 3: THE INFLUENCE OF THE STATE OF SURROUNDING COMMUNAL WOODLANDS ON HOUSEHOLD RESOURCES USE AND FOOD SECURITY

4.1. Introduction

4.1.1. Understanding food security

Food security continues to be one of the most fundamental challenges facing Africa (Sanchez and Leakey, 1997; Kirkland *et al.* 2011;). Africa has the highest population growth rate of any other region in the world (2.9% per year) as well as the highest rate (30%) of degradation of land (Cleaver and Schreiber, 1994). It has been recognised that to achieve food security it is essential to safe guard the natural resource base (IFPRI, 1996). Complex political, social, and economic factors as well as environmental stressors (Kirkland *et al*. 2011) impact the persistence of Africa's ecosystem.

Food security is not just about increasing food yields, but rather, only exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs (Richardson, 2010; Poppy *et al.* 2014). Food security is determined by availability, sustainable supplies, access and utilization of food (Poppy *et al.* 2014). Addressing food insecurity requires a multidisciplinary perspective (Poppy *et al*. 2014). Savanna ecosystems are managed by humans, to ensure and optimize the provisioning ecosystem services, such as food, fibre, fuelwood and other timber and non-timber products, yet these benefits are dependent upon regulating ecosystem services (Poppy *et al*. 2014).

Food security, is heavily dependent on the availability of fuelwood and water which are essential for the cleaning, cooking and preparing of food for safe consumption (Mazet *et al*. 2009). In cases where there is poor access to fuelwood, people may resort to collecting other burnable material, such as twigs gathered from hedges and fallen from trees, crop stalks or animal dung (Agarwal, 1995; Hill *et al*. 1995; Mahiri, 2003; Masekoameng *et al*. 2005). In Limpopo cooking occurs in small huts and excess smoke deters households from using crop residues and animal dung, as they produce a large amount of smoke (Mahiri, 2003; Masekoameng *et al*. 2005). If people are unable to cook or prepare sufficient food, they may shift to consuming lower quality meals or eating fewer meals per day (McMichael *et al*. 2005; World Food Programme, 2012). This has a huge impact on the health and nutrition of households, especially those that have young children and the elderly.

It is evident that natural resources and ecosystems services play a huge role in rural household's daily livelihoods. Ecosystems services are the functions of an ecosystem that generates benefits or value to humans and can be defined as the conditions and processes through which natural ecosystems sustain and fulfil human life (Daily *et al*. 1998; Daly and Farley, 2004). The ecosystem services framework in which services and goods provided by the natural and semi-natural ecosystems are explicitly linked to human well-being, has the potential to shape land management objectives, that can lead to both food security and environmental sustainability (Poppy *et al.* 2014). Ecosystem services provide a range of benefits to people through provisioning, cultural and supporting services (Millennium Ecosystem Assessment, 2005), which contribute to human welfare both directly and indirectly (Costanza *et al*. 1997).

Ecosystem services affect all three pillars of food security (availability; access and utilisation) by supporting the production of food, the provision of resources that help enhance livelihoods, and a way to earn income as well as the production of resources for safe and sanitary food utilisation (Barrett, 2010). It is important to understand the level of degradation happening in natural woodlands, the impact this has on woodland integrity, and the impact this has on household food security. Through this understanding there is the potential to ensure ecosystem sustainability and food security (Poppy *et al*. 2014)

4.1.2. The relationship between food and the environment

Examining the role that ecosystem services play in advancing food security, highlights the complex relationship between food security and environmental sustainability. In their own right, the structure, function and services of ecosystems are complex (Richardson, 2010). In conjunction with the numerous flows that exist in ecosystems, the added dimension of food security for humans within this context is not yet fully understood (Loomis *et al.* 2000; Farber *et al*. 2002; de Groot *et al*. 2002; Richardson, 2010). Despite the fact that there have been numerous studies that have reviewed and recorded the contributions of certain ecosystem services to human socioeconomic welfare and food security (Angelsen and Wunder, 2003, Vedeld *et al*. 2007, Angelsen *et al.* 2014). Pimental *et al*. (1997). Through the research of the aforementioned scientists, on forest resources, it was found that the integrity of a forest is essential to food security, as the poor rely so heavily on available natural resources. An example of the value that natural products play in rural household's food security is shown below (Table 3.1).

Table 3.1. Natural forest products and services that help support food security (Adapted from Daily *et al*. 1998; Poppey *et al*. 2010)

Forest/ Natural Products	Examples
1. Wild fruits	Wild plant roots, leaves, fruits, nuts; animal meat, fish and insects
2. Fodder	Trees, shrubs, grasses as fodder for livestock
3. Employment	Wage employment in forestry or forest based enterprises; self-employment in gathering and sale of forest products
4. Forest-related fuels	Biomass fuels for cooking and heating; such as fuelwood, charcoal, crop residues and dung
5. Soil Conversion	Trees in forests and used in agroforestry practices help control soil erosion and protect cropland, pastoral land and forest ecosystems
6. Water conservation	Forests slow water runoff, helps prevent flooding
7. Biodiversity preservation	Forests enhance food yields by protecting biodiversity that is essential to human survival, waste treatment, nutrient cycling, pollination of crops and other vegetation, pest control

Ecosystems provide many raw materials such as fodder and forage that contributes to food availability, through the sustenance of livestock for meat and dairy consumption (Richardson, 2010). Moreover, seeds, grains, herbaceous legumes, trees, grass leaves, crop residue and fishmeal are also used to supplement feed for livestock., as a stock flow resource, raw material harvest, shares similar characteristics to food production. M many raw materials can be harvested at any rate by households, used immediately or stored for the future (Daly and Farley, 2004). The harvesting of natural resources is dependent on a households' livelihood objectives and decisions. humans, largely have control over the rate of resource flows, ecosystem stock and resource depletion, which arises from the unsustainable overuse of a particular resource (Daly and Farley, 2004).

Although, the role that ecosystem services play in ensuring access to food, food availability and security is not initially evident, ecosystem function, directly and indirectly supports household level access to food in a multitude of ways. Ecosystem support households through the provision of ecosystem services that allow households to harvest resources, process food, farm agriculture and access the available raw materials that can be used or sold as additional income (Richardson, 2010). The relationship between food security outcomes and the environment is complex and multi-directional (Poppy *et al*. 2014). Food security does not depend solely on the use of ecosystem services, it is one of the main drivers of the loss of ecosystem services due to unsustainable use of the ecosystem. This relationship, is also affected by a variety of internal and external drivers of varying predictability and intensity. Households may be able to adapt to gradual changes, such as changes in climate, soil fertility or demographic changes (Sanchez *et al*. 1997). Conversely, sudden shocks, such as drought, can lead to excessive pressure being placed on the environment and can result in and cause degradation of the surrounding ecosystems (Hunter *et al.* 2007). The death or illness of a family member or breadwinner also can contribute to the degradation of the surrounding ecosystem, in order to survive, the affected household may become more dependent on natural resources. The pursuit of food security through the increased utilisation of natural resources can lead to changes in land-use and land-cover, regardless of land management practices (Poppy *et al.* 2014).

Food availability, for many poor people depends on the ability to benefit from non-agricultural ecosystem services (Figure 3.1) (Poppy *et al*. 2014). This dependence is evident in many ways; firstly, through the regular and direct consumption of wild foods. For example, research has shown that wild food makes up one-fifth of children's diet who live in rural parts of South Africa (Poppy *et al.* 2014; Marshall *et al*. 2006). Wild foods also act as a safety net for farmers when crops fail, or food stock are depleted (Shackleton and Shackleton, 2004), Secondly, food availability is also dependent on access to crops, specifically, water for crop irrigation, and timber, for fencing to prevent theft or consumption of crops by roaming animals.

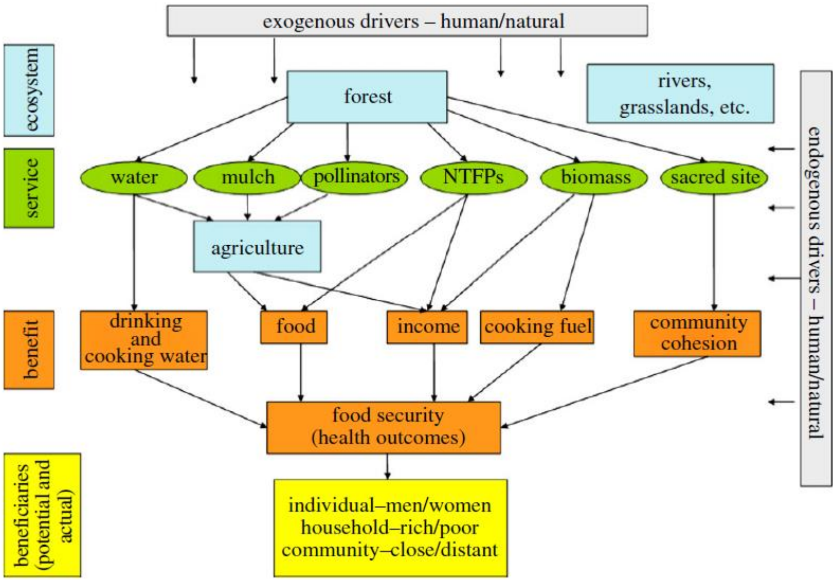

Figure 3.1. Diagrammatic representation of the direct and indirect ways in which ecosystem services and the associated benefits contribute to human food and nutritional outcomes (Poppy *et al.* 2014).

Many rural households harvest and use timber and non-timber products for numerous purposes that help enhance their livelihood strategies and increase their access to food, which in turn affects their food security (Pimentel *et al.* 1997, Pattanayak *et al.* 2004). Due to the seasonal nature of agricultural practices, the production and sale of charcoal, wood, food and other non-timber products help sustain many rural households during the off season (winter) (Osemeobo and Njovu, 2004)., the use and sale of natural products allows rural households to purchase basic household necessities. Wealthier households are also less dependent on natural resources than asset-poor households, due to the presence of personal savings or safety nets to support them during economic or environmental shocks (Shackleton and Shackleton, 2006).

Household level purchasing power is essential to access to food, and the benefits of ecosystem resources and ecosystem flows can provide numerous opportunities to enhance household livelihoods and increase income and ensure their food security. the excessive and arbitrary harvesting of these natural resources threatens the sustainability and the integrity of these natural resources which underpins the very livelihood opportunities that can improve access to food. The overuse of resources jeopardizes the ability of a household to ensure their food security in the future.

The removal of wood in rural areas is greatest in Africa and Asia, where food security and access to food is most vulnerable. Open access natural resources and the removal of fuelwood, is a result of unenforceable property rights (Daly and Farley, 2004), in the long term this can lead to the overall degradation of the woodlands and rural fuelwood demands and food security not being met. It is widely accepted that an analysis of rural livelihoods cannot be complete, without the inclusion of a natural resource component (Campbell *et al*. 2002; Shackleton *et al.* 2007). Unfortunately, the amount of literature on this issue in Southern Africa and South Africa, is particularly low, as most of the research is based in tropical ecosystems (Twine *et al*. 2003a; Shackleton *et al*. 2007). Understanding how rural households depend on and the state of their natural resources can assist in determining how food secure these households are in the face of climate change. It will also provide insight into their resilience to stress and external shocks. The value of this study, is that its intention is to highlight the link between the state of surrounding communal woodlands and the impact that this has on household level food security in rural Limpopo.

4.2. Methods

4.2.1. Study Site

For information of the biophysical characteristics and livelihoods of the people in the study villages see Chapter 1, Section 1.4 of this dissertation.

4.2.2. Resource use data

Household interviews were conducted in the four case study villages of Vyeboom, Mafarana, Ga-Selwana and Ka-Ndengeza, Limpopo, South Arica, to investigate the link between the state of communal woodlands and their impact on the surrounding villages' food security. Prior to data collection, permission to conduct the study was requested from the tribal authorities in the four villages and was granted. Ethical clearance from the Human Research Ethics Committee (HREC Non-Medical) was applied for, and subsequently granted (Protocol Number H/14/07/02). Data collection was carried out in February 2015, on a per household's basis, using a structured household's questionnaire (Appendix 1). The participating households were randomly selected during the data collection. The person responsible for daily household tasks such as income expenditure, resource collection and energy consumption were preferably interviewed as the focus of this research was on perceptions of natural resource availability and resource use. This person is often the senior female in the family, the wife of the household head. Verbal consent was obtained from all participants. If household members were not at home or declined to participate, they were replaced by another randomly selected household.

In the case that the senior female was not available or present, the person responsible for the household task was interviewed, regardless of gender. The household interviews were conducted with the aid of local translators from each village. In total 124 households were interviewed across all four villages;32 in Mafarana and Ga-Selwana, 29 in Vyeboom and 31 in Ka-Ka-Ndengeza.

Prior to conducting any interviews, the purposes of this research were explained to the willing participants. The interviewer also explicitly explained that participation in the survey was voluntary, that there were no personal gains for the participant for their involvement in the survey. That personal information would remain confidential, and that the interview may be discontinued at any time All interviews were documented in writing and recorded with a voice recorder. The GPS location of the interview site was logged. In accordance with human ethics, the verbal consent form (Appendix 2), the front page of the questionnaire (Appendix 1), bearing the GPS co-ordinates of the homestead location and the participant's name were kept separately from the participant's answers and the two sets of information were not connected in any way. The survey consisted of 28 questions, divided into five categories (Appendix 1). The first two sections focused on collecting information regarding the household characteristics, income and expenditure. The following section, focused on the use of the suite of local natural resources. The survey also focused on descriptions of the source of the fuelwood used within the household; how the fuelwood was obtained, specifically if the wood was purchased or collected; species preference; as well as perceived declines or increases in fuelwood availability. The survey also explored food security, nutrition, food shortages and the diet of interviewed participants' households.

Data from the household surveys, was captured in Microsoft Excel and then analysed using STATISTICA 13.1. For questions with discrete variable responses, the responses were coded, and a frequency analysis was carried out on each response (Appendix 3). The normality of continuous variables was assessed, and summary statistics were calculated for all numeric variables.

4.2.2.1. *Resource prevalence and quantities*

The 'Resource Use' section of the survey, specifically looked at a list of seven resources commonly used by households, they were firewood, wood to make charcoal, mushroom/ wild vegetables, wild fruits, honey, medicinal plants and other, which was defined as any other unspecified resources used). The details on the resource use focused on three areas, the frequency of use (when in season), how many months in the previous 12 months each resource was used and then the quantity consumed per month. The data collected for resources consumption was expressed in local units such as a ‘donkey cart’, ‘bakkie-load’, ‘bundle’, ‘wheelbarrow’ or ‘cups’. These were then converted to convention units of measurements (Table 3.2).

Table 3.2. Households consumption units and their respective volume metric

Unit description	**Volume of unit**	**Reference**
Mug	0.4l	(Twine *et al*. 2003a)
1l bucket / plastic packet	1l	Inherent to container
5l bucket	5l	Inherent to container
10l bucket	10l	Inherent to container
20l bucket	20l	Inherent to container
Bundle / headload	14.5 kg of firewood	(Matsika *et al.* 2013)
50kg maize meal bag	50 kg	Inherent to container
80kg maize meal bag	80 kg	Inherent to container
Wheelbarrow	39.6 kg of firewood	(Matsika *et al.* 2013)
Bakkie-load / donkey cart	532 kg of firewood	(Matsika *et al.* 2013)
Individual	0.2kg	Weighed an individual mango fruit

The household resource use checklist of the seven resources was recorded in a binary format, which was employed to calculate the percentage of households in each village using each of the selected resources. A Pearson Chi-Squared test was then applied on the raw data to compare the use of each resource across the four villages. this was done using “Yes” or “No” coded responses from household interview checklist. The data was combined to see the number of resources used across all four villages. The data was tested to see if it was normally distributed using a Kolmogorov-Smirnov test. Since the data was normally distributed, a one-way ANOVA was carried out to test the mean number of resources used per village.

To analyse household resource consumption in each of the villages, each resource consumed was averaged per household and then per village. The analysis excluded medicinal plants, despite having collected this data, as the results revealed that only a small sample of households recorded using this resource, as well as the broad nature of medicinal plant products used (e.g.: leaves, roots, tubers etc.). Annual household consumption of the other resources was calculated as follows:

- Firewood - An increase in utilisation of 35% during winter months which was determined to be (91 days. It was assumed, based on findings by other studies (Twine *et al.* 2003), that the wood was used for heating. Since the data in this dissertation was collected in summer, the firewood collected per month was divided by the number of days in a month to calculated amount used per day then multiplied by 274 days to account for summer. The Amount used per day was then multiplied by 35% to account for firewood used in winter and then was applied to 91 winter days. For households that did not use firewood during summer months, a 1:3 ratio (Twine *et al*. 2003) was applied for annual consumption as firewood has been recorded to be three times higher in winter months than during summer months.
- Wood used to make charcoal - Charcoal use was calculated in the litres used per month. To calculate the annual amount used the amount used was multiplied by the number of months used to get l/p.a.
- Wild vegetables and fruit – The monthly volume consumed, was multiplied by the number of months the respondent reported using this resource. Volume was converted to mass on the assumption that 1l is equivalent to 625 g, and then converted into kg/p.a. An individual fruit or vegetable was assumed to weigh approximately 200 g (Twine *et al*. 2003).
- Honey – monthly volume consumed was multiplied by the number of months this was used to get l/p.a.

Once the household consumption had been calculated for each of the above-mentioned resources, the figures were averaged across all households per village. The data was tested to see if they were normally distributed using a Kolmogorov-Smirnov test. If the data was normally distributed, such as firewood consumption per annum, then a one-way Analysis of Variance and a Tukey post-hoc tests were used to investigate the statistically significant differences between village means for firewood. If the data was not normally distributed, then transformations of the data was attempted to get normally distributed data, in the case of wild vegetables a Log_{10} transformation gave normally distributed data. Then once again a one-way Analysis of Variance and a Tukey post-hoc tests were used to test for significant differences between village means. Where transformations of the data failed to produce normally distributed data, such as for wild fruit, honey and charcoal then a Kruskal-Wallace non-parametric test and multiple comparisons test was applied to investigate the statistically significant differences between village means for each resource.

4.2.2.2. Household perception of resource availability

Respondents were asked what their perception of fuelwood, wild vegetables and fruit availability was over the past five years. Considering that the respondents were predominately women, or the person in charge of resource collection, this was taken as a proxy for that household's perception and is hereafter referred to as perception. The responses on perception of resource availability fell into four options:

- Increase in resource availability over the past five years;
- Decrease in resource availability over the past five years;
- No change in the availability of the resource over the past five years
- Don't know if there has been a change in the availability of resource over the past five years.

Once the household perception data was captured for each resource, the figures were averaged across all households per village to get the percentage of households' perception per village. A Pearson Chi-squared test was then run on the perception of availability for each resource per village. The data was then analysed to determine the relationship between resource use and households resource consumption. A one-way Analysis of Variance and a Tukey post-hoc test was used to test if there was a statistically significant difference between the perception of firewood and wild vegetable availability and the average amount of these resources consumed per annum. A Kruskal-Wallace test and a multiple comparisons test was run to identify if there was a statistically significant difference between the perception of wild fruit availability and the average amount of wild fruit consumed per annum.

4.2.2.3. Food security

To analyse food security in each village, four proxies were used to get an overall composite food security rating. These included the experience of hunger, food shortages, dietary diversity and coping strategies during time of food shortages (Kirkland *et al.* 2011).

The experience of Hunger in the last month was based on the sum of a households' response to three questions relating to

- How often was there no food at all in a household because there was not enough money to buy food,

- How often was any member of the household hungry when they went to sleep at night because there was not enough food
- How often did any member of the household go a whole day without eating anything because there was not enough food.

The responses to the experience of hunger in the last 30 days, fell into four options:

- Never;
- Rarely (1-2 times);
- Sometimes (3-10 times); and
- Often (more than ten times).

These responses were coded, with ‘Never’, being given a code of Zero and Often’, a code of Three. The sum of the food security questions was then divided by the highest possible score a household could receive, which was 9, to get an overall score of between 0 and 1. This score was then used to categorise a household’s experience of hunger in the last 30 days. From this the percentage of households’ experience of hunger category was calculated per village. A Pearson Chi-squared test was then applied to investigate if there was a statistically significant difference between the experience of hunger across each village.

The experience of Food Shortages was based on a simple “Yes” or “No” answer, in which participants were asked if the household had experienced food shortages in the last year. The answers were coded to get binary data where a response of “Yes”, was coded for as 1 and a response of “No”, was coded for as 0. From this, the sum of household’s responses was calculated for each village. T then the proportion of households that experienced food shortages and those that did not experience food shortages was calculated for each village. A Pearson Chi-squared test was then performed to assess if there was a statistically significant difference of the experience of food shortages across each village.

The coping strategies of a household over the past week were calculated from the sum of four questions relating to whether the household had

- reduced the size of servings of food to household members because of a shortage of food,
- eaten food that they don’t enjoy because of a shortage of food,
- reduced the number of meals eaten per day because of a shortage of food

- asked neighbours, friends or other households for food because of a shortage of food.

Again, the answers for each question were coded to get binary data where a response of “Yes,” was coded for as 1 and a response of “No”, was coded as 0. The sum of these four questions was then divided by the highest possible score a household could receive, which was 4, to get an overall score of between 0 and 1. This score was then used to categorise a household’s coping strategies in the last week during food shortages. From this, the percentage of households’ applying coping strategies was calculated per village. A Pearson Chi-squared test was then applied to investigate if there was a statistically significant difference between the experience of hunger across each village.

Dietary Diversity was calculated based on a checklist of food consumed by any members of the household in the last 24 hours prior to the interview. The food consumed was categorised into 13 food groups, including: Maize or maize products, other cereals, roots and tubers, Vitamin A-rich fruit, other fruit, Vitamin A-rich vegetables, other vegetables, reincluding poultry and fish, eggs, legumes including (nuts and seeds), dairy products, oils and fats as well as sugars. The answers for each food group were coded to get binary data where a response of “Yes”, was coded for as 1 and a response of “No”, was coded for as 0. The sum of these three questions was then divided by the highest possible score a household could receive, which was 13, to get an overall score of between 0 and 1. This score was then used to categorise a households’ dietary diversity in the 24 hours. From this the percentage of households in each category was calculated per village. A Pearson Chi-squared test was then applied to investigate if there was a statistically significant difference between the dietary diversity of households across each village.

Using all four proxies of food security ratings an overall composite food security score was calculated for each household. The scores for each household between 0-1 for the experience of Hunger, experience of Food Shortages, Coping Strategies and the inverse score of a Dietary Diversity were summed and then divided by 4 to get a final composite food security score of between 0 and 1. The data was then categorised into households who were highly food secure, food secure, moderately food secure, food insecure and highly food insecure., the percentage of households which fell into each food security category was calculated per village. The data was then tested to see if it was normally distributed using a Kolmogorov-Smirnov test. Since the data was normally distributed a one-way Analysis of Variance and a Tukey post-hoc test was applied to investigate if there is a statistically significant difference of the mean composite food security scores across each village.

4.2.2.4. *Relationship between food security and resource use*

The relationship between household's food security and resource use was assessed based on the five measures of the experience of food security as mentioned above, hunger, food shortages, coping strategies, dietary diversity as well as composite food security rating and the amount of natural resources used. Four explanatory variables were used to assess resource used, these included, the amount of firewood, wild vegetables and fruit consumption per annum as well as the number of resources used. A multivariate linear regression analyses using Ordinary Least Squares was used to model the link between the experience of hunger and the influence this had on the Four Explanatory variables. A Logistic regression analysis was used to model the link between the experience of food shortages and firewood, wild vegetables and fruit consumption per annum as well as the number of resources used, using village as a random effect in the mixed effect models. A multivariate linear regression analysis was also used to model the relationship between dietary diversity, coping strategies as well as the overall composite food security rating and the four explanatory variables. any relationship found between food security variables and any explanatory variables this was then graphed to visually represent the link.

4.2.2.5. *Relationship between resource use, state of communal woodlands and food security*

The relationship between household's food security and resource use was assessed based on the five mentioned measures of food security, hunger, food shortages, coping strategies and dietary diversity. The relationship between the composite food security rating and the average rangeland biomass and the average canopy cover of the four sub-canopy characteristics for each village, was also assessed. This relationship was explored in STASTICA 13, through regression analyses.

4.3. Results

4.3.1. Natural Resource Use

The proportion of households that utilised the suite of natural resources available to them, varied across the four case study villages. Almost all of the households across all four villages used firewood, wild fruit and wild vegetables (Figure 3.2). Firewood was used by 97% of households in Ga-Selwana, Mafarana and Ka-Ndengeza, while it was used by all households interviewed in Vyeboom see Figure 3.2). The prevalence of the use of firewood did not differ significantly between villages (χ^2=0.9393, df=3, p=0.816).

Of households interviewed, wild fruit was used by between 90% in Vyeboom) and 97% in (Mafarana and Ka-Ndengeza, the difference between villages was not significant (χ^2=1.9467, df=3, p=0.583).,

The prevalence of the use of wild vegetables was more variable, ranging from 62% in Ga-Selwana to 92% in Mafarana, although the difference between villages was not significant at the 95% confidence level (χ^2=6.8707, df=3, p=0.076).

All four villages had very low percentages of households that used charcoal, honey or medicinal plants and there was no significant difference between the use of these resources across villages.

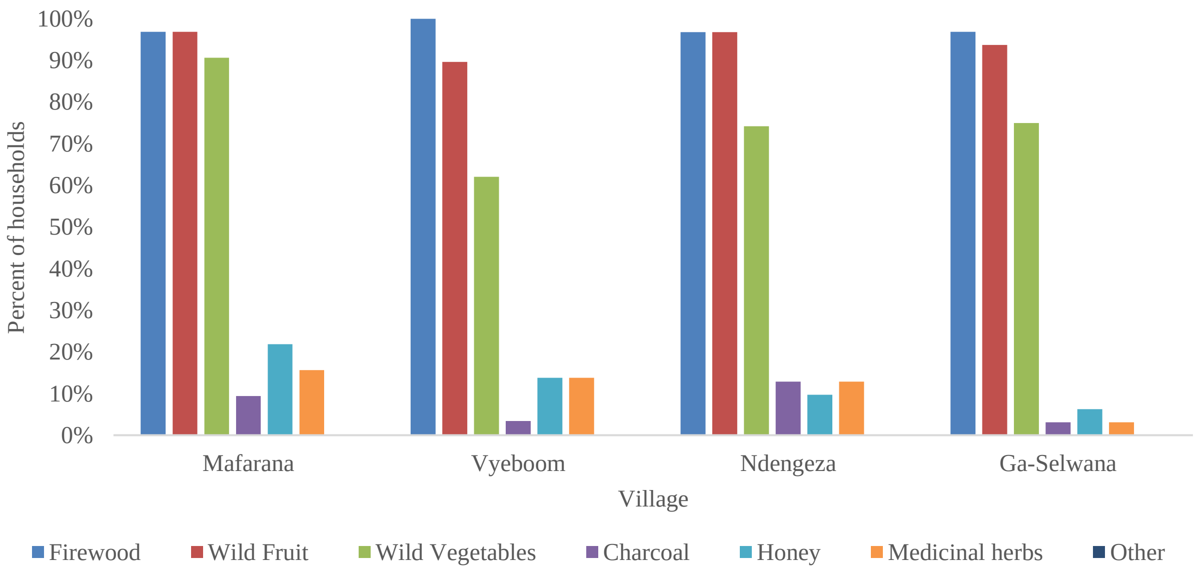

Figure 3.2. The percentage of households per study village that use the seven natural resources available (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa.

Most households interviewed, used between two to four resources available to them (Figure 3.3). Mafarana had the highest percentage being31% of households using four resources. In comparison Vyeboom, Ka-Ndengeza and Ga-Selwana only had 7%, 12% and 9% respectively. The only two villages that had households using five resources were Mafarana which was 6% and Ka-Ndengeza, which was 10%. No villages used six resources, while

Vyeboom was the only village that had 4% of the interviewed households using all seven resources., although there appeared be a variety of resource used across the four villages, an ANOVA showed no significant difference in the mean number of resources used between villages ($F_{(3;120)}$=2.416, p=0.69).

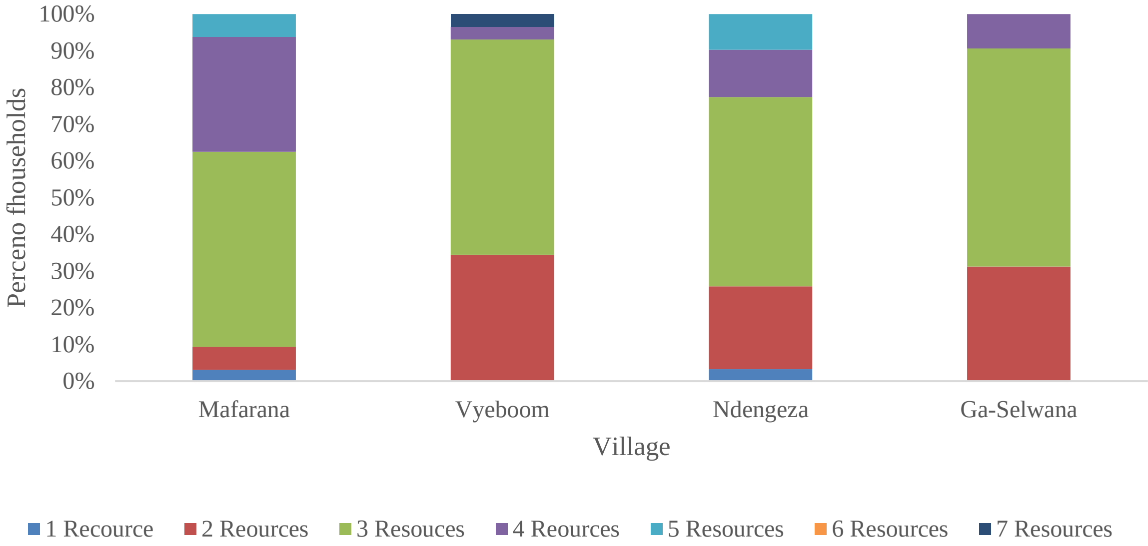

Figure 3.3. The proportion of households across four villages that use the seven available natural resources (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa.

4.3.2. Annual Resource Consumption

The average amount of firewood used per households in Ga-Selwana, 4946 kg/annum), was almost double the amount used in Ka-Ndengeza, 2086 kg/annum, this difference is statically significant ($F_{(3,120)}$=5.418, $p<0.001$) (Figure 3.4a). Firewood consumption in Mafarana and Vyeboom was intermediate between these two extremes, and very similar, roughly 3700 kg/annum, and therefore did not differ significantly from the other villages ($F_{(3,120)}$=2.161 $p>0.05$) (Figure 3.4a).

The average amount of charcoal used per households in Ka-Ndengeza was 2071 l/annum, which was very high in comparison to the other villages where the amount of charcoal used ranged from 4 l/annum to 181 l/annum refer to Figure 3.4b)., there was no statistically significant difference between the villages in charcoal use ($F_{(3,120)}$=0.937; $p>0.05$).

Households interviewed in Mafarana consumed the greatest quantity of wild vegetables (82.5 kg/annum) and wild fruit (113 kg/annum) which was significantly higher than the average amount of wild vegetables and fruit used in Vyeboom and Ka-Ndengeza ($F_{(3,120)}=4.319$; $p<0.05$) (Figure 3.4c and Figure 3.4d). Although Mafarana had a large amount of wild vegetables and fruit used per households, there was no significant difference between Mafarana and Ga-Selwana refer to Figure 3.4c and Figure 3.4d). There was also no significant difference between the average amount of wild vegetables and fruit used in Vyeboom, Ka-Ndengeza and Ga-Selwana ($F_{(3,120)}=5.381$, $p>0.05$) (Figure 3.4c and Figure 3.4d .

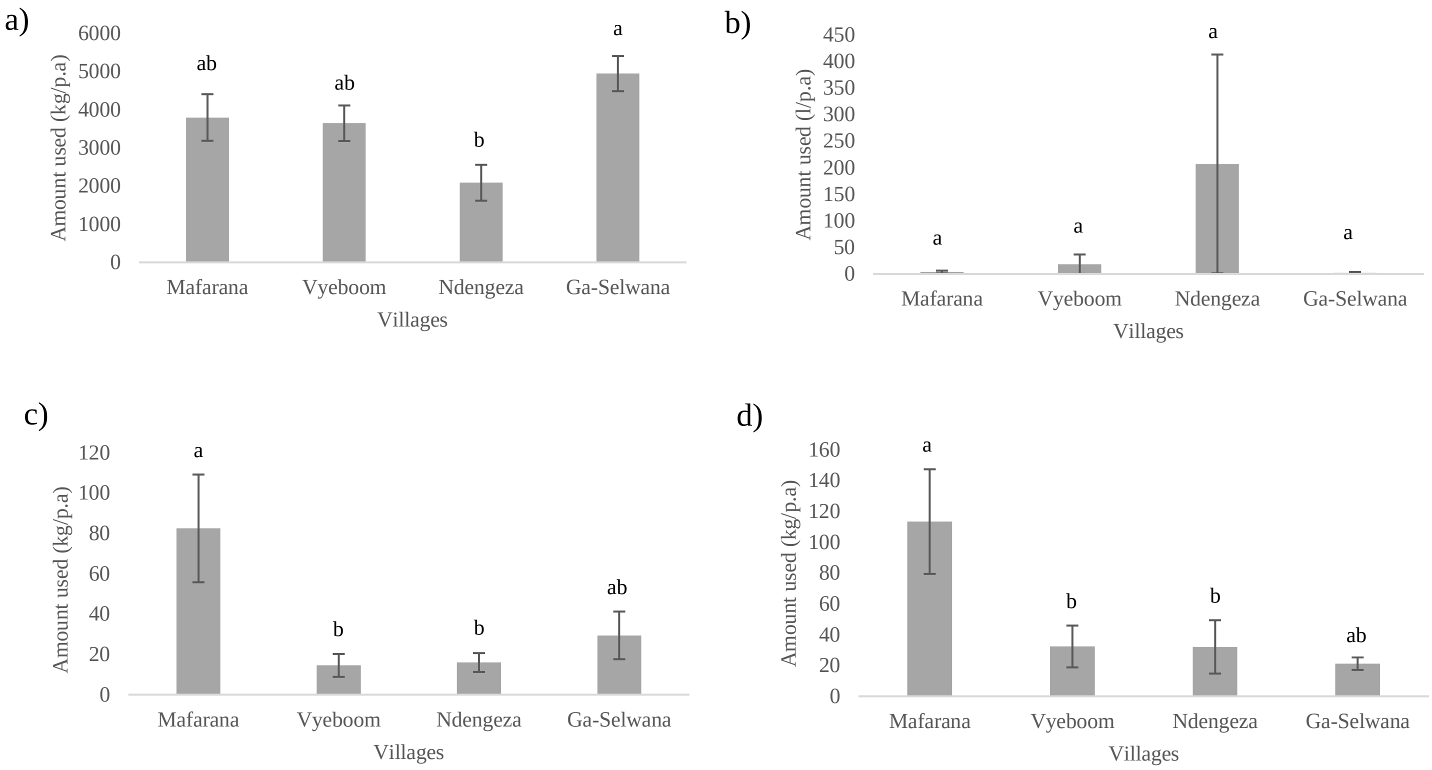

Figure 3.4 Average amount of a) firewood, b) charcoal, c) wild vegetables and d) fruit used per household annually across all four villages. (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa. Error bars represent Standard Deviation.

4.3.3. Perceptions of resource availability

The perceptions of the change in the availability of firewood, fruit and wild vegetables over the past five years between the four villages was diverse and statically significantly different ($\chi^2=19.4854$, df=9, $p<0.05$) this is illustrated in Figure 2.5a).

Most households interviewed perceived a decrease in the amount of firewood available of the past five years. Vyeboom a79% t and Ga-Selwana at 87.5%, had the highest percentage of respondents that perceived this decrease, this is depicted in Figure 4.5a. Whereas only around half, (50%), of the respondents from Mafarana and Ka-Ndengeza perceived there to be a decrease in the availability of firewood over the past five years also seen in Figure 4.5a). Ga-Selwana was the only village where no respondents perceive there to be an increase in the availability of firewood. Conversely, 16% of respondents from both Mafarana and Ka-Ndengeza and 14% of respondents of Vyeboom perceived there to be an Increase in the availability of firewood. Mafarana had the highest proportion of respondents at 28%who perceived there to be no change in the availability of firewood in comparison to Vyeboom 7%, and Ka-Ndengeza, 19%, see Figure 4.5a).

The perceptions of changes in the availability of wild fruit and vegetables over the past five years was similar across all villages, and there was no significant difference between the perceptions of the availability of wild fruit (χ^2=13.9425, df=9, p=0.12) and vegetables (χ^2=10.0932, df=9, p=0.34) between villages refer to (Figure 2.5b and Figure 2.5c). The most common perception, was that there has been a decrease in the availability of wild fruit of between 44-56%)and vegetables 41%-59%, over the past five years, seen (Figure 4.5b and Figure 4.5c). Mafarana and Ga-Selwana had the highest proportion of respondents who perceived there to be no change in the availability of fruit, 34% and 37.5% respectively, as well as wild vegetables, 31% and 34% respectively. Vyeboom had the highest number of respondents (17%) who perceived there to be an Increase in the availability of fruit in comparison to Mafarana and Ka-Ndengeza (Figure 4.5b and Figure 4.5c). Conversely, Mafarana had the highest proportion of respondents (16%) who perceived there to be an increase in the availability of wild vegetables in comparison to Vyeboom (10%) and Ka-Ndengeza (13%) (Figure 4.5b and Figure 4.5c).

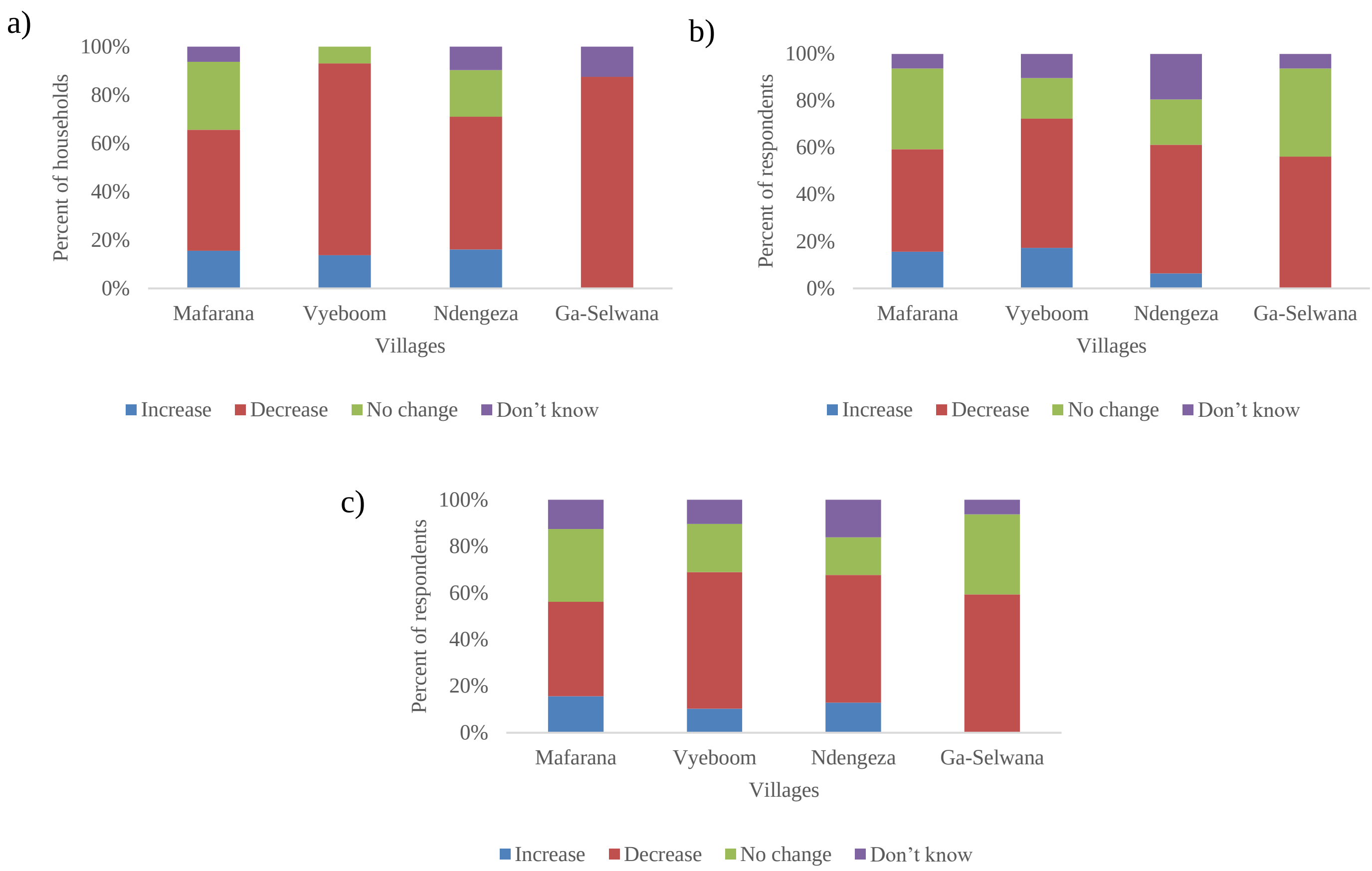

Figure 2.5 The percentage of households that perceived there to be a change in the availability of a) firewood, b) fruit and c) wild vegetables between 2010-2015. (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa

4.3.4. Household perception of the impact of resource availability on resource consumption

The perception of the availability of firewood over the past five years shows that there was an impact on the average amount of firewood used per annum per household. The households of respondents who perceived no change in the firewood availability, used significantly more firewood ($p<0.05$), than those who perceived an Increase in the availability, and with those who perceived a decrease being intermediate (Figure 3.6a). Household use of firewood was very low among respondents, who did not know how the availability had changed. There was no significant relationship between mean amount of firewood used and perception of change in availability ($\chi^2=4.9941$, df=3, p=0.17) (Figure 3.6b).

The perception of the availability of wild vegetables did have a significant impact on the amount used per household ($F_{(3;120)}=2.206$, $p<0.05$) (Figure 3.6c). There was no significant difference between the amount of wild vegetables used between the respondent who perceived there to be no change in availability (p=0.209) and those who did not know how the availability had changed (p=0.085) (Figure 3.6c). There was a significant difference between the respondents who perceived an increase in the availability of wild vegetables in comparison to those who perceived there to be no change or who didn't know how the availability had changed ($p<0.05$) (Figure 3.6c). There was no significant difference between the amount of wild vegetables used and respondents who perceived the availability of wild vegetables to have Decreased (p=0.085) (Figure 3.6c).

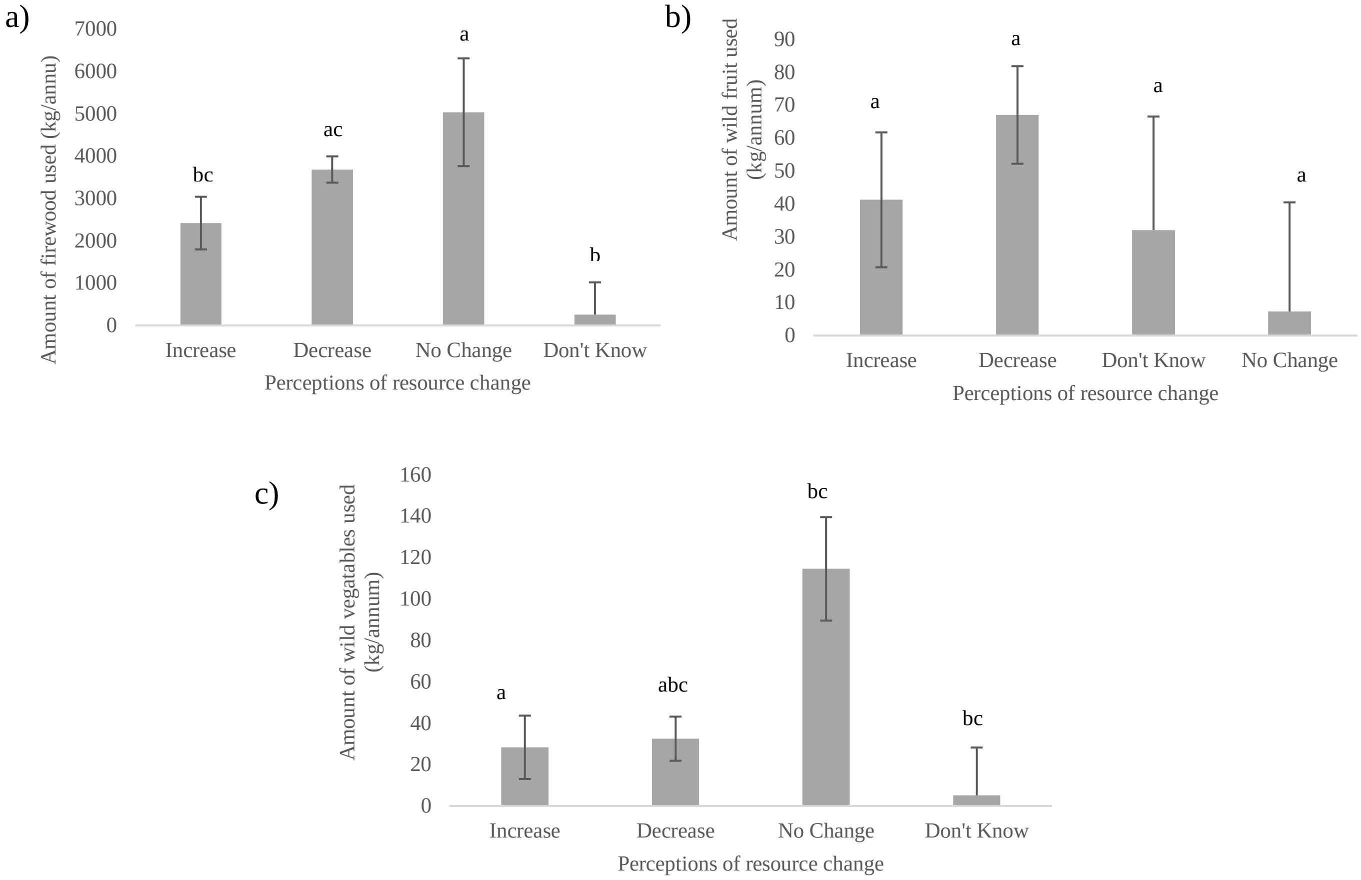

Figure 3.6. The impact of household perceptions of resource availability over the past five years on the average household resource consumption averaged across all four villages. a) the perception of firewood availability in comparison to average amount of firewood use per household per annum, b) the perception of fruit availability in comparison to average amount of fruit use per household per annum and c) the perception of wild vegetables availability in comparison to average amount of wild vegetables used per household per annum.

4.3.5. Experience of hunger

There was a significant difference between household level experience of hunger across the four villages (χ^2=24.766, df=3, $p<0.05$) (Figure 3.7). In all four villages, most of the respondents Rarely or Never experienced hunger in the last 30 days prior to the interviews. Despite this Mafarana had the highest percentage of this experience at 72%, while households 'in Vyeboom and Ga-Selwana had only 62% (Figure 4.9). Interestingly Ka-Ndengeza had the lowest percentage of households that had rarely to -never experienced hunger (at 48%), but had the highest proportion of households that rarely experienced hunger ,23%, and who experienced hunger all the time ,13% (Figure 3.7). Ga-Selwana was the only village where no households experienced hunger all the time. At 16%, Ga-Selwana and Ka-Ndengeza had the same proportion of households that sometimes-experienced food shortages, in comparison to Mafarana and Vyeboom (Figure 3.7).

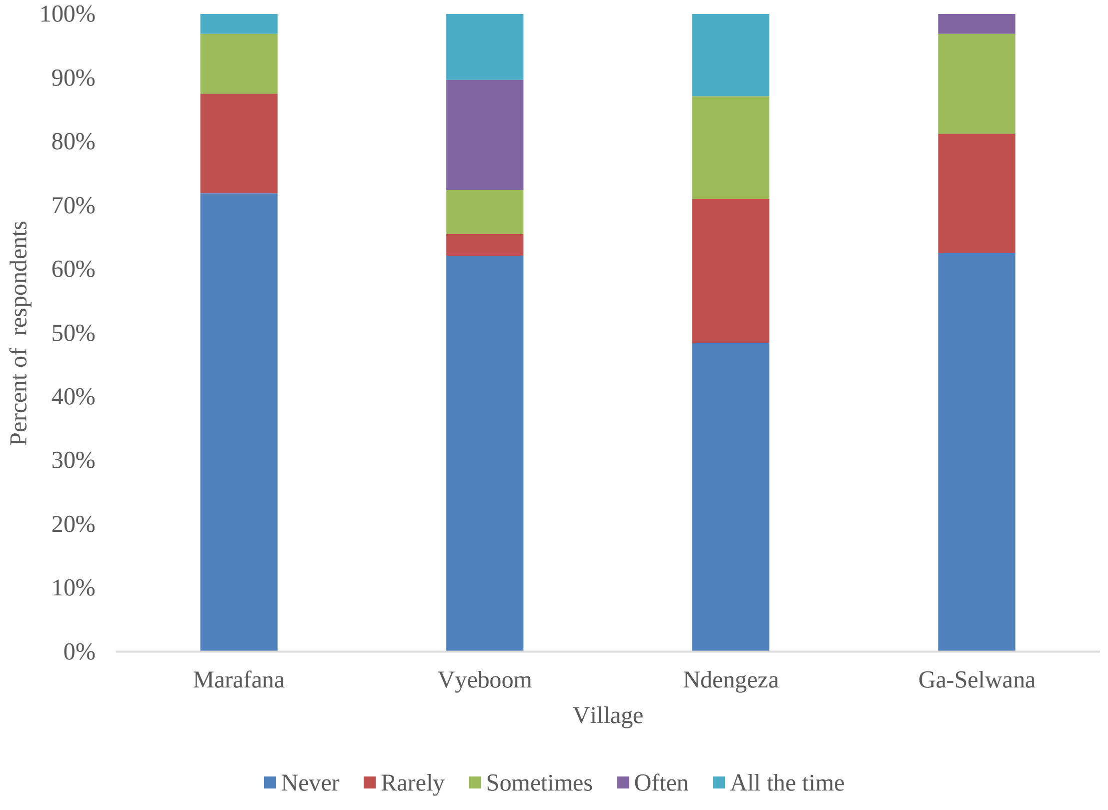

Figure 3.7. The proportion of respondents across all four villages who experienced hunger in the last 30 days (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa.

4.3.6. Experience of food shortages

The experience of food shortages over the past 12 months varied significantly across the four villages (χ^2=12.2894, df=3, p<0.001) (Figure 3.8) Mafarana, 66% and Vyboom 55%, had the highest proportion of households that did not experience any food shortages in the last year, while Ka-Ndengeza and Ga-Selwana had the highest proportion of households that did experience such food shortages at 61% and 72% respectively (Figure 3.8).

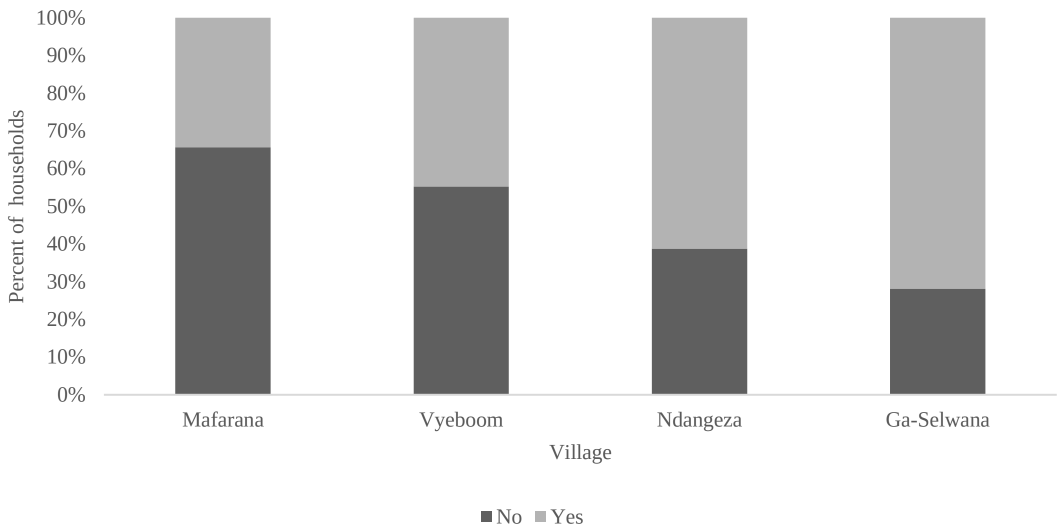

Figure 1. Proportion of households that experienced food shortages in the last 12 months (February 2014-Febuary 2015) across the four villages (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa.

4.3.7. Coping strategies during times of food shortage

Of all the households interviewed, Mafarana had the highest porportion of households 54%, that did not implement any coping strategies in the last week (Figure 3.9). Conversly, Ga-Selwana had the lowest percentage of the interviewed households, 9% that did not implement any coping strategies during times of food shortages. Yet Ga-Selwana also had 34% of housholds in that did implement 3 types of coping strategies during times of food shortages (Figure 3.9). Vyeboom had the largest proportion of households that implement 2 coping strategies over the last week, which was 31% of households, in comparison to the other villages (Figure 3.9). Overall, there was no significant difference between the implementation of coping strategies in the last week across the four villages (χ^2=19.5292; df=12; p=0.076).

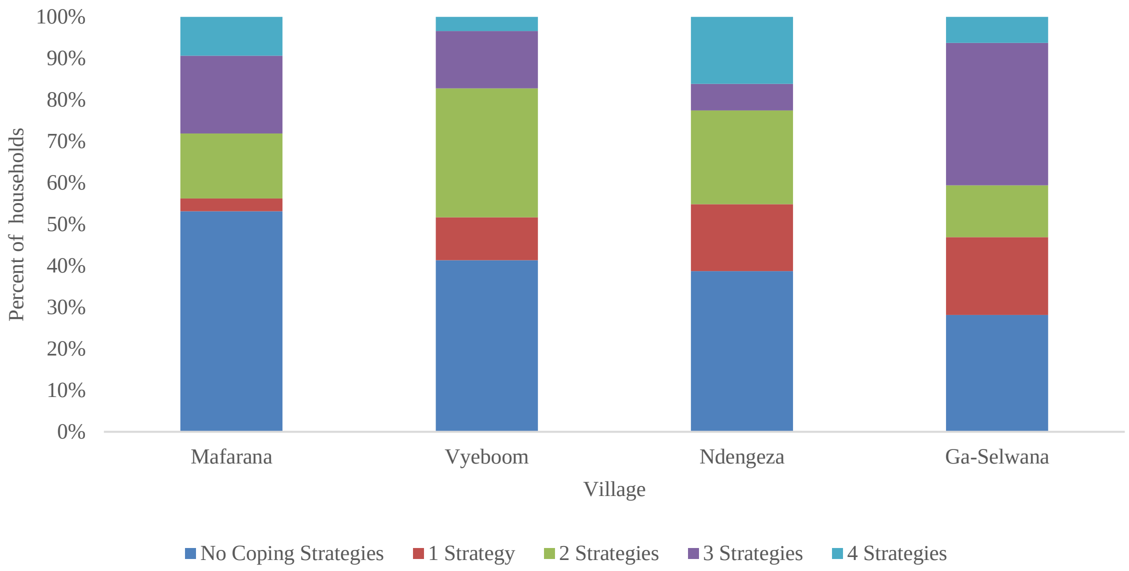

Figure 3.9. The proportion of households that implemented the five possible coping strategies during times of food shortages over the last seven days (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa.

4.3.8. Dietary Diversity

The dietary diversity of households varied significantly across the four villages (χ^2=34.3982, df=12, p=0.005; p<0.05) depicted in (Figure 2). Mafarana had the highest proportion of households with a low dietary diversity at 25%) as well as a weak dietary diversity at 56%) depicted in (Figure 3.10). Ka-Ndengeza and Ga-Selwana had a similar number of households with a weak dietary diversity, roughly 33%. 31% of households in Vyeboom and Ga-Selwana had a strong dietary diversity, which was also similar to households in Ka-Ndengeza, 29%, (Figure 3.12). Ka-Ndengeza had the highest proportion of households with a high dietary diversity of 13% in comparison to Mafarana at 6%, while no households in Ga-Selwana or Vyeboom had a high dietary diversity.

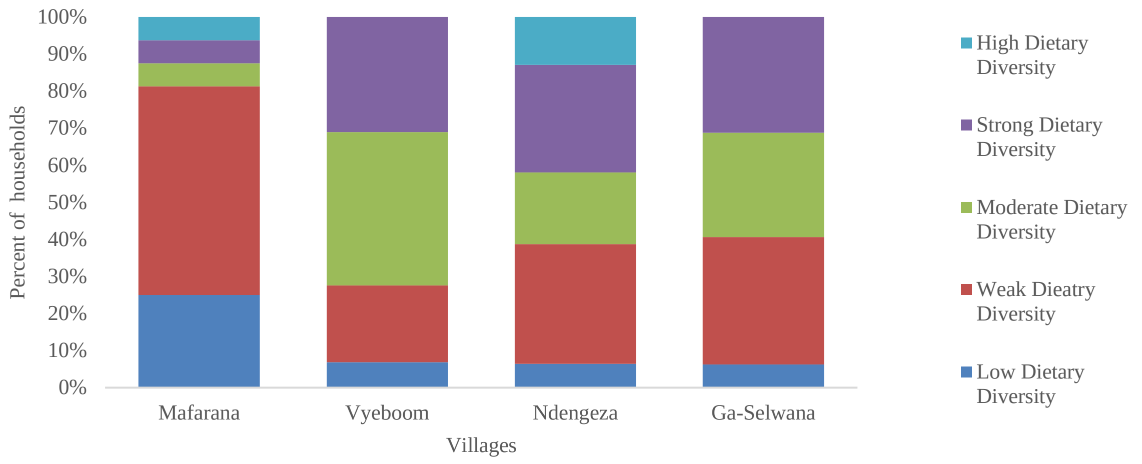

Figure 2. The percentage of households with varying dietary diversity across the four villages (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32).

4.3.9. Overall food insecurity

The food security of households across all four villages varied. Ga-Selwana at 34% and Ka-Ndengeza at 16%, had the highest proportion of households that were highly food Insecure). W while only 3% of households in Mafarana and 7% of households in Vyeboom were classified as highly food insecure, seen in (Figure 3.11). Although half of the households in Mafarana were classified as highly food secure, only 13% of households in Ga-Selwana were classified as highly food secure (Figure 3.11). Overall, there is a significant difference between the proportion of households' composite food insecurity scores across villages ($F_{(3;120)}$=18.3390; $p<0.05$) (Figure 3.12). There was no significant difference in the composite food insecurity scores between Mafarana and Vyeboom (p=0.31) (Figure 3.12). There was also no significant difference in the composite food insecurity score between Vyeboom and Ka-Ndengeza (p=0.08) as well as Vyeboom and Ga-Selwana (p=0.69) (Figure 3.12). There is also no significant difference in the composite food insecurity scores between Ka-Ndengeza and Ga-Selwana (p=0.99) (Figure 3.12).

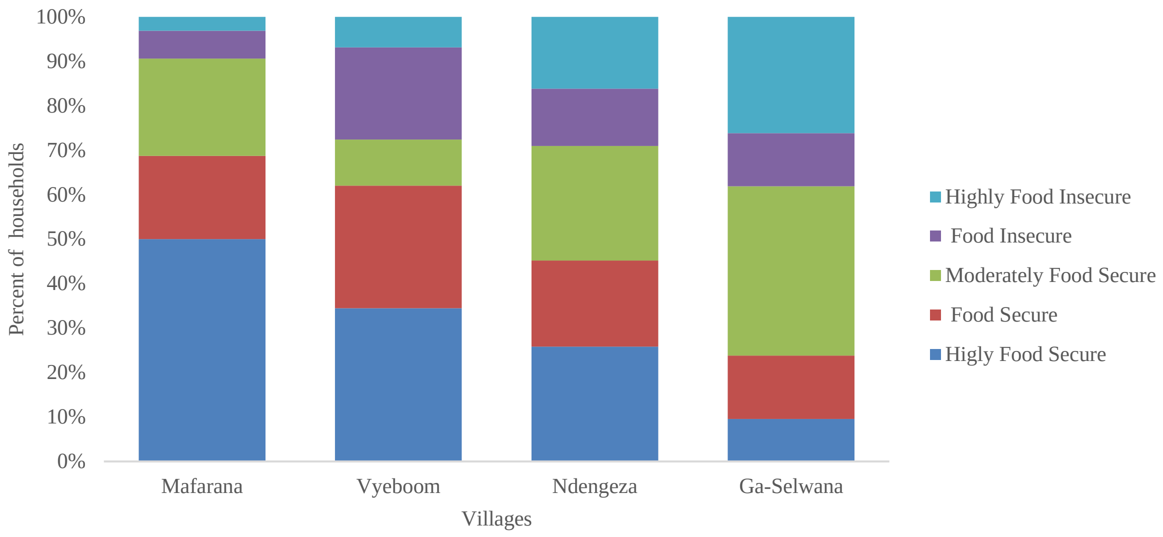

Figure 3.11. Proportion of household's overall food insecurity level across all four villages (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32) in Limpopo Province, South Africa.

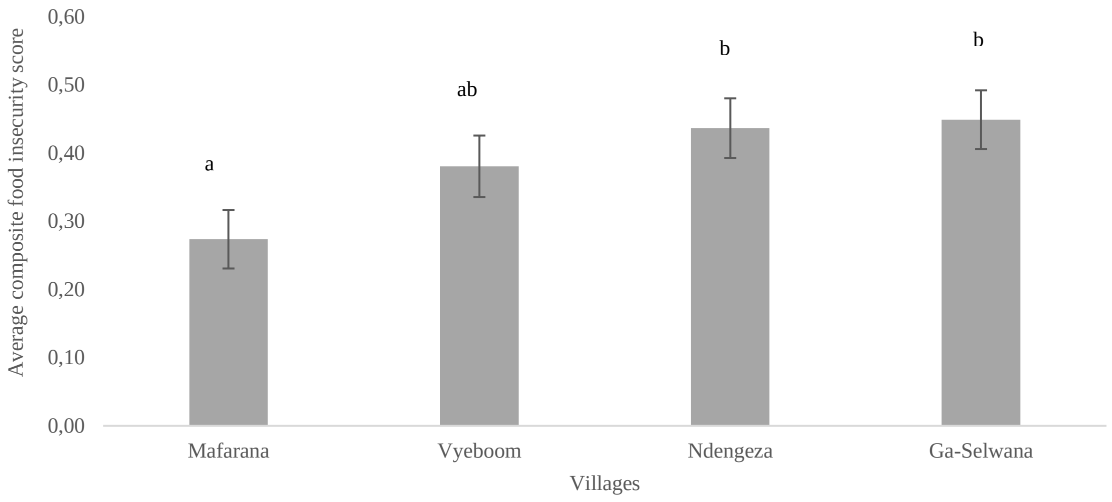

Figure 3.12. Average composite food insecurity score across all four villages (Mafarana n=32; Vyeboom n=29, Ka-Ndengeza n=31 and Ga-Selwana n=32).

4.3.10.Food security and state of environment

Ka-Ndengeza and Ga-Selwana have similar composite food security scores and so these villages are classified as moderately food insecure. In comparison Vyeboom and Mafarana are classified as food secure., Ka-Ndengeza has the highest rangeland biomass (98.17 Mg/ha) compared to the other villages (Figure 3.13). Although Vyeboom and Ga-Selwana have similar average rangeland biomass (74.30 Mg/ha and 73.10 Mg/ha respectively), Ga-Selwana is classified as moderately food secure and Vyeboom is classified as food secure see Figure 3.13 Mafarana has and intermediate average rangeland biomass of 83.03 Mg/ha, and is classified as only moderately food secure. There is no significant relationship between average rangeland biomass and composite food insecurity across the four villages ($p>0.05$; $R^2=0.00439$).

Mafarana has the highest average canopy cover of low trees as well as high trees in comparison to the other villages, coupled with being the most food secure village (Figure 3.14). Vyeboom has the highest canopy cover of tall trees in comparison to the other villages (Figure 3.14). In relation to the other village Ga-Selwana and Ka-Ndengeza have significantly higher canopy cover of shrubs and are classified as only moderately food secure. When the relationship between composite food security and subcanopy structures was explored, there was no significant relationship between composite food insecurity and canopy cover of shrubs across all four villages ($R^2= 0.387$; $p=0.15$). There was however, a significant relationship between composite food insecurity and the canopy cover of low trees ($R^2=0.51651$; $p=0.0001$), high trees ($R^2=0.75147$) and tall trees ($R^2=0.30970$) ($p<0.05$).

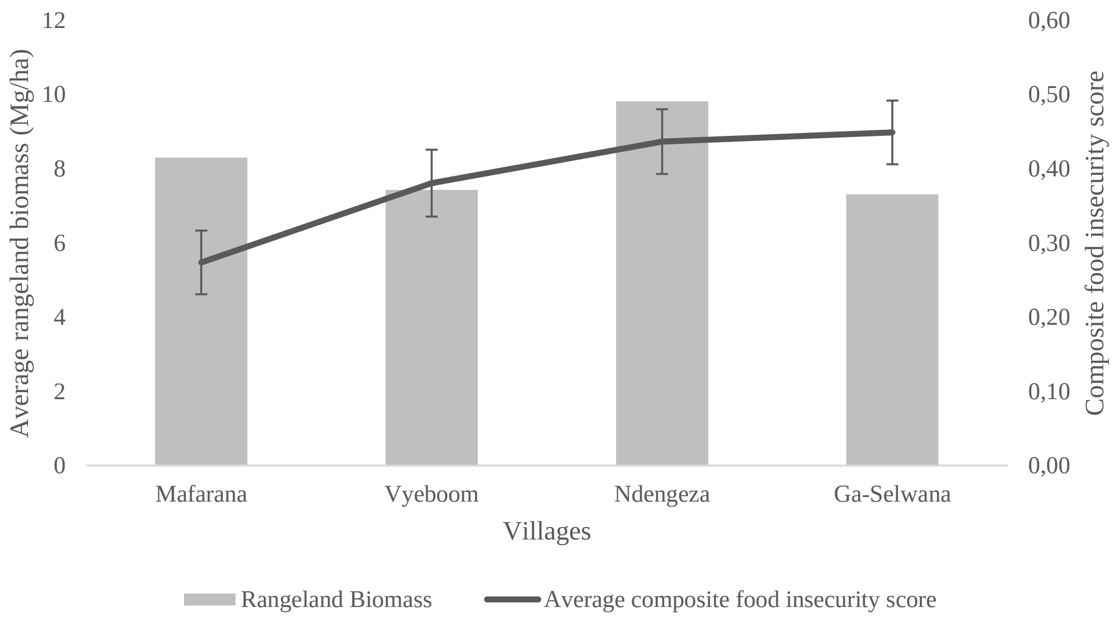

Figure 3.14. Average rangeland biomass (Mg/ha) in comparison to average composite food insecurity score across all four study villages, Limpopo Province, South Africa.

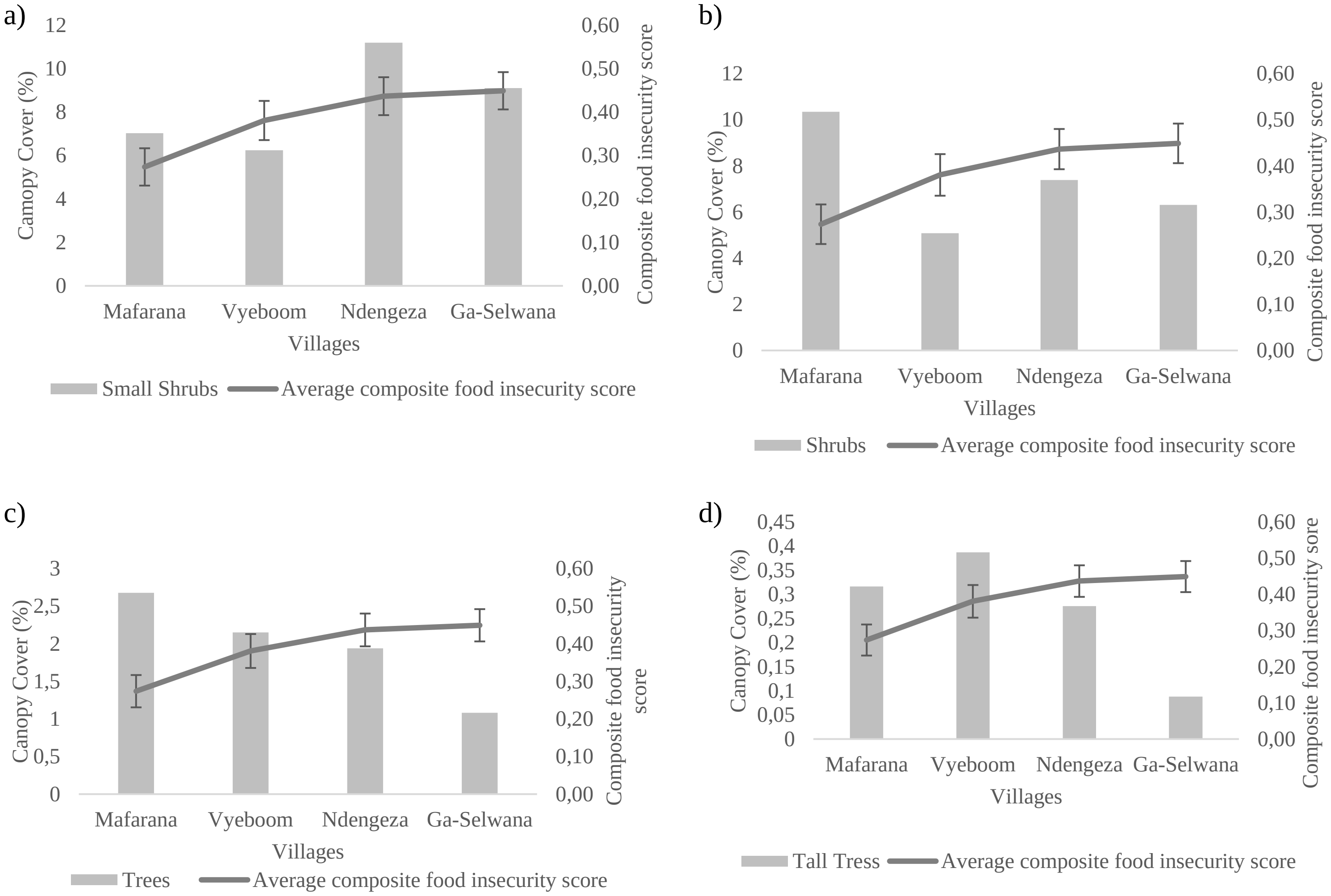

Figure 3.15. Average percent of rangeland canopy cover for all four sub-canopy structures a) shrubs (1 – 3 m), b) low trees (3 - 6 m), c) high trees (6 – 10 m) and d) tall trees (>10 m), in comparison to average composite food security score across all four study villages, in Limpopo Province, South Africa.

4.3.11.Relationship between household food security and use of natural resources

There was no significant relationship between the experience of hunger and the amount of firewood, wild fruit and vegetables used per annum, nor was there a significant relationship between the experience of hunger and number of resources used ($F_{(4:119)}$=1.8477, p=0.125)., there was also, no statistically significant difference between the experience of food shortages and the amount of firewood, wild fruit and vegetables used per annum, nor the number of resources used (p=0.290). There was a statistically significant relationship between household dietary diversity, the amount of firewood, wild fruit and vegetables and the number of resources used per annum, ($F_{(4:119)}$=3.795; p<0.01). A statistically significant relationship was found between the amount of wild fruit used per annum and household dietary diversity (p<0.05).

This showed that the amount of wild fruit used by a household, directly increased the households' dietary diversity. The was no statistically significant difference between household utilisation of coping strategies and natural resource use ($F_{(4:119)}$=1.331; p=0.263)., there was a statistically significant relationship between a household's composite food security score and their resource use ($F_{(4:119)}$=4.07; p<0.01). The difference occurred between the amount of wild vegetables and fruit used and a household's composite food insecurity score (p<0.05), which showed that the amount of wild fruit and vegetables consumed per annum by a household directly decreases their composite food insecurity score.

4.4. Discussion

4.4.1. Village use of natural resources

The state of the communal woodlands in terms of biomass stocks and sub-canopy structures, supports the fact, that based on the household interviews, virtually all of the households across all four villages used firewood, wild fruit and wild vegetables (Figure 3.2). This is particularly significant as firewood, wild fruit and wild vegetables are all directly linked to food security. But the amount of resources used per household varied across the study villages as shown in Figure 3.3.

the use of natural resources in rural livelihood strategies plays a key role in these rural villages., if not managed, the unsustainable harvesting of firewood and natural resources has the potential to cause substantial loss in the value of the role that natural resources play in rural areas (Twine *et al.* 2003). There are a variety of factors that influence the local use of natural resources, such as environmental conditions, resource availability, socio-economic characteristics, and access to alternatives (Twine *et al.* 2003). For example, Brouwer *et al*. (1997) found that smaller households' per capita wood collection is greater than that of larger households. The factors influencing resource use needs to be considered when assessing the use of natural resources in rural villages.

4.4.2. Perceptions of resource change and use

Few studies have examined how households perceive natural resource abundance or availability (through ease of access) as determinants of resource use. Hosier and Dowd (1987) found, that households who perceived fuelwood to be easily accessible did not move away from fuelwood use or switch to another energy alternative due to this perceived abundance. (Hosier and Dowd, 1987). In this study, most households interviewed, said that there was a decrease in the amount of firewood available of the past five years.

This study found that the perception of the availability of firewood over the past five years impacted the average amount of firewood used per annum per household. The households of respondents who perceived no change in the firewood availability used significantly more firewood than those who perceived an increase in the availability, with those who perceived a decrease being intermediate (Figure 3.5a). This research further substantiates the behaviour that Hosier and Dowd (1987) described in which households will not change or lessen their consumption patterns where wood is generally perceived to be in abundance. This is in line with previous research that found that households who did not perceive fuelwood to be hard to collect used more firewood than household who felt that firewood collection was difficult to access (Matsika, 2012; Matsika *et al.* 2013).,

The perceptions of changes in the availability of wild fruit and vegetables over the past five years was similar across all four villages with the most common perception being that there has been decrease in the availability of wild fruit of 4% - 56% and vegetables of 41% - 59% over the past five years (Figure 2.5b and Figure 2.5c). The perception of the availability of wild vegetables, like firewood did have a significant impact on the amount of wild vegetables used per household.

4.4.3. Household experiences and indicators of food security

When trying to assess food security, the choice of indicators is important to identify vulnerable households. Often multiple indicators are required to accurately determine household levels of food insecurity (Kirkland *et al.* 2007). In this study, four indicators were used to assess household and village food insecurity, namely: experience of hunger, experience of food shortages, coping strategies during time of food shortages and dietary diversity. Across all four villages, most of the respondents rarely or never experienced hunger in the last 30 days prior to the interviews. Ga-Selwana was the only village that had no households that experienced hunger all the time. Mafarana and Vyboom had the highest proportion of households that did not experience any food shortages in the last year (Figure 3.7). This shows that some households are clearly more vulnerable to food insecurity than others.

A vast amount of research has been conducted to access the varying levels of households' vulnerability (Corbet, 1988, Hoddinott and Yohannes, 2002; Hatloy and Oshaug 1998; Maxwell, 1996; Misselhorn, 2005; Webb *et al.* 2006; Kirkland *et al.* 2011). It is important to note, that the experience of hunger, can be permanent or a temporary. This experience is directly influenced by a variety of external factors such as income, the death of a breadwinner, retrenchment or environmental factors. Coates *et al*. (2006) found that insufficient food quantity and food quality, coupled with uncertainty and worry about food, are universal experiences of food insecurity. These finding highlights similarities in how households across varying areas manage food insecurity.

The dietary diversity of households varied significantly across the four villages. Previous research has found that dietary diversity is greater in households with higher socio-economic status (Kirkland *et al.* 2011). This finding was evident in this study. Ka-Ndegneza had the highest proportion of households with high dietary diversity, which can be attributed to the close access to Giyani for jobs and the higher number of migrant labours () present, which was verbally mentioned by the Chief. This is consistent with other findings that have examined the relationship between socioeconomic status and household food security (Ferguson *et al*. 1993; Leatherman, 1994;). Poor households often cope with poverty and address their basic nutritional needs, by resorting to a very monotonous diet (Charlton, 2002).

When faced with food insecurity, households tend to adopt coping strategies to combat times of food scarcity. Coping strategies include: collection of wild fruits and vegetables, migration in search of employment, altering harvesting practices, selling household assets (such as livestock or other household possessions), rationing available food, skipping meals or even asking neighbours or family members for help (Corbett, 1988; Kirkland *et al*. 2007; Twine and Hunter, 2008; Kirkland *et al.* 2011). The responses of households to food shortages has become more extreme over time shown in Figure 3.9, as have the mechanisms households implement to ensure and sustain their livelihoods.

Of all the households interviewed, Mafarana had the highest porportion of households, 54%, that did not implement any coping strategies in the last week. Vyeboom had the largest proportion of households that implement two coping strategies in the last week, in comparison to the other villages. The coping strageties that these housholds implemented, included reducing the size of food served to household member, eating food they did not enjoy, reducing the number of meals eaten per day or asking neighbours or family members for help. The most common coping strategy adopted was reducing the size of servings of food. This study shows that in times of food insecurity households do implement coping strageties which further justifies that coping strategies are “fall-back mechanisms” that help households manage short-term food shortages (Kirkland *et al.* 2011). Longer-term changes in households food procurement are considered adaptive strategies. Although these adaptive strategies are shown in Figure 3.15, they were not examined in this study.

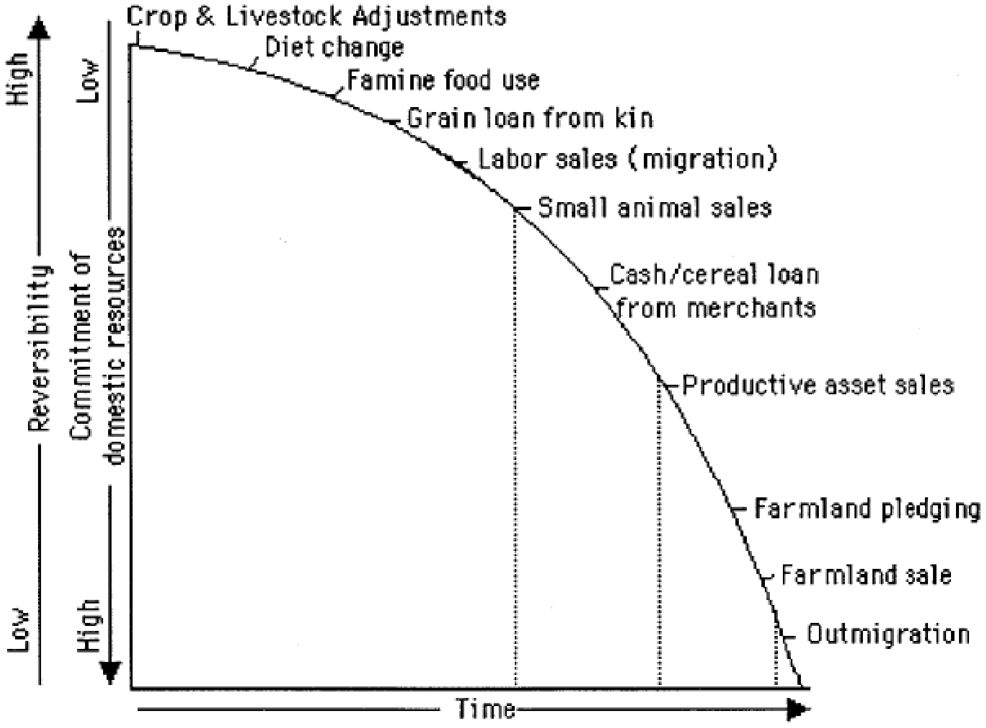

Figure 3.16. Diagrammatic representation of household responses to food shortage (Adapted from Watts 1983).

From these food security indicators, an overall composite food security matrix was compiled to access a household's overall food security. Kirkland *et al.* (2007) found that to classify households as food insecure, the use of multiple indicators measuring different aspect of food security are required. In this study, the food security of households across all four villages varied. Ga-Selwana with 34% and Ka-Ndengeza with 16%, had the highest proportion of households that were highly food insecure (Figure 3.11). Overall, there is a significant difference between the proportion of household's composite food security scores across villages. This highlights the fact, that food security policies cannot be based on broad generalisations, as food security is household and village specific. This is substantiated by the dynamic tensions between increasing population, declining farm-size, declining farm labour supply, diversification of income sources and the management of natural resources are all dynamic and varies between and within regions (Sanchez and Leakey, 1997).

4.4.4. Link between state of communal woodlands and food security

The examination of the role that ecosystem services plays in food security is underpinned by the availability, access, and utilization of these resources. This h reveals the complex interactions between the ecosystems and the chronic problems of hunger and poverty (Richardson, 2010). In some cases, household use of natural resources and services may alter the access and utilization dimensions and undermine the ecosystem functions which support food availability (Richardson, 2010). This relationship was seen in the similar composite food security scores of Ka-Ndengeza and Ga-Selwana. While only Ka-Ndengeza has the highest rangeland biomass (Figure 3.13)., Ga-Selwana and Mafarana have similar average rangeland biomasses, while Ga-Selwana is classified as moderately food secure and Mafarana is classified as food secure (Figure 3.13)

Mafarana had the highest average canopy cover of low trees as well as high trees in comparison to the other villages coupled with being the most food secure village, while Vyeboom had the highest average rangeland canopy cover of tall trees in comparison to the other villages (Figure 3.14). In relation to the other village Ga-Selwana and Ka-Ka-Ndengeza had significantly higher shrub canopy cover and canopy cover of low trees and are classified as moderately food secure. The variations in canopy cover may be due to either coppicing or bush encroachment which can alter the species composition of the area and influence food security (Neke, 2005). As previously mentioned, this could be attributed to the conservation of these sub-canopy structure in these two villages (Shackleton *et al.* 2003; Kirkland *et al.* 2007) (Chapter 2). The results suggest, that improved food security might be associated with a healthier state of the communal woodlands, but more detailed analysis of this relationship needs to be explored. Brouwer *et al.* (1996) found that a decrease in the availability of fuelwood is associated with a reduced food energy intake from cooked foods, showing that the decreased use and collection of fuelwood lowers the already marginal quality of a household's diet. They further concluded that there is a relationship between fuelwood availability and nutrition (Brouwer *et al.* 1997).

4.5. Conclusions

It is evident that villages are heavily reliant on the natural resource of their communal rangeland and the high utilisation of this is having an impact on the biomass and sub-canopy characteristics of these communal rangelands. Without intervention, there is a likelihood that this high utilisation will change the composition and structure of these communal rangelands. This will negatively impact the communities' s that rely on them., the food security within and between villages is varied, this exacerbates the problem facing policy makers when addressing food security in rural Africa. there is very little action from a policy level focused on addressing food security in rural villages and the high dependence on natural resources.

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CHAPTER 4: SYNTHESIS

5.1. Introduction

Anthropogenic activities are resulting in the degradation and loss of woodlands globally, which can cause significant harm to human well-being (Millennium Ecosystem Assessment, 2005). Although the data collected in this thesis covers a small portion of South Africa, the impacts of human activities on vegetation structure and biomass allows for the application of this type of research to be extrapolated across greater areas and to understand if patterns observed in this study hold true elsewhere.

The spatio-temporal drivers and dynamics of woody vegetation in savannas has been widely explored (Scholes and Walker, 1993; Scholes and Archer, 1997; Gillson, 2004; Sankaran *et al.* 2005; Sankaran *et al.* 2008; Levick and Rogers, 2011). Most of this research has focused on the impact of fire (Scholes and Archer, 1997 Sankaran *et al.* 2005; Helm *et al.* 2011; Levick *et al*. 2012) and herbivory (Asner and Levick, 2012; Levick and Asner, 2013), with some exploration on the impacts that human activities have on the landscape (Twine, 2005). A variety of research has been conducted in communal rangelands exploring the impact that human activities has on woody vegetation (eg. Fisher, *et al*. 2013; Matsika *et al.* 2012; Mograbi *et al.* 2015) the research has focused on as these areas as they present an interesting mix of social and ecological dynamics. Human activities in savannas are classified as disturbance events, similar to fire and herbivory, because of the impacts and disturbances human activities have on the landscape (Twine, 2005; Mograbi *et al.* 2016). It is essential to understand the dynamic relationship between savanna vegetation and human use, especially as populations continue to grow and increasingly harvest natural resources.

This chapter summarises, synthesizes and integrates the findings of chapter 2 and 3. Recommendations and limitations are also discussed (Section 5.3).

5.2. Synthesis

5.2.1. State of communal woodlands

Historically, remote sensing techniques have been used in an effort to assess the impact of anthropogenic activities on vegetation structure through mapping vegetation types, land use and land cover (Colgan *et al.* 2013). The use of LiDAR for vegetation measurements and monitoring has been widely used in forestry research (Lefsky *et al.* 1999; Lefsky *et al.* 2002; Skowronski *et al*. 2007; Hudak *et al.* 2008; Pascual *et al.* 2008). Recently, in African savannas, LiDAR has been used successfully to measure the effects of herbivory (Asner *et al*. 2009;

Asner and Levick, 2012; Levick and Asner, 2013), fire (Smit *et al*. 2010; Levick *et al*. 2012), the effects of land management and land-use (Wessels *et al*. 2011; Fisher *et al.* 2012; Wessels *et al.* 2013; Fisher *et al.* 2014; Mograbi *et al*, 2015) on woody vegetation structure. This thesis presented a LiDAR, Chapter 2, analysis of 3-D vegetation structure in four savanna communal woodlands. In Chapter 2, of this study examined the relationships between woody vegetation structure and biomass, across multiple communal rangelands, to better understand the context of woody structural patterns and dynamics in human modified landscapes.

Previous research has explored the presence of vegetation gradients with increasing distance from villages and the factors driving these gradients (Shackleton *et al.* 1994; Banks *et al.* 1996; Fisher *et al.* 2011; Wessels *et al.* 2013; Mograbi 2015). The presence of vegetation gradients was examined further in this thesis to see if this theory held true in Limpopo, Chapter 2. It was found that the presence of biomass gradients (**Error! Reference source not found.**.) a nd changes over time in vegetation vertical structure (**Error! Reference source not found.** (c and) and **Error! Reference source not found.** (b and c)) was presented in this study, changes in the biomass and subcanopy,. This study found that levels of human disturbance varied with increasing distance from the village settlements. Highlighting, the impact that human activities has on biomass and subcanopy structure patterns in communal woodlands.

To explain some of the variance seen, the impact that roads have on vegetation vertical structure and biomass was explored in Chapter 2). The exploration of roads as an impact on biomass and subcanopy structure was due to previous research, conducted by (Smit and Asner, (2012). They found that roads and their associated edges have a variety of effects on biodiversity patterns and process (Smit and Asner. 2012). The impact that roads have on vegetation includes mortality from road construction, mortality from collision with vehicles, modification of animal behaviour, alteration of the physical environment, alteration of the chemical environment, spread of exotic species and the spread of human settlements into land that was previously used for agriculture or resource harvesting (Trombulak and Frissell, 2000; Smit and Asner, 2012, Coetzer *et al.* 2014). Research conducted in Bushbuckridge also found that roads have an impact on biomass gradients and subcanopy characteristics (Mograbi *et al*. 2015, Fisher *et al.* 2012). Similarly, this study found that roads have an impact on the biomass gradients and vegetation vertical structures (Chapter 2). More noticeable than this, was the combined impact that village settlements located along main roads had on biomass and vegetation subcanopy structures, in comparison to villages not located on a main road. This study revealed that villages located along main roads showed higher levels of disturbance.

The biomass gradients observed in this study, can be viewed as a function of the interaction between the distance from the nearest road and the distance from settlements. This study also revealed that coalesced areas of high biomass are associated with high density shrub layers. This interaction was particularly evident in the communal rangelands of Ka-Ndengeza and Ga-Selwana biomass gradients (Figure 2.9) and subcanopy characteristics (Figure 2.10). This study detected that there was a notable difference in these gradients in villages that were located along a main road,namely Ga-Selwana and Ka-Ndengeza in comparison to Mafarana and Vyeboom.

The findings of this study then raised three questions. Firstly, what value does assessing the state of an environment add in human modified and human utilised landscape? Secondly, does the pattern of biomass buffer zones necessarily imply resource use? Lastly, what role does the access to these resources play in their utilisation?

Based on these questions, the cost associated with harvesting a particular resource was assessed, in this case fruiting trees, which was classified as shrubs, based on the voxel data collected in Chapter 2 Section 2.2.3, Table 2.2. The aim of this study was to take the "Central Place Theory" a step further and explore the accessibility of households to firewood.

The cumulative cost surface maps generated for the four villages in Limpopo showed that the cost to access a natural resource was neither uniform, nor did it increase linearly with increasing distance from the village settlement (Section 2.3.4, Figure 2.13. 2.12 and Figure 2.13). The data showed that the least cost pathway associated with a given resource overlapped with other pathways. This was attributed to the open nature of the pathways. People also utilise similar pathways to access different resources. Based on the results, it was concluded that there are numerous pathways to a given resource depending on where an individual enters and exits the landscape When the least cost pathways were examined on a smaller scale, the cost associated with a given pathway is easy to explain, based on the landscape features and vegetation., the only constraint in a cost pathway is the initial slope as there are multiple pathways on a certain slope with the same cost value. Only as an individual gets closer to the destination, does shrub cover then become a constraining factor affecting the cost pathway., Although the least cost pathway is a possible extension of the "Central Place Theory", it is hard to apply to large areas.

Although this study sheds some light on the cost associated with collecting a given resource, it does not answer adequately answer what role the access to a resource plays, in household's utilisation. It would be interesting to further explore the role that distance from a village plays in the cost pathways, while incorporating the containing factors such as slope and shrub cover. It could be possible that people are willing to walk further to collect a resource if the cost path is low, in comparison with a resource that is located close to the village but has a high cost associated. For example, it may be harder for an individual to collect a resource in an area that is heavily impacted by coppicing. Coppicing close to the village has been recorded in other areas, as past research has shown that there is a disturbance gradient from villages, with high disturbance and coppicing occurring close to the villages where it is easier to harvest and decreasing with increasing distance from the villages (Shackleton *et al.* 1994)., it is possible that distance may not be a limiting factor in accessing a resource but, this needs to be explored further.

5.2.2. Natural resource use and food security

The household interview data, which is based and structured on the SLA framework, forms a complex web of interactions, which this study aimed to understand (; Carney, 2003; Serrat, 2010; Ragie, 2015). The livelihood capitals that were examined in this study are Natural capital although data on the Physical and a small section of Human capital were captured during the household interviews and assessed, including households' income and expenditure (Figure 4.1).

Understanding how rural households depend on their natural resources and the state of these natural resources assists in understanding the food security, in the face of climate change and their resilience to stress and external shocks. Understanding the relationship between resource use and food security can hopefully lead to better management of these resources and ensure their sustainable use and assist in alleviating poverty.

Food security, which was the focus of this dissertation is an outcome of the utilisation of a certain livelihood strategy, such as employment, receiving social grants, livestock husbandry, resource collection and crop cultivation (Figure 4.1). This study was aimed at assessing how household use their livelihood strategies in an effort in improve their food security and the sustainable use of their resource base (Figure 4.1), The ability of a household to utilise a strategy depends solely on the households' access to livelihood capitals.

If a household has no access to financial capital to purchase food, during times of need, then the household may depend on another livelihood capital, such as social capital which could for example, entail another household contributing to their livelihood by giving them food or money in order ensure their sustainability. If a household does not receive assistance from another household or family member a household will depend on their surrounding local natural resources. Many household respondents mentioned cultural barriers prevented them from asking for help (,) This shows how households utilise different livelihood strategies to ensure the sustainability of their household during times of insecurity.

Although households utilise different livelihood strategies, a problem arises when many households are relying on the same natural resource base in times of insecurity or on a regular basis to supplement their livelihood income. The overuse of the natural resource base then becomes unsustainable, which affects a households' livelihood capital and strategies. The continued unsustainable use of natural resources in communal woodlands leads to woodland degradation, through changes in vegetation structure. If the integrity of a rangeland is compromised, which will likely happen if they are continuously over harvested, then so will the quality and quantity of provisioning ecosystem services such as wild fruits, firewood and medicinal plants This over utilisation threatens the food security of rural communities. The reduction in food security was mentioned during the household interviews in the four case study villages. They mentioned that the availability of 'mopane worms' had decreased in their communal lands and they felt that was because there are not enough tall trees for the breeding and feeding of the 'mopane worms'. As a consequence of this, a household that collects and sells dried mopane worms would lose an income generating source and may become food insecure if they cannot purchase food or access firewood either purchased or harvested, to cook their food . The SLA cycle links the complexity of household livelihood strategies, incomes and capital highlights what an important role natural resources plays in household food security (Figure 4.1).

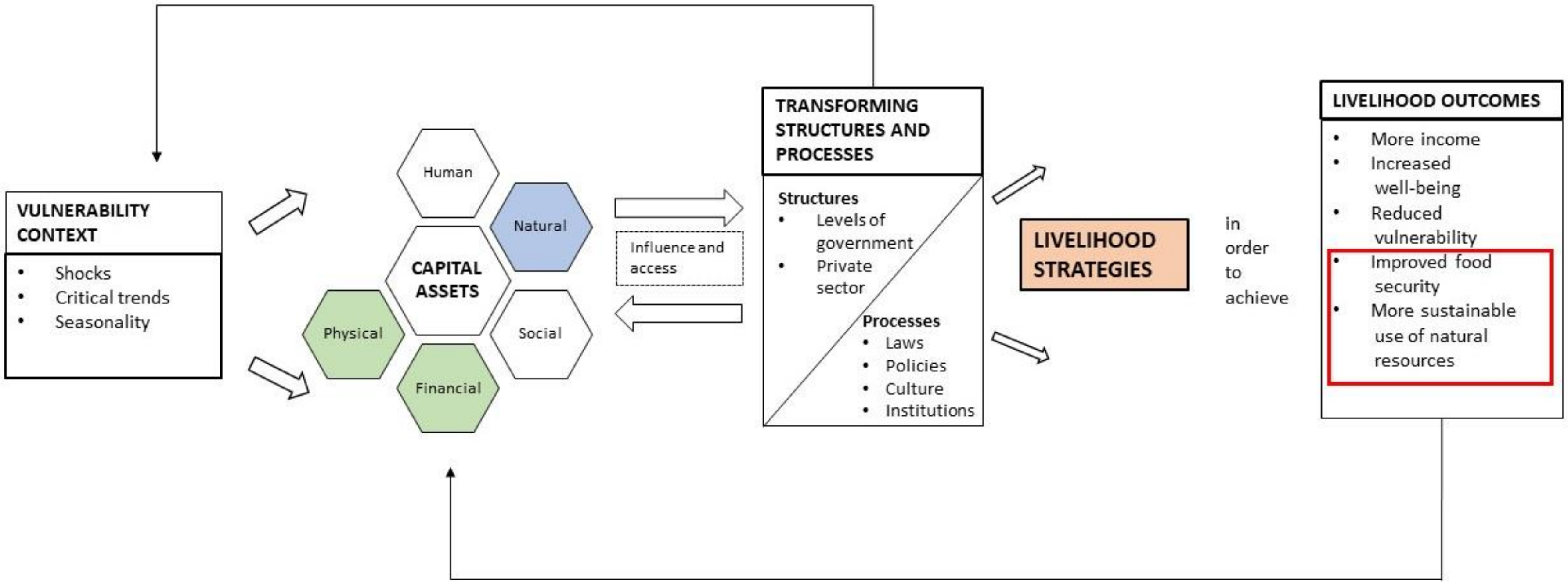

Figure 4.2. Graphical represenatation of the SLA showing the links between capital assests, transforming structures and livelihood outcomes examined in this study through household's questionnaires that were then aggregated to a village level. These are all influenced by a vulnerability context as well as anthropogenic processeses and structures. The information highlight in blue was the main focus of the study and those in green were a small component of the study, both are avaliable from the household interviews. The orange block highlights the livelihood strategies households utilise (avalable from household interview data) to improve their food security and sustainably utilise their resources (red) (adapted from : Carney, 2003; Serrat, 2010).

Most of the world's poor, live in rural areas (Lee *et al*. 2009). As mentioned, a large portion of the people living in rural areas depend on natural resources as part of their livelihood strategies. Even though the Apartheid regime has been abolished, resource shortages persist in the former homelands, where biomass represents a fundamental resource and energy source (Griffin *et al.* 1993; Levin and Weiner 1997; Kirkland *et al.* 2007). Today many rural households still struggle to meet their daily subsistence needs (Twine *et al.* 2003). In the face of tough economic times, natural resources bring substantial value to some households (Kirkland *et al.* 2007), as they are a financially inexpensive alternative to purchased goods (Griffen *et al.* 1993; Letsela *et al.* 2002; Twine *et al.* 2003). Natural resources, also provide households with opportunities to generate an alternative income through resource trade (Shackelton, 1996; Shackelton, 2004) and can directly contribute to households provisioning of needs (Hunter *et al.* 2011). The value that natural resources add to household's livelihood highlights the close link between rural poverty and natural resource use (Lee *et al.* 2009). The full impact of this link cannot be understood unless rural households have an improved and more equitable access to their natural resources, coupled with better management of this resource base (Lee *et al*. 2009).

In some cases, the financial value of harvesting natural resources in rural households is often similar to, or higher than, other livelihood activities or government grants (Shackleton *et al.* 2000). This dissertation confirmed the distinct relationship that exists between people and the environment, by exploring households' use of natural resources (Chapter 3).

The presence of the relationship between people and their environment is not novel, previous studies have found that communal woodlands provide a variety of natural resources to the surrounding communities (Ashley and La Franchini, 1997; Shackleton *et al.* 1999; Shackleton and Shackleton, 2000; Shackleton *et al.* 2002; Twine *et al*. 2003Twine, 2005; Matsika *et al*. 2012). What is particularly noteworthy, is that the data collected in this study found, that across all four study villages the most frequently used natural resources were firewood, wild fruit and wild vegetables (Figure 3.3, Chapter 3. This is significant as firewood, wild fruit and wild vegetables are all directly linked to food security. The findings in this dissertation are supported by research conducted by Kaschula *et al*. (2005), where the authors found that food products influence a household's resilience and sustainability when facing food scarcity., Pimental *et al*. (1997) found that the integrity of a forest is essential to food security, primarily because the poor rely so heavily on these natural resources.

This study also explored the relationship between household's perception of natural resource abundance or availability as a proxy to determine resource use (CHAPTER 3**:**). This study found that households do not change or lessen their consumption patterns when firewood was perceived to be in abundance. This is in line with previous research which found that households who did not perceive fuelwood to be hard to collect used more firewood than household who felt that firewood collection was difficult to access (Matsika *et al.* 2012). In contrast to this, the perception of the availability of wild vegetables did have a significant impact on the amount used per household. Households who perceived there to be a decrease in the availability of wild vegetables used more than households who perceived there to be an increase in the availability.

This thesis also explored the food security of households in the four study villages. For the purposes of this study four indicators were used to assess household and village food insecurity; experience of hunger, experience of food shortages, coping strategies during time of food shortages and dietary diversity. From these food security indicators, an overall composite food security matrix was compiled to assess a household's overall food security. The use of multiple indicators measuring different aspects of food security was done as was done as Kirkland *et al.* (2007) found that this was necessary to classify households as food insecure. Overall, there was a significant difference between the proportion of household's composite food security scores across the studied villages (Chapter 3). When making, decisions regarding food security broad generalisations cannot be used as food security is household and village specific.

Much research has been focused on food security (Bonti-Ankomah, 2001; Misselhorn, 2005; Webb *et al.* 2006; Kirkland *et al.* 2011). There are a variety of factors that influence the local use of natural resources such as environmental conditions, resource availability, socio-economic characteristics, and access to alternatives (Twine *et al.* 2003). The factors influencing resource use, needs to be considered when assessing the use of natural resources in rural villages.

In this study, the aim was to assess village food security and link it to the state of communal woodlands. This study found that there was evidence to suggest that natural resource use in the four communal rangelands was having an impact on the surrounding vegetation structure (Chapter 3). The impact of human utilisation on the landscape, evident in the villages in Limpopo, in the long term may cause the ecosystem to change states, and alter overall structure and functioning of these ecosystems. These changes may have huge negative knock-on implications for households' resource use, food security and vulnerabilities in the face of socio-economic and environmental changes.

In this study it was expected that improved food security might be associated with a healthier state of the communal woodlands, but this study did not find significant evidence that suggests that biomass or vegetation structure is a predictor of improved food security. , This does not necessarily imply that food security is not linked to a healthier woodland state, it may mean that the proxies used to assess a woodlands state may not be accurate predictors. The examination of the role that ecosystem services plays in food security is underpinned by the availability, access, and utilization of these resources which reveals the complex interactions between the ecosystems and the chronic problems of hunger and poverty (Richardson, 2010), which was highlighted in this study. In some cases, household use of natural resources and services may alter their actual access and utilization to natural resources as it could alter the ecosystem functions that support food availability (Richardson, 2010).

5.3. Limitations and opportunities

5.3.1. Household questionnaires on resource use and food security

One of the challenges faced when conducting the household interviews in rural communities was the language barrier. Often the English word for something, such as an avocado or cucumber did not have a direct translation into the local language. This may have skewed the answers on the food security data, purely due to misunderstandings or misinterpretations. The translators were selected in most cases by the village headmen and they were experienced and friendly., Since the translators were from the same villages as the participants, they often knew the participations, there were times when I felt that the translators were guiding the participants' answers. I felt this influenced the participants' responses, and I was concerned that the selection of participants was not random and was guided by the translators. There were times the translators told the participants that they were lying about their income or expenditure. This often resulted in some confrontation between the participants and translators, and when I enquired what was happening, the translators said that they know the participant is lying. One example I was given by translator was the fact that he and the participant attended the same church and the translator believed he knew the amount of money that the household donated to the church, He believed that the participants responses to income were inaccurate. This raised concerns as I was then unable to gauge if the translator had given me the participants' actual response or altered the participants response based on their perceptions of the participants' answers. It would be interesting to see if there were variations between the recorded household responses, which were recorded with voice recorders and the answers given to us by the translators.

A pilot study was carried out prior to conducting the household interviews to ensure that the roll out of the interviews went as smoothly as possible. Despite this there were some unforeseen problems. Firstly, one of the translators used in Ga-Selwana had recently been promoted by the tribal authority to the role of overseeing and controlling the use of ploughs in the communal rangelands. This created problems during the interviews as participants felt that their responses may influence their ability to access ploughs particularly if they were perceived to have access other resources that they could rely on in times of food scarcity. . Secondly, on one of the days that household interviews were meant to be conducted in Mafarana, the National government handed out social grants and most of the household residents were not in the village. They were waiting at the clinic for their social grants. This meant that the interview process was delayed, and may also have skewed the respondent's answers to certain questionnaires as they had just received their social grants. This may have resulted in the participants perception of hardships and food scarcity may have been skewed as they were in high spirits and had done their monthly shop.

The results of research are subject to time sensitivity, and this holds true for household questionnaires. the timing of the year (2014) that interviews are conducted influenced participants' responses, as during winter the associated dry season may result in participant's answers being negative due to seasonal availability of resources. To limit this, the household questionnaires were conducted in summer., the timing in summer also skews the data as during the summer growing season, the households have more abundant access to resources. It would be interesting to explore the relationship between resources use answers at different times during the year. in addition to the impact of seasonality, there are problems associated with information recall after a certain period especially, when asked focused on a time horizon that exceeded the memory of respondents (Kirkland *et al.* 2011). We found this in our study, for example some respondents struggled to remember the exact months during which they experienced food shortages.

It is not uncommon to use people's perceptions as proxies' in scientific research. Critics of this method argue that such qualitative data does not provide representative estimates of a study population and furthermore fails to capture information in an objective framework that reduces bias (Hope, 2006). Despite these considerations, the numerous benefits of perception-based research arguably outweigh the drawbacks. Beyond providing government authorities with the information that they need to improve resources use in rural communities, this research method directly benefits participants and local stakeholders by initiating productive conversations about resource use and rangeland sustainability. Ultimately, perception-based research is an established methodology and has been shown to elicit important insights into resource use.

In perception based research, it is difficult to separate the politics, agendas, and the fears of participants from the information collected. The results of this study should be viewed, not through the traditional scientific lens where the researcher and all the study subjects are objective and independent; but rather through a poststructuralist lens through which the information gathered is a product of the process used to gather the data.

5.3.2. LiDAR derived biomass modelling and vegetation structure analysis

One of the limitations of this study was based on the lack of field-derived biomass data. Historically, the use of LiDAR estimated biomass maps have been coupled with field data. Although, based on previous research it is not uncommon to estimate LiDAR-derived biomass without corresponding field collected biomass estimates (Dubayah *et al*. 2010; Huang *et al*. 2013; Meyer *et al.* 2013).

The reason that no field-data was collected during this study, was primarily due to time constraints. Field-data is a destructive method of collecting data and requires a huge amount of man power, which was not logistically practical in this study. This study was carried out in communal rangelands, which are already heavily utilised by the surrounding villages, and resources are already scarce. The likelihood of permission being granted by the local authorities for the removal of valuable natural resources was unlikely and not appropriate in villages where communities already have scarce natural resources. Field collection is costly, and budget constraints limited the application of both field data collection and a LiDAR campaign.

As mentioned in Chapter 1, historical methods of field data collection have been widely used (Xie *et al*. 2008; Colgan *et al.* 2013; Fisher, 2013) and have proved effective in measuring a tree or an areas biomass (Mabowe, 2006). With the move, away from field data collection methods and the growing use of LiDAR derived biomass estimates, the benefit of the application of a LiDAR campaigns outweighed those of collection field data. Previous research has been carried out on granite savanna landscapes in Bushbuckridge, with an extensive look at the value of using LiDAR derived data as predictors of vertical structure and biomass (Fisher *et al.* 2012; Colgan *et al*. 2012; Colgan *et al.* 2013; Fisher *et al*. 2014; Mograbi *et al*. 2015). The focus of this study was to assess the state of the communal woodlands and not the application of LiDAR derived biomass estimates there was no need to collect field data to compare with the LiDAR data. LiDAR derived biomass estimates would perform better and be more ecologically meaningful if the allometry used on LiDAR data was based on spatially and temporally matched LiDAR and field data (Mograbi, 2014). The applicability of LiDAR derived biomass estimates in different areas should be explored further. As well as the tree heights should have been ground-truthed.

Another limiting factor within this study, was that only one LiDAR campaign was conducted. The biomass and structure of the communal woodlands explored in this study are only a snap-shot in time. The assessment and monitoring of changes in woodland structure and biomass using repeat LiDAR campaigns would allow for continued monitoring of these woodlands, and resource use as natural resources decrease.

The LiDAR data collected in this study, as previously mentioned was collected in July 2014 (Chapter 2), while the household questionnaires were carried out in February 2015 (Chapter 3). This is important as during 2015 and 2016, Southern African experience one of the worst El-Niño weather events in 50 years (Phys.Org, 2016) Which resulted in an El-Niño induced drought that crippled the livelihoods of many people in southern Africa (UNRCO, 2016). It is expected that the impacts of the El-Niño on food security and agricultural livelihoods will continue to be felt right through into 2017. Although this has had a detrimental effect on the whole of Southern Africa, people living in rural areas have been have been more severely impacted, due to their pre-existing vulnerability and their inability to withstand the impact of this weather event (UNRCO, 2016).

The timing of data collection in this study, provides a unique opportunity for future research to assess the impact that an El-Niño event has on a variety of research areas. This research could explore; communal rangeland biomass and subcanopy structure; resource availability and rural households' perceptions of resource availability in communal rangelands, and 3 households resource use and food security. The above research opportunities are all crucial in the face of climate change., especially considering that the majority of food-insecure

South Africans live in resource poor rural areas (Shisana *et al*. 2014), and such weather-related shock, as recently experienced, is likely to translate into even more severe food insecurities (FAO, 2008; Nhemachena *et al.* 2010; Nelson, 2010; Shields and Fletcher, 2013). The need for this research is further exacerbated by the looming notion that climate variability is expected to become more pronounced in the future. Research suggests that, rural households will likely increase their dependence on natural resources to ensure their survival.

5.4. References

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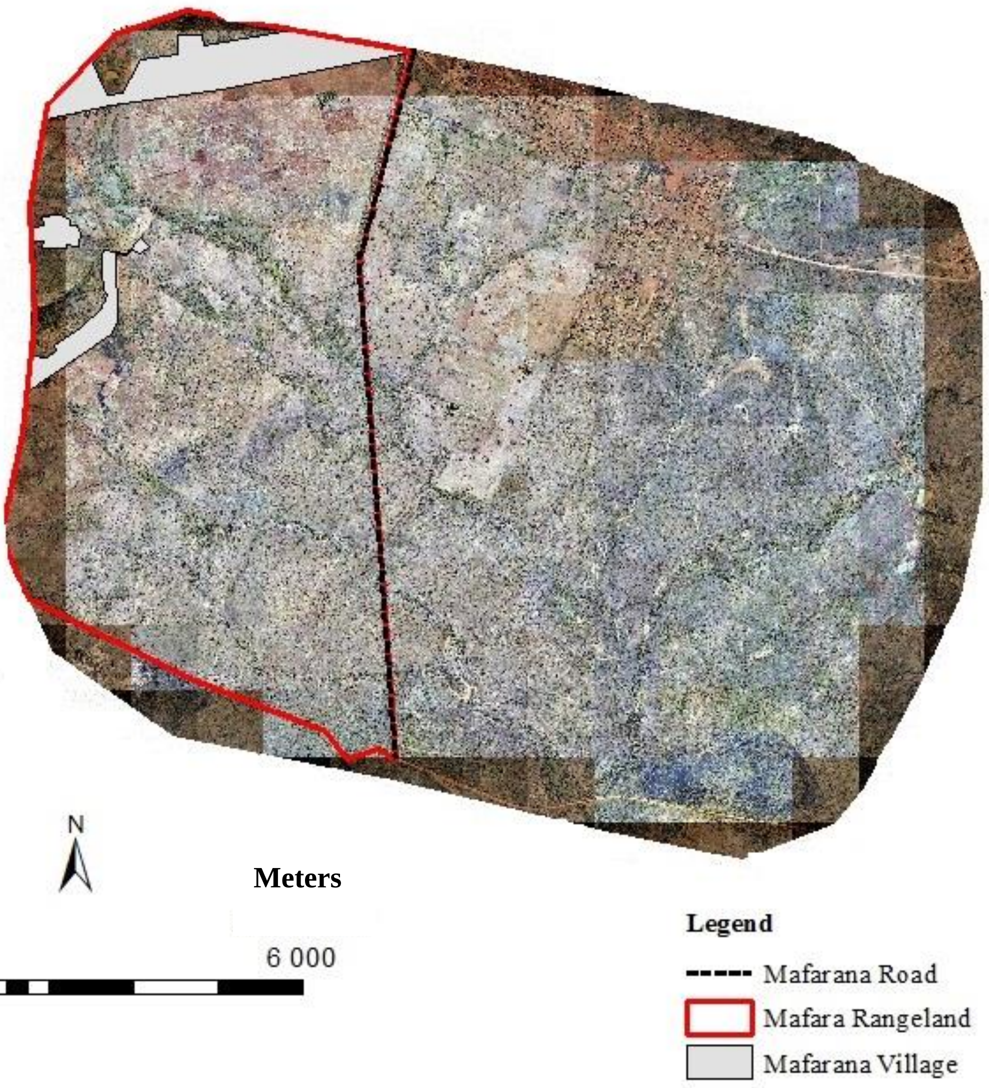
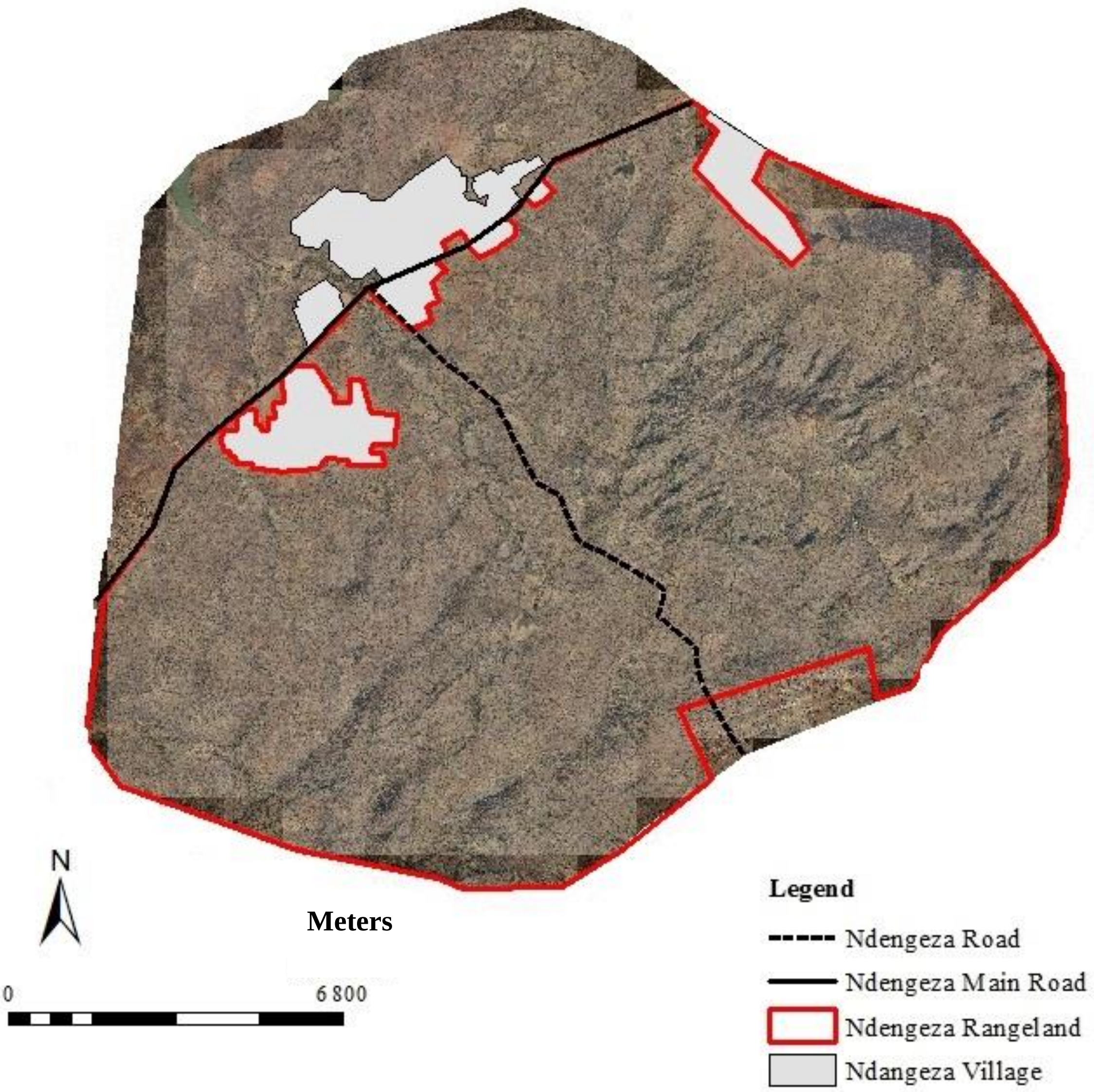
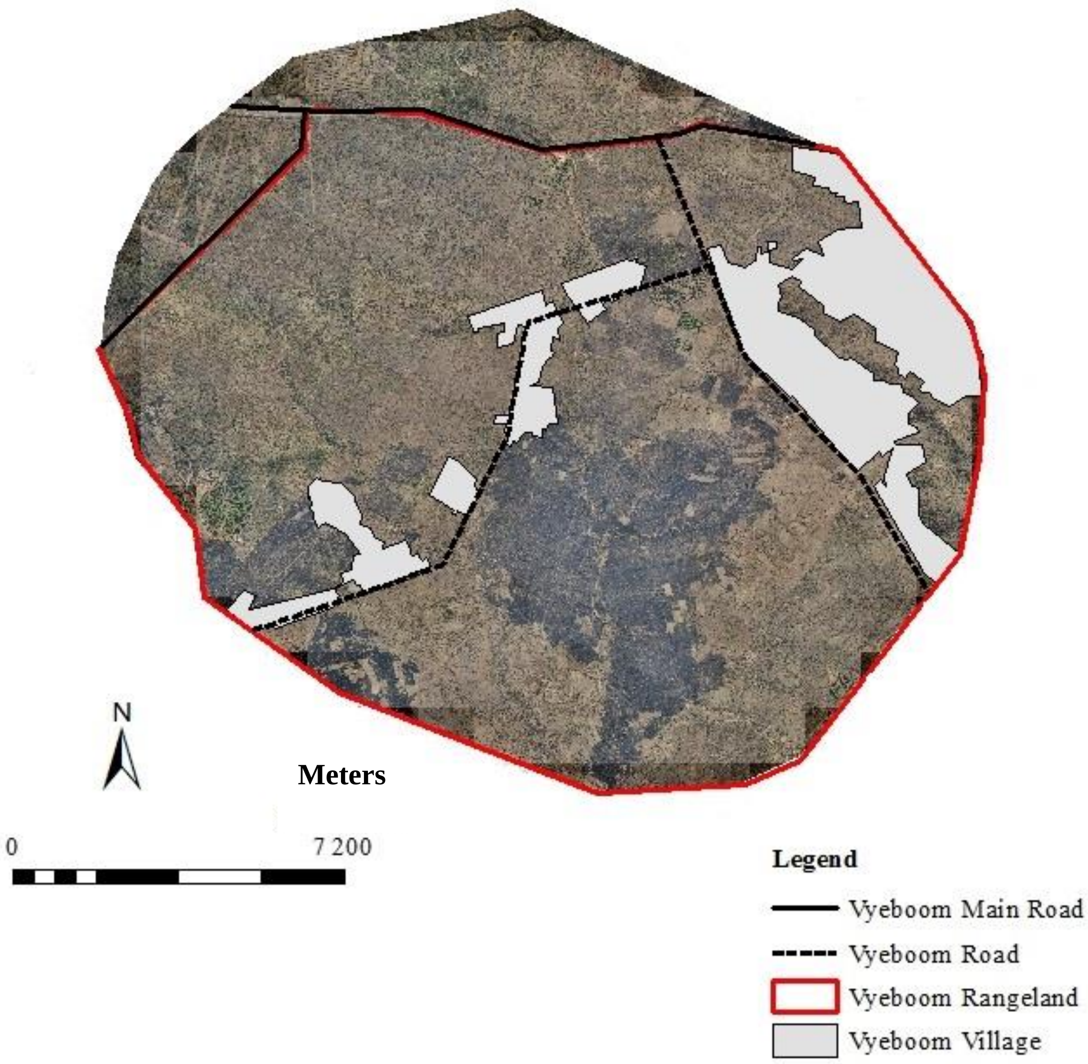
5.5. Appendices



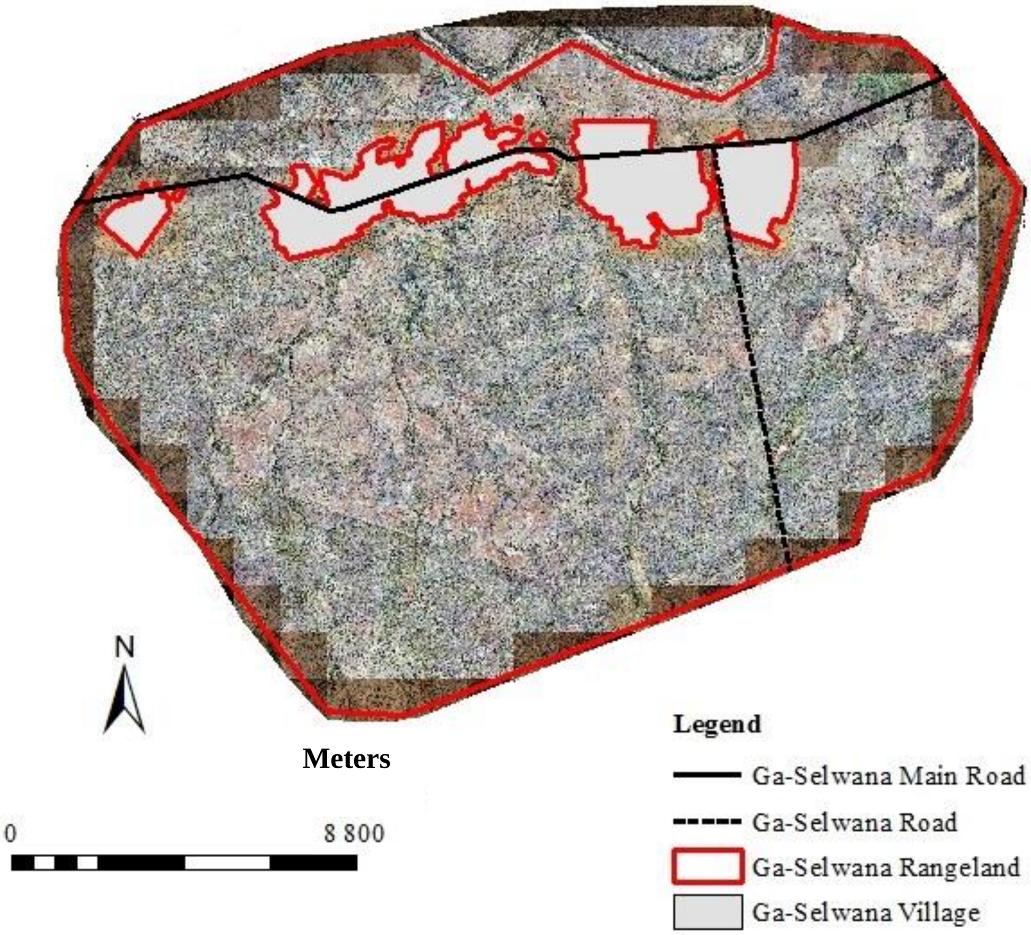
Appendix 1. Map of the Mafarana village area (e.g. roads, villages, rangeland area), manually digitized in ArcMapTM V10.4 (ESRI ®2014-2016) using the orthophotos of the village study area, Limpopo Province, South Africa.



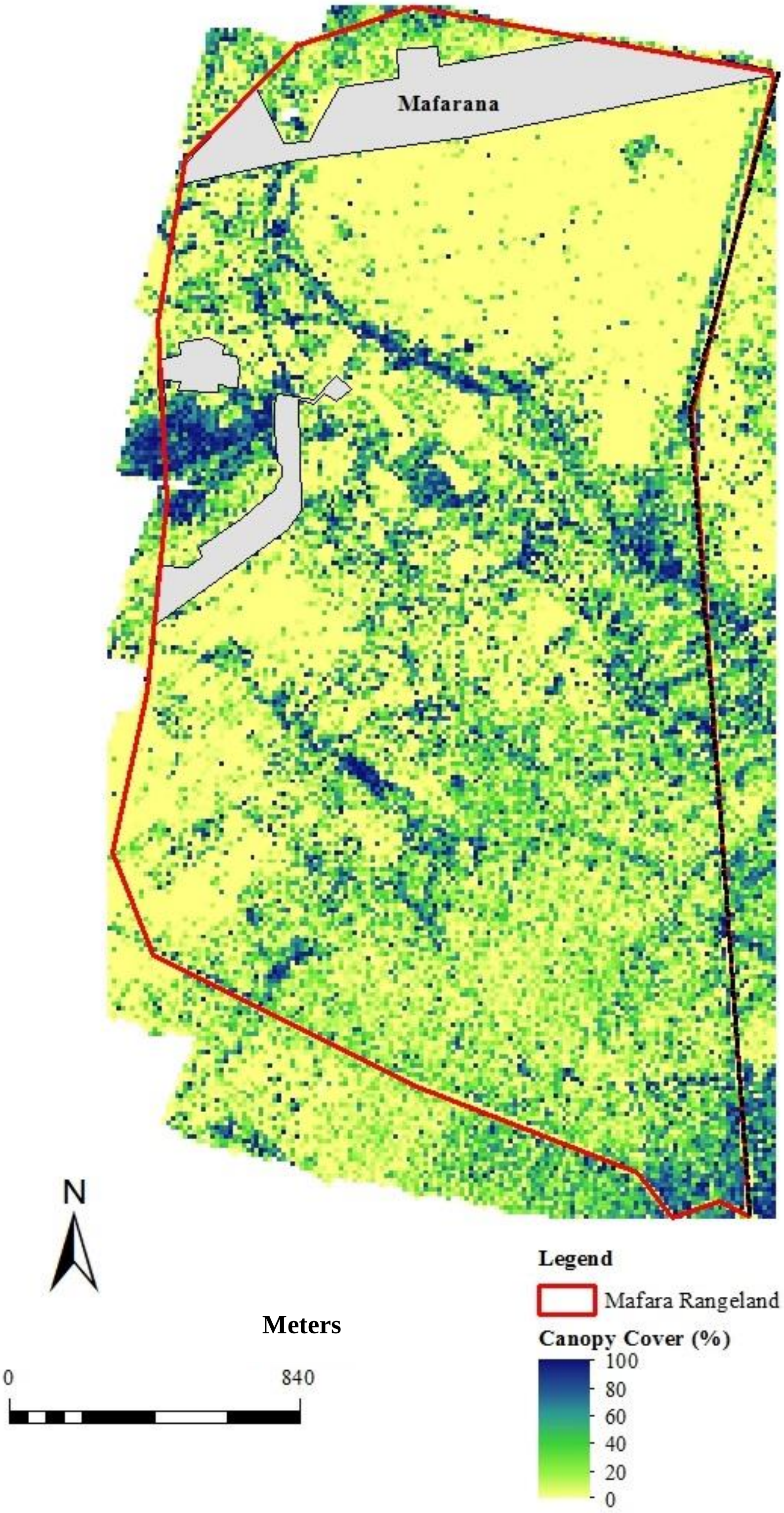
Appendix 2. Map of the Ka-Ndengeza village area (e.g. roads, villages, rangeland area), manually digitized in ArcMapTM V10.4 (ESRI ®2014-2016) using the orthophotos of the village study area, Limpopo Province, South Africa.



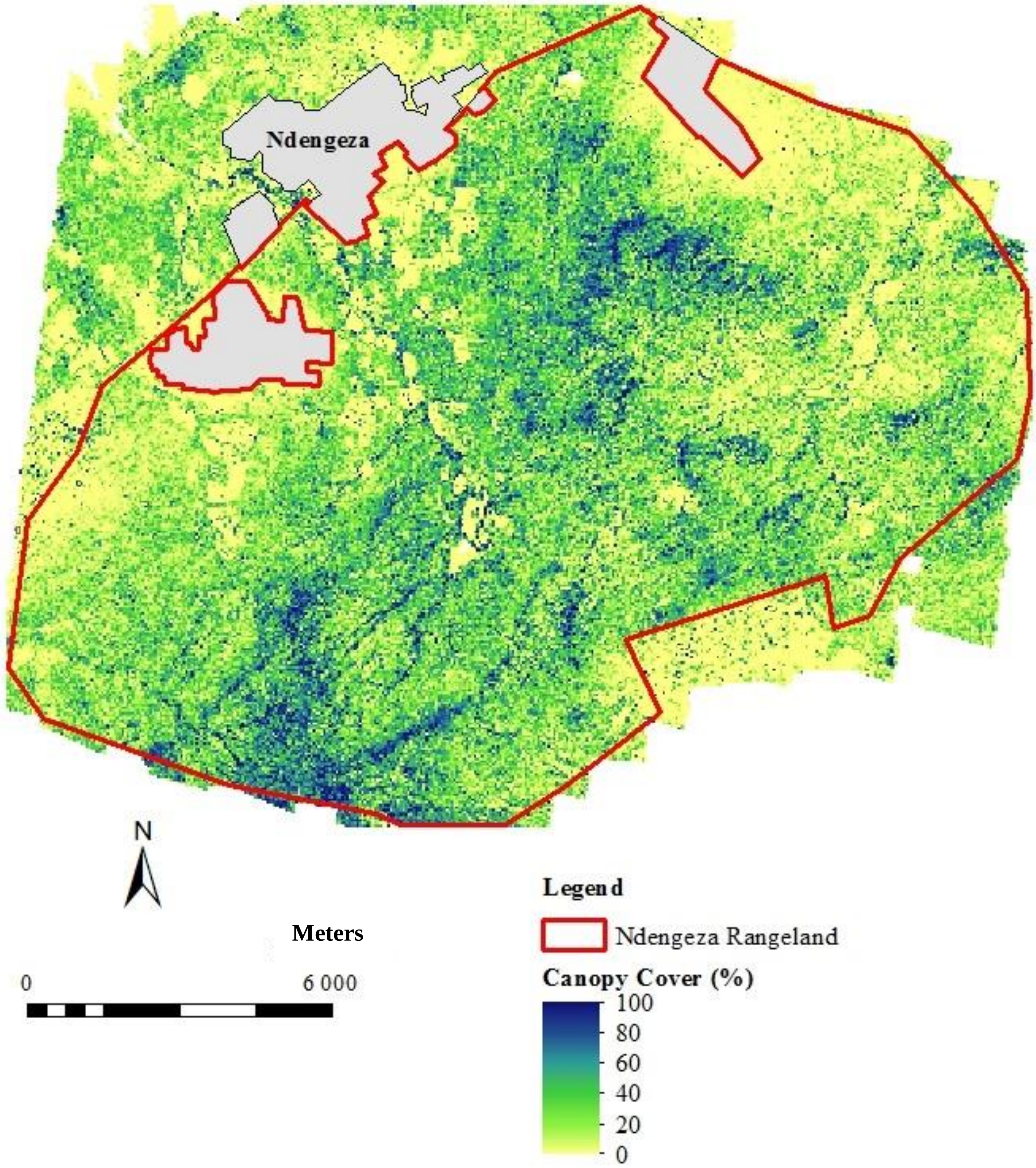
Appendix 3. Map of the Vyeboom village area (e.g. roads, villages, rangeland area), manually digitized in ArcMapTM V10.4 (ESRI ®2014-2016) using the orthophotos of the village study area, Limpopo Province, South Africa.



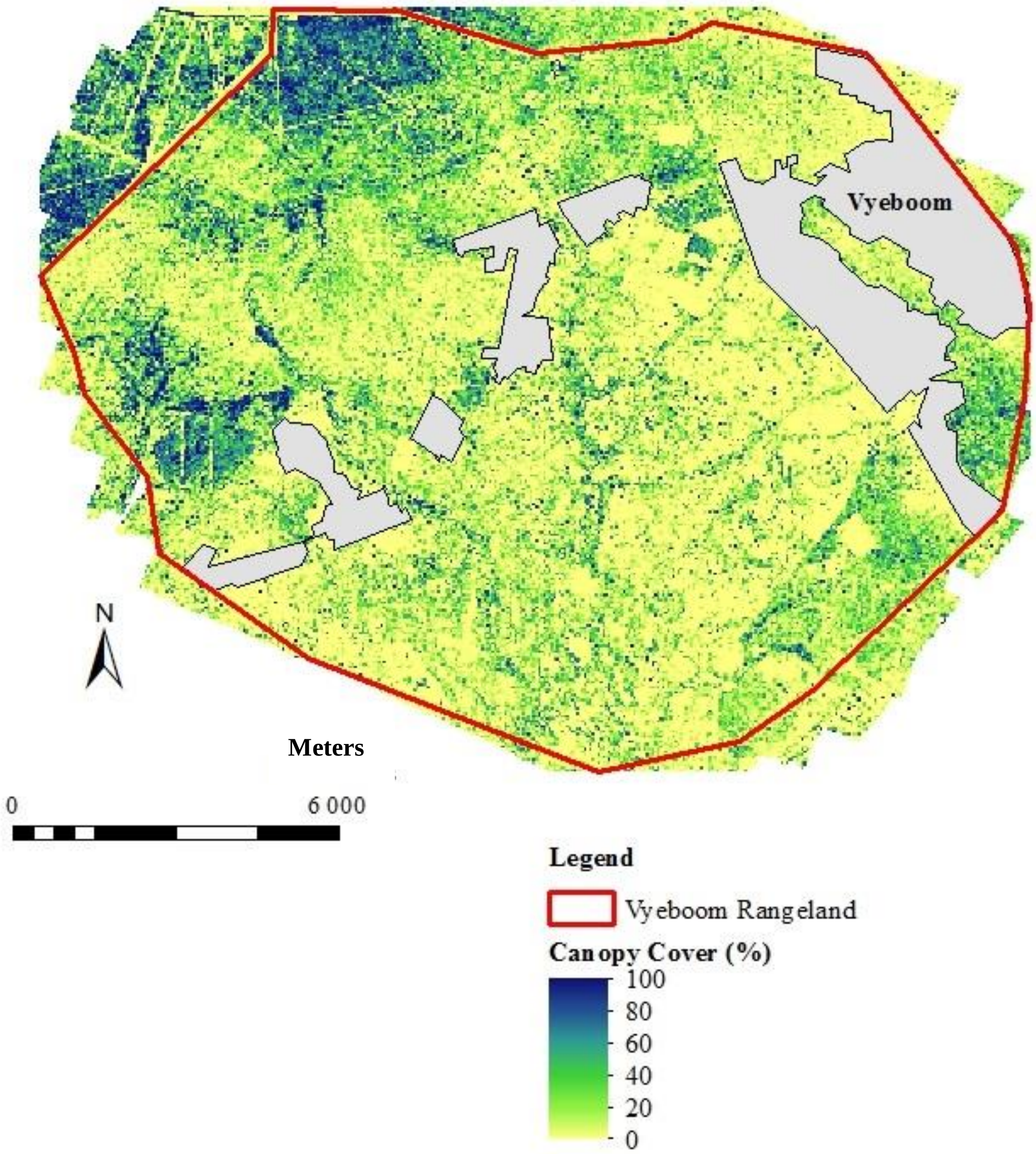
Appendix 4. Map of the Ga-Selwana village area (e.g. roads, villages, rangeland area), manually digitized in ArcMapTM V10.4 (ESRI ®2014-2016) using the orthophotos of the village study area, Limpopo Province, South Africa.



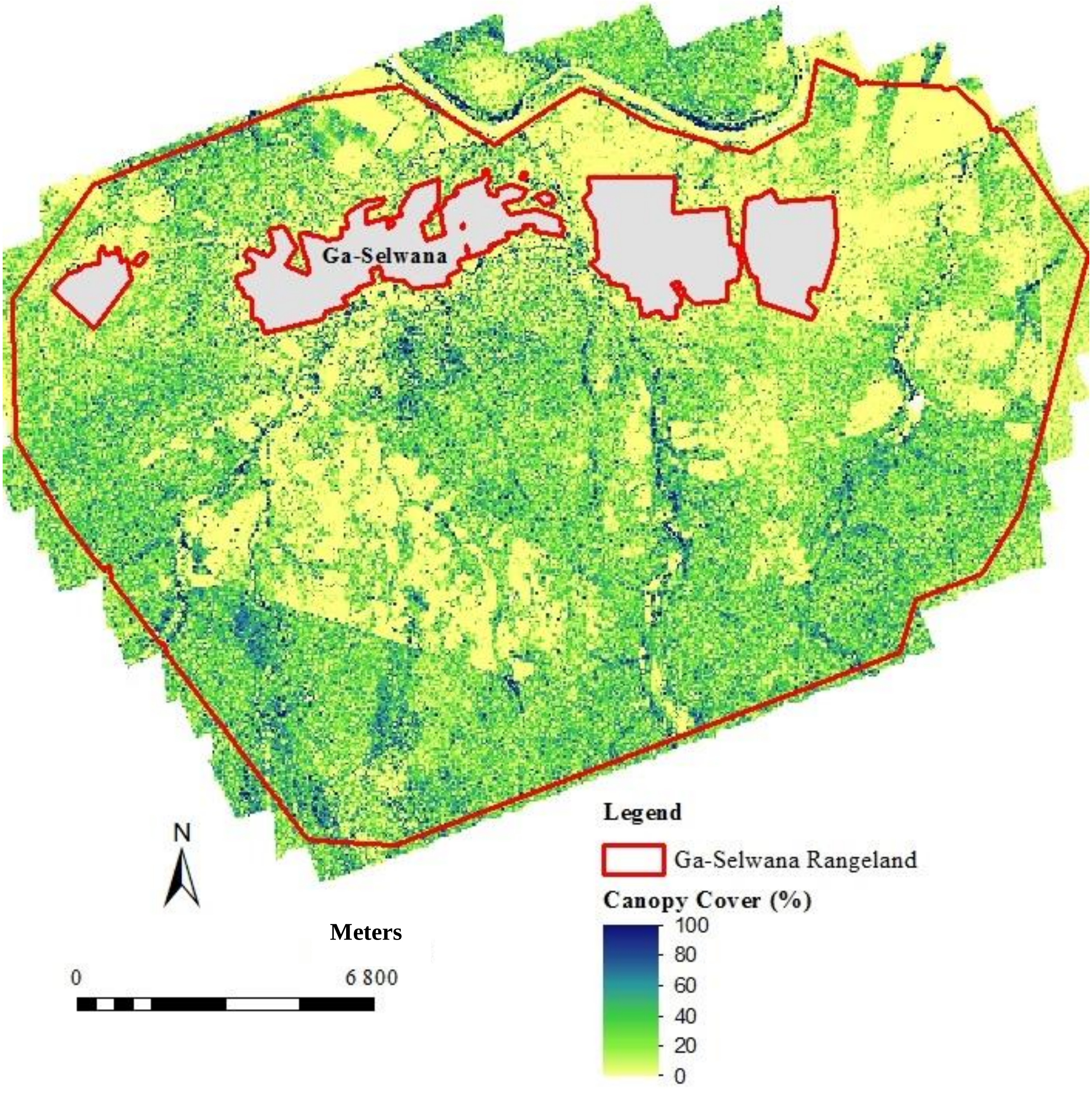
Appendix 5. Canopy Cover of Marana's communal rangeland, in 25 x25 m grid cells, Limpopo Province, South Africa.



Appendix 6. Canopy Cover of Ka-Ndengeza’s communal rangeland, in 25 x25 m grid cells, Limpopo Province, South Africa.



Appendix 7. Canopy Cover of Vyeboom's communal rangeland, in 25 x25 m grid cells, Limpopo Province, South Africa.



Appendix 8. Canopy Cover of Ga-Selwana's communal rangeland, in 25 x25 m grid cells, Limpopo Province, South Africa.

Appendix 9. Households Resource Use Questionnaire 2015

DETAILS OF THE HOUSEHOLD

Name of head of household:

Indicate if translation used: Yes ☐ No ☐

Household agreed to Participate: Yes ☐ No ☐

Informed Consent Obtained: Yes ☐ No ☐

Completed interview successfully: Yes ☐ No ☐

Village Name:

Village Code:

Date:

Start Time:

End Time:

Questionnaire Number:

Recording Number:

Household GPS Location:
S
E

***The questionnaire is to be administered to the oldest woman in the household and / or another member who is knowledgeable about the living arrangements and household spending patterns and resources use.**

Questionnaire Number:		Recording Number:

SECTION A: HOUSEHOLD INFORMATION

1. How many people permanently reside in your household? (eat meals together at least 4 days a week)

2. How many members of this household are migrants? (away for more than 3 nights a week, studying, working, looking for work)

3. Ages of household members (Indicate migrant and non-migrant)

   a. How many members of your household are over 45 years old?

	Migrant		Non-migrant	

   b. How many members of your household are between 18 and 45 years old?

	Migrant		Non-migrant	

   c. How many members of your household are younger than 18 years old?

	Migrant		Non-migrant	

4. Now I would like to ask you about your families employment:

   a. How many people in your household are permanently employed?

   b. How many people in your household are temporarily employed?

5. How many rooms are in your homestead?

SECTION B: HOUSEHOLD INCOME AND EXPENDITURE

6. Does your household have any of the following items? (Please also indicate quantity if applicable)

			Yes / No	**Number**
Grants		Child support		
		Disability support		
		Pension		
		Foster care support		
Agriculture/Livestock		Field/Orchards on homestead		
		Field/Orchards in communal lands		
		Goats		
		Donkeys		
		Chickens/guinea fowl		
		Cattle (how many)		
Essential bought items		Electricity		
		Fridge		
		Freezer		
Non-essential bought items	**Utility**	Car		
		Donkey cart		
		Stove		
	Luxury	TV		
		DSTV		
		Radio		

7. Now I would like to ask about your household's total income last month.
Last month, how much money did this household receive from the following sources?

Source		**Amount (Rands)**
1	Salaries or wages from people living in the household	
2	Remittances (money sent from members of this household who are away most of the time)	
3	Trade (income from selling something e.g. Clothes, vegetables, crafts, retail goods)	
4	Other self-employment (e.g. fixing cars, doing building, hair dressing)	
5	Social grants (e.g. child support grants, old age pensions etc.)	
6	Financial support from friends or relatives	
7	Estimate total income last month from all sources	
8	Category of total household income last month from all sources	

Key 1: Monthly income
1 = Less than R100
2 = Less than R500

1 = R500 - R1, 000

2 = R1, 000 – R1, 999

3 = R2, 000 – R4, 999
4 = R5, 000 – R9, 999
5 = R10, 000 – R19, 999
6 = R20, 000 or more

8. What does the household spend in a month and a year on the following?

Source		Indicate average monthly or yearly amount.	
		Monthly	**Yearly**
1	Food and groceries (excluding fuels)		
2	Clothes		
3	Transport		
4	Repayment of loans		
5	Savings including saving clubs, including stokvel		
6	Church contributions		
7	Burial society		
8	Water		
9	Furniture, appliances		
10	Medical expenses		
11	School / tertiary education fees		
12	Telephone (mobile)		
13	Labour (home help, gardeners, cooks etc)		
14	Eating / drinking outside the home		
15	Electricity		
16	DSTV		
17	Other (specify)e.g. lawyer, remittances…………………...		

SECTION C: USE OF NATURAL RESOURCES

9. Did this household use any of the following resources during the past 12 months?

	a	**b**	**c**	**d**
	Used	How often do you use this resource when it is in season?	How many months in the last 12 months was this resource used?	How much of this resource do you use per month?
Firewood				
Wood to make charcoal				
Mushrooms / wild vegetables				
Fruits				
Honey				
Medicinal plants				
Other				

Key 2: Frequency of use / collection / buying

1 = less often than 1 x per month (e.g. once every 6 weeks)

2 = Once a month

3 = Between 1 – 4 times a month (Once a week)

4 = More than 1 x per week (more than 4 x per month)

Key 3: Volume unit

1 = Mug

2 = 5 litre bucket

3 = 10 litre bucket

4 = 20 litre bucket

5 = Bundle / Basket

6 = 50 kg maize meal bag

7 = 80 kg maize meal bag

8 = Wheelbarrow

9 = *Bakkie*-load

10 = Individual (e.g. fish)

11 = head Load

12 = plastic bag

10. Now I would like to ask you about where you get your resources.

	a	b	c	d	e
	Did this household collect this resource?	Did this household buy this resource?	Where did you collect / buy this resource?	Frequency of collection / buying when in season?	What is the local price per unit of this resource?
Firewood					
Wood to make charcoal					
Mushrooms / wild vegetables					
Fruits					
Honey					
Medicinal plants					
Other					

11. What type of trees do you use for firewood at the present time? (Please list them in order of the type of tree you prefer to use the most?)

Local Name		**Scientific Name (fill in later)**
a		
b		
c		
d		
e		

aaaaaaa

12. Did anybody in this household sell any of the following natural products in the last 12 months?

		a	b	c	d
Product / Material		**Sold?** (1 = Yes, 0=No, X = Don 't know)	**Number of months in last 12 months in which this was sold?** (X = Don 't)	**Average income per month when sold** (X = Don 't)	**Total income over 12 months** (X = Don 't)
1	Firewood				
2	Furniture made from wood from the bush				
3	Wooden carvings				
4	Poles				
5	Reed mats				
6	Beer				
7	Nuts				
8	Fresh wild fruit				
9	Wild Vegetables				
10	Edible insects				
11	Thatching grass				
12	Twig hand brooms				
13	Grass hand brooms				
14	Medicinal Plants				
15	Other				

13. Has there been any change in the availability of the following resources around this village over the past 5 years?

		a	b	c
Resource		**Change in supply of resources** (1 = Decrease, 2 = Increase, 0 = No Change, X = Don't Know)	**Local name of the species most affected if there has been a change** ***<u>(Only one)</u>*** (X – Don't Know, - Not Applicable)	**Reason in perceived change in supply?**
1	Fire wood			
2	Wild fruits			
3	Wild Vegetables			
4	Edible Insects			
5	Bush meat			
6	Medicinal Plants			
7	Reeds for mats			

SECTION D: FOOD AND NUTRITION SECURITY

14. Did this household plant any crops in the past 12 months?

1 = Yes 0 = No	

15. How many fields outside the homestead does this household own?

____

16. Which crops did your household grow in your homestead yard or fields outside your homestead in the past 12 months?

		a	**b**	**c**	**d**	**e**
Type of crop		**Grown in the past 12 months?** **(**1 = Yes, 0=No)	**Where was this grown?**	**Did this homestead sell any of this resource?**	**Total amount sold?**	**Income per season?**
1	Maize					
2	Peanuts					
3	Cow pea					
4	Pumpkin					
5	Pumpkin leaves					
6	Squash					
7	Sweet Potato					
8	Sorghum					
9	Water Melon					
10	Spinach					
11	Cucumber					
12	Tomatoes					
13	Onions					
14	Carrots					
15	Beetroot					
16	Lettuce					
17	Cabbage					
18	Green peppers					
19	Chilli’s					
20	Mangos					
21	Paw					
22	Guavas					
23	Bananas					
24	Peaches					
25	Avocado					

13	Sugars	Sugar (including in tea), honey, jam, sweets & chocolate, syrup, cool drinks	

17. I would like to ask you about food that you or other permanent residents in your household ate yesterday during the day and at night, at home or elsewhere.
Was yesterday a normal day for your household, concerning food you ate (i.e no funeral, feast or special occasion)?

1 = Yes 0 = No	

If it was an unusual day, please choose another day of the previous week that was normal for answering the next question.

18. Since yesterday, did you or anyone in your household consume the following?

Eating Occasion		1 = Yes 0 = No
1	Any food before the morning meal	
2	The morning meal	
3	Any food between the morning and midday meal	
4	The Midday meal	
5	Any food between the midday and evening meal	
6	The evening meal	
7	Any food after the evening meal	

19. Did you or anyone else in the household eat at least one of the following foods yesterday during the day and night?

Food group		**Examples**	**1** = Yes **0** = No
1	Maize or maize products	Mielies (sweet corn), pap, soft maize porridge, samp, mageu	
2	Other cereals	Rice, sorghum, wheat, oats, mabella, pasta, bread, breakfast cereals, biscuits, vetkoek, any other food made from flour	
3	Roots and Tubers	Potatoes, potato chips, cassava roots, sweet potatoes	
4	Vitamin A-rich fruit	Mango, paw, yellow peach	
5	Other fruit	Apple, banana, guava, avocado, orange, naartjie, lemon, grape, raisin, melon, grapefruit, pineapple, mulberry, wild fruit (e.g. marula), dried fruit, jam	
6	Vitamin A-rich vegetables	Butternut, carrot, pumpkin, spinach, muroho	
7	Other Vegetables	Beetroot, tomato, cabbage, cauliflower, broccoli, green & red pepper, lettuce, onion, mushroom, etc.	
8	Meat, poultry and fish	Beef, pork, mutton, chicken, turkey, guinea fowl, game, wild birds, fish, edible insects, sausage, canned meat, polony	
9	Eggs	Eggs	
10	Legumes, nuts and seeds	Beans, peas, lentils, cow peas, bambara nuts, peanuts, marula nuts, sunflower seeds, pumpkin seeds	
11	Dairy products	Milk, maas, yoghurt, condensed milk, milk powder, chocolate	
12	Oils and fats	Any food made with cooking oil, margarine or butter	

1 = Yes 0 = No	

20. Over the past **12 months**:

a. Has your household ever experienced a shortage of food?

b. Which were the worst months? (Name the months separated by commas)

21. What was the main cause of the food shortage? (List the shortages, separated by commas)

22. Please thing to what has happened in your household in the last 30 days, and tell me how often you have experienced the following situations which I will read. The options are never (zero times), rarely (1-2 times), sometimes (3-10 times) or often (more than 10 times) in the last 30 days.

Household food insecurity and access scale		**Frequency**
1	How often was there no food at all in your household because there was not enough money to buy enough food?	
2	How often were you or any member of your household hungry when you went to sleep at night because there was not enough food?	
3	How often did you or any member of your household go a whole day without eating anything because there was not enough food?	

23. What was the main cause of the food shortage? (List the shortages, separated by commas)

24. Did everyone in your household have enough food to eat last night?

1 = Yes 0 = No	

25. In the last 7 days, have you reduced the size of servings of food served to household members because of a shortage of food?

1 = Yes 0 = No	

26. In the last 7 days, has this household eaten food you don’t enjoy because of a shortage of food?

1 = Yes 0 = No	

27. In the last 7 days, has this household reduced the number of meals eaten per day because of a shortage of food?

1 = Yes 0 = No	

28. In the last 7 days, has your household asked neighbours, friends or household for food because of a shortage of food?

1 = Yes 0 = No	

Appendix 10. Verbal Consent Form

The following form should be formally signed once the participant has read and understood the information sheet and has agreed to take time to participate in the research project.

The boxes should be checked only once the participant has been briefed about the project (time, process, safety from disclosure) and a signature should be obtained once he/she has agreed to be interviewed.

---

1. The participant was invited to participate in the research project conducted by Ms Veronique Evans from the University of the Witwatersrand and he/she has read the participation sheet and understands his/her role in the study.
   Yes ☐ **No** ☐
2. The participant understands that the project is designed to gather information for academic purposes and may only be indirectly beneficial in informing his/her community about energy usage in and around the village.
   Yes ☐ **No** ☐
3. The participant understands that this interview will be audio-recorded for the purposes of cross referencing answers during the study and has agreed to allow the interview to be audio-recorded.
   Yes ☐ **No** ☐
4. The participant understands that this project is voluntary and he/she will not be paid for their participation.
   Yes ☐ **No** ☐
5. The participant is aware of time required to conduct the interview.
   Yes ☐ **No** ☐
6. The participant is aware that he/she may withdraw and discontinue participation at any time without any penalty.
   Yes ☐ **No** ☐
7. The participant is aware that he/she may refuse to answer any question and/or end the interview if he/she is uncomfortable with it.
   Yes ☐ **No** ☐
8. The Participant understands that the researcher will not identify him/her by name in any reports using information obtained from this interview. The information collected will remain confidential and anonymous at all times.
   Yes ☐ **No** ☐
9. The participant has volunteered to participate in the research project and has agreed to be one of the households being interviewed, i.e. **Participant Consent Obtained:**
   Yes ☐ **No** ☐

Participants Signature	**Researchers Signature**	**Date:**

Appendix 11. Coding

Part A: Household Information		
Question		
1	Count	Count
2	Count	Count
3a	Count >45_N	
	Count >45_M	
3b	Count 18-45_N	
	Count 18-45_M	
3c	Count <18_N	
	Count <18_M	
4a	Count	
4b	Count	
5	Count	
Section B: Household Income and expenditure		
6	No	0
	Yes	Count
7	0	0
	R1-R99	1
	R100-R499	2
	R500-R999	3
	R1000-R1999	4
	R2000-R4999	5
	R5000-R9999	6
	R10000-R19999	7
	>R20000	8
8	0	0
	R1-R99	1
	R100-R499	2
	R500-R999	3
	R1000-R1999	4
	R2000-R4999	5
	R5000-R9999	6
	R10000-R19999	7
	>R20000	8
Section C: Use of Natural Resources		
9a	No	0
	Yes	1
9b	N/A	0
	less often than 1 x per month (e.g. once every 6 weeks)	1
	Between 1 x per month and 1 x per week (1 -4 per month)	2
	More than 1 x per week (more than 4 x per month)	3
9c	Count	

9d	Mug	1
	5 litre bucket	2
	10 litre bucket	3
	20 litre bucket	4
	Bundle	5
	50 kg maize meal bag	6
	80 kg maize meal bag	7
	Wheelbarrow	8
	Bakkie load	9
	Individual (e.g. fish)	10
	headload	11
	Plastic packet	12
10a	No	0
	Yes	1
10b	No	0
	Yes	1
10c	Descriptive	
10d	less often than 1 x per month (e.g. once every 6 weeks)	1
	Between 1 x per month and 1 x per week (1 -4 per month)	2
	More than 1 x per week (more than 4 x per month)	3
10e	0	0
	<R49	1
	R50-R99	2
	R100-R249	3
	R250-R499	4
	>R500	5
11		
a	Descriptive	
b	Descriptive	
c	Descriptive	
d	Descriptive	
e	Descriptive	
12a	No	0
	Yes	1
	Dont know	3
12b	Count	
12c	0	0
	<R49	1
	R50-R99	2
	R100-R249	3
	R250-R499	4
	>R500	5
12d	R 0	0
	<R499	1

	R500-R999	2
	R1000-R1999	3
	>R2000	4
13a	No Change	0
	Decrease	1
	Increase	2
	Dont know	3
13b	Descriptive	
13c	Descriptive	
Section D: Food and Nutrient Security		
14	No	0
	Yes	1
15	Count	
16a	No	0
	Yes	1
16b	N/A	0
	Homestead	1
	Communal rangelands	2
	Both	3
16c	No	0
	Yes	1
16d	Count	
16e	<R49	1
	R50-R99	2
	R100-R249	3
	R250-R499	4
	R500-R999	5
	R1000-R1999	6
17	No	0
	Yes	1
18	No	0
	Yes	1
19	No	0
	Yes	1
20a	No	0
	Yes	1
20b	Descriptive	
21	No food shortage	0
	Crops failed	1
	Not enough money because of unemployment	2
	Not enough money because household member was retrenched	3
	Not enough money because the breadwinner passed away	4
	Not enough money because the breadwinner was ill	5
	Not enough money because a pensioner passed away	6

	Person who grew the crops passed away	7
	Person who grew the crops was ill	8
	Drought	9
	Other (Specify)	10
22	Never	0
	Rarely	1
	Sometimes	2
	Often	3
23	No food shortage	0
	Crops failed	1
	Not enough money because of unemployment	2
	Not enough money because household member was retrenched	3
	Not enough money because the breadwinner passed away	4
	Not enough money because the breadwinner was ill	5
	Not enough money because a pensioner passed away	6
	Person who grew the crops passed away	7
	Person who grew the crops was ill	8
	Drought	9
	Other (Specify)	10
24	No	0
	Yes	1
25	No	0
	Yes	1
26	No	0
	Yes	1
27	No	0
	Yes	1
28	No	0
	Yes	1