THE SPATIO-TEMPORAL DYNAMICS OF WOODY BIOMASS SUPPLY AND DEMAND IN RESPONSE TO HUMAN UTILISATION IN AN AFRICAN SAVANNA WOODLAND

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A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

September 19, 2012 in Johannesburg, South Africa

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Ruwadzano Matsika

Submitted on 19 September 2012 in Johannesburg, South Africa

Abstract

The thesis presents a thorough, in-depth study that fills some of the gaps in the knowledge of the impacts of woodland utilisation in communal areas. The chosen case study villages are in Bushbuckridge, a government gazetted Integrated Sustainable Rural Development programme node, making the results pertinent to sustainable energy policy reform in South Africa. A case-study of two villages was used to investigate the spatial and structural changes in fuelwood supply in response to fuelwood extraction as well as the changes in use-patterns over time. A survey of the structure and composition of the woody vegetation and wood harvesting patterns around the villages was conducted and compared against historical data, spanning 17 years. Total wood stock in the communal woodlands of both villages declined over the study period; the loss being greater in Welverdiend. Significant, negative change in the structure and species composition, particularly of species that are commonly harvested for fuelwood has occurred in Welverdiend but not in Athol. The absence of negative impacts in Athol implies that harvesting regimes here are more sustainable but it is more likely that this is due to the lower human population and lower fuelwood extraction pressure. The changes in woodland structure were linked to landcover change patterns that occurred in the villages over the last 44 years, from their creation through forced resettlements on old farms in the area. Landcover change patterns were similar in both villages since 1965 but there was significantly greater woodland loss in Welverdiend (48% woodland loss) in comparison to Athol (25% woodland loss). The systematic loss of woodland areas to agricultural fields was linked to expanding residential areas due to human population growth. Deforestation occurred where woodlands were already impacted through selective harvesting. The physical changes in woodland structure and landcover were linked to a detailed socio-economic analysis of the two villages, providing critically important data for the sustainable management of woodlands in South Africa. The impact of access to electricity on fuelwood consumption rates was carried out through analysis of the economic, time and opportunity costs of fuelwood collection, compared against the different fuelwood availability in each village. In Welverdiend demand for fuelwood has so far proved inelastic; households have adjusted their fuelwood collection regimes, going on fewer collection trips but spending longer times for each trip but ultimately household investment is similar to that in Athol. Fuelwood demand is maintained in Welverdiend by the availability of purchased fuelwood and harvesting in new sites. A model to predict the socio-economic factors at the household and per capita level which affect fuelwood consumption was developed. Revealing in the process that households with access to electricity used less fuelwood annually and the amounts of fuelwood used were influenced by the household perceptions of fuelwood scarcity in the village, Household population size had a direct bearing on the likelihood of households switching to electricity with every addition to the household size decreasing the likelihood of switching by 48%. This study has major implications for the government’s on-going rural electrification programme. Interventions are required that raise awareness about fuelwood availability trends, based on landscape developments and targeting women as the main users of fuelwood.

For my mother, Katherine, who has always been there and for my father, Greenwell, who never got to see me succeed.

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"*To make an end is to make a beginning*"*- T.S. Elliot*

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Chapter 1

1. Introduction

1.1 Problem statement and rationale for the study

Why is there need for yet another African fuelwood study? The need for this research was driven by the observed continuing use and dependence on woodfuels in rural and urban southern Africa, mostly in the form of fuelwood and charcoal, despite the availability of other cleaner energy options such as electricity. The intention was to provide information about the factors that drive energy choices in rural southern Africa, the environmental implications of the continued dependence on woody biomass, and the policy implications of these findings. The lack of up-to-date and reliable information about the status quo of the environmental and social dimensions of the continued use of fuelwood is a major factor hindering the development of such models and instituting adequate national policy and planning (Shackleton *et al* 2007b). The strength of this study is that it compares current state of the fuelwood resource base and fuelwood extraction and use patterns with earlier data in the study area. In doing so this study provides new insights into how rural wood-energy systems have changed over time in South Africa.

The Fuelwood Problem has been the source of major debate in the sustainable development arena for over 30 years and still, there is no clear consensus on the sustainability of wood-based energy systems (de Montalambert & Clement 1983, Dewees 1989, Arnold *et al* 2006). The much-debated "problem" revolves around the nature of the environmental impacts, whether deforestation or degradation (Grainger 1999, Geist & Lambin 2001), the prediction of widespread fuelwood shortages (de Montalambert & Clement 1983)) and the social and health consequences that have been linked to the use of fuelwood (de Montalambert & Clement 1983, Dewees 1989, Arnold *et al* 2006). Fuelwood remains the dominant domestic energy source for rural households in southern Africa (Karekezi 2002, IEA 2010), despite the availability of electricity in many rural areas, particularly in South Africa (UNDP & WHO 2009). This highlights the continued importance of wood as a cheap or free renewable energy source in the context of widespread poverty. The wood resource base around rural settlements is coming under increasing pressure from harvesting to meet both local and external demands, especially in areas of high human density, such as rural areas in South Africa. At the same time, institutional governance of common property woodlands resources is weakening across the sub-region (Twine 2005, Kirkland *et al* 2007). The sustainability of fuelwood harvesting thus remains a highly topical issue, with important implications for both the environment and human well being. Furthermore with time has come the realisation that the predicted collapse of the fuelwood resource base has not occurred to the extent anticipated. These models have either overestimated consumption or underestimated the regenerative capacity of savannas and human adaptive capacity in light of changes in fuelwood availability (Dewees 1989, Arnold *et al* 2003). Importantly, most models developed to simulate rural energy systems were based on simplistic assumptions or sub-models of wood supply and production. There is thus a need for better, more ecologically realistic models which predict the production of fuelwood at different scales.

This study contributes to the knowledge about the sustainability of wood-based rural energy systems in Africa, specifically in terms of the stability of the biomass resource-base over time and the development of rural socio-ecological landscapes. The colonial and post-colonial histories of many Sub-Saharan countries has created country-specific rural communal landscapes that bear similar legacies as a direct result of government policies that were prejudiced against indigenous populations along racial lines (Adams *et al* 1999, UNECA 2003). Poor infrastructure, low economic development and high dependence on ecosystem services from the immediate natural environment are characteristic of these landscapes (Adams *et al* 1999, UNECA 2003). Thus the outcomes and implications of this research are broadly applicable within the context of rural African environmental and economic development issues. This body of work will enhance the understanding of rural energy systems as a whole. Given the link between energy security and economic development (UNDP 2005), such information is of absolute importance today, to all stakeholders concerned with addressing issues of sustainable development, energy security, poverty alleviation and the reduction of environmental degradation across the communal savanna rangelands of southern Africa.

1.2 Biomass energy: the mainstay of the poor

Reliance on biomass energy is highest amongst the developing countries (UNDP & WHO 2009, IEA 2010). There is a direct relationship between the extent of household use of biomass to meet domestic energy needs and the degree of impoverishment of a country (IEA 2000, UNDP 2003). Generally, the poorer the nation, the higher the dependence of its populace on biomass energy to meet its primary domestic needs. As such, energy security is central to the achievement of poverty alleviation and ultimately sustainable development in developing countries. Policy interventions to ensure this have been focused on facilitating the switch from traditional biomass energy, mostly in the form of fuelwood and charcoal, to "cleaner" energy sources such as electricity through electrification programmes (Karekezi *et al* 2002).

Biomass energy, mainly from wood, charcoal, agricultural residues and animal wastes accounts for 49% of the total primary energy use in Africa (Karekezi 2002, IEA 2003). It is predominantly used to meet household domestic energy needs such as cooking, lighting, boiling water and space heating (Howells *et al* 2003). The exact figure of the proportion of households depending on biomass energy varies widely from region to region with the highest dependence being in Sub-Saharan Africa where over 70% of the population depends on this traditional source of energy (Hall 1994, Eberhard 1992, IEA 2002). Although biomass refers to fuelwood, charcoal, leaves, agricultural residue, animal and domestic waster, in Sub-Saharan Africa the bulk of biomass energy is derived from wood, either burnt directly as fuelwood or as processed charcoal (Karekezi *et al* 2004). The majority of the populations using biomass energy reside in rural areas (Shackleton & Shackleton 2000). In spite of the widespread rural electrification programmes that are prevalent in many sub Saharan African nations, the reliance on this energy source is set to increase, almost in parallel with the human population growth in the immediate future (Broadhead *et al* 2001, IEA 2003). The International Energy Agency (IEA) predicts that by 2030 biomass energy will still account for at least 75% of total residential energy in Africa (IEA 2002).

The dependence on biomass energy is supported by the large scale extraction of biomass in the form of woody plant material (trees and shrubs) from the remaining tropical forests and savanna woodlands of Africa (FAO 2003, Karekezi *et al* 2004). These woodland resources are free or cheap, abundant and renewable sources of energy and their use represents a safety net against the effects of widespread poverty (Shackleton & Shackleton 2002). There is a feedback relationship between poverty, (lack of) access to energy and environmental sustainability. The concerns about unsustainable woody biomass harvesting practices leading to environmental degradation and a negative feedback in the decline of human wellbeing are still valid (Twine *et al* 2003, FAO 2003, Biggs *et al* 2004, Kaschula *et al* 2005). Due to limited financial resources, most rural households are unable to make the transition to cleaner sources of energy, such as electricity as they cannot afford them or the appliances needed to fully utilise them (Williams & Shackleton 2002). As such these societies remain dependant on the free indigenous natural resources around them for their livelihoods (Twine *et al* 2003), especially the woodlands as a source of biomass energy (Biggs *et al* 2004). As such, fuelwood provision remains a vital ecosystem service, particularly in the savannas of southern Africa where household dependence on fuelwood is predicted to remain high (Karekezi *et al* 2004).

1.3 The fuelwood crisis: identifying the gap

In light of the recent increases in the price of crude oil and other fossil fuel derivatives such as paraffin and gas, fuelwood may become less economically feasible for poor low-income rural communities to access. The relevance of studying the sustainability of the continued extraction of woody biomass from the savannas of southern Africa cannot be emphasised enough. The current global situation of increasing crude oil prices and a resurgence of interest in energy alternatives is similar to the situation that arose in the 1970s during the time of the Energy Crisis, which in turn led to the “discovery” of the Fuelwood Crisis.

The “Fuelwood Crisis” came about in the mid 1970s after rising fossil fuel prices precipitated an energy crisis. This brought about the realization that a large and growing portion of the world’s population, especially in developing countries was dependant on fuelwood for energy (Eckholm 1975). With this came an interest in the potential impact of this continued, widespread dependence on the wood resource base at such a massive scale. The initial projections were based on rough estimates of the rates of fuelwood extraction held up against the annual growth rates of existing forests, which were used as proxies for sustainable fuelwood off-take (de Montalambert & Clement 1983, Dewees 1989, Arnold et al 2006). It was predicted that based on the then current fuelwood usage patterns and projected population growth rates, woodfuel demand would rapidly outstrip the available standing forest stocks in the immediate future. Future projections of increasing demand were linked to increasing human populations and projections of biomass productivity were carried out based on tropical forest standing stocks and annual productivity (de Montalambert & Clement 1983). As a result, predictions of fuelwood deficits between demand and the available woody biomass stock were identified across the developing world. It was thought that this gap would be filled by overcutting of available fuelwood stocks and that this would lead to widespread deforestation as fuelwood became increasingly scarce. These fuelwood gap theories predicted dire consequences if there was insufficient action to combat the fuelwood crisis. One such prediction was that by the year 2000, 2.4 billion people would be in situations of acute woodfuel scarcity (De Montalambert & Clement 1983) and that this would have serious negative implications on the wellbeing of these societies in terms of food security, quality of life, health and economic development.

The looming fuelwood gaps in the developing world and the severity of the predicted social and environmental consequences gave rise to the development of intervention programmes that would address the root causes, that is, the need for fuel for cooking (FAO 1981, de Montalambert & Clement 1983). These programmes included encouraging the use of fuelwood alternatives such as Liquid Petroleum Gas, LPG, and Kerosene/Paraffin and encouraged the development and use of improved wood-burning cook-stoves (Dewees 19898). Most low-income households could not afford to use the alternative fuel sources or the specialised appliances that were required to make use of them. Furthermore, the “improved” cookstoves were often engineered and tested in sterile lab conditions which did not perform as well in the field and under the actual conditions of use in rural outdoor kitchens (Gill 1987). The interventions aimed at decreasing the perceived gap in fuelwood supply focused on increasing fuelwood availability and managing existing woodland reserves more sustainably (Dewees 1989). One of the recommendations to combat the fuelwood gap in Africa was to increase the rate of tree planting fifteen-fold (Anderson & Fishwick 1984). This gave rise to ambitious afforestation and reforestation programmes that encouraged the development of communal woodlots to provide fuelwood by cultivating fast-growing tree species (Arnold & Persson 2003, Arnold *et al* 2006). Ultimately these interventions failed because they encouraged the planting of fast-growing, exotic tree species such as *Eucalyptus* species which were unsuitable for use as fuelwood (Dewees 1989). Furthermore they did not take local land-tenure and resource governance practices into consideration in developing these woodlots, meaning it was not always clear who had resource-use rights and control of the woodlots (Arnold *et al* 2006). Ultimately many of these intervention programmes failed because the models upon which they were based were flawed (Dewees 1989, Arnold & Persson 2003, Arnold *et al* 2006).

1.4 The shortcomings of the energy gap models behind the fuelwood crisis

As time passed and both the rates of deforestation and the negative socio-economic scenarios that had been predicted were not realized, it became evident that there were in fact serious shortcomings with the energy gap theory behind the fuelwood crisis (Leach & Mearns 1988, Dewees 1989). The initial reports were based on supply predictions for tropical forests whereas actual use was from woodlands and shrublands and other woody plant resources that are able to regenerate if harvested (Dewees 1989). At this time there were few generally accepted estimates of standing woodland biomass stock and productivity (Bradley & Campbell 1998) therefore the figures for available woody biomass stock that were used were grossly underestimated and based on figures for tropical closed forests (Grainger 1999). Another important factor that was overlooked in the formulation of many of these models is the ability of trees and shrubs to regenerate after harvesting through coppice regeneration (Banks *et al* 1996). Therefore the assumption was that fuelwood harvesting resulted in clear cutting of woodlands, and that harvesting resulted in the mortality of the individual trees and shrubs, which is an erroneous assumption and one that should be redressed in any future models of these systems.

Furthermore these models did not take people's adaptive strategies into account when making the predictions of increasing consumption even in the face of fuelwood scarcity and this was a grave oversight. These models assumed a logical progression that increasing populations result in higher total consumption and this may have resulted in overestimation of future demand for fuelwood (Dewees 1989, Brouwer *et al* 1997Arnold *et al* 2006). In actual fact, reduced access to wood supply encouraged users to use available resources more economically and to switch to alternatives (Dewees 1989, Brouwer *et al* 1997, Kaschula 2003). No real attempts were made to relate the distribution of woody biomass to human population distribution (Top *et al* 2004) or to local land tenure and resource governance systems so as to better understand the spatial heterogeneity that is inherent in these systems and how it changes over time. Further studies have since shown that fuelwood extraction from a woodland landscape is unlikely to cause widespread deforestation on a large scale but it may result in localized woodfuel scarcities as a result of the imbalances between the patterns of demand and availability at the village scale (Dewees 1989, RWEDP 1997, Kaimowitz & Angelsen 1998, Geist & Lambin 2006). These gap theories dealt only with the quantitative aspect of fuelwood supply and completely ignored the spatial distribution and variation of woodfuel supply and demand (Hosier 1985, Bradley and Campbell 1998). Fuelwood scarcity is not only a function of the physical availability of the biomass resource, it is also determined by the actual accessibility of the resource as well as the availability of labour to harvest the fuelwood (Dewees 1989, Dovie *et al* 2004) and these models did not account for this.

1.5 The economics of fuelwood harvesting

The extraction and utilization of fuelwood is related to the economic cost of fuelwood collection and resource availability (Dewees 1989, MacDonald *et al* 2001, Hegan *et al* 2004, Pattanayak *et al* 2004), where the collection cost is determined by either opportunity cost and/ or average local wage (Dewees 1989) or caloric cost (MacDonald *et al* 2001, Hegan *et al* 2004, Hartter & Boston 2007). These are in turn determined by the distances traveled to the fuelwood resources, the difficulty of extraction and resource quality which in this context is preferred species and woody plant morphology availability. As such changes in fuelwood consumption regimes can be anticipated as the cost of its collection increases and its supply decreases. Over time, this behaviour may cause savanna woodland degradation. If fuelwood collection cost is a function of the distances traveled to collect it (Hatton-MacDonald *et al* 2001, Hegan *et al* 2004) then ideally, if one wanted to predict the likelihood of a particular fuelwood harvesting choice being chosen over the other alternatives, this could be done by assessing the cost and choosing the most cost-effective choice. However, measuring the cost of fuelwood collection means one has to derive opportunity costs for the harvester’s time spent during collections and assign monetary values to them (Remme pers comm.). This in turn requires one to know something of the local wage systems in that particular area (Macdonald *et al* 2001).

The basic economic problem is that resources are always limited or in scarce supply relative to our unlimited demands as consumers, this scarcity makes it necessary for us to choose among the available alternatives for resources (Horgan 2002). In terms of fuelwood harvesting, this choice is expressed in terms of choice of where to harvest, which species and woody plant morphology to harvest, how much fuelwood to harvest and at the household level, these decisions are made depending on the travel-cost of the fuelwood collection trip. It is most likely that the woodland patches that are most heavily impacted by fuelwood collection are those areas that have the least cost to the collectors. This may be a function of the terrain, the distance traveled to the collection site (Hartter and Brent 2006), the accessibility of the site (access roads, pathways) and the load carried back to the homestead (MacDonald *et al* 1998, Hegan *et al* 2004, Pattanayek *et al* 2004). If information such as cost per collection trip per household, together with the fuelwood load collected, distances traveled per collection trip, location of the fuelwood collection sites are collected then investigations into what factors determine where people go to collect fuelwood become possible.

Fine-scale village level fuelwood consumption and supply data can be used to identify fuelwood "hotspots" which are areas where urgent action is required to balance potential fuelwood deficits in the future (Masera *et al* 2006). These notions are spatial in nature and would be best described and anlaysed using Geographic Information Systems. The majority of people who depend on woodfuels have relatively limited access to alternative energy sources to meet their domestic needs, thus they are constrained to utilize locally available energy that is gathered at the cost of their time and physical exertion (Horgan 2002). Fuelwood harvesting regimes involve choices that allow them to maximize from their expenditure in light of the return from the fuelwood harvested.

1.6 The global development context, energy poverty and the South African perspective

Ultimately, the interest in understanding fuelwood supply-demand dynamics relates to the future sustainability of these wood-energy systems and the implications of this for the development of appropriate policies and programmes. The renewed interest in fuelwood supply-demand systems comes at a time when the global arena is realising the importance of household energy security in achieving sustainable development (UNDP & WHO 2009), referring to the need to eradicate global energy poverty on the road to achieving this goal (IEA 2010). The concept of energy poverty refers to the lack of choice in access to modern energy services that are "adequate, safe and reliable for economic and human development" (Perreira et al 2010). The International Energy Agency, IEA, recognises two indicators of energy poverty at the household level; the lack of access to electricity and the consistent use and dependence on woodfuels for cooking (IEA 2010). The important role of rural household energy security in achieving the Millenium Development Goals (MDG) has long been recognised yet there is no specific MDG relating to energy (CSD9 2002, UNDP 2005, IEA 2010).

Currently approximately 2.5 billion people living mostly in the developing regions of Latin America, Africa and Asia depend on traditional biomass (woodfuels) for cooking and heating (IEA 2009). Of that total figure, 1.5 billion people do not have access to electricity and another 1 billion have unreliable and in some cases financially inaccessible electricity supplies (UNDP & WHO 2009). This lack is now apparent in that the issue of energy security is seriously putting the global achievement of the MDGs at risk (AGECC, 2009). A co-ordinated global effort will be required to combat energy poverty and meet the Millenium Development Goals (AGECC 2009), particularly in Sub-Saharan Africa which has been identified as lagging the furthest behind amongst all developing regions (UNDP 2007). The use of household access to electricity as an indicator of energy poverty means has pushed most developing countries to set targets deadlines for universal access to electricity to within the next 5 years (IEA 2010).However this also means that few are explicitly putting policies in place to deal with the reality of current extensive dependence on woodfuels amongst their populations. Few countries, including South Africa, have set targets to improve access to modern fuels and improved cookstoves or to explicitly reduce the reliance of their populations on woodfuels (UNDP 2007, IEA 2010).

Meeting the energy challenge to transform energy systems at all levels of technological capability over the intermediate future needs to be a governmental priority irrespective of the major challenges faced by Low-, Middle- and High-Income countries respectively (Table 1.1, AGECC 2009). South Africa faces particularly difficult circumstances as it has the economic and energy-use characteristics that straddle the full spectrum of each one of these categories-having both developed and developing economy characteristics (Madubansi & Shackleton 2006). As of February 2012, South Africa is classified by the World Bank as an Upper-Middle Income economy, with an average Gross National Income per capita income ranging from USD $3,976-USD $12, 275 (World Bank, 2012).Thus the South African government must take all of these aspects into consideration with respect to future energy planning. This research contributes to the necessary body of knowledge required to meet the planning aspects for the rural energy poor populaces of South Africa.

Table 1.1 Summary of the challenges faced by governments in transforming national energy delivery services to ensure universal household access to electricity classified according to per capita annual income (based on AGECC, 2009). Designation into Income class is based on World Bank classifications as of 2012 (World Bank 2012).

Income level (average annual per capita income)	Transformational energy challenges
Low Income (<USD$1005)	High infrastructural investment to create, improve and expand technological capacity and networks for household electricity access Rural areas are often remote and inaccessible Financial challenges as high investment costs are involved Reduce widespread dependence on woodfuels Provide modern energy-services such that they are competitive with traditional woodfuels
Middle Income (USD$1,006-USD$12,275)	Enable the development of energy systems in a manner that enables the decoupling of economic growth from high fossil-fuel based energy consumption Improved energy efficiency and decreased energy related green-house gas emissions
High Income (>USD$12, 276)	Challenge to replace large infrastructural investments (power plants) made in the past with cleaner energy-generating activities Decarbonisation of the energy sectors Require new financial and technological investments

Household electrification has been a policy priority since the advent of democracy and majority rule in 1994 (DME 2000). This was carried out through an intensive national electrification programme to redress the imbalances of the previous Apartheid government policies (DME 2000). Inspite of the availability of electricity in South Africa (75%, IEA 2009), most low-income rural households continue to use fuelwood to meet their basic household energy needs for cooking and boiling water (Howells et al 2003). For the most part these households use electricity for household lighting and other light energy needs (Davis 1998, Thom 2000). Thus fuelwood use and extraction from rural landscapes remains highly relevant, requiring renewed studies about how the biophysical environments have responded over time.

1.7 African Savannas: woodland resource base

1.7.1 The structure of African Savanna landscapes

Savannas cover over 50% of the total surface area of Africa they are the most extensive vegetation type across Africa, support the majority of the human population on the continent are the most extensive vegetation type across Africa; they cover over 50% of the total surface area of the continent (Scholes & Walker 1993), support the majority of the human population, thus the bulk of woodfuels in Africa are extracted from savannas. They are wide-ranging tropical or sub-tropical seasonal ecosystems that are essentially a mixture of a continuous grass layer and a discontinuous tree and/or shrub layer (Frost 1986, Skarpe 1992, Scholes and Walker 1993, Frost 1996, Scholes 1997, Scholes & Archer 1997). The exact composition and spatial configuration of the tree: grass ratio across a Savanna landscape is highly variable as it is determined by environmental factors, predominantly rainfall and soil characteristics (Skarpe 1992, Frost 1996), fire (Skarpe 1992, Frost 1996) herbivory (Skarpe 1992) and human activities (Frost 1996). The spatial variability in the composition and spatial configuration of the tree: grass interface means that savannas range from open tracts of grassland interspersed with clumps of trees and shrubs at one end of the spectrum to woodlands that are dominated by trees and woody plants, but since the tree canopies are not continuous also have a significant grass component (Skarpe 1992, Scholes & Walker 1993, Scholes 1997, Scholes & Archer 1997, Higgins *et al* 1999). Savannas show high temporal and spatial variability even in their natural, undisturbed (by humans) state (Walker 1986, Skarpe 1991b, Frost 1996) and the savanna landscape's physiognomic characteristics will vary with changes in climate and edaphic characteristics. These mechanisms and interactions have been extensively studied; however the exact determinants of the tree: grass composition of savannas remains one of the unanswered questions in ecology. More work is required to understand African savanna landscape dynamics under the influence of human use.

The savannas of southern Africa share many genera and species with those of Central and East Africa but fewer with the savannas of West Africa (Scholes 1997). In Southern Africa there are two distinct Savanna types, fine- and broad-leafed savannas (Scholes 1997). Fine-leafed savannas occur on well drained, nutrient-rich soils, mostly in low-lying arid areas.

They are dominated by "fine-leaved" Mimosaceae, have higher grass production and support larger numbers of herbivore species. Broad-leafed savannas occur on nutrient poor, well-drained soils. This type of savanna generally occurs in less arid, higher rainfall areas. The dominant trees belong to the Combretaceae and Cesalpinoideae Families and are characterised by an absence of thorns and broad leaves, with a leaf surface area of at least 5 cm^2 (Mueller-Dombois & Ellenberg 1974 in Scholes 1997). The vegetation in the study area is termed semi-arid savanna which is characterised by a mixture of broad- and fine-leaved trees, shrubs and grasses with dense bushlands on the lowlands and open-woodlands on the uplands.

This study focused on the impacts of human utilisation, through continued extraction of woody biomass for energy, in semi-arid savannas in the Lowveld of South Africa.

1.7.2 Savannas in the former homelands of South Africa as cultural landscapes

Landscapes evolve in response to the complex interplay between human and biophysical influence on landscape structure and processes (Turner 1987, Farina 2000, Antrop 2005). In human-modified landscapes, ecological, socio-economic and cultural factors interact to create reflexive feedback mechanisms over time, aggregating at different hierarchical spatial scales to create "cultural landscapes" (Farina 2000). Current cultural landscapes are a product of the constant reorganisation of landcover elements in space and time, as a result of, and in adaptation to, past societal needs and land-use patterns (Antrop 2005, Carr & McCusker 2009). Together with environmental factors, human disturbances are largely responsible for the manner in which African savanna landscapes have developed over time (Scholes & Walker 1993). Indeed, the savanna woodland structure and composition in place at the beginning of the colonial period has been attributed to the disturbance activities of Iron Age agro-pastoralist societies that inhabited those areas (Scholes 1997). The human impact on savannas is expressed through the altering of natural fire regimes, woodland clearing activities for agricultural land (Frost & Chidumayo 1996, Frost 1996), the extraction of non-timber forest products for livelihood and subsistence (Shackleton & Shackleton 2000, Twine 2003), the impact of domestic livestock (grazing and soil compaction) and through woody biomass extraction for timber and fuelwood (Dovie *et al* 2002, Twine *et al* 2003). This is particularly apparent in areas of high human population density, as seen in the communal lands of South Africa (Shackleton 1993, Neke 2004). These villages on communal lands are located in former Bantustans or homelands of the Apartheid Era in South Africa. The government of the day forcibly relocated large numbers of black people onto marginalised, infertile regions to pursue “separate development” away from white South Africa (Thornton 2002). The human settlements or villages in these former Bantustans are highly impoverished, with limited employment opportunities and a dependence on agro-pastoralism and the savannas in which they are located for subsistence and livelihood (Shackleton & Shackleton 2002, Thornton 2002, Kaschula et al 2005). The evidence of this can be seen across these landscapes; they are very heterogeneous with a strong agricultural component, there is a noticeable element of organisation with respect to land use and this can be observed at different scales (Giannecchini et al 2007). These factors are all characteristic of cultural landscapes as defined by Farina (2000). Such a classification allows us to describe such systems in socio-ecological and economic terms for the purposes of modelling local savanna woodland development as a result of interactions with human society- the ultimate goal of this project.

1.7.3 The characteristics of South African communal areas

Communal areas are multiple-use landscapes, shaped and transformed by interacting environmental and human factors (Batterbury 2001, Twine 2005). In South Africa, this is State-owned land, on which communities have been granted communal rights of use and access governed by local traditional authorities (Thornton 2002, Kaschula *et al* 2005). The dependence on natural resources in communal areas as a livelihood strategy and security net against the effects of poverty have been well discussed (Shackleton & Shackleton 2002, Shackleton *et al* 2005). This situation is not likely to change in the immediate future. As the focus shifts towards sustainable management of these systems, that they may continue to support these communities into the future, it is important for to understand how these cultural landscapes (Farina 2000) have developed over time, so that appropriate plans to ensure resource availability into the future can be developed.

A key issue is always that of ecosystem resilience, where this refers to the capacity of the system to withstand or recover from shocks through self-organisation and adaptation (Berkes

& Folke 1998, Farina 2000, Carpenter *et al* 2001, Folke 2006). Fuelwood harvesting may affect the resilience of these systems. At landscape level, this should be evident through an evaluation of the landscape heterogeneity and woodland response to harvesting- reductions in density canopy cover thinning and changes in structure. Livestock stocking rates are high in communal rangelands (Scoggins *et al* 1999) and grazing has resulted in significantly reduced grass biomass (Harrison & Shackleton 1999) which influences the occurrence and intensity of fires (Shackleton *et al* 1994). Woodland vegetation structure is influenced by land-use practices in the area; the communal rangelands have lower aboveground wood biomass density, species richness and altered species composition in comparison to neighbouring protected areas and cattle farms (Higggins *et al* 1999). However there is no clear differentiation in stem diameter and height size class distribution by land-use (Higgins *et al* 1999) as some communal rangelands have higher densities of large trees than alternative land-use areas (Fisher *et al* 2012). Tree and shrub species in communal rangelands are resilient to harvesting (predominantly for fuelwood) (Higgins *et al* 1999), most likely due to the ability of most species to resprout from the main stem or root stock in response to damage to the stem (Shackleton 2000, Kennedy 1998).

In modelling the woody biomass supply demand relationships, many studies have focused on the quantitative relationships that are observed, ignoring the spatial variability that arises as a result of fuelwood harvesting as part of the woodland dynamics (Top *et al* 2003). The spatial heterogeneity in supply of the fuelwood resource base in response to continued harvesting must be investigated to understand how these socio-ecological landscapes develop and how best to sustainably manage them for the future. The spatial aspects of fuelwood harvesting matter because the configuration of the resource stocks across the landscape influence the welfare of the villagers as well as the ability of the woodlands to provide the ecosystem services upon which those communal societies are dependent (Diamond 1975, Shaefer 1990, Heltberg 2001, Masera *et al* 2006).

1.8 The dynamics of communal savanna rangelands

1.8.1 Evaluating woody biomass stock dynamics in communal savanna rangelands

For the purposes of this research understanding the dynamics of communal savanna woodland denoted assessing the current status of that woody plant community, how it has changed and how it will continue into the future, in the context of its ability to produce fuelwood as an ecosystem service. This was carried out by assessing the population species composition, size structure of trees in the communal woodlands in the study areas and how this has changed in light of continued use over a set period of time. A healthy plant population has a size class distribution with the form of an "inverse J", any deviation from this often indicates disturbance (Owen-Smith 2007). Carrying out a woodland inventory through plot sampling of the same woodlands now would allow not only for an assessment of current standing biomass stocks but also a detection of how this has changed over 17 years. Comparative studies over a long time can be used to assess changes in woodland structure and species composition. This allows for investigation of the woodland response to selective harvesting of preferred species and plant sizes, as well as changes along the observed utilisation gradient (Shackleton *et al* 1994) and an assessment of coppicing in the woodlands. The selective harvesting pressure caused by humans extracting particular species and size classes often brings about a change in size class distribution and increased mortality of target species (Grainger 1999, Luoga *et al* 2004) as well as an overall decrease in species richness of the entire woodland (Shackleton *et al* 1994); indicative of woodland degradation.

1.8.2 Identifying the human drivers of woodland change

The main drivers of the observed changes in these communal woodlands are most likely the harvesting practices of the village residents. If one is to understand these dynamics adequately then one must also quantify the demand for woody biomass, which in this case, is a focus on demand for fuelwood for fuelwood and charcoal production. In understanding these fuelwood harvesting regimes, the information that is required is quantitative (amounts of biomass removed over a given time horizon) as well as qualitative (preferred species and size) (Banks *et al* 1996, Mlambo & Huizig 2004, Shackleton *et al* 2005 Madubansi & Shackleton 2007). Recommended methods to establish this include observation (Abbott & Homewood 1999, Mlambo & Huizig 2004), structured interviews, key informant interviews and focus group discussions (Mlambo & Huizig 2004). From these data sources it is possible to quantify household fuelwood demand.

1.8.3 Land cover/ land use change: understanding landscape woodland dynamics

The fuelwood supply potential of an area is a function of several factors. The key environmental factors are soil nutrient availability as well as soil moisture. On a cultural landscape, land use and landcover change, land tenure systems and the location of the harvest sites come into play. These factors determine effective biomass availability. The importance of resource availability or accessibility lies in the fact that not all the woodland resource base is exploited for fuelwood and the likelihood of woody plants being exploited is determined by physical availability and legal accessibility (Top *et al* 2006). Together these two terms describe biomass accessibility; the Food and Agricultural Organisation (FAO) defines this as a qualitative or categorical variable that defines the degree to which a given biomass source is effectively accessible for use; it is relative and differs depending on the location and technology available to the group using it (FAO 2002).

The ability to model the spatial variability in the woody biomass capacity as it stands now and in the future would be a powerful planning tool when looking to create sustainable management plans for the continued use of these woodlands. Such a tool would enable us to project where fuelwood harvest hotspots are and will be in the future (Masera *et al* 2003) and also to test the potential for implementing rotational harvesting schemes etc. It is probable that the woodland patches that are most heavily impacted by harvesting are those areas that have the least collection cost to the harvesters. This likelihood may be a function of distance, terrain (Hartter & Brent 2006), physical accessibility of the site through access roads, pathways, the load carried back to the homestead (MacDonald 1998, Hegan *et al* 2004) and legal availability

1.8.4 Woodland degradation processes

In this thesis the term "degradation" is defined as "a persistent decrease in the capacity of an arid or semiarid ecosystem to supply a range of (ecosystem) services (Scholes 2009) where the focus of the study was fuelwood provision. By definition the concept of degradation is relative as it requires comparison (over time or space) to show a decrease in quality between two ecosystems. Thus, in this study comparison was over time for both villages, as well as between the two villages relative to each other in 2009. There is some degree of subjectivity which is unavoidable but in this study the term was used to describe the ability of the communal rangelands to produce fuelwood of a desired quality based on the harvester's expressed preferences.

Communal savanna rangelands are multi-use landscapes with multiple users; therefore human impacts are varied and the degrees of severity differ, with the most severe being deforestation. Land clearing activities for agricultural and human settlement expansion are the primary causes of deforestation, whereas grazing by livestock and selective harvesting for construction and fuelwood bring about woodland degradation (Grainger 1999, Abbott & Homewood 1999). Grainger (1992) defines woodland degradation as "the temporary or permanent reduction in the density, structure, species composition or productivity of the vegetation cover". Fuelwood harvesting whether it be for direct combustion as fuelwood or for further processing into charcoal, does not usually result in deforestation in savanna woodlands (Grainger 1999, Abbott & Homewood 1999), rather unsustainable fuelwood harvesting brings about woodland degradation. Fuelwood is considered to be a renewable source of energy but this is true only if it is harvested sustainably, where sustainable harvesting means that the total woody biomass removed is less than or equal to the total annual growth (Shackleton 1997).

Fuelwood harvesters select for certain tree species and within those species for certain morphological types (Shackleton *et al* 1994, Luoga *et al* 2004, Neke *et al* 2004). The results of this selective harvesting are thinning of canopy cover, reduction in stem density, changes in woodland structure and species composition and changes in the productivity of the vegetative cover (Grainger *et al* 1993, Higgins et al 1999, Shackleton 2000). In quantitative terms these degradation processes can be measured by changes in canopy cover, biomass density and biodiversity (Grainger *et al* 1999). To trace such degradation processes, one requires a long term data base of landcover (vegetation) information over the area of interest- this may be in the form of woodland inventory information collected from permanent woodland plots or, pictorial record of the changing landcover.

The question is whether the woodlands of Africa will survive the continued, increasing extraction of woody biomass, or whether this extraction pressure will ultimately lead to the disappearance of the woodland landscape across Africa. The resilience of this resource base to human use can only really be predicted and tested through the use of biomass supply-demand models, taking into consideration the mistakes of the past. By revisiting and re-evaluating the models of the past, testing and comparing their predictions with real data it will be possible to identify the shortcomings of these models, if any, and build better models from there.

1.8.5 Unsustainable fuelwood harvesting in Bushbuckridge Municipality, South Africa

In their study in 1992 Banks *et al* (1996) claimed that there was a "woodland resource crisis" in Bushbuckridge. In the woodlands surrounding their two study villages, Welverdiend and Athol, they claimed that there was insufficient woody biomass supply to meet the apparent demand. Based on the supply-demand model they constructed they predicted there would be rapidly declining woodland resources (through deforestation) and that this would ultimately lead to resource base collapse- complete deforestation of the woodlands surrounding one village-Welverdiend but not for Athol. The obvious question is "Why the difference in predictions?" The same predictive model was applied to both villages and they are located in the same municipality and environmental context. The great interest in revisiting this model in particular at this time is that 2007 was the year given as the point in time at which complete woodland deforestation was to have occurred. This places us in the unique position of being able to test the predictions given by Banks *et al* (1996) right down to the timeframe given. The model constructed by Banks *et al* (1996) was able to test scenarios of potential wood supply in response to changing demand, where demand was derived from an increasing population growth, per capita consumption and seasonal variability of the consumption rates. According to the model, the reason for the predicted woodland collapse was increasing harvesting pressure with constant per capita harvest rates. In other words, based on the assumptions upon which the model was constructed, the human population in Welverdiend would continue to increase, and as the population grew so would the demand, each individual of which would increase fuelwood consumption by the constant per capita rate. Furthermore, the woody biomass module of the model suggested that the biomass productivity rates of the woodlands surrounding Welverdiend were significantly less than the rates of consumption and that this deficit would ultimately lead to the collapse of these woodlands.

Studies in this area have described a breakdown of the traditional rules and social constructs that govern the use of land and the woodland natural resources (Kaschula *et al* 2005, Shackleton *et al* 2007, Twine et al 2003). With a noted influx of external users and an increasing population in the area of interest, based on the assumptions of the model above, one would expect to see the evidence of the reality of the Banks model- extreme deforestation and denudation of the woodlands surrounding Welverdiend, and a measure of this is necessary. The study sites need to be revisited and the predictions made evaluated. An assessment of the woodland condition at present day in comparison to the time when the woodlands were first assessed is required to understand what, if anything has changed. Changes could be in the guise of harvesting regimes, socio-economic circumstances or the introduction of alternate energies. Furthermore, it is of interest to re-evaluate the model itself- perhaps the shortcomings are within the construction of the model? The answers to these issues will act as the building blocks towards the construction of a more realistic supply-demand model of woody biomass extraction from savanna woodlands.

In the years since the study carried out by Banks *et al* (1996) there has been an intensive electrification programme in the area and both villages are now connected to the national electric grid (Madubansi & Shackleton 2006). One could assume that the provision of electricity to this village would have had reduced the fuelwood consumption and harvesting regimes of the residents of Welverdiend and that this may have influenced the realization of the Banks *et al* (1996) model predictions. This would be an erroneous assumption. Madubansi & Shackleton (2006, 2007) included both Athol and Welverdiend in a long-term study of changing fuelwood use and energy profiles with electrification. The time horizon of their study encompassed the time at which the Banks study was carried out and used about consumption patterns from 1991 to 2002. Their results showed that the residents of these two villages had not changed their dependence on fuelwood; there were no significant decreases in per capita woody biomass consumption. They did however find that the fuelwood harvest regime had changed- that there was a significant increase in the time spent collecting fuelwood, as well as in the number of households purchasing fuelwood. Furthermore a larger number of tree species are now collected and used for fuelwood than before. These are indicative of increasing scarcity of desirable woody biomass in the woodlands around these villages (Brouwer *et al* 1997).

1.9 Research Aim, objectives and layout of thesis

The study was part of a larger collaborative, multidisciplinary research initiative funded by the VW Foundation under the title "Modelling of the domestic energy system based on biomass energy in rural areas in southern Africa- BioModels" hereafter referred to as the BioModels project. The aim of the overarching BioModels project was to contribute to the knowledge about the energy and energy-technology requirements and choices made by low-income, rural villages in southern Africa. The BioModels project consisted of five PhD studies, each tackling different aspects of rural domestic energy systems. The five modules addressed questions around existing rural energy utilisation patterns, the socio-economic issues around and consequences of these energy choices, the existing technologies that are widely used in rural communities and the dynamics of the savanna woodlands surrounding these communities in response to their use-patterns. This PhD study tackled the last topic.

The aim of this study was to investigate the dynamics of fuelwood supply and demand, in space and time, around selected rural communities in a South African savanna woodland. "Rural community" refers here to the coupled socio-ecological landscape (Azar *et al* 1996), consisting of a human settlement and the natural environment in which the residents conduct their livelihood activities, specifically the extraction of fuelwood to meet their domestic energy needs on communal land. An inter-disciplinary approach was used to assess the dynamics of the biophysical fuelwood supply resource base and the human demand characteristics of the coupled human wood-energy system. The general methodology broached the fields of landscape ecology, involving fine-scale woodland biodiversity assessments and remote sensing and social ecology. The broad objectives of the research were split into three categories:

1.9.1 Objectives

1.9.1.1 Changes in the fuelwood resource base:

1. Establish the woody biomass stock potential in the communal woodlands and evaluate model predictions made about the sustainability of fuelwood harvesting in the rural communities within the study area (addressed in Chapter 2)

2. Investigate the spatial dynamics of communal woodlands in the study area over time (1965-2009) (addressed in Chapter 3).

1.9.1.2 Human fuelwood use patterns according to fuelwood availability

3. Investigate the strategies employed by rural households to secure access to fuelwood where electricity is available (addressed in Chapter 4)
4. Investigate the main determinants of household fuelwood consumption characteristics (addressed in Chapter 5)

1.9.1.3 Sustainability considerations

5. Based on the outcomes of the research, create a conceptual framework to explore strategies for the sustainable utilisation of communal savanna rangelands as a continued source of fuelwood in the study area (addressed in Chapter 6).

1.9.2 Structure of thesis

The content chapters, addressing objectives 1-4 (Chapters 2-5), were written in the format of scientific papers ready for submission. Chapter 2 and Chapter 4 have already been submitted to journals and are currently under review at *Environmental Conservation* and *Energy Policy* respectively; Chapter 3 and Chapter 5 will shortly be submitted for publication. Because of this, a modest level of repetition, especially in descriptions of the study site and motivations for the studies, was unavoidable. Each chapter has been written such that the introduction links back to and expands upon the literature that has been discussed thus far. The results are described in detail and discussed with reference to their contribution to understanding fuelwood dynamics in rural landscapes. The final chapter, Chapter 6, provides a synthesis of the preceding chapters towards the greater understanding of the dynamics of rural fuelwood supply-demand systems. The main outcomes of each of the preceding chapter are discussed within the framework of improving the knowledge about the sustainability of rural wood-energy systems in the future and South Africa.

1.9.3 Approach to the study

The research is orientated towards contributing to the knowledge about the potential future impact of the continued dependence of rural sub-Saharan communities on their natural resource base for energy provision. It is understood that such ecosystem services are generated at a range of spatial scales and are exploited by people at a range of institutional scales (household, village, municipality etc) (Hein *et al* 2006, Shackleton *et al* 2007). Furthermore it is recognised that the processes behind the supply and demand of biomass energy as well their implications for sustainability will change depending on the scale at which one is focusing. For example, at a national scale in South Africa the use of woody biomass energy for domestic energy needs has been shown to be sustainable (von Maltitz & Scholes 1993); however it has resulted in localised fuelwood shortages in rural communal villages and may be ultimately unsustainable in these communities (Dovie *et al* 2003).

This project focused on the landscape level, with the village as the focal unit deriving benefit from the woodlands. Although data on issues of demand and extraction of biomass energy were collected at the household level, this was aggregated to village-level to show the impact of the village on the dynamics of the woodlands in which it exists. The spatial extent of the resource base was defined by the legal boundaries of the villages but also considering the boundaries from the perspective of the village households, as determined by the spatial range of their resource use-patterns.

Quantitative assessment of the standing woody biomass stock was carried out using standard biomass inventory techniques. The woody biomass, size class distributions, species composition and coppice representation were assessed along the utilisation gradient radiating outwards from the village settlement area. These parameters were compared against the same measurements taken in 1992 to assess how the woodlands have developed in response to wood extraction. Demand for fuelwood was assessed using a standardised questionnaire administered to a representative sample of households. This questionnaire was developed in the course of the larger BioModels project.   In South Africa it was applied to households as well as in key informant interviews and focus group discussions. Empirical evidence from the investigations into the present woody biomass supply and extraction/consumption by the village were used to "test" the predictions of sustainability by Banks *et al* (1996) through comparison with the baseline data. The findings of the empirical studies were supported by evidence from the literature to assess the possible shortcomings of the Banks *et al* (1996) model.

The traditional approach to describing biomass energy systems considered only the temporal quantitative perspective of woodland biomass dynamics (Banks *et al* 1996, Shackleton 1993, Dovie *et al* 2002). However, such models ignored for the most part, the spatial heterogeneity of woody biomass supply that is an inherent part of the system. The spatial aspects of fuelwood extraction matter because the configuration and quality of the remaining available resource stocks influence the provision of ecosystem services by woodlands, villager welfare, as well as decisions as to if and how the remaining woodland resources are to be used. It was obvious that the spatial aspects could not be ignored and perhaps a major oversight of the past has been the attempt to understand such socio-ecological systems in purely mathematical terms. The spatial analysis of the woodland dynamics of the study area was carried out using standard GIS techniques. The data were derived from time sequential aerial photographs of Welverdiend and Athol, from 1965to 2009. The available database gives a decadal account of landscape development for 1965, 1974, 1986, 1997 and 2009. Based on the land cover change observed, transition matrices can be derived and projections into the future landscape development carried out (Pontius *et al* 2004).

The use of this array of investigative techniques enabled the thorough investigation of the status quo of rural household demand for fuelwood in South Africa and the impacts of that use on savanna woodland structure over time. The policy implications of this demand were explored as are the possible socio-economic factors that influence the inability of rural households to transition to the use of electricity when it is provided.

1.10 Study area: Bushbuckridge

1.10.1 Biophysical characteristics

This study was carried out in the Bushbuckridge Municipality in the Mpumalanga Province of South Africa (centring on 31º 17’ E; 24º 39’ S). The district falls between the Sabie River in the south and the Klaserie-Orpen Road in the north. Bushbuckridge falls within the Transition zone of the Kruger to Canyons Biosphere Reserve (Coetzer *et al* 2010).Rainfall is received mainly in the form of convectional thundershowers and averages 650 mm per annum in the west and 550 mm per annum in the east along a rainfall gradient. There is a distinct rainfall season and this occurs the summer season (October to May). Drought is common and prolonged droughts may occur every 10 years. Mean annual temperature is 22 ºC, summers are hot, with a mean maxima 30 ºC and winters are mild with a mean daily maxima of 23 ºC (Shackleton *et al* 1994). The topography of the region is described as gently undulating with an average altitude less than 600m above sea level (Banks *et al* 1996). Soils are underlain by granitic gneiss with local intrusions of gabbro.

The vegetation in the study area is defined as Mixed Lowveld Bushveld and is mostly dominated by species of the Combretaceae (van Rooyen & Bredenkamp 1996). In this area the vegetation is dominated by members of the *Combretum* and *Terminalia* genera (especially *T. sericea)* as well as some *Acacia* species. The Marula (*Sclerocarya birrea*) and sickle bush, (*Dichrostachys cinerea*) contribute significantly to the woody biomass in this region (Shackleton 1997).

1.10.2 Land use and land tenure in Bushbuckridge

Savanna woodlands cover almost one third of the total surface area of South Africa (Low & Rebelo 1996) and support almost 9.2 million people living in rural settlements (Shackleton 2000). These rural settlements are mostly located in the former homelands or Bantustans of the Apartheid-era government. Bushbuckridge region was created from the consolidated territories of two districts from two homelands, Mhala in Gazankulu and Mpulaneng in Lebowa. The rural villages in what is now Bushbuckridge were mostly established on old cattle-ranching farms, thus the initial village boundaries were defined by the cadastral boundaries of the farm (Thornton, 2002). Traditional authorities in a hierarchical system of chiefs and headmen were given limited administrative authority over these villages (Butler *et al* 1978). Most of the land in Bushbuckridge therefore falls under State control and customary communal land tenure, whereby the land around a given settlement or village is zoned by the traditional authorities into residential and arable plots. The rest of the communal land is available to the residents of the settlement for the grazing of their livestock and for harvesting of natural resources such as thatch, fruit, medicine and fuelwood and other non-timber forest products (Shackleton & Shackleton 2000).

1.10.3 Bushbuckridge within the Kruger to Canyons Biosphere Reserve

The Kruger to Canyons (K2C) Biosphere Reserve was established in 2001 under the United Nations Educational, Scientific and Cultural Organisation's (UNESCO) Man and the Biosphere Programme. The purpose of Biosphere reserves is to promote solutions to reconcile the conservation of biodiversity with its sustainable use (UNESCO, 1996). The communal settlements of Bushbuckridge were incorporated into the transition zone, outside of the core conservation areas of the K2C Biosphere Reserve where they are hemmed in between state and private-owned conservation areas. As such protected areas are the next most common land use types in Bushbuckridge, either for nature conservation, commercial game hunting or eco-tourism. In comparison with the surrounding communal woodlands and rangelands, there is lower grazing pressure as well as resource harvesting pressure since they are usually fenced off from the surrounding communities.

1.10.4 The socio-ecological context

As is characteristic of most former homelands, there is poor infrastructure in these rural settlements, high unemployment and as a result, a high dependence on government social grants, pensions and remittances from migrant workers (Shackleton *et al* 2005). Agricultural production is low or sporadic at best due to poor soils and low rainfall. Because unemployment is rampant households are forced to depend on informal income generating activities such as agriculture, livestock, use and sale of natural resources from the communal woodlands for their subsistence and livelihoods (Pollard *et al* 1998, Shackleton & Shackleton 2000, Twine *et al* 2002, Dovie *et al* 2002). Historically, high population growth rates were characteristic of this region but this has declined rapidly over the last decade. Low household incomes, linked to poor economic development and high unemployment, mean that households in this region will remain heavily dependent on the communal woodlands as sources of non-timber forestry products (NTFPs) to buffer them against the effects of poverty

(Shackleton & Shackleton 2004, Kaschula *et al* 2005, Shackleton *et al* 2007a). This high pressure on the limited communal woodland resource base needs to be appropriately managed if this is to be sustainable. Unfortunately, the traditional and institutional regulatory mechanisms that were once in play to control the extraction of these communal resources, especially fuelwood are becoming progressively weaker (Kaschula *et al* 2005).

In direct response to the prevailing conditions of wide-scale poverty and poor economic development, Bushbuckridge was specially mentioned by the South African Presidency as an area needing special development intervention (Mbeki, 2001). Bushbuckridge was selected as one of thirteen flagship nodes to pioneer the Integrated Sustainable Rural Development Programme (RSA, 2000). These nodes were designated high-priority areas for accelerated infrastructural intervention, including greater investment into improving household access to electricity and running, potable water (RSA, 2000). Therefore the evaluation of the continued dependence of communities within this area on fuelwood inspite of the heavy investment into household electrification is pertinent in the future roll-out of similar interventions in other high-poverty areas.

1.10.4 The case study villages: Welverdiend and Athol

Welverdiend and Athol are located in the north east of Bushbuckridge Municipality in Mpumalanga Province, South Africa and can be found at 24º 35’ S; 31º 20’ E and (24° 43’S 31° 21’E respectively (Figure 3.1). In this study the village was defined as the settlement area, arable fields and communal woodlands encapsulated within the boundaries of the farm upon which the original settlement was established. In most instances, these village fence-lines or boundaries do not guarantee the exclusion of resources harvesters from neighbouring villages. They are however recognised by the village residents.

Over 95% of the households in the villages have electricity and yet fuelwood is still the preferred energy source for thermal applications such as cooking and heating, (Madubansi & Shackleton 2006, 2007). Madubansi & Shackleton (2007) observed that most households spend more time collecting fuelwood per collection trip than they did 15 years earlier. Madubansi & Shackleton (2007) also observed that more households were purchasing fuelwood than before and that there had been a shift in the species collected, with a wider variety collected presently than before; these are taken as indicators of increasing fuelwood scarcity. Up to 93% of the total demand for fuelwood is not met by the available deadwood produced in these woodlands; this demand is met by harvesting livewood (Shackleton & Shackleton 2000). At least half the households in Welverdiend openly admit to livewood harvesting, stating that there is insufficient deadwood available to meet their demands (Madubansi & Shackleton 2007).

Welverdiend and Athol were the case study villages used by Banks *et al* (1996) to model biomass supply and demand in a rural savanna village. They predicted that by 2007, unless fuelwood demand lessened, the woodlands in Welverdiend would have been completely denuded and in comparison, the woodlands in Athol would still be in a healthy state. Madubansi & Shackleton (2007) have since shown that the demand for fuelwood in both villages has not changed in the years between 1992 and 2002 and there has not been complete deforestation around either Welverdiend or Athol. There is some evidence that the woodlands around Welverdiend are also targeted by fuelwood vendors who sell fuelwood in other villages but harvest from Welverdiend (Twine & Siphugu 2002). There is thus continued high selective harvesting pressure on these woodlands. It is expected that this will be reflected in changes in the structure and composition of the woodlands (Shackleton 1994). Madubansi & Shackleton (2007) listed the preferred species for fuelwood, and noted those that were perceived as becoming increasingly scarce. For Welverdiend, these were recorded as *Dichrostachys cinerea*, *Terminalia sericea*, *Dalbergia melanoxylon*, *Sclerocarya birrea*, *Combretum collinum* and *C. imberbe.*

Chapter 2

2. A tale of two villages: assessing the dynamics of fuelwood supply in communal landscapes within the Kruger to Canyons Biosphere in South Africa

Abstract

This study evaluates impacts of fuelwood harvesting from 1992 – 2009 on the woodland structure and species composition surrounding two rural villages (Welverdiend and Athol) with similar village spatial extents and socio-economic characteristics located within the Kruger to Canyons Biosphere Reserve (Mpumalanga Province, South Africa). There has been an overall decline in the total wood stock in the communal woodlands of both villages (greater loss in Welverdiend) and a change in the woodland structure and species diversity of species commonly harvested for fuelwood in Welverdiend but not in Athol. The woodlands in Welverdiend have become degraded and no longer produce fuelwood of preferred species and stem size in sufficient quantity or quality. The absence of similar negative impacts in Athol suggests more sustainable harvesting regimes as a result of the lower human population and lower fuelwood extraction pressure. The Welverdiend community has annexed neighbouring unoccupied private land in a social response to fuelwood scarcity. Such actions have also been documented in Athol during drought. The potential for future conflict with neighbouring conservation areas within the Kruger to Canyons Biosphere is high if land-use and fuelwood extraction are maintained.

2.1 Introduction

Fuelwood is the dominant source of energy used by most rural households in southern Africa to meet daily domestic energy requirements, such as cooking, water and space heating (Biggs *et al* 2004). In South Africa, the post-apartheid government implemented an accelerated electrification programme to address the historical developmental imbalances in rural areas in South Africa (DME, 1998). All households get a small free monthly allowance but most rural households are unable to make effective use of additional electricity provided due to the prohibitively high cost of monthly tariffs and electrical appliances (Williams & Shackleton 2002, Madubansi &Shackleton 2006). Fuelwood is free or cheap in comparison, saving households the cost of using additional electricity against the backdrop of widespread poverty (Shackleton & Shackleton 2002). Rural South Africa thus remains dependant on fuelwood and without substantial changes in the local economy will continue to be so into the foreseeable future (Williams & Shackleton 2000, Karekezi *et al* 2004).

Fuelwood supply-demand models have been used as tools to predict the long-term implications of the fuelwood harvesting, at both national and local village scales in South Africa. These models showed that at the national level, aggregate wood supplies are adequate to meet demand (von Maltitz & Scholes 1995), but that fuelwood shortages occur at a localised village level and the degree of scarcity varies (Shackleton *et al* 1994, Banks *et al* 1996). National models tend to overestimate the effectively available fuelwood supply since they do not take into account the spatial location of the rural settlement or demand centres. Often these models included data from commercial and natural forests or remote areas inaccessible to the communities that require the fuelwood (von Maltitz & Scholes 1995, Arnold *et al* 2006). Spatially explicit models operating across various scales, from national through to district level, that capture the spatial variability of fuelwood supply relative to demand-centres have been developed and applied in various countries including Mexico, Senegal and Tanzania (Ghilardi *et al* 2009). These models are useful for identifying "hotspots", areas of critical fuelwood scarcity, on the landscape. Harvesting of livewood stems occurs once the deadwood stocks become insufficient to meet local demand (Shackleton 1993) irrespective of the local traditional and societal control mechanisms in place to discourage this (Kaschula *et al*, 2005). In such situations, up to 90% of household energy need is met by livewood harvesting (Shackleton 1993). This exerts a selective pressure on the communal woodlands as most harvesters select certain species and particular size classes within these species (Luoga *et al* 2000). Over time, this may bring about a change in size class distribution and increased mortality of target species (Luoga *et al* 2004) as well as an overall decrease in species richness of the entire woodland (Shackleton *et al* 1994). At landscape level this should be evident by evaluating the long-term woodland response to harvesting through reductions in stem density, changes in structural and species composition (Frost 1996) and increased coppice re-growth, a survival mechanism against damage to the stem through fire, herbivory and felling (Shackleton 2000).

Banks *et al* (1996) constructed and parameterised a predictive fuelwood supply-demand model using empirical data collected from two villages, Athol and Welverdiend, in South Africa in 1992. The model predicted that if fuelwood demand remained constant, wood harvesting around Welverdiend village would be unsustainable, resulting in severe deforestation by 2007. In contrast, harvesting in Athol would not result in negative change in the local communal woodlands. The annual per capita wood consumption was similar for both villages, at over 500 kg $cap^{-1}yr^{-1}$. Banks *et al* (1996) provided baseline data for a long term natural experiment that enabled us to quantify the environmental impacts of continuous fuelwood harvesting on communal woodlands between 1992 and 2009, and to evaluate whether the different trajectories of woodland development predicted by the model had been realised. This paper examines the ecological impacts of 17 years of increasing fuelwood harvesting on the communal woodlands of Athol and Welverdiend. The dynamics of fuelwood supply against the backdrop of the contrasting projections of sustainable fuelwood use in both villages were tracked (Banks *et al* 1996). Specifically, the aim was to assess the impacts of increasing, continuous wood harvesting on fuelwood availability. The changes in the total wood stock availability, woodland population structure and species diversity were quantified. We also assessed the impact of fuelwood harvesting by measuring stem size distribution and species diversity of harvested species within the communal woodlands.

2.2 Methods

2.2.1 Study Area

The case study villages, Welverdiend (24° 35'S 31° 20'E) and Athol (24° 34'S 31° 21'E), are located in Bushbuckridge Municipal District, in the Kruger to Canyons (K2C) Biosphere Reserve (Figure. 1). Bushbuckridge consists of the consolidated area of two former "homelands", established by the South African Apartheid-era government (Thornton 2002). Boundaries of village settlements are thus defined by the original boundaries of the farms upon which the settlements were established and consist of a residential area and village commons consisting of arable fields, and communal woodlands (Banks *et al* 1996). The maintenance of fencelines in the case-study sites does not guarantee the exclusion of residents from neighbouring villages. Agricultural productivity within the communal lands is minimal; households engaging in this activity do so at a small-scale, growing crops and vegetables to supplement food supplies or keeping livestock. Economic development is marginalised, unemployment is rife, monetary income is low and human settlements are densely populated, averaging 150-350 people km^{-2} (Pollard *et al* 1998). Most villages have access to electricity but fuelwood dependence remains high; over 90% of all connected households use fuelwood to meet their thermal energy needs (Madubansi & Shackleton, 2006). There is a thriving trade in fuelwood in those villages where local reserves are insufficient to meet the demand (Madubansi & Shackleton, 2007).

2.2.2 Land–use and land tenure

The communal village settlements of Bushbuckridge were incorporated into the transition zone of the Kruger to Canyons Biosphere Reserve outside the core conservation areas (Coetzer *et al* 2010). Village settlements fall under communal land tenure, wherein traditional authorities apportion land-use rights to residents and zone the land into residential areas, arable plots and communal woodlands (Shackleton & Shackleton 2002). The communal woodlands are open-access, there is little effective regulation of natural resource harvesting due to the waning power of the traditional chiefs (Kaschula *et al* 2005). The woodlands provide a resource base for village residents to browse livestock and extract various non-timber forestry products (Shackleton & Shackleton 2002). State or privately-owned conservation areas are the next most common land use type in Bushbuckridge, used for nature conservation, commercial game hunting or eco-tourism (Coetzer *et al* 2010). Grazing and resource harvesting pressure in these areas is much lower than in the neighbouring communal rangelands as a direct consequence of the land use and management plans which prescribe lower stocking rates and exclusion of village residents.

2.2.3 Village Development (1992-2009)

The number of households in both settlements has more than doubled since 1992; In Welverdiend this figure rose from 564 (Banks *et al* 1996) to 1508;an increase of 56 households annum^{-1} or 9.8% households annum^{-1}(Ruwadzano Matsika, unpublished data 2009). In Athol the increase was from 292 (Banks *et al* 1996) to 517, giving an average increase of 13 households annum^{-1} or 4.5% households annum^{-1}(Ruwadzano Matsika, unpublished data 2009). Consequently the residential zones in both villages have expanded outwards into the communal woodlands. Landcover change analysis using aerial photographs of both villages from 1986/7 to 2009 revealed that 1000 ha of woodland area was lost in Welverdiend compared to 300 ha in Athol (Ruwadzano Matsika, unpublished data 2011). Since the severe drought in the early 1990s residents of Athol have been allowed to graze their cattle in the communal rangelands belonging to the neighbouring village of Utah (Figure. 1, Giannecchini *et al* 2007). Welverdiend residents began to use and extract resources from Morgenzon, an unoccupied private property on their western boundary (Figure. 1) that was perceived to be "un-used" at the time (Rex Mnisi, personal communication 2009). It is now considered part of the Welverdiend resource base.

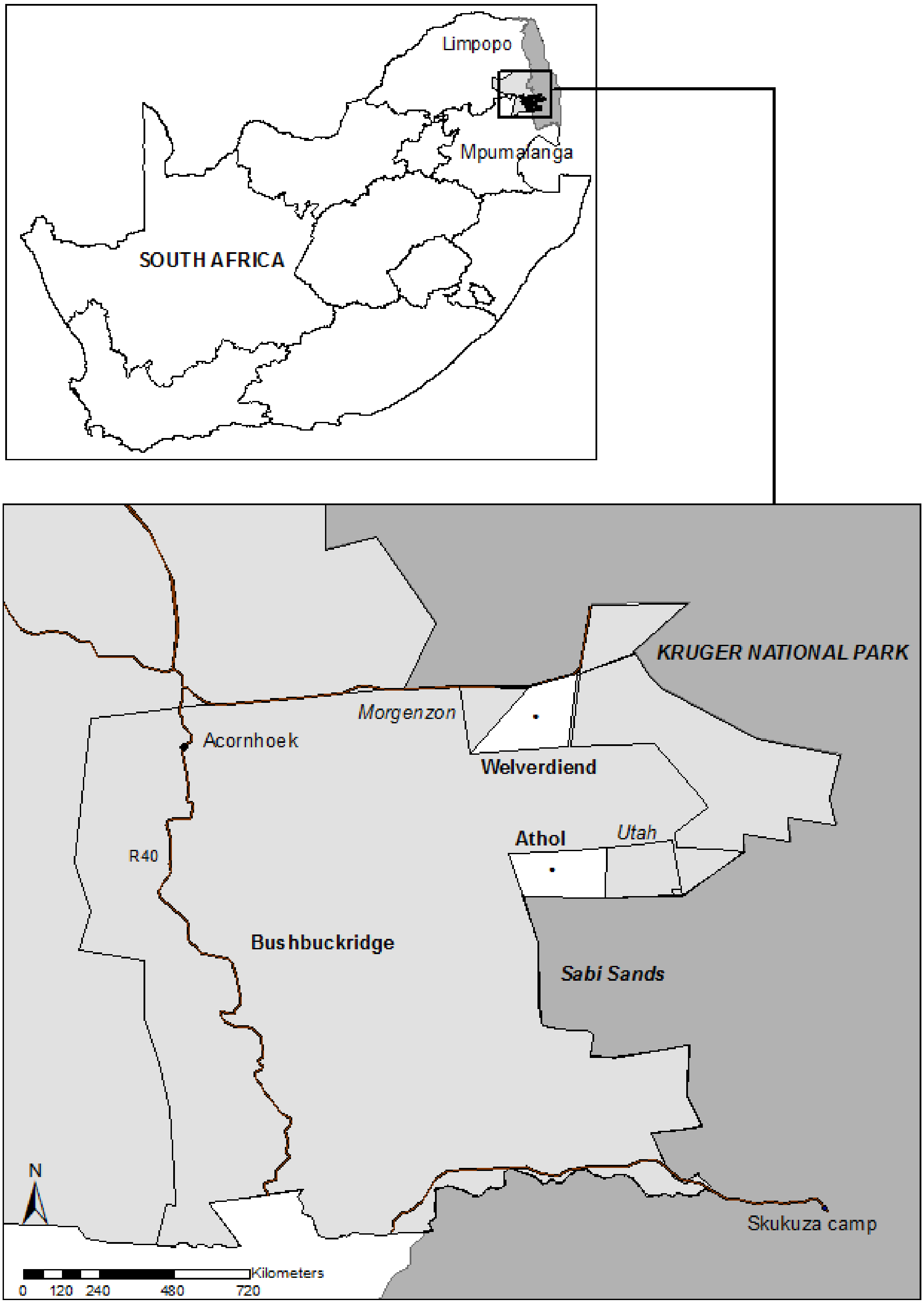


Figure 2.1. The locations of Welverdiend and Athol villages relative to the Kruger to Canyons Biosphere Reserve and the Kruger National Park in South Africa. Clear polygons show the extent of the original farm boundaries of each settlement.

2.2.4 Biophysical characteristics

The topography of the region is gently undulating with an average altitude < 600 m a.s.l. The vegetation is Mixed Lowveld Bushveld, characterised by a mosaic of dense bushland on the lowlands and open savanna woodlands on the uplands, dominated by species of *Combretum* and *Terminalia* (van Rooyen & Bredenkamp 1996). *Sclerocarya birrea* and *Dichrostachys cinerea* contribute significantly to the woody biomass (Shackleton 1997). Rain falls in the austral summer (October to May) mainly in the form of convectional thundershowers with mean annual rainfall of 600 mm. Drought occurs on average once every decade. Mean annual temperature is 22 ºC; summers are hot, with a mean daily maxima of 30 ºC and winters are mild and dry with a mean daily maxima of 23 ºC (Shackleton *et al* 1994).

2.2.5 Data collection

The authors of the baseline study provided the raw data describing woodland conditions for each village in 1992 published in, amongst others, Shackleton (1993) and Banks *et al (*1996). Therefore, the woodland sampling design in 2009 was modelled on the previous study to allow for comparisons. Following Banks *et al* (1996) sampling was carried out along four transects radiating outwards from the residential areas towards the border of the communal lands of each settlement (Figure. 2). Each transect consisted of three rectangular 5x50m (250 m^2) plots. The near plot was placed 350 m from the last agricultural field or residential stand. Agricultural fields were excluded from both studies as they were generally cleared of all trees except for a few large indigenous fruit trees. The far plot was placed as close to the village commons boundary as possible, in a representative patch of vegetation and the mid plot was located mid way between the two. This method captured any effects of distance from the settlement on resource-use, as has been observed in other studies in the region (Shackleton *et al*, 1994, Fisher *et al,* 2012). The exact location of the original plots was not recorded in the first study as such, the same sites could not be re-measured. However, GPS points of all plot locations were taken to allow for future follow-up studies (Figure. 2).

Following the methodology used in the original study (Shackleton *et al* 1994, Banks *et al* 1996) the unit of measurement was woody stems not individual trees and every woody stem was measured at 35 cm above ground level (basal diameter, BD). Forestry convention dictates measuring the diameter at breast height (DBH) at 1.3 m, is situations where the dominant tree structure is multi-stemmed or coppice shrubs such as in this area, the taper and form of tree stems at DBH may be irregular and BD may be a better reference diameter for predicting tree characteristics (Chhetri & Fowler 1996). If the stem split/forked lower than this point then the stems were measured as separate woody stems but if forking occurred after this point (35cm above ground level) then it was considered a single stem. All stems emerging from a chopped stump were measured. Data recorded for each woody stem included species, diameter at 35 cm or just above the basal swelling, height, whether the stem had been chopped and whether the stem was a coppice shoot. Only stems that had been chopped within the last year where recorded as such; this determination was based on the colour and freshness of the exposed wood (Luoga *et al*, 2002). This may have resulted in an underestimate of chopping but the information provided a comparative index of harvesting intensity between villages in 2009 and thus served its purpose. Species identification was carried out by the authors, based on bark and leaf identification, with the assistance of a local expert fully conversant with the tree species in the local xiTsonga or English common names; where there was any uncertainty, a specimen of the bark and leaf was taken for identification using the field guide and for comparison with the specimens in the WITS Herbarium. Stem height and diameter were used to calculate woody biomass using Rutherford's allometric equation for mixed species woodlands [1] (Rutherford 1979). Stumps were also measured as an indicator of past resource quality, data recorded included species, basal diameter and stump height. Parameters were converted to per hectare density. All statistical analyses, unless otherwise stated were performed using SAS Enterprise Guide v4.2.

Total biomass (kg): $$\ln Y = -8.5997 + 1{,}0472x \qquad [1]$$

Where Y= total biomass, *x= ln (stem diameter)*^{2} ** height (cm)*

2.2.6 Data analysis:

2.2.6.1 Total wood stock

Following Shackleton (1993) and Banks *et al*. (1996) the woodland area was divided into three concentric ring-zones defined by the near, mid and far plots along each transect (Figure. 2). All spatial measurements and calculations were carried out in ArcGIS v9.3 (ESRI, Redlands, USA) using 2009 aerial photographs of each village. Woody biomass (aboveground biomass density, kg ha^{-1}) for each zone was calculated by averaging the plot biomass densities of the near, mid and far plots respectively. The woody biomass sub-totals for each ring were summed to give the total on-farm woody biomass stock. Proportional change in woody biomass, relative to 1992 levels, was calculated to establish the magnitude of change.

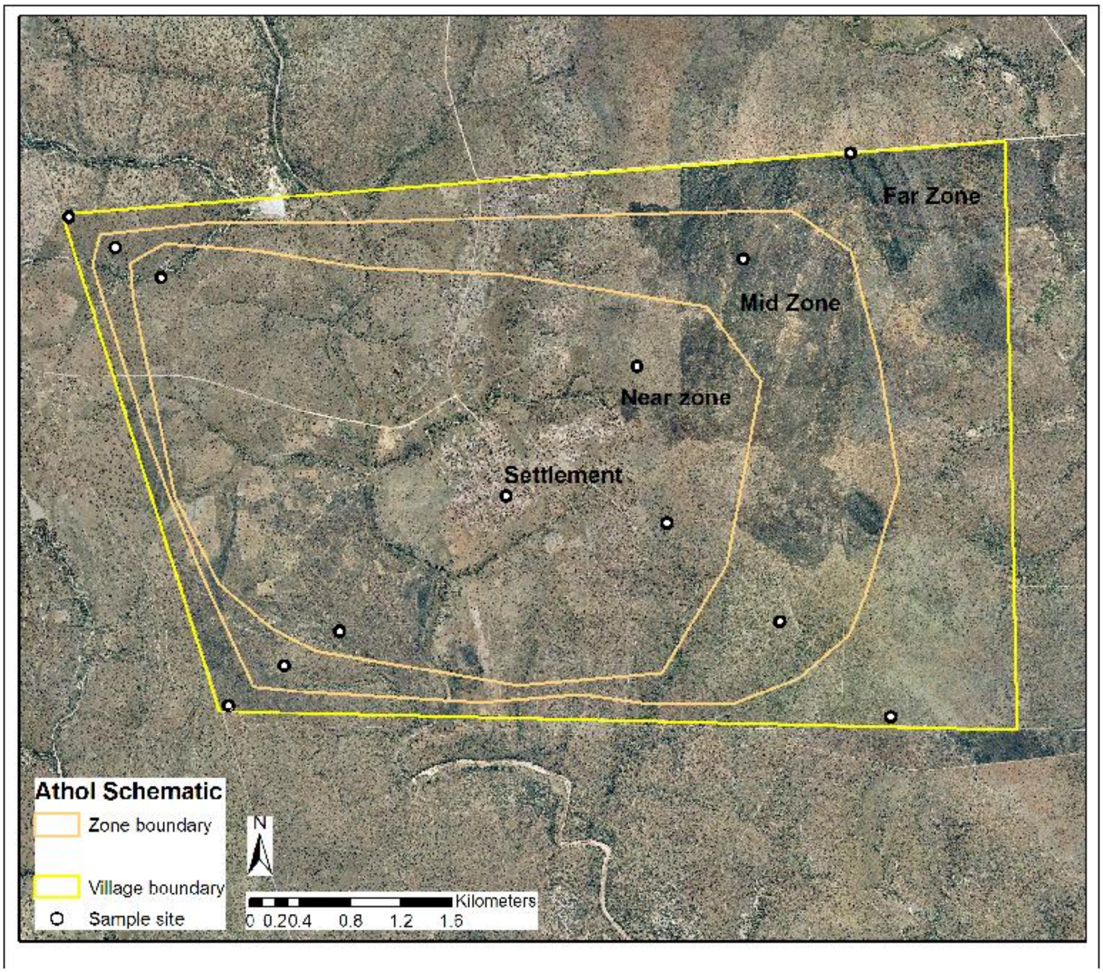


Figure 2.2 Schematic map showing how the woodland sampling plots were positioned and the woodland "zones" used to divide the communal woodlands into rings of average biomass density around Athol .

2.2.6.2 Change in woodland structure and species composition

The variables chosen to indicate changes in woodland structure were the average stem height and diameter, woody biomass (kg ha^{-1}), number of woody stems, seedlings and coppice stems. Following Luoga *et al* (2002), seedlings were defined as newly established shoots < 1 cm diameter, different from coppice resprouts, which were stems re-growing from stumps or roots after some sort of damage, through cutting or otherwise, to the main stem. The structural and functional stem-diameter classification put forward by Luoga *et al* (2002) was used in this study to reflect the user-perspective of the woodland resource base.

- < 1cm: new regeneration by seedling or resprouts
- 1 to < 4cm: "saplings"
- 4 to < 10 cm: "poles"
- 10 to < 20 cm: "small reproductive woody plants"
- ≥ 20 cm: "large reproductive woody plants"

The variables were tested for normality using the Kolmogorov-Smirnov test. After examining the frequency distribution for woody stem diameter and height for both village datasets the median value was deemed to be the best descriptor of central tendency as the data did not follow normal distribution and were heavily skewed. Therefore the significance of changes in average woody stem diameter and height were tested using the Wilcoxon Two Sample test. The values for woody biomass and coppice stem density values were not normally distributed so the log (ln) transformation was applied to stabilise the variances. Two sample T-tests were then used to assess the significance of observed changes in density of the woodland parameters between 1992 and 2009. The proportions of coppice stems and seedlings were calculated and since they were not normally distributed, these values were arcsine transformed; the significance of changes with time was assessed using Two Sample T-tests.

The Kolmogorov-Smirnov (KS) two-sample goodness-of- fit test were used to contrast stem size class distributions (SCD) and assess whether overall population structure had been altered. Paired t-tests were used to test differences in the mean stem densities of each size class over time.

The relevant methods described in Kindt & Coe (2005) were used to establish and test any changes in species composition using Biodiversity R. (Kindt & Coe 2005) This statistical software package, written in R, provides utility functions for statistical analyses of biodiversity and ecological communities including diversity indices, species accumulation curves and Renyi profiles (R Development Core Team, 2011). Species richness (S), the total number of species observed, the Shannon-Weiner Diversity Index (H') [1] and Simpson's Inverse Diversity Index [2] for each year's dataset were used as metrics to describe diversity, and displayed graphically on a Renyi diversity curve (Tothmeresz 1995).

$$H' = -\sum_{i=1}^{R} p_i log p_i \qquad [1]$$

$$1/\lambda = \frac{1}{\sum_{i=1}^{R} p_i^2} \qquad [2]$$

p_i = proportion of individuals of species in the community, R= the total number of species in the community

The shape of the Renyi curve indicates evenness, the steeper the slope of the curve the less evenly distributed are the species in that dataset. The Shannon-Weiner and Inverse Simpson's diversity indices can be read at α=1 and α= 2 respectively on the Renyi Curve. Where the profile of one site is completely above the profile of another, the higher profile curve shows the dataset with the higher species diversity. If the profiles intersect then there is no distinction in diversity between datasets.

2.2.6.3 Changes in harvesting pressure patterns

The stem-diameter size-class frequency distributions of cut stems for each village in 2009 were compared against those of 1992 and tested for the significance of any observed differences using the Two-Sample KS test. The density of cut stems in each size class for each year were log transformed compared over time and tested for significant differences using paired T-tests. The median stem diameters found in 1992 and 2009 were calculated and compared to detect shifts in the size of available species using the Wilcoxon-Two Sample test.

2.2.6.4 Impact of harvesting pressure on species population structure and stability

The impact of harvesting on plant population structure was assessed by evaluating how stable the stem-diameter size-class distributions (SCD) of harvested species (with cut stems) were over time, compared to the SCDs of selected non-harvested species (no cut stems). However, it was necessary to limit the analysis to those species that had sufficient data points in both 1992 and 2009 datasets. SCD slopes were calculated according to Lykke (1998). A least squares regression was carried out on the species SCD using class midpoint (ln transformed) as the independent variable and the average size class density (ln (AveN+1) as the dependant variable. The ln-ln transformed values were used as they gave the best regression (Lykke 1998). The slopes of these regressions indicate the shape of the SCD slope as well as the health and vigour of the population, a negative slope indicates an inverse J-shaped curve, with abundant recruitment (seedlings and saplings) relative to other size classes, as the slope value approaches 0, this suggests equal numbers of recruitment and larger size classes (mature trees) and a positive slope indicates no or very low recruitment densities and relatively abundant mature plants (Shackleton 1993, Lykke 1998). Following Gaugris & van Rooyen (2010) Analysis of Covariance, ANCOVA (F-test), was used to compare the regression slopes and intercepts for each village between both points in time using GraphPAD Prism 5 (GraphPad software, San Diego, California, USA. www.graphpad.com). If the slopes are not significantly different the software compares the Y-intercepts, if these are not significantly different it calculates pooled slope and intercept values to represent both datasets.

Biodiversity R was used to calculate species diversity indices for the harvested species in both Welverdiend and Athol in 1992 and 2009. These were qualitatively compared to describe how harvester species selection has changed over time in each village.

2.3 Results

2.3.1 Changes in total wood stock and woodland structure

The total standing wood stock of both villages declined over the period of interest (Table 2.2.1). The greater loss of wood occurred around Welverdiend (40% loss) compared to Athol (12% loss. The high standard error values reflect the heterogeneity inherent to savanna communal woodland landscapes and incorporates the well-documented influence of catenal effects (Venter *et al* 2003) and disturbance gradients (Shackleton 1993) although they are not explicitly explored in this paper. The high variance may also be linked to the relatively low plot sampling intensity at each site, a methodological limitation of the study upon which this was based.

Table 2.1. Total wood stock in the Welverdiend and Athol communal areas in 2009; sub-totals for each zone and total wood stock values are given in kg ± SE.

Sampling zone	**Characteristics**	**Welverdiend**	**Athol**
Near zone	Wood biomass (kg ha^{-1})	4,948 ± 2,244	11,677 ± 2,466
	Area (ha)	443	550
	Wood sub-total (* 10^3 kg)	2,194 ± 995	6,419 ± 1,355
Mid-zone	Wood biomass (kg ha^{-1})	3,251 ± 708	18,652 ± 5462
	Area (ha)	497	655
	Wood sub-total (*10^3 kg)	1,614 ± 351	12,210 ± 3576
Far-zone	Wood biomass (kg ha^{-1})	13,449 ± 10,725	16,410 ± 3,214
	Area (ha)	1,344	1,003
	Wood sub-total (*10^3 kg)	18,068 ±14,408	16,456 ±3,223
Total wood stock 2009 (*10^3 kg)		**21,876 ± 15,754**	**35,085 ± 8,154**
Total wood stock 1992 (*10^3 kg)[§]		**36,672 ± 23,056**	**39,875 ± 15,146**

[§]*1992 values of total wood stock as given by Banks* et al *(1996).*

The increased stem abundance in Welverdiend is linked to the significantly higher abundance of coppice stems within the woodland population (Table 2.2), specifically within the sapling size class, which has increased in abundance between 1992 and 2009 (Figure. 3a, $Df=19$, $t=-2.01$, $p<0.05$). There were fewer woody stems belonging to the larger size classes, the most significant decrease being the 89% drop in density of small reproductive stems ($DF=19$, $t=2.12$, $p<0.05$). The average woody stem in Welverdiend is significantly taller but narrower in diameter than in 1992 (Table 2.2).

Table 2.2 Comparison of woodland structural parameters for Welverdiend and Athol in 1992 and 2009 using the Wilcoxon Two-Sample and the Student's T-test. Unless otherwise stated all values presented are the mean ± S.E. * indicates a significant result.

Woodland structural characteristics	**Welverdiend**			**Athol**		
	1992	**2009**	**Results**	**1992**	**2009**	**Results**
Median stem diameter (cm)	2.5± 0.1	2.3± 0.1	Z=4.86 *** KS D=0.17***	2.2±0.1	2.2± 0.1	Z=0.18 KS D=0.14*
Median stem height (cm)	109.0± 2.7	132.0± 2.0	Z=-8.36 *** KS D=0.14***	103.0± 3.4	150.0± 2.1	Z=-9.93* KS D=0.19*
Median harvested stem diameter (cm)	6.2±0.4	2.2±0.1	Z=15.2*** KS D=0.89***	5.7± 0.2	6.1± 0.3	Z=-0.36 KS D=0.19*
Wood biomass (kg ha^{-1})	5,927± 3,333	4,168± 974	Df=19, t=0.57	6,383±3016	15,578±2,230	Df=19, t=-2.51*
Stem density (stems ha^{-1})	4,997 ± 610	6,460± 706	Df=19, t=-1.5	4,069±588	8,290±1,348	Df=19, t=-2.56*
Seedling density (stems ha-1)	864± 189	727± 205	Df=19, t=0.48	844±198	820±221	Df=19,t=0.08
Harvested stem density (stems ha-1)	612± 113	473± 133	Df=19, t=0.76	627±190	1,323±279	Df=19, t=-1.76*
Coppice density (stems ha-1)	291± 101	873±216	Df=19, t=-2.36*	405±208	760±279	Df=19, t=-0.96
Coppice % (% of all stems)	6.6% ±2.5%	15.6% ±2.8%	Df=19, t=-2.36*	9.9%± 5.2%	7.4% ±1.6%	Df=19, t=0.54

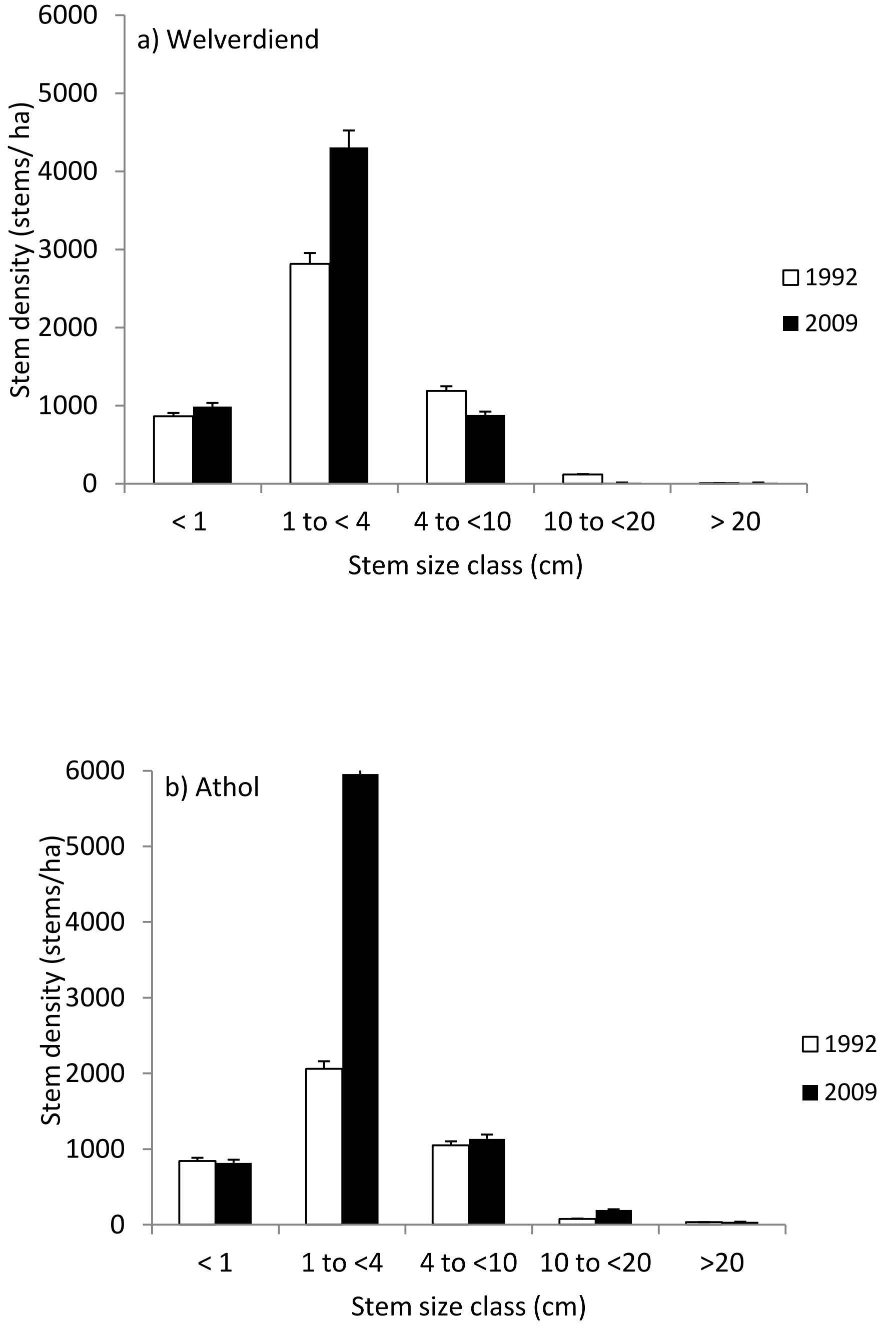
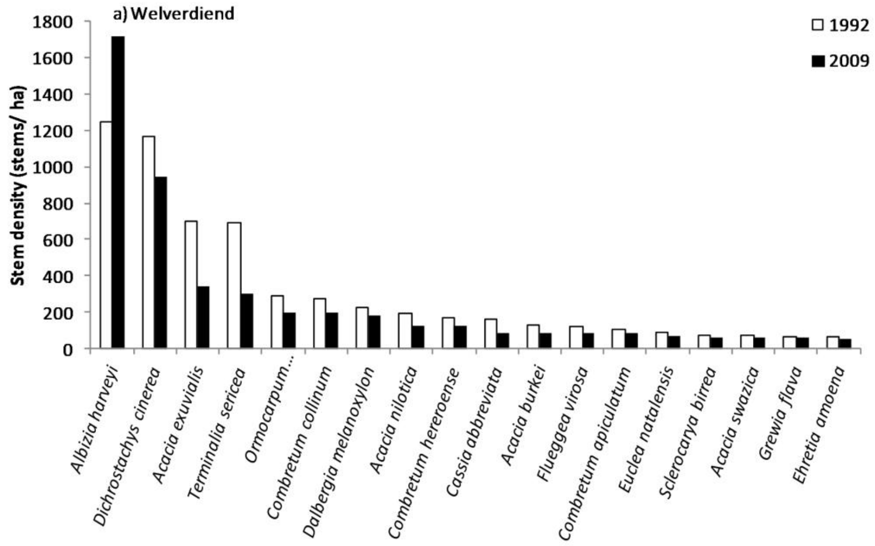


Figure 2.3 The size class frequency distribution of stem density within the communal woodlands, divided into functional size classes defined by Luoga et al (2002) for a) Welverdiend and b) Athol.

Both stem density and wood biomass (kg ha^{-1}) around Athol more than doubled (Table 2.2) yet standing wood stock in 2009 is 12% less than in 1992 (Table 2.1); as observed around Welverdiend, increased stem density is linked to the increase in the sapling size class (189%, Figure. 3b, DF=19, t=-2.74, $p<0.05$). However, for Athol this is not because of coppice regeneration, as there is no significant change in absolute coppice abundance or proportion (Table 2.2). This suggests that conditions within Athol may be conducive to high survival rates of saplings (perhaps due to lower fire frequency or intensity) as well as high recruitment of seedlings into this size class. There are significantly more small trees (150%, Figure. 3b, DF=19, t= -2.40, $p<0.05$) and slightly higher numbers of large trees (not significant) surviving to produce seeds and this may account for the sharp rise in seedling and sapling abundance. There has been no change in the abundance of poles in Athol (Figure. 3b, DF=19, t=-0.35 $p>0.05$).

2.3.2 Changes in woodland species composition

The species-abundance rank order of all woodland species in Welverdiend has changed; with lower stem densities for *A. harveyi* and *D. cinerea* (Figure. 4a) although they have remained the most dominant species, together accounting for 53% and 37% of all observed stems in 1992 and 2009 respectively. The biggest increases in abundance were observed for *Terminalia sericea* (725%), *Ormocarpum trichocarpum* (357%), *Acacia nilotica* (182%), *Combretum hereroense* (150%) and *Acacia exuvialis* (133%), (Figure. 4a). Species richness (S) and diversity measured by the Shannon-Weiner Index (H') and Simpson's Inverse Index (S') for Welverdiend were higher in 2009 than in 1992 (Figure. 5a, S_{1992}=28, S_{2009}=40, H'_{1992}=2.37, H'_{2009}=2.76, S'_{1992}= 5.889 and S'_{2009}=9.723).



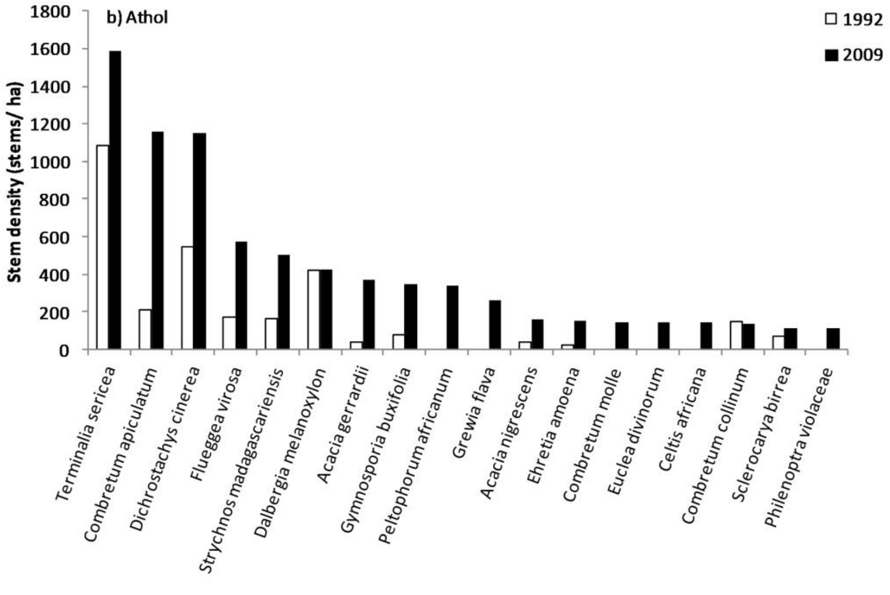
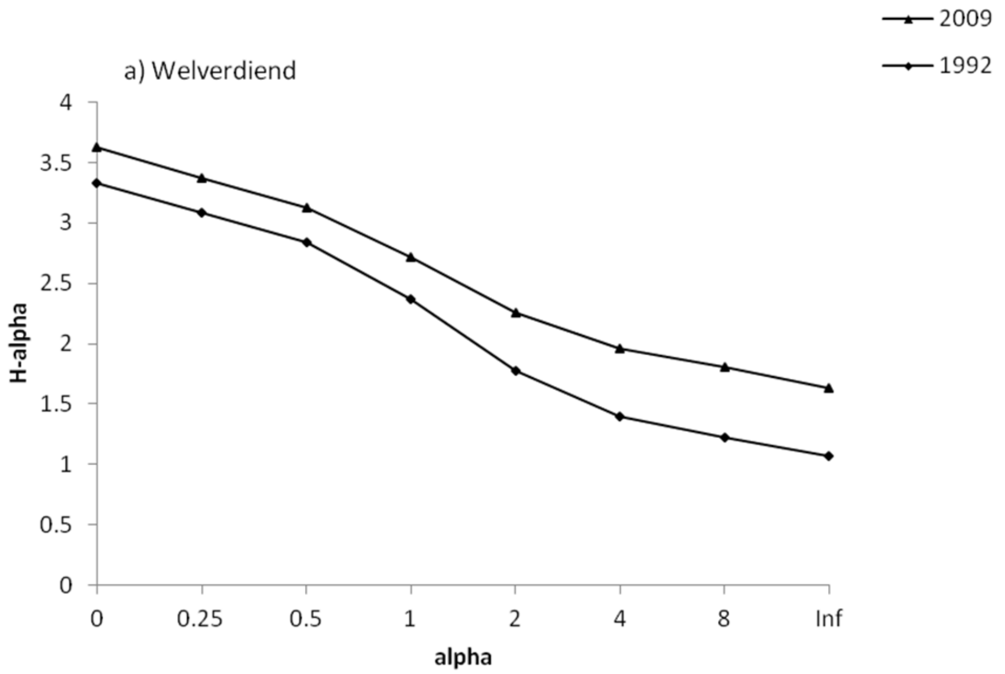


Figure 2.4 The species abundance profiles of a) Welverdiend and b) Athol showing the total abundance (stem density) of all species greater than 20 stems/ha in 1992. Species are ranked according to abundance in 1992.

The Athol woodlands have been consistently dominated by *T. sericea* and *D. cinerea* stems over time (Figure. 4b). Like Welverdiend, the changes in the abundance of lower ranking species in the rank abundance diagrams account for the different abundance profile, particularly increases in *Combretum apiculatum, Flueggea virosa, Strychnos madagascarensis*, *Acacia gerrardii*, *Gymnosporia buxifolia*, *Acacia nigrescens* and *Sclerocarya birrea*. The Renyi curve indicates that there has been no clear or significant change in species richness and diversity in the Athol woodlands since 1992. (Figure. 5b, S_{1992}=33, S_{2009}=34; H'_{1992}=2.65, H'_{2009}=2.71 S'_{1992}=8.52 and S'_{2009}=10.44).



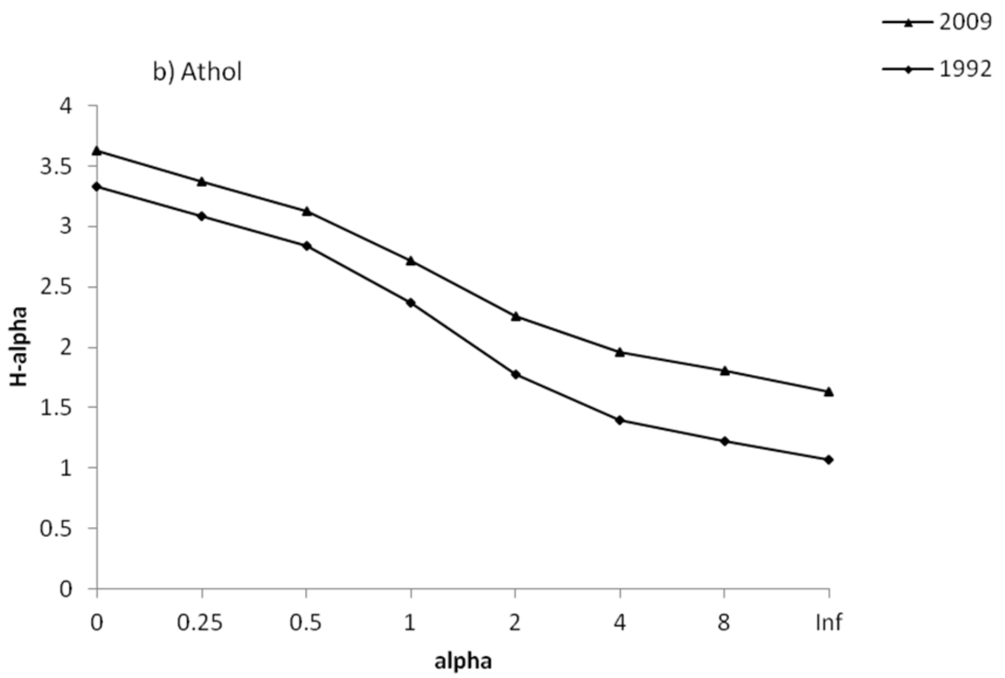


Figure 2.5 The Renyi profiles for a) Welverdiend and b) Athol display the species diversity information for each village dataset in 1992 and 2009 respectively. Shannon-Weiner and Inverse Simpson's diversity indices can be read at alpha (x-axis) =1 and 2 respectively.

2.3.3 Change in harvesting pressure patterns over time

The decreased availability of larger stems for fuelwood in Welverdiend is reflected in the significant decrease in the average diameter of harvested stems and the predominant harvesting of smaller stem size classes (Table 2.2, Figs 3a, 6a). There are significant differences in the stem Size Class Distribution (SCD) of harvested stems in Welverdiend (KS D=0.89, p<0.0001); no woody stems larger than 10 cm in diameter (trees) were chopped in 2009, although this may be due to the reduction in abundance of individuals from this size class. In Welverdiend, saplings rather than poles were most commonly harvested of all observed stems and for the first time seedlings also showed evidence of harvesting (Figure. 6a). There has been little change in the number and diversity of harvested species in Welverdiend (S_{1992}=12, S_{2009}=13, H'_{1992}=2.00, H'_{2009}=1.99, and S'_{1992}=5.30, S'_{2009}=5.29). Eight species were commonly harvested in both 1992 and 2009, (Figure. 7a). The four species that are no longer harvested in 2009 were already low in abundance in 1992 (<50 stems ha^{-1}, Figure. 4a). Three of these species (*Acacia caffra, Euclea divinorum and Combretum molle*) were not observed in the 2009 survey the fourth, *Philenoptra violaceae* has persisted in Welverdiend, but declined in abundance (Figure. 4a).

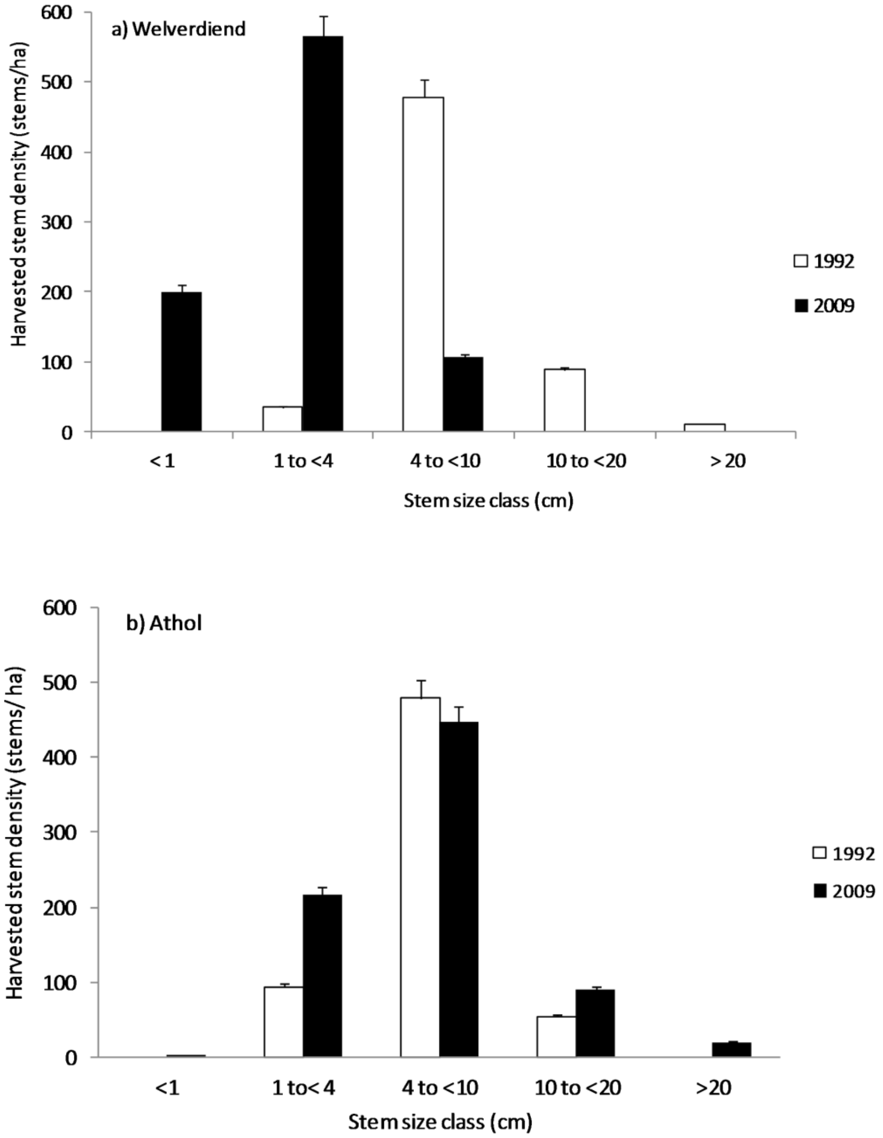


Figure 2.6 Size class frequency distribution of harvested stems in the woodlands around a) Welverdiend and b) Athol in 1992 and 2009.

Poles remain the most harvested size class in Athol (Figure. 6b, DF=19, t= p>0.05); with no change in the median diameter of harvested stems (Table 2.2). This is concurrent with the persistence of this size class within the woodland population (Figure. 3b). Stems from all five functional size classes showed evidence of harvesting where previously only saplings, poles and small trees were harvested, resulting in a significantly different SCD curve shape (KS D=0.19, p<0.01). There has been an increase in the diversity and richness of harvested species in Athol (S_{1992}=13, S_{2009}=20; H'_{1992}=1.448, H'_{2009}=2.146; S'_{1992}=2.313, S'_{2009}=5.304). It is not clear whether this is in response to decreasing abundance but *A. exuvialis* and *D. mespiliformis* had very low stem densities in 2009 and no stems belonging to either species were harvested. In contrast *A. nigrescens* has increased in abundance in Athol since 1992 with a concurrent switch to harvesting this species in 2009 (Figure. 6b).

2.3.4 The impact of harvesting on species SCD and population dynamics

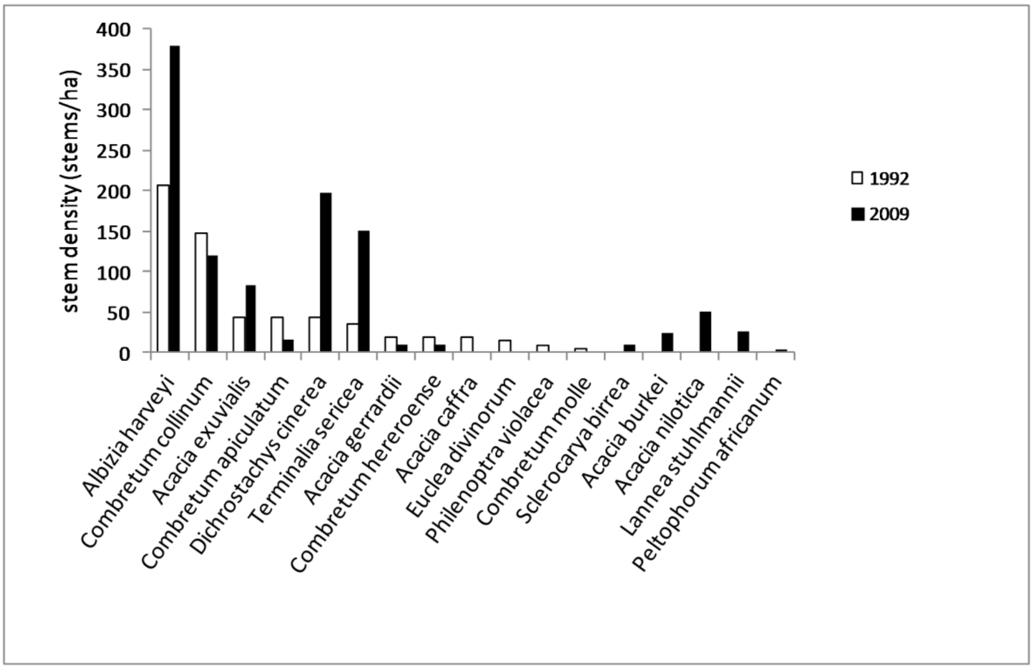
The results of the SCD slope comparison analysis for Welverdiend showed that irrespective of species harvesting and the length of time over which harvesting was observed, that is, either only in 1992 or 2009 or in both years, there was no significant difference in the SCD slope values between 1992 and 2009 (Table 2.3). The ANCOVA therefore produced pooled slope and intercept values for all species (Table 2.3), the pooled slope values were used to categorise the species into four groups, based on the classification used by Obiri *et al* (2002). This classification was also applied to the ANCOVA results for Athol.

Group 1 species had flat SCD slopes > -0.04 and approaching 0 (Table 2.3). These species are consistently low in abundance within the woodlands with overall densities < 120 stems ha^{-1} (Figure. 4a). The populations are characterised by poor seedling and sapling recruitment (density < 60 stems ha^{-1}) and the absence of stems larger than poles. The majority of the remaining species fell into Group 2 (Table 2.3), with SCD slope values between - 0.04 and -0.1. Stem densities in the smaller size classes of this group are still low but comparatively higher than those in Group 1. There is poor survival of woody stems into the seed-bearing size classes (stem diameter >10cm). Group 3 species had SCD slope values ranging between -0.1 and -0.2; in Welverdiend only *A. harveyi* and *D. cinerea* had slope values consistently steep enough over time to qualify for this group. The relatively high slope and y-intercept values for this group denote that there is vigorous recruitment of the seedling and sapling size classes and also survival into the seed bearing size classes. *Albizia harveyi* and *D. cinerea* are the most abundant and also the most frequently harvested species in Welverdiend (Figure. 4a, Figure. 7a). These species coppice prolifically in response to harvesting and this may account for the high seedling and sapling densities, as there was a noticeable absence of seed-bearing stems in 2009.

Table 2.3 Stem size class frequency distribution and Size Class Distribution slope comparisons for Welverdiend woodlands in 1992 and 2009. Regressions were compared for significance using ANCOVA.

SPECIES		SCD regression analyses										
		1992			2009			Slope comparison		Intercept comparison		Slope classification
	Harvest duration	Slope	Intercept	r^2	Slope	Intercept	r^2	p-value	Pooled slope	p-value	Pooled intercept	Group
Albizia harveyi	1992/2009	-0.11	4.92	0.79	-0.10	4.32	0.56	0.96	-0.11	0.61	4.62	3
Dichrostachys cinerea	1992/2009	-0.10	4.30	0.61	-0.11	4.51	0.61	0.94	-0.10	0.91	4.41	3
Combretum collinum	1992/2009	-0.07	3.31	0.82	-0.04	2.03	0.21	0.67	-0.06	0.33	2.67	2
Acacia exuvialis	1992/2009	-0.08	3.14	0.56	-0.09	3.69	0.52	0.82	-0.08	0.76	3.41	2
Acacia gerrardii	1992/2009	-0.07	3.06	0.60	-0.02	1.03	0.17	0.32	-0.05	0.17	2.05	2
Combretum apiculatum	1992/2009	-0.05	2.45	0.88	-0.03	1.29	0.17	0.63	-0.04	0.26	1.87	1
Combretum hereroense	1992/2009	-0.03	1.30	0.21	-0.05	2.04	0.36	0.69	-0.04	0.60	1.67	1
Terminalia sericea	1992/2009	-0.04	2.05	0.84	-0.08	3.66	0.60	0.37	-0.06	0.21	2.85	2
Philenoptra violacea	1992	-0.04	1.72	0.61	-0.01	0.72	0.14	0.40	-0.03	0.26	1.22	1
Sclerocarya birrea	2009	-0.05	2.26	0.47	-0.05	2.04	0.50	0.86	-0.06	0.89	2.15	2
Acacia nilotica	Not harvested	-0.02	0.90	0.33	-0.06	2.63	0.56	0.34	-0.04	0.13	1.76	2
Dalbergia melanoxylon	Not harvested	-0.05	2.21	0.35	-0.07	2.82	0.57	0.84	-0.06	0.59	2.47	2
Ehretia amoena	Not harvested	-0.05	2.20	0.51	-0.05	2.00	0.41	0.94	-0.05	0.86	2.09	2
Ormocarpum trichocarpum	Not harvested	-0.05	1.94	0.35	-0.07	2.92	0.41	0.72	-0.06	0.58	2.43	2
Diospyros mespiliformis	Not harvested	-0.05	1.99	0.87	-0.02	0.85	0.67	0.39	-0.03	0.17	1.42	1
Grewia flava	Not harvested	-0.04	1.54	0.36	-0.04	1.73	0.27	0.92	-0.04	0.91	1.63	2
Zizyphus mucronata	Not harvested	-0.03	1.35	0.36	-0.02	0.73	0.20	0.57	-0.03	0.56	1.04	1

a) Welverdiend



b) Athol

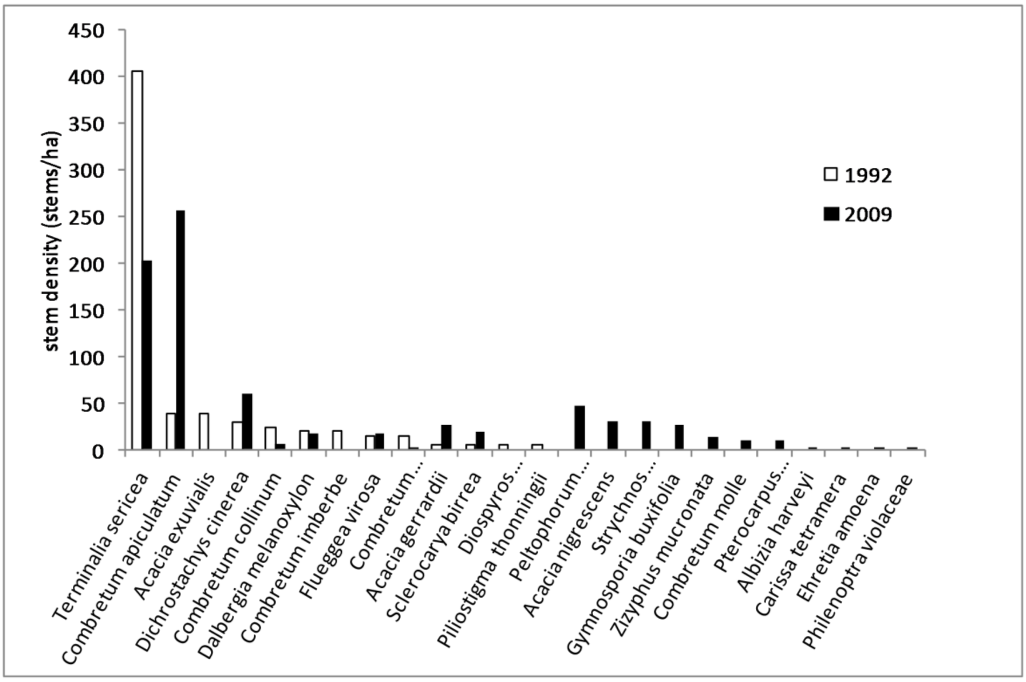


Figure 2.2.7 Species composition profiles of harvested species in a) Welverdiend and b) Athol showing changes in abundance (1992-2009)

The species population structures of all the assessed species in Athol have remained stable since 1992 with no significant changes observed in the SCD slope comparisons (Table 2.4). Based on the classification used by Obiri *et al* (2002) and applied to Welverdiend, all woodland species in Athol fell under Group 4 except *D. mespiliformis* which was classified as a Group 2 species (Table 2.4). Group 4 species have clearly inverse J-shape distribution curves with high persistence of stems into the larger seed-bearing size classes and high recruitment vigour with high density in the seedling and sapling size classes. As in Welverdiend, harvesting pressure or the duration of harvesting has had no discernable impact on species stem diameter distribution and the population structures have remained stable since 1992. *Diospyros mespiliformis* (Group 2) has had persistently low stem densities since 1992 (Figure. 4b), particularly in 2009 with an absence of seedlings.

Table 2.4 Stem size class frequency distribution and Size Class Distribution slope comparisons for Athol woodlands in 1992 and 2009. Regressions were compared for significance using ANCOVA.

		SCD regression analyses										
SPECIES		**1992**			**2009**			**Slope comparison**		**Intercept comparison**		**Slope classification**
	Harvest duration	**Slope**	**Intercept**	**r^2**	**Slope**	**Intercept**	**r^2**	**p-value**	**Pooled slope**	**p-value**	**Pooled intercept**	**Group**
Terminalia sericea	1992/2009	-1.19	6.67	0.76	-1.20	6.76	0.70	0.99	-1.20	0.92	6.72	4
Acacia exuvialis	1992/2009	-1.26	5.65	0.91	-0.24	1.29	0.13	0.05	-0.75	0.14	3.47	4
Combretum collinum	1992/2009	-0.27	1.96	-0.08	-0.90	4.14	0.75	0.35	-0.58	0.74	3.05	4
Combretum apiculatum	1992/2009	-0.83	4.26	0.68	-1.14	6.13	0.62	0.63	-0.98	0.28	1.38	4
Dichrostachys cinerea	1992/2009	-1.41	6.64	0.88	-1.17	6.45	0.71	0.66	-1.29	0.47	6.54	4
Dalbergia melanoxylon	1992/2009	-1.35	6.46	0.90	-1.15	5.81	0.87	0.60	-1.25	0.92	6.14	4
Combretum hereroense	1992/2009	-0.18	1.27	0.08	-0.28	1.49	0.13	0.86	-0.22	0.91	1.38	4
Flueggea virosa	1992/2009	-1.21	5.31	0.86	-1.39	6.34	0.82	0.72	-1.29	0.43	5.83	4
Acacia gerrardii	1992/2009	-0.83	3.49	0.79	-1.34	6.14	0.89	0.21	-1.08	0.08	4.82	4
Sclerocarya birrea	1992/2009	-0.78	3.72	0.91	0.23	1.69	0.07	0.32	-0.50	0.62	2.70	4
Diospyros mespiliformis	1992	-0.14	1.04	0.08	-0.05	0.43	0.05	0.76	-0.09	0.41	0.74	4
Strychnos madagascarensis	2009	-0.84	4.03	0.68	-1.33	6.65	0.98	0.22	-1.09	0.06	5.34	2
Gymnosporia buxifolia	2009	-0.75	3.72	0.30	-1.27	6.01	0.74	0.09	-1.01	0.14	4.87	4
Vanguerai infausta	Not harvested	-0.73	3.37	0.88	-0.19	1.28	0.10	0.20	-0.46	0.44	2.33	4
Acacia nigrescens	2009	-0.53	2.50	0.80	-0.59	3.29	0.44	0.88	-0.56	0.31	2.89	4
Ehretia amoena	1992	-0.62	2.64	0.80	-0.94	4.42	0.80	0.37	-0.78	0.11	3.53	4
Philenoptra violaceae	1992	-0.45	1.91	0.79	-1.06	4.72	0.86	0.07	-0.76	0.09	3.32	4

2.4 Discussion

2.4.1 Woodland degradation and the sustainability of fuelwood harvesting in communal landscapes

Communal savanna landscapes are complex, disturbance-driven, socio-ecological systems in which humans are the main agents of structural and functional change (Giannecchini *et al* 2007). Disturbance here is fuelwood harvesting which is deemed unsustainable if it results in persistent changes in the woodland structure, such that the quality of fuelwood is diminished for a length of time that is inconvenient to the users, resulting in a decline in their social and economic capital (Shackleton *et al* 1994, Scholes 2009). By this definition the predictions made by Banks *et al* (1996) have been upheld. The fuelwood resource around Welverdiend has become degraded with systematically smaller stems being harvested due to the dearth of more suitable stems within the woodlands. Conversely, woodland harvesting patterns have not changed at all in Athol indicating the maintenance of the resource at desired levels. However, the mechanisms behind the apparently divergent woodland-harvest response trajectories are not as predicted. Complete woodland denudation has not yet occurred around Welverdiend two years after the date predicted by Banks *et al* (1996).

Fuelwood availability is a function of woody stem density, size class distribution, and harvestable resource area. For Welverdiend, stem density and the woody biomass have not changed significantly. The absolute loss of wood stock may be partially explained by the disappearance of large trees, most likely due to felling, that have been replaced by a proliferation of coppice stems that do not contribute as much to the total woody biomass stock value thus accounting for the slight decrease in wood density in Welverdiend. The changes in the size class distribution for Athol indicate greater seedling recruitment and survival to the larger size classes. The higher wood density is due to the preservation and increase in abundance of individuals within the larger size classes, including the pole size class which is usually the target size class for harvesting (Luoga *et al* 2000). Despite these very different woodland structural developments, the total amount of wood available for both villages has decreased. This indicates woodland clearing, driven by human population growth in both villages, to create space for agriculture and outward residential expansion (Giannecchini et al. 2007). With over 1000 ha woodland area lost around Welverdiend and 300 ha around Athol (Matsika, Ruwadzano Matsika unpublished data 2011), landcover change partially accounts for the decline in total woody biomass in both settlements. However in Athol, the decline has occurred in spite of a large increase in stem density. While confident that some of the decline can be linked to woodland area, it is acknowledged that this highlights shortcomings in the accuracy of the methods used to determine area in the initial study. Furthermore, as the woodland areas have shrunk, the spatial location of sample sites has moved. Given the high spatial heterogeneity of savanna landscapes, the high variance between the two studies, especially in Athol, may also be as a result of comparing sites that have moved spatially over time. The methodology described in the original study prescribed the location of plots at a set distance from the last residential stands until the village fencelines but not the exact coordinates (Banks *et al.* 1996). However as the village residential area has expanded outwards with increasing human populations, this means the location of the follow-up study sites have moved outward, but remain near, mid and far with reference to distance from the human settlement area. Following up on this study meant following the same methods, even though there was this inherent weakness in the design study. Similar studies should endeavour to control for this by establishing permanent plots of known location that can be revisited and re-evaluated in the future. Because this study was conceived as a follow-up study of Banks *et al* (1996), the choice of methods and analysis, including the allometric equations that were used were constrained by those used originally. It is acknowledged that Rutherford's allometric equations, which were developed for different species and different growth forms (Rutherford 1979), may not be the best allometric equations to calculate woody biomass for this study area. These equations are better suited for undisturbed trees rather than the stems of coppicing shrubs such as in the woodlands of Athol and Welverdiend.

Increasing human populations, alongside landcover and land-use change have been identified around other African settlements as being the major drivers of deforestation rather than targeted harvesting for fuelwood or timber (Cline-Cole *et al* 1990). Fuelwood harvesting has contributed to degradation and the loss of stock around Welverdiend, where degradation, following Scholes (2009), refers to a decline in the ability of the woodlands to provide fuelwood. The observed biophysical changes are a reflection of the higher harvesting pressure per unit area of remaining woodland in Welverdiend compared to Athol, as the harvestable area gets smaller and the human population depending on it increases (Cline-Cole *et al* 1990).

The extent of woodland degradation is highly dependent on the social context within each settlement and includes changes in species composition and structure. The disappearance of certain species, together with prolific coppicing of others has brought about changes in the species composition profiles of both village woodlands. Since data were collected at stem level and not aggregated to individual tree or shrub, the observed changes reflect changes in the species diversity of the available stems (fuelwood resource). Species switching is a common response to scarcity of the preferred resource (Luoga *et al* 2000). Harvesters in Athol have switched from mainly harvesting *T. sericea* to previously ignored species such as *A. nigrescen*s. This may be a direct response to the decrease in absolute abundance of this species within the woodlands (Figure. 4b) and may have reduced the impact on the fuelwood resources (Luoga *et al* 2002). That there was no change in the diversity of species harvested in Welverdiend despite the decline of certain species reflects the dominance of *A. harveyi* and *D. cinerea*. The other species are in such relative low abundance to these two that they stand less chance of being harvested.

With time, harvesting has resulted in significantly different stem frequency distributions in Welverdiend manifesting as a measureable decline in the quality of available fuelwood. The lack of individuals in the larger size classes in 2009 is most likely due to the effects of past selective harvesting practices and overharvesting of the preferred pole size class of stem (Luoga *et al* 2000). The lower abundance of woody stems within the larger, more optimal size classes in turn may have forced a switch to harvesting predominantly available smaller stems (Luoga *et al* 2000). Selective harvesting behaviour is also evident in Athol where the sapling size class is the most abundant but the pole size class was most harvested. Similar mechanisms were observed elsewhere in South Africa by Gaugris & van Rooyen (2010). Ultimately this will lead to the loss of heterogeneity in Welverdiend as the landscape becomes increasingly dominated by species that flourish on high-impact use landscapes such as *D. cinerea, A. harveyi* and *T. sericea* but are limited to the lower size classes due to the high harvesting pressure (Scholes 2009).

2.4.2 Woodland persistence in response to fuelwood harvesting

The loss of seed-producing trees in Welverdiend, which has not occurred in Athol, may be linked to the low seedling densities in the former. Both woodlands are dominated by stems <

4 cm in diameter, suggesting a high regenerative capacity but the regenerative mechanism differs for each village. In Welverdiend this is occurring via the coppice response to harvesting, whereas in Athol the woodlands seem to be persisting due to seedling recruitment. Although the coppice response may compensate for the lost stems in terms of numbers, the loss of seed-producing plants may have implications for future woodland persistence. The long term ecological stability of this loss has yet to be established since the effects of continuous harvesting on coppice regrowth vigour in savanna systems have been little studied (Shackleton 2000). The dbh of the pre-cut stems influences the coppice regrowth vigour, as well as the survival of the resprouts (Shackleton 2000), the trend towards cutting smaller stems may have an influence on the ability of the stems to survive through coppicing. Furthermore, if recruitment and therefore persistence is occurring as a result of the coppice response, this may leave the woodland population vulnerable to extreme events such as droughts, disease or fires.

2.4.3 Plant population dynamics

SCD slopes are used as an indicator of population structure and health, summarising in a single number the relative regenerative vigour of a species population (Lykke 1998, Obiri *et al* 2002). Tracing changes in SCD slopes over time can be used as an indicator of species population dynamics (Gaugris & van Rooyen 2010). The results of the ANCOVA of the SCD slopes of both villages showed that the population characteristics and regenerative vigour of the woodlands around both Welverdiend and Athol have remained at 1992 levels. Per capita demand for fuelwood had not changed significantly since 1992 (Madubansi & Shackleton, 2006). There has been an increase in human population numbers and a decrease in available fuelwood yet harvesting intensity has not increased in either village. However, the classification used by Obiri *et al* (2002) does not adequately incorporate the differing functional ecology of the tree species within the study area. These species range from re-seeders (e.g. *Sclerocarya birrea*) to resprouters, with varying degrees of shade tolerance, palatability to livestock and different uses (such as *Pterocarpus* for timber and carving). These factors, together with the differing land-use histories in both villages suggest caution in drawing wide assumptions about the influence of village social conditions on plant population dynamics based on the analysis recruitment curves

If the different observed impacts are not contradictory, then the two villages are examples of communal landscape development at different points along the same trajectory. This leads us to identify potential for future conflict between village communities and conservation practitioners (private and government-owned) within the area, given the well-documented resentments and tensions over natural resource sharing (Pollard *et al* 2003). There is an urgent need for the development of more inclusive land management plans, provided that this does not result in the diminishing of ecosystem services (Scholes 2009*)*. This needs to be balanced with the conservation mandate of the K2C Reserve, as the social needs of the communities, if not pre-emptively managed present a real threat. Greater investment is required into mechanisms to reduce fuelwood demand through the use of more energy-efficient, low-cost woodstoves or energy alternatives. Alternatively, methods to manage supply via integrated agro-forestry systems, the development of woodlots using indigenous tree species and through integrated rotational harvesting and coppice- management in the communal woodlands need to be investigated.

2.5 Conclusion

The impacts of fuelwood harvesting on vegetation structure and species composition in the communal woodland vary significantly depending on the unique social characteristics within that settlement. The absolute loss of standing woody biomass in each village is linked woodland clearing for residential space as the human populations have increased. The decreased density of stems in the preferred size classes for fuelwood in Welverdiend suggest that the woodlands have become degraded in their ability to provide fuelwood. Communities change their resource use behaviour and seek alternatives before the collapse of the woodland resource, whether it is a favoured species or the communal woodland itself. While the resilience of savannas to disturbance has been widely acknowledged in resource management, the resilience of resource users has been under-appreciated. This highlights the need to view these rural areas as complex, adaptive socio-ecological systems when assessing sustainability of resource use.

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Chapter 3

3. Cultural landscapes in motion: Tracing changes in land-use and land-cover and communal woodland loss in rural South Africa (1965-2009).

Abstract

Changes in human social and political sub-systems, operating at different scales in space and time, have a direct impact on landcover patterns. This study investigated landcover change processes occurring in two communal rural villages, in South Africa that were created as part of the forced resettlements of the Apartheid Era government of South Africa in the 1960s These two villages were established in semi-arid savanna areas on undeveloped farms. Land-cover change in each village was traced from 1965 to 2009 using aerial photographs at approximately decadal time-slices. There was greater conversion of Mixed Woodlands to other landcover classes in Welverdiend (48%) than Athol (25%) over 44 years. The systematic loss of woodland areas to agricultural fields was a common characteristic in both villages and residential areas expand outward into land that has already been cleared (such as Cropland or Parkland). A systematic pattern of degradation from the natural woodland vegetation to cleared, open land for agriculture was identified which showed that woodland clearing (deforestation) is most likely to occur where there has been some level of prior human disturbance and degradation, through selective harvesting for fuelwood for example, The land-cover change trends reveal potential landscape dynamics for the future.

3.1 Introduction

Land-use and land-cover change processes are inter-linked but not synonymous; the manner in which human beings make use of the land often shapes land-cover (Mwavu & Witkowski 2008). In human-modified landscapes, ecological, socio-economic and cultural factors interact to create reflexive feedback mechanisms over time, aggregating at different hierarchical spatial scales to create "cultural landscapes" (Farina 2000). Current cultural landscapes are a product of the constant reorganisation of landcover elements in space and time, as a result of, and in adaptation to, past societal needs and land-use patterns (Antrop 2005, Carr & McCusker 2009). Thus changes in human land-use systems can be traced through changes in land-cover patterns in human-populated landscapes (Geist & Lambin 2002). Current cultural landscapes are a product of the constant reorganisation of landcover elements in space and time, as a result of, and in adaptation to, past societal needs and land-use patterns (Antrop 2005, Carr & McCusker 2009). Land-cover, land-use and land-based livelihood strategies are inextricably linked in these landscapes (Carr & McCusker 2009) and are shaped by historical and on-going socio-political activities (King 2011). Thus past and current land-use and land-cover change (LUCC) processes have a direct bearing on the future sustainability of socio-economic development (Fox *et al* 1995, Lambin *et al* 1999, King 2011) and natural resource use (Lambin 1999). Rural communal landscapes in South Africa are prime examples of cultural landscapes within this context (Giannecchini *et al* 2007).

Communal rural areas cover approximately 6 million ha and support over 2.5 million households (van Horen & Eberhard 1995, Shackleton *et al* 2001) in South Africa. These settlements consist predominantly of the remainders of the former Bantustans or homelands created by the Apartheid-era South African government (May 2000). Few studies have investigated how rural settlements in former Bantustan areas have developed spatially since establishment in the 1960s (Giannecchini *et al* 2007, McCusker & Ramudzuli 2007, Botha & Donaldson 2000**)**. This is surprising, given the link between land-use and land-cover change (LUCC) and shortages in natural resource availability (Fox *et al* 1995). If these communities develop coping strategies in response to crisis and resource-scarcity, they are short-term in nature and ultimately unsustainable (Adams *et al* 1998, cited in Giannecchini *et al* 2007), leaving rural households increasingly vulnerable to future environmental change (Giannecchini *et al* 2007). There is great value in quantifying and understanding past land-cover change processes within these rural settlements. This information could aid the prediction of future land-cover patterns and the identification of potential trouble spots, thus enabling stakeholders to develop effective sustainable resource management plans as well as inform socio-economic development interventions (Lambin *et al* 2003).

3.1.1 Land-cover change detection

Land-cover change detection analyses may be carried out using either field-based observations or multi-date comparisons of remotely-sensed data such as satellite images and aerial photographs. Field-based observations, which have been addressed elsewhere within this thesis provide exhaustive quantitative descriptions of vegetation structure and species composition but with few or no indicators of the spatial nature of any observed change (Petit *et al* 2001, Coppin *et al* 2004). Analysing land-cover change in a spatially relevant way requires the use of historical databases of remotely-sensed data, comparing the land-cover composition over time and analysing change trajectories (Mertens & Lambin 2000, Coppin *et al* 2004). Multi-spectral satellite images are commonly used in these analyses (Lu *et al* 2001, Coppin *et al* 2004) but their use in historical comparisons is constrained by non-availability before the mid-1970s (Coppin *et al* 2004) and the coarse spatial resolution of early imagery which may result in the loss of information about fine-scale, local changes over relatively small areas, such as village-level dynamics (Gennaretti *et al* 2011**)**. For such analyses aerial photographs provide a better option for assessments of landcover change (Petit *et al* 2001). Lambin (1997) suggests that characterising change in a given landscape requires the measurement of the rates, location, spatial patterns and temporal characteristics of any observed changes. Furthermore, land-cover changes may result in the complete conversion of a particular land-class (Grainger 1999, Khorram *et al* 1999), change shape or size or shift location on the landscape (Khorram *et al* 1999).

Large-scale LUCC assessments are used to monitor and quantify changes occurring at the ecosystem level irrespective of the causal agents of the observed changes (Lambin *et al* 2003, DeFries *et al* 2004, Coppin *et al* 2004, Pereira & Cooper 2006). Such landcover changes filter down to impact ecosystem service delivery to human beings at a much finer scale of spatial organisation (Lambin *et al* 2003). Monitoring these LUCC processes thus becomes particularly relevant in rural landscapes where livelihood strategies are linked to access to land (Shackleton *et al* 2001). The value of LUCC assessments at the fine-scale village or community level, where humans are the identified principal agents of change (McCusker 2004), rests in the ability to detect how human activities shape and bring about changes in the landscapes (Lambin & Meyfroidt 2010) and conversely how these landcover changes affect human wellbeing (Antrop 2003) These socio-ecological feedbacks between land use\cover and negative change in the quality of ecosystem services provided by the landscape are often linked to degradation that occurred previously as a result of historical land-use regimes (Lambin & Meyfroidt 2010). These coupled socio-ecological system impacts and feedback mechanisms, operating at the village level, aggregate to the landscape level with far-reaching impacts on ecosystem service sustainability (Lepers *et al* 2005). Thus there is great value to be added to the body of knowledge of landcover change in understanding the fine-scale trends in land-use and land-cover change patterns.

3.1.2 The development of rural communal landscapes in South Africa

Beginning in the 1960s until the 1980s millions of black South Africans were the victims of forced relocations into specially designated areas (Platzky & Walker (SPP), 1985) to pursue "separate development" away from white South Africa (Thornton, 2002). Black South Africans were moved to arid and semi-arid areas with low agricultural productivity and limited infrastructure (Platzky & Walker 1985). Settlements were created on parcels of land that had been formerly ceded to white owners, as farms for livestock ranching, forming "villages" whose boundaries were defined by the cadastral boundaries of the farms (Thornton 2002). Apartheid government policies limited investment into infrastructure, education and economic development within these areas (de Wet 1995), fostering a heavy social dependence on remittances from migrant labour for income and resource extraction from the natural environment for survival (Butler *et al* 1978, Carter & May 1999, Niehaus 2002). Access to natural resources was governed by a traditional hierarchy of chiefs and village headmen who controlled and monitored harvesting of resources such as live trees (Thornton 2002); more importantly, the traditional authorities governed land-use rights in the village (within the farm boundaries) following spatial planning systems prescribed by the Apartheid government through "betterment" schemes which planned the use of space in the resettled areas (Niehaus 2002, de Wet 1995). The village settlement was divided into separate zones for settlement, agriculture and future residential expansion (McCusker & Ramudzuli 2007). Households were allocated a plot of land within the residential zone, large enough to build a home and maintain a small garden; the agricultural zone was used for crop and livestock production and families were allocated additional land within the agricultural zone, away from the homestead, to cultivate additional crops (Niehaus 2002). The rest of the area consisted of communal rangelands from which households could harvest resources and represented the reserve space for future expansion (McCusker & Ramudzuli 2007). Thus, there was a high degree of functional and spatial organisation, which is still evident across rural landscapes in South Africa today (Giannecchini *et al* 2007).

The legacies of past land-use and management processes are still evident today, even though the institutional controls of traditional authorities have weakened since the advent of majority rule and democracy in 1994 (Twine *et al* 2003, Kaschula *et al* 2003). The systems of land-use apportionment and village development for the most part still follow those instituted under the "betterment" schemes of the past (Giannecchini *et al* 2007, Carr & McCusker 2009). These legacies mean that the areas are still economically marginalised and although development and infrastructural reforms to provide households with electricity and running water are in action (RSA 2000), there is still a heavy dependence on the communal rangelands to provide resources for cooking, construction, medicinal purposes etc (Shackleton *et al* 2001, Shackleton & Shackleton 2002, Twine *et al* 2003, Twine 2005). As human populations have grown and expanded, so too have the spatial extent of the residential areas within the village boundaries (Giannecchini *et al* 2007, Coetzer *et al* 2010). It follows, therefore, that the areal extent of the village-specific communal rangelands have shrunk or disappeared as a result of land-use/ land-cover change, potentially resulting in localised resource scarcity (Petit *et al* 2001, Giannechhini *et al* 2007).

3.1.3 Land-use, land-cover and livelihood strategies in Bushbuckridge

Bushbuckridge Municipality in Mpumalanga Province, South Africa (Figure 3.3.1) consists of the remnants of two homeland areas: Gazankulu and Lebowa. Resettlement onto farms in the homelands can be traced to the 1960s, although they were only proclaimed as self-governing homeland areas in 1973 (Platzky & Walker 1985). Poverty is widespread, with marginal agro-pastoralism, limited employment opportunities and heavy dependence on remittances from migrant labour (Thornton 2002, Twine 2005). The communal woodlands are interlinked with community livelihood strategies, providing various essential non-timber forest products, such as fuelwood, (Shackleton *et al* 2002) for use within the households and as potentially income-generating products. This highlights the value of the communal woodlands as "buffers" against the effects of widespread poverty in rural areas (Shackleton & Shackleton 2002, Kaschula *et al* 2005). The environmental impacts of the continued dependence on and extraction of, woodland resources is compounded by the high densities of people resident in the villages, ranging between 150-300 people km^{-2} (Pollard *et al* 1998, Matsika *et al*, In Review, Chapter 4). The high populations are due, in part, to natural population growth of the "original" village inhabitants (Giannecchini *et al* 2007) however, the arrival of Mozambican refugees fleeing from the civil war in their country in the mid

1980s contributed significantly to current population figures. Prolonged intense resource extraction, such as is the case in the study area, may result in land-cover change through degradation or modification (Grainger 1999, Lambin *et al* 2003) or land-cover conversion, for example, through woodland clearing for agriculture or settlements (Grainger 1999, Coppin *et al* 2004). Such processes influence and shape future resource availability; therefore understanding the fine-scale village mechanisms, which may ultimately aggregate at the landscape level as resource-shortage “crises” is of utmost importance in rural areas.

3.1.4 Socio-economic development and land-cover change

Both the historic and present social and political geographies existing in the study area would have been sufficient to warrant investigation into land-use/cover change processes. However, Bushbuckridge is also the focus of special government notice and socio-economic intervention (Mbeki 2001). Bushbuckridge is one of 13 high-priority poverty nodes that have been identified under the first phase of the Integrated Sustainable Rural Development Programme (ISRDP) by the national government (RSA, 2000). Under this programme the government has intervened to create conditions that promote and fast-track infrastructural and economic development within these nodes (RSA, 2000). The success or failure of these interventions in promoting development and addressing the socio-economic challenges faced in these historically under-developed areas, such as Bushbuckridge will determine the roll-out of this programme nationally (RSA 2000, Haarmse 2010). Given the high dependence of these communities on the natural environment, there is great value in quantifying and understanding local landcover change processes as they shape livelihood strategies (King 2011). Understanding past land-cover trends aid in the prediction of future land-cover dynamics and resource availability and assists in identifying potential hotspots of deleterious environmental impacts and resource scarcity (White *et al* 1997, Masera *et al* 2003); all of which assist in developing sustainable resource management plans and better inform socio-economic development interventions (Lambin *et al* 2003).

3.1.5 Contextualising the relevance of fine-scale rural land- cover change assessments

The main objective of this study is to assess land cover dynamics in two villages, Welverdiend and Athol, in Bushbuckridge Municipality, a former homeland area in South Africa. The land-cover change assessment will identify the changes in landcover, particularly the woodlands in both village landscapes from around the time of their establishment in the 1960s until the time of this study in 2009 in the context of the impacts on and implications of the fuelwood use and harvesting systems which are characteristic of the area. Field-based studies of woodland vegetation structure dynamics (1992-2009) revealed that there was extensive woodland degradation in the communal woodlands of Welverdiend but not Athol (Matsika *et al*, In Review- Chapter 2). Consequently, woodland resource scarcity, particularly of fuelwood is commonly cited by Welverdiend residents as a major issue (Twine *et al* 2003b, Matsika *et al* In Review, Chapter 4). Furthermore, the villages presently have similar average household demographic and socio-economic characteristics. Given that they were established at similar times, there is value in investigating the long-term trends in woodland cover change that may add to our understanding of how and why the woodlands structural changes differ so markedly. Such information has broader implications for understanding resource shortages in other rural communal rangelands in the area and in South Africa. It is not the intention of this study to determine the causal factors of land-cover change through an in-depth analysis of socio-economic conditions, however there is need to understand the overarching contextual cultural and social histories that have shaped present-day land-use/land-cover in the study area (King 2011).

This study addressed the following key questions:

1. What are the LUCC characteristics in each village in terms of net change: gains, losses and conversion between land-classes, rates of change and what are the most systematic transitions?
2. What is the spatial extent of the remaining communal woodlands and how have they changed with time?
3. Has there been land-cover change in Morgenzon (an unoccupied private property on the western boundary of Welverdiend) since the social annexure in the early 1990s?
4. How will the landscapes potentially develop in the future?
5. What are the implications of the land-cover change trends for communal areas in Bushbuckridge?

3.2 Methods

3.2.1 Study Area

The case study villages Welverdiend (24° 35'S 31° 20'E) and Athol (24° 34'S 31° 21'E) lie 30 km apart in the Bushbuckridge municipality (Figure. 1); both are situated in close proximity to conservation areas within the Kruger to Canyons Biosphere Reserve. Welverdiend is located adjacent to Manyeleti Game Reserve on its eastern boundary (Figure. 1). Athol shares its southern boundary with the Sabi Sands Nature Reserve. Economic development is marginalised, unemployment is rife, monetary income is low and human settlements are densely populated, averaging 150-350 people km^{-2} (Shackleton & Shackleton 2002, Thornton 2002, Kaschula *et al* 2005). Grazing and resource harvesting pressure in the communal village areas are often higher in comparison with the conservation areas since the local communities are denied access to these lands through various fencing and security measures (Pollard *et al* 2003). At the time of the study in 2009, there was a higher human population in Welverdiend in Athol, with about 1500 households in Welverdiend compared to 500 in Athol (Matsika *et al*, In Review, Chapter 4)

3.2.2 Biophysical characteristics

The topography of the region is described as gently undulating with an average altitude less than 600m above sea level. Soils are underlain by granitic gneiss with local intrusions of gabbro. The vegetation in the study area is defined as Mixed Lowveld Bushveld and is mostly dominated by species of the Combretum and Terminalia genera (van Rooyen & Bredenkamp 1996). *Sclerocarya birrea* and *Dichrostachys cinerea* also contribute significantly to the woody biomass in this region (Shackleton 1997). Rainfall is received during the austral summer season (October to May), mainly in the form of convectional thundershowers and averages 650 mm per annum in the west and 550 mm per annum in the east along a rainfall gradient. Drought is common and prolonged droughts may occur as often as every 3.5 years. Mean annual temperature is 22 ºC; summers are hot, with a mean daily maxima 30 ºC and winters are mild with a mean daily maxima of 23 ºC (Shackleton *et al* 1994).

Small-scale farming is carried out by individual households tending home gardens and, where access is granted by the traditional authorities, in larger arable fields within the village commons (Shackleton *et al* 2002, McCusker & Ramadzuli 2007). In spite of the low agricultural productivity in the area (Shackleton S *et al* 2002) households maintain home gardens as a safeguard against the unpredictability of monetary incomes, even though most households receive more from government welfare than farming (May 2000). Home-gardens represent a reliable outcome, except in years of drought or other environmental stress-related problems (Murphy 1995).

The boundaries of the original farms of Welverdiend and Athol were used to define the extent of the villages over the period of interest (Figure 3.3.1). However in the course of data collection, it came to light that the residents of Welverdiend informally appropriated Morgenzon, a privately-held plot of land that lies adjacent to Welverdiend along its western boundary (Figure 3.3.1). This happened in response to severe drought in the early 1990s. Prior to this Morgenzon was formerly a farm but by the time of annexure had been emptied due to extreme drought at the time, leaving it unused and available for village use (Rex Mnisi, deputy chairperson of the Welverdiend Community Development Forum, 2009, pers comm.) Welverdiend residents now consider it a part of their communal rangelands and claim land-use and harvesting rights. Therefore, landcover change dynamics from when the villagers began accessing the nature reserve until 2009 were included in the assessment.

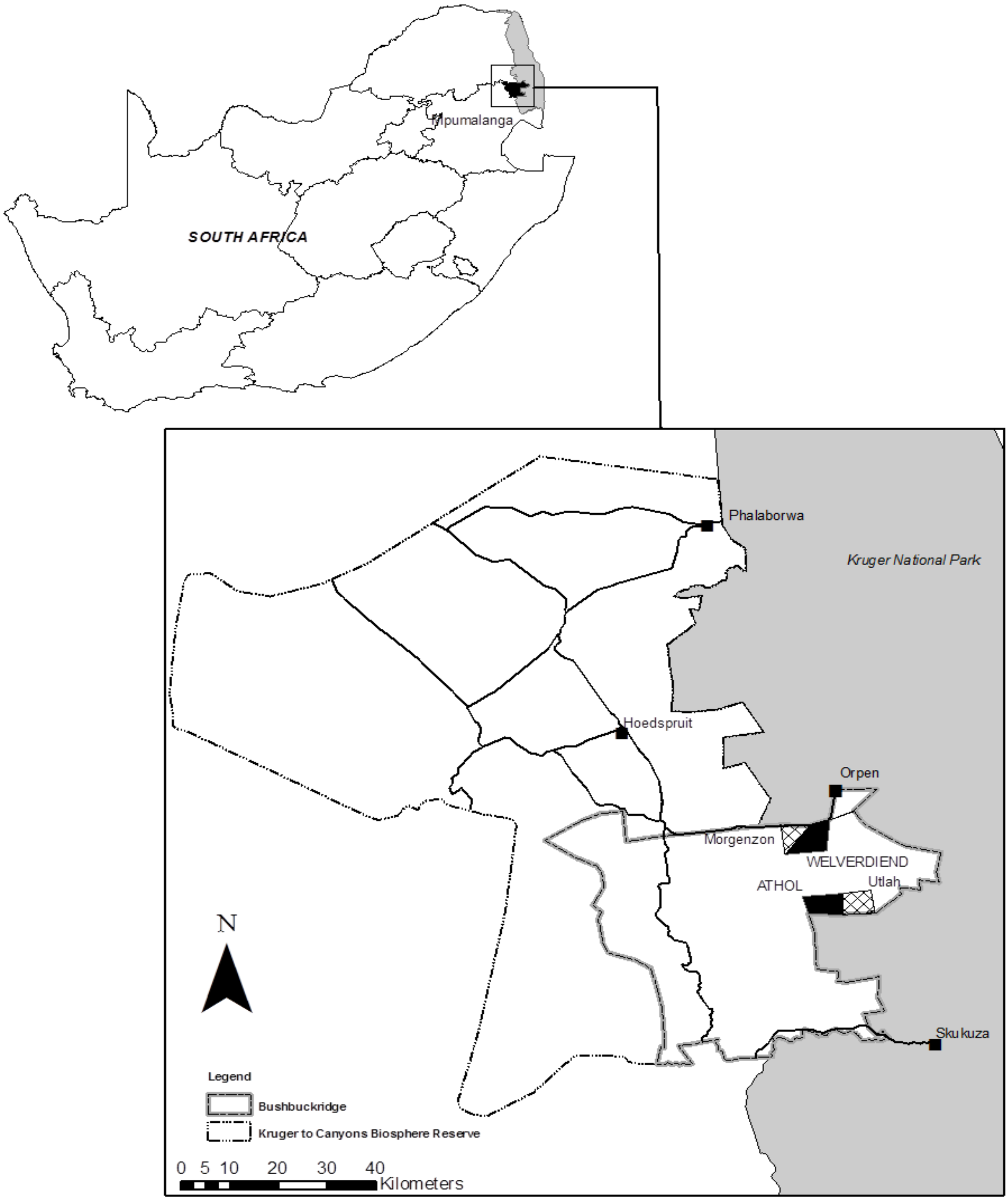


Figure 3.1 The locations of Welverdiend and Athol villages relative to the Kruger to Canyons Biosphere Reserve and the Kruger National Park in South Africa. Solid polygons show the extent of the original farm boundaries of each settlement. Hatched polygons are the spatial extent of Morgenzon, adjacent to Welverdiend and Utah adjacent to Athol; these are commons into which residents of each settlement have expanded resource harvesting during drought or scarcity since the early 1990s.

3.2.5 Methods and analysis

The overall objective was approached by tracing landscape development by manually digitising the built-up residential areas, fields, open areas and wooded areas of each village using time-sequential aerial photographs covering the time from 1965 to 2009. The study period covers the time from village- establishment until the time of this study in 2009. The aerial photographs were obtained from the Chief-Directorate: Surveys and Mapping ((CD: SM), Cape Town, South Africa) at approximately decadal intervals from 1965 depending on availability. Thus coverage for each village was obtained for 1965, 1974, 1986, 1997 and 2009.

3.2.5 Image processing: Ortho-rectification (1965-1997)

The images used were provided in digital format; all images except the 2009 dataset were black and white and lacked spatial information. The 2009 dataset consisted of ortho-rectified colour images. These were used as reference images to do image-to-image orthorectification of the other time series photographs. Orthorectification was carried out using the ERDAS Imagine 2011Autosync workstation programme (Leica Geosystems Geospatial Imaging, Norcross, United States of America) using the 2009 orthophotograph as the reference image. The Direct Linear Transform (DLT) output geometric model was applied to the image to minimise image warping. A minimum of 5 ground control points (GCPs) in both images were manually selected. Based upon this initial selection, the programme was set to automatically generate a host of GCPs from which sites were manually deleted or moved until the root mean square registration error (RMSE) was between 5-8m. The orthorectified images were set to the same geographic co-ordinate reference system as the reference image (WGS1984) and used the file Digital Elevation Model in ERDAS Imagine. The rectified images were then resampled using a nearest-neighbour resampling algorithm so that they would have the same geometry as the reference images.

3.2.6 Landcover classification & digitisation

The orthorectified images were imported into ArcGIS 10 (ESRI, Redlands, California, United States of America) and then projected in the Universal Transverse Mercator (UTM) projection to UTM Zone 36S- the zone which covers the study area with minimum distortion. Thereafter all images were clipped to the extent of the original farm boundaries upon which each village was initially established. The Welverdiend images were clipped to the spatial extent of both Welverdiend and Morgenzon (figures 2, 3, 6). A landcover classification system was devised (Figure 3.1) based on the National Landcover Classification system for South Africa developed by Thompson (1996) and applied by Giannecchini *et al* (2007). It is acknowledged that differences in geology do have an effect in vegetation structure and cover, with a marked division in tree height and structure between the granitic and doleritic bedrocks in both villages. However since this study aims to investigate and identify systematic changes in structure over time and not the inherent differences across the village landscapes in each study year, these structural differences are adequately captured in the chosen landcover classes. Digital automated classification methods could not be applied since the aerial photographs lack the necessary spectral information required to apply supervised and unsupervised classification techniques successfully (Petit & Lambin 2001).

Figure 3.3.1 The landcover classification system used to determine landcover types and create landcover maps for each village at each point in time. This classification system is derived from the NLC 1994 classification system developed by Thompson (1996).

Land cover class	**Description**
Mixed woodland	Lightly disturbed woodland, mixed tree classes
Parkland	Partially deforested woodland with scattered large trees (e.g. abandoned fields), open patches of ground close to settlement
Shrubland	Disturbed woodland, characteristic of fuelwood harvest sites; high incidence of coppice growth.
Cropland	Cultivated or fallow fields
Settlement	Homesteads, yards and other structures associated with human habitation
Dam	Water body

Landcover classification was carried out by visual photo-interpretation of the images, based on the basic interpretation elements of tone, texture, shape, size, position and association (King 2011). For example, croplands and parklands (Figure 3.1) were easily identifiable as open, bare areas with straight edges within the wooded areas. Once identified, a polygon delineating the boundary of that patch of landcover within the landscape was created using the Auto-Complete Polygon tool in ArcGIS 10 Editor. This tool allowed for the creation of adjacent polygons that do overlap or have gaps during the manual digitisation process (ESRI, 2012) This process was repeated until all the land within the village area, as defined by the farm boundaries, had been classified and digitised. The output of this process was a shapefile in the same spatial reference system as the aerial images (WGS 84 UTM 36S). This shapefile was converted into a raster grid, with cell resolution of 3m x 3m, where every pixel was allocated the landcover class according to the maximum area represented within that cell.

Ground-truthing of the landcover classes was carried out through extensive site visits within both villages in 2009 in the course of data collection within the village settlement (residential) areas as well as in the communal woodlands. Classification accuracy was quantified based on a simple assessment of the correct classification rate of ground truthing sites and the manually digitised Village Landcover map (VLC) of each village. Ground-truthing sites were assessed and classified during data collection of two other studies in Welverdiend and Athol in 2009. These sites were used to assess the classification accuracy of the 2009 VLC and by proxy, the accuracy, in terms of correct classification rate of the technique used to create the other VLC for the previous years. Sampling sites at which woodland vegetation structural data were collected as part of the field campaign for Matsika *et al* (In Review, Chapter 2) and Paradzayi (2012 unpublished Thesis) were used to ground truth the classification of the vegetation cover classes (that is separation into Mixed Woodland, Shrubland and Cropland). All landcover classes were captured and descriptions of land-use, vegetation structure and human impact (through harvesting and coppice regrowth) at different locations within the study sites were noted. Some ground-truthing sites were also located in the woodland areas within the study sites where there had not been much change over the period of interest to verify the visual interpretations of the difference in texture and shading between patches classed as Mixed Woodlands and Shrublands. This was used as a means of validating the visual assessment technique that was then applied to create the landcover maps of the previous years in the study period.

Correct classification of settlement area was based on a spatial database provided by the Bushbuckridge Municipality, which captured the spatial location of every house in a GIS database which could be overlaid with the VLC map. Thus a sample set of known household sites was selected using a random number generator in Microsoft Excel. This household subset of 200 data points was overlaid with the 2009 VLC of each village and the number of correct classifications (household points that fell within the polygons classified as Settlement) was assessed.

3.2.7 Land-cover change analysis

3.2.7.1 Determining the trends in landscape development (1965-2009)

All post-classification spatial analyses were carried out in ArcGIS v10. Coverage for each landcover type was calculated as the relative frequency (%) of pixels in each landcover class for each year. Post-classification comparisons of landcover coverage were carried out by comparing changes in relative frequency (%) per landcover type between the four inter-decadal periods (1965-1974, 1974-1986, 1986-1997 and 1997-2009). Percentage values for landcover persistence and conversions per landcover class were also calculated. The absolute rate of landcover change per annum during each successive inter-decadal period was calculated using Equation 1. The annual rate of change in relative cover for each landcover class was calculated using Equation 2 (based on Giannecchini *et al*., 2007)

$$R_{ab,i,j} = ((C_{b,i,j} / C_{a,i,j}) - 1) / Z_{ab,j} \qquad \text{[Equation 1]}$$

$R_{ab,i,j}$ = annual rate of change in cover between year a and b for landcover i in village j in ha per annum
$C_{a,i,j}$ = Cover in year a of landcover i in village j (ha)
$C_{b,i,j}$ = Cover in subsequent year b of landcover i in village j (ha)

$$X_{ab,i,j,} = (((Y_{b,i,j} / Y_{a,i,j}) - 1) \times 100) / Z_{ab,j} \qquad \text{[Equation 2]}$$

$X_{ab,i}$ = annual rate of change in relative cover (%) between year a and b for landcover i in village j
$Y_{a,i,j}$ = the % cover of landcover i in village j in year a
$Y_{b,i,i}$ = is the % cover of landcover i in village j in subsequent year b
$Z_{ab,j}$= is the number of years between year a and b for village j

3.2.7.2 Determining Gains, Losses and Persistence per landcover type for each time interval

The outputs of the manual digitisation process were 5 village landcover maps (VLC) for each successive year. Individual cover maps for each landcover type (Landcover Specific Map, LSM) in every VLC were created using the Reclassification function in Spatial Analyst. The pixel values of all landcover classes, except the particular landcover class of interest, were reclassified as “NoData”. The output of this process was a time series of 5 raster surfaces for each specific landcover type from 1965-2009 (Figures 3, 4). A modified image-differencing methodology (Petit *et al* 2001, Lu *et al* 2003, Coppin *et al* 2004) using the VLC maps and the LSMin successive years was applied to detect both areas of persistence and areas of change (gains and losses) for each landcover type. In order to detect persistence and landcover change per landcover class between two dates at times, t=1 and t=2, (between $VLC_{t=1}$ and $VLC_{t=2}$) a two-step approach was devised and this was applied for each landcover type.

The first step was to determine whether there had been any changes in the landcover type of interest between the two dates. Using the raster calculator (Spatial Analyst) the $LSM_{t=1}$ was subtracted from $LSM_{t=2}$. The output of this was a change/no change map where positive and negative values showed areas of gains and losses respectively and zero values showed areas of persistence or no change for that landcover class (derived from $LS_{t=1}$ and $LS_{t=2}$) between the two dates (Coppin *et al* 2004). Two maps were derived from this change/no change map using the Reclassify function (Spatial Analyst) one showing only gains (positive values) and the other only losses (negative values). The map showing gains was added to $VLC_{t=1}$; the output was a modified landcover map of $VLC_{t=1}$ displaying the landcover classes that had contributed to the observed gains in the landcover class under investigation at the second date (Figure 3.3.2). The pixel values of the map showing losses were reclassified to positive values and likewise added to $VLC_{t=2}$; the magnitude of the change in pixel value was used to identify the nature of the landcover conversion from $LSM_{t=1}$ since the first date (t=1).

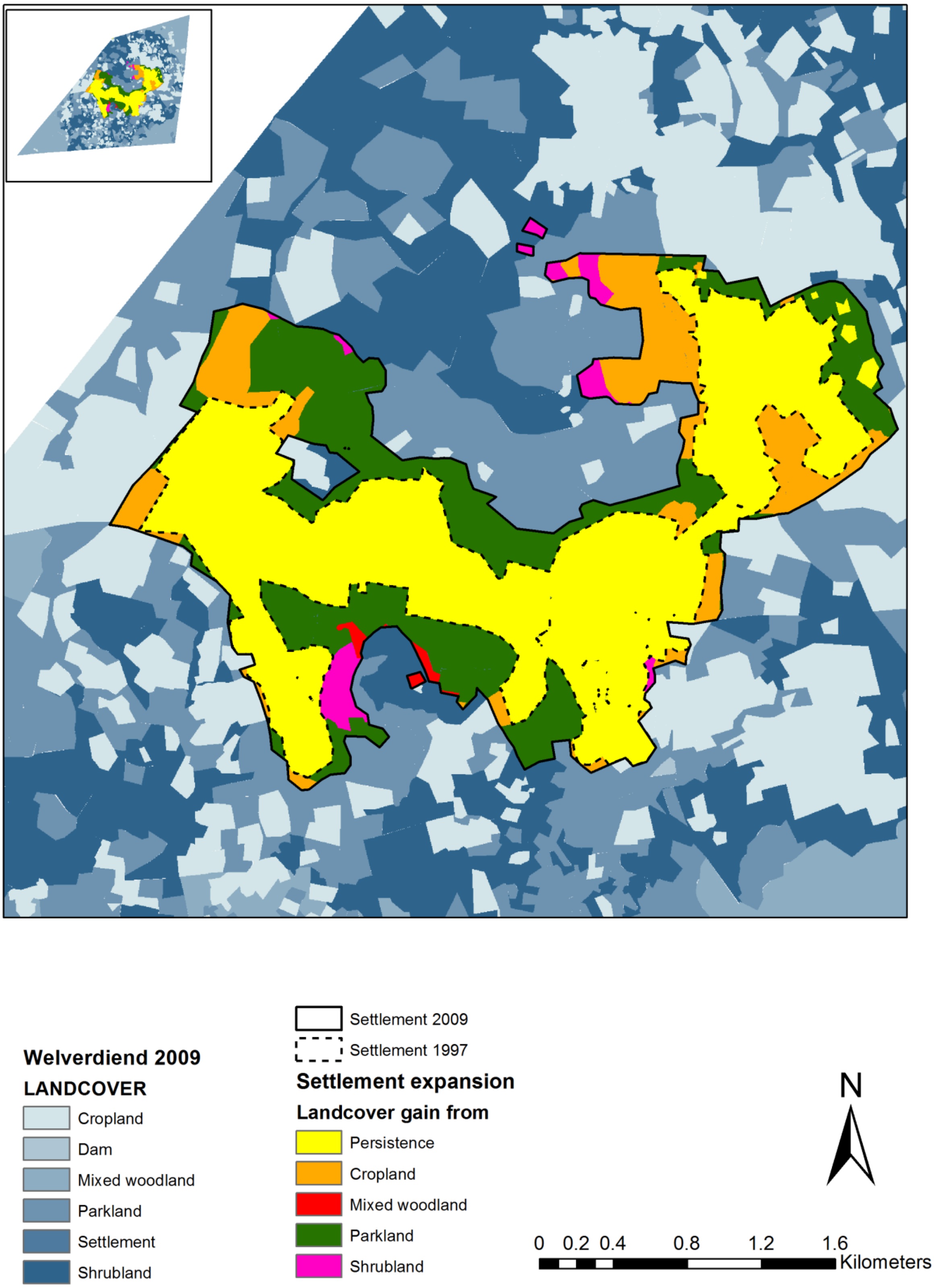


Figure 3.3.2 Example of output of landcover gains in the Welverdiend settlement area (1997-2009) and how the change/no change maps were used to identify the source of gains and losses between landcover classes.

3.2.8 Identifying systematic transitions in landcover change trajectories (1965-2009)

The relative cell frequencies of persistence, gains and losses for each landcover class during the study period were thus derived from the change/no change maps together with the modified VLC maps. These data were used to populate the transition matrix of landcover change from 1965 to 2009, following the structure of Figure 3.2 (Pontius *et al* 2004). The rows show the relative cell frequencies (%) of the landcover classes at time =1 and the columns show this information for the landcover classes at time=2. The entry in the *(i)*th row and the *(j)*th column shows the proportion of landcover class *i* at time=1 in landcover class *j* at time=2 (P_{ij}). The total at the end of *i*th row, in the Total time=1 column shows the proportion of the landscape in class *i* at time =1 (P_{i+}). The total at the bottom of the *j*th column, in the Total time=2 row shows the proportion of the landscape in class *j* at time= 2 (P_{+j}). The column at the end of the table shows the pattern of losses for landcover class *i* between timer =1 and 2, that is it shows loss of class *i* to the other landcover classes (column *j*) as a proportion of the total landscape. Conversely the bottom row shows the gains in landcover class *j* at time=2, from all other classes at time =1, as a proportion of the total landscape.

Persistence values ($P_{ij,\ i=j}$) for each landcover class run along the diagonal and are highlighted in gray and bold type. The second value is the proportion of the landscape that would have been expected in that landcover class if transitions were occurring as a result of random process rather than systematic change (Equation 3). This value is calculated by holding the persistence of the landcover class *i* constant and redistributing the observed losses amongst the other classes relative to their proportion on the landscape. The logic being that landcover classes will exhibit random transitions due to chance and perhaps error in direct relation to the proportion of the landscape they cover

$$L_{ij} = (P_{i+} - P_{ii})\left(\frac{P_{+j}}{\sum_{j=1,\ j\neq i}^{J} P_{+j}}\right) \qquad [Equation\ 3]$$

L_{ij}=expected proportion of landcover i (in the total landscape area) if losses to landcover j are from random process

P_{i+} *=total % area (as a proportion of total landscape area) in landcover i at time=1*

P_{ii} *= persistence of landcover i*

P_{+j} *= total % area of landcover i at time =2*

The third value in circular parentheses is the actual proportion of that landcover class on the landscape (the first value) minus the expected value (Figure 3.2, Equation 4). This gives the residual proportion of the landscape that has undergone transition once random processes are taken into account.

Observed – Expected $= P_{ij} - L_{ij}$ *[Equation 4]*

P_{ij}*= Observed proportion*

L_{ij}*= Expected proportion (Equation 3)*

The number in the final row of each class cell in Figure 3.2 is used to identify systematic transitions. This is calculated by dividing the difference value (row 3) by the expected value (Figure 3.2, Equation 5), giving a ratio of the magnitude of the difference between the observed and expected value, relative to the size of the expected value. This ratio is analogous to the Chi-square ratios and the magnitude of the ratio describes the relative strength of the signal indicating systematic transition. If the observed changes are occurring by random chance then the value of this row will be zero or very close to zero.

Ratio $= (P_{ij}-L_{ij}/L_{ij})$ *[Equation 5]*

P_{ij}*= Observed proportion*

L_{ij}*= Expected proportion (Equation 3)*

Figure 3.3.2 The structure of the landcover transition matrix used to identify and quantify change processes between two maps at different points in time; adapted from Pontius *et al* (2004).

	Time 2				
Time 1	**LANDCOVER 1**	**LANDCOVER 2**	**LANDCOVER 3**	**$Total_{time=1}$**	**Gross Loss**
Landcover 1	**P_{11} (persistence)**	**P_{12}**	**P_{13}**	**P_{1+}**	**P_{1+}-P_{11}**
	0	*L (Expected loss)*			
	0	$P_{12} - L$ (Observed - Expected)			
	0	$(P_{12} - L)/L$			
Landcover 2	**P_{21}**	**P_{22} (persistence)**	**P_{23}**	**P_{2+}**	**P_{2+}-P_{22}**
	L (Expected loss)	*0*			
	$P_{21} – L$ (Observed –Expected)	0			
	$(P_{21} – L)/L$	0			
Landcover 3	**P_{31}**	**P_{32}**	**P_{33} (persistence)**	**P_{3+}**	**P_{3+}-P_{33}**
			0		
			0		
			0		
$Total_{time=2}$	**P_{+1}**	**P_{+2}**	**P_{+3}**	**1**	
Gross Gain	**P_{+1}- P_{11}**	**P_{+2}-P_{22}**	**P_{+3}-P_{33}**		

Interpretation of the transition matrices followed the method put forward by Pontius *et al* (2004). Entries on the diagonal indicate the proportion of the landscape that shows persistence of that particular landcover class. Off-diagonal entries indicate transition from class *i* to class *j*. The matrices were used to quantify the landcover characteristics in each time interval in terms of net change per category as well as gains, losses and swap amongst categories. Following Pontius *et al* (2004) the off-diagonal values in the transition matrices were used to identify which landcover conversions were more the result of systematic process rather than random chance or methodological error. This method was also applied by Schulze *et al* (2010) analysing landcover change patterns in Chile.

The method to interpret the transition matrix figures follows Pontius *et al* (2004) closely. This method identifies systematic landcover change processes and also the magnitude of the observed changes relative to all other transitions occurring on the landscape at that time. If number in round parentheses is positive then that class lost more to whatever class in column *j* than by random chance/error. If the difference in parentheses is negative then the category in column *j* gained less, or alternatively, the category in that row *i* lost less to the category in that column *j* than would have been expected by a process of random chance or error. The fourth number in each cell is the ratio of the actual number minus the observed proportion divided by the expected proportion of change and is analogous with the basis of Chi-square tests (Pontius *et al* 2004). The magnitude of this number indicates the difference between the observed value and the expected value, relative to the expected value. This value is used to identify systematic landcover transitions rather than changes occurring randomly. If the processes of observed loss are random then the differences shown in the transition matrices will be zero or very close to zero. These figures indicate the main processes through which landcover is occurring in both village landscapes (Question 4, page 86). Furthermore they indicate how they will most likely develop in the future, if the overarching socio-economic conditions remain true (Question 5, page 86).

3.3 Results

3.3.1 Landcover Classification accuracy

The Settlement area classification was 97% accurate for Welverdiend and 95% accurate for Athol. The small difference in classification accuracy for this landcover class was most probably due to the slight time-lag and consequent settlement expansion between the time of the household surveys carried out by the Bushbuckridge Municipality in 2007 and the aerial photographs being taken in 2009. Croplands and Parklands were correctly classified 100% of the time being easy to identify, often occurring as straight-edged open patches in the landscape. Mixed Woodland areas were correctly classified 88% (Welverdiend) and 96% (Athol) of the time, with the incorrect classification due to similar texture on the aerial photograph with the Shrubland cover. Shrubland cover was correctly classified 92% (Welverdiend) and 98% (Athol) of the time. The mean classification accuracies for each image were 95% and 98% for Welverdiend and Athol respectively.

3.3.2 Landscape development trends in Welverdiend and Athol (1965-2009)

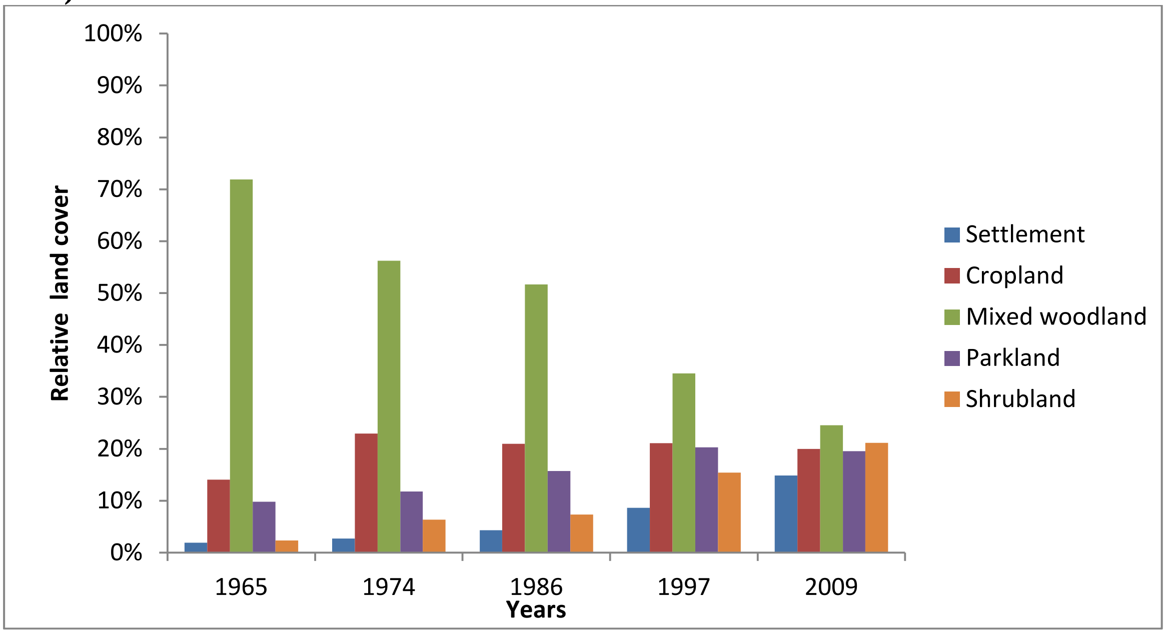
Landcover composition (relative composition) was similar for both villages at the beginning of the study period, but by 2009 the village landscapes showed markedly different landcover patterns and composition. Welverdiend experienced a greater degree of transformation than Athol. Initially Mixed Woodland was the predominant landcover class in both villages, accounting for over 70% of each village landscape (Figure 3.3, Figure 3.4 and 5). Although there was a characteristic decline in Mixed Woodland in both villages, Welverdiend underwent a greater degree of Mixed Woodland loss, such that by 2009 this landcover class accounted for only 26% of the total landscape, compared to 60% in Athol. The steady increase in relative cover of all landcover classes was paired with the decline in Mixed Woodland (Figure 3.3).

Settlement areas were initially small, relative to the other classes, and comparable in size between the two villages, comprising 2.6% (81 ha) in Athol and 1.7% (74 ha) in Welverdiend. Over time, settlement areas in both villages showed exponential increase in area over the study period, a trend which was clearly mimicked by the growth pattern of areas of human impact, that is, parkland and shrubland in both villages (Figure 3.3). Cropland areas in Athol increased steadily over the study period but in Welverdiend the proportion increased only between 1965 and 1974 and thereafter remained constant at about 20% of the total village area in each successive year (Figure 3.3).

3.3.3 Spatial descriptions of landcover transitions

The village settlement areas were initially established in relatively central locations within the farm boundaries (Figures 3, 4) with no clear pattern to the arrangement of croplands and parklands relative to the settlements themselves. However, after 1974 as the ecological footprint of the settlements expanded, clear disturbance gradients were detectable in each village. The settlement areas were surrounded by a heterogeneous mosaic of bare land (very little woody cover was present), classified either as Croplands or Parkland, that transitions into Mixed Woodland through a buffer of Shrubland, clearly illustrating the lessening of human impact on the landscape with distance from the settlement areas. Conversely, the Mixed Woodland areas contracted away from the settlement areas with time as the settlements expanded; this is particularly visible in Welverdiend. Over time, in Welverdiend, as the Mixed Woodland contracted further away from the village and space has become a limiting factor, the disturbance gradient has become less evident (2009, Figure 3.3a). Given that the relative proportion of Cropland within the original Welverdiend bounds was relatively constant from 1974, it follows that most outward expansion of the village disturbance footprint was driven by settlement, parkland and shrubland expansion, which points to population growth and increasing human use as drivers of landcover conversion. Similar patterns are evident in Athol, the primary difference being the smaller degree in the outward expansion of the village disturbance footprint.

a) Welverdiend



b) Athol

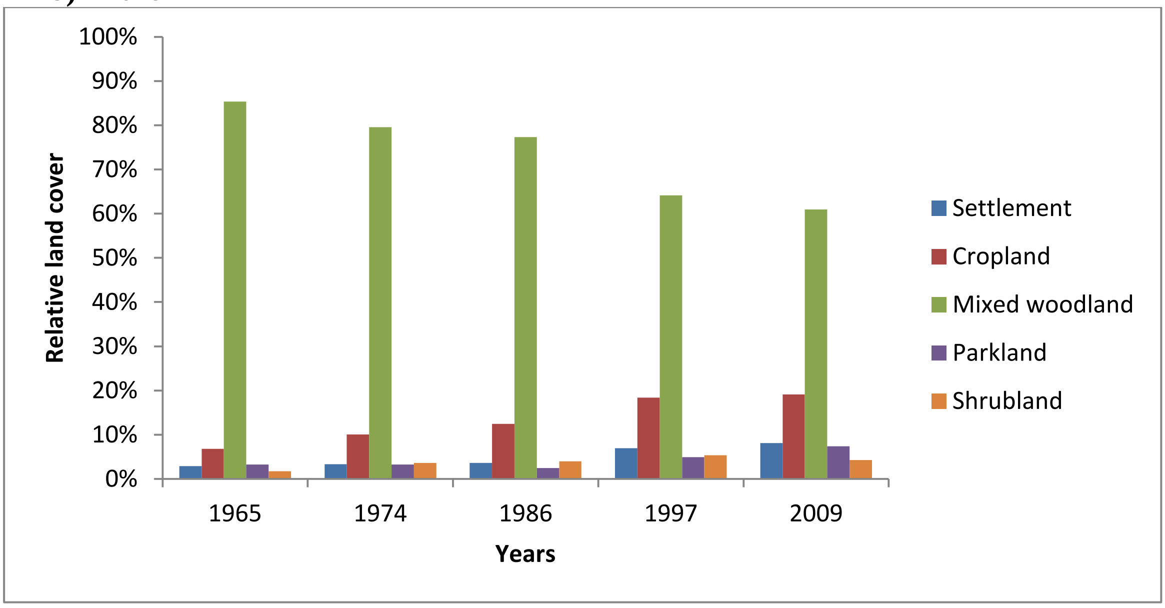


Figure 3.3.3 Landscape composition in terms of relative land-cover (%) in a) Welverdiend and b) Athol for each year included in the analysis. Pixel frequency per landcover class relative to the total image pixel count was used to calculate the relative landcover for each year.

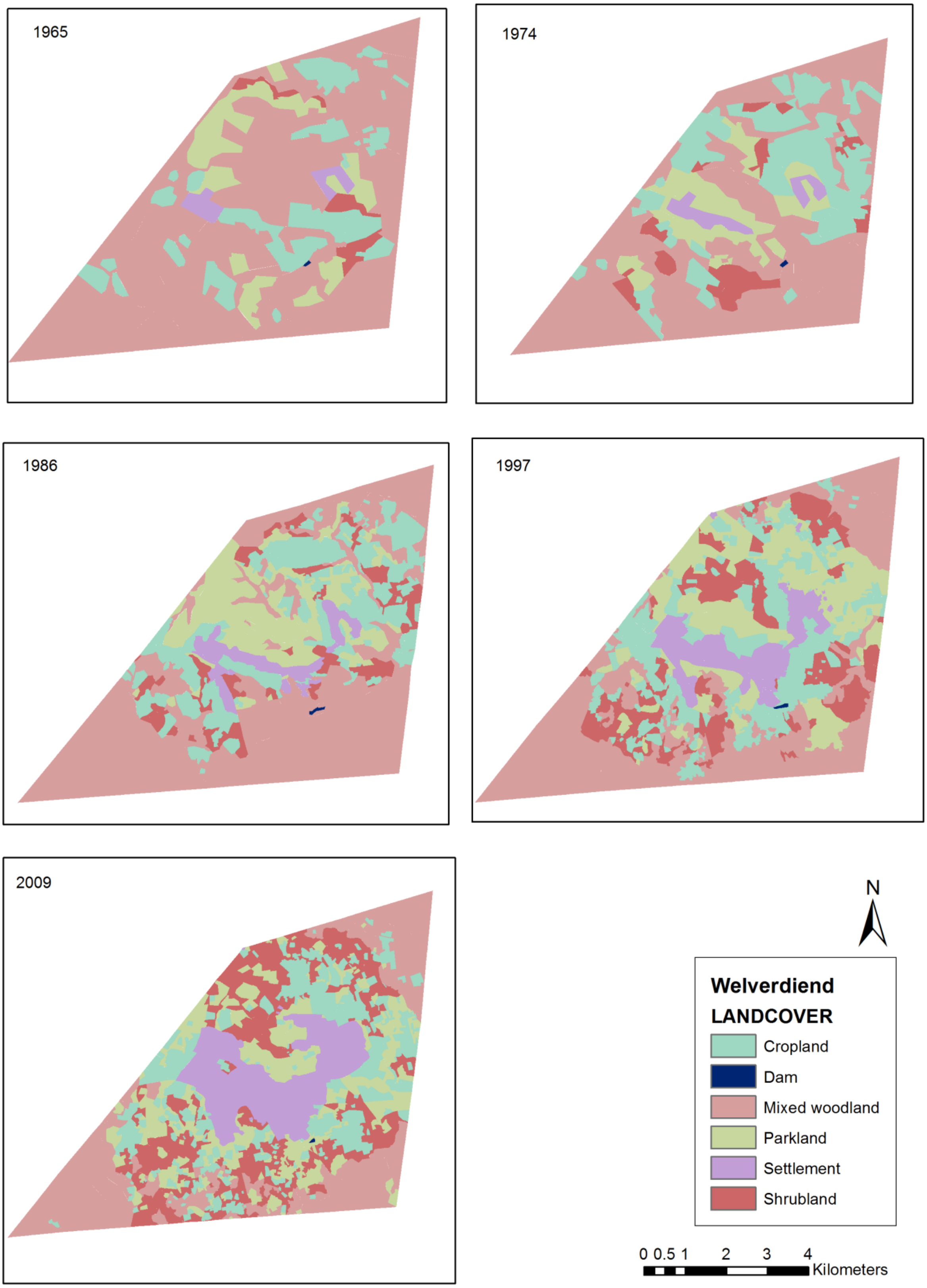


Figure 3.3.4 Landcover maps of Welverdiend village for every successive year in the study period (1965-2009).

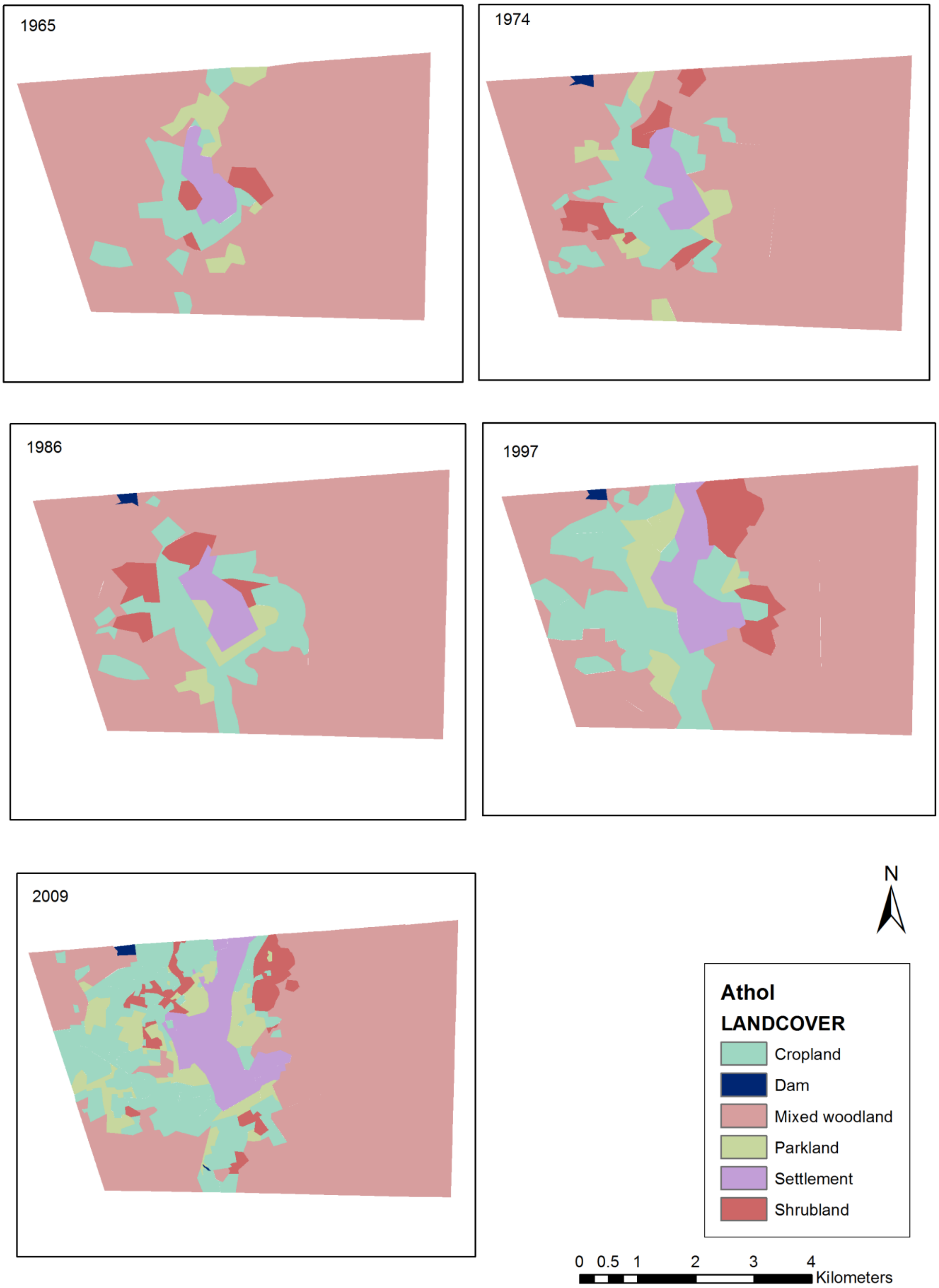


Figure 3.3.5 Landcover maps of Athol village for every successive year in the study period (1965-2009).

3.3.4 Landcover change in Morgenzon (1986-2009)

The expansion to Morgenzon added 1900 ha of Mixed Woodland to the Welverdiend resource base. There was already some degree of pre-existing landcover transformation with respect to cropland and parklands (Figure 6) but this was located in close association with the small settlement within the former nature reserve (Figure 7). Although Mixed Woodland has remained the dominant landcover class since 1986 there has been a 473% increase in relative landcover of Parkland area since 1997, indicating extensive woodland clearing (272 ha of Mixed Woodland converted to Parkland) along the north-eastern corner boundary with Welverdiend (Figure 7).

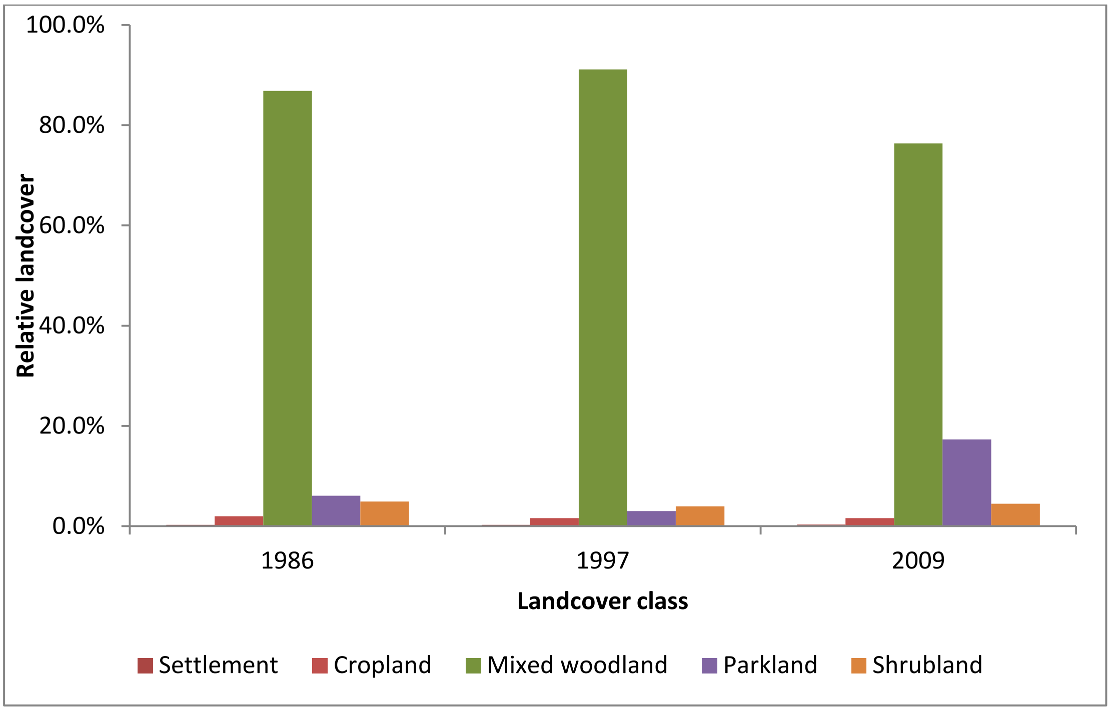


Figure 3.3.6 Relative cover in Morgenzon per landcover class for each successive year (1986-2009)

The location of the observed landcover transitions from Mixed Woodland to shrubland and parkland, along the boundary adjacent to Welverdiend, (Figure 7) represent the continuation of the human disturbance gradient emanating outward from the settlement area.

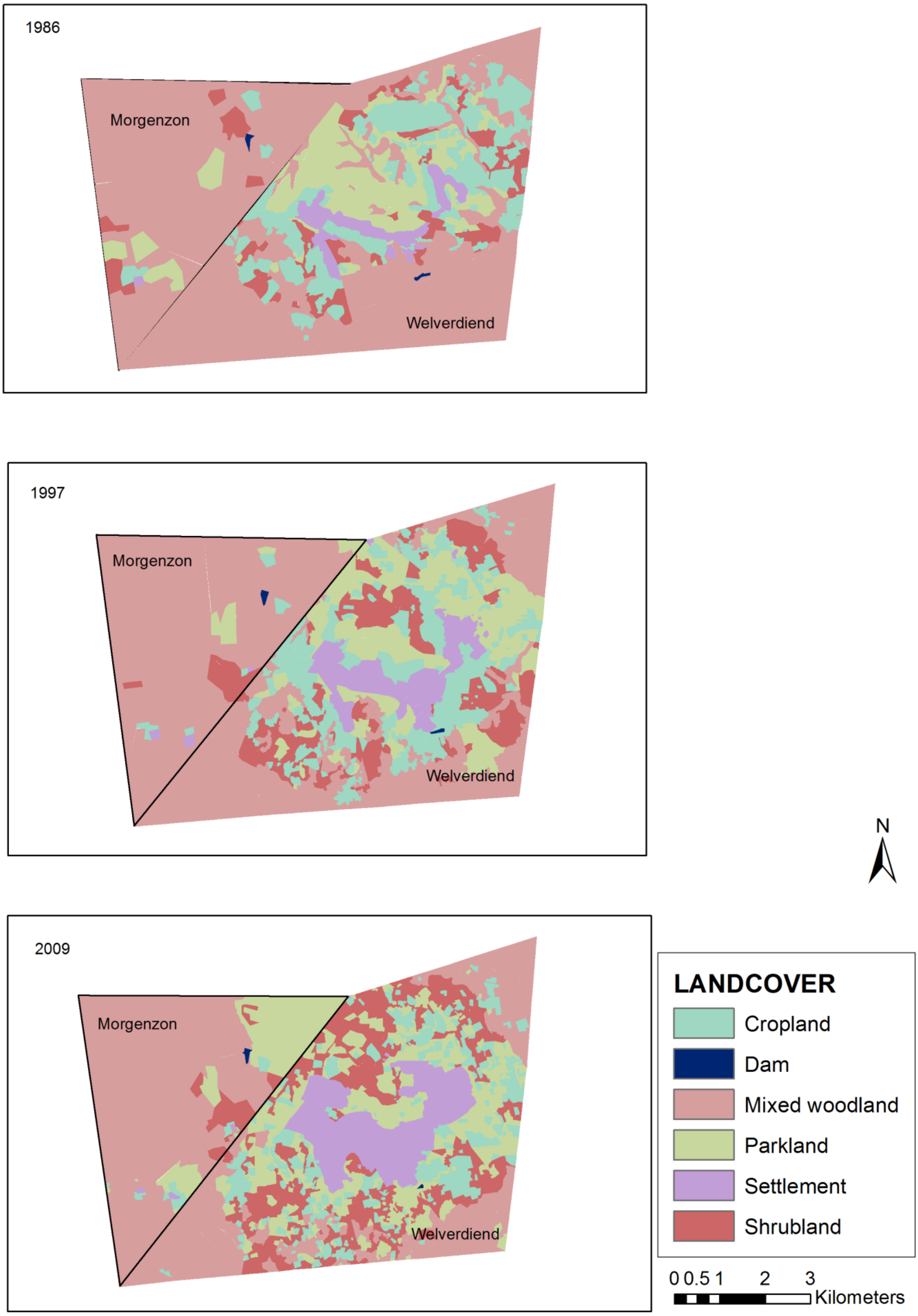


Figure 3.3.7 Landcover maps Morgenzon in relation to Welverdiend village. The landcover was mapped for every year since Welverdiend residents reported to accessing Morgenzon (1986-2009).

3.3.5 Temporal characteristics of landcover change: rates of change (1965-2009)

Mixed Woodland consistently showed a negative rate of change, consistent with the steady decline in Mixed Woodland area over the years (Figures 3, 4); likewise the rate of change in the Settlement class was consistently positive, with a more pronounced pulse-like pattern in Athol than Welverdiend. Welverdiend consistently underwent more rapid landcover conversion during every stage of the study period; the relative rates of annual landcover change are 3 times faster for most landcover classes . This may indicate that the starting population that was resettled onto Welverdiend was larger than Athol; this trend is still in evidence today. The human population in Welverdiend is currently (as of 2009) approximately thrice that of Athol (Matsika *et al,* In Review, Chapter 4).

Land-cover changes did not occur at equal rates during all four time intervals. Furthermore, the rates of change were episodic rather than constant (Figure 8), showing a strong pulse in increased rates of settlement expansion (Athol) and woodland clearing during the first interval and then again in the third time-interval (1986-1997).

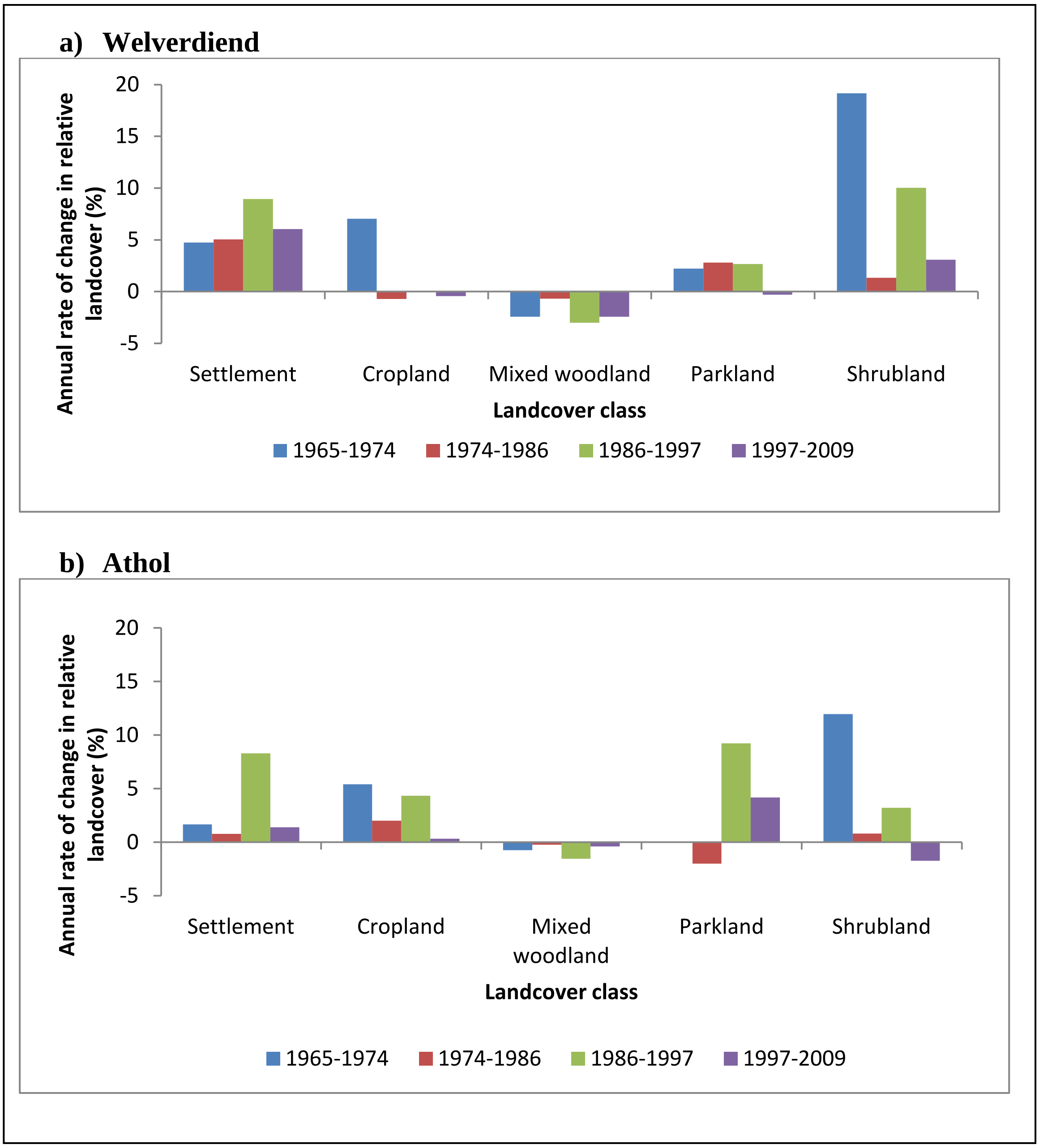


Figure 3.8 Annual rates of per cent change in relative landcover for each landcover class since 1965 in a) Welverdiend and b) Athol.

3.3.6 Characteristics of landcover change: Net change and conversions between classes

Descriptions of change are presented relative to each landcover class, for both villages. The interest is more in understanding how communal villages developed within the study area, rather than the exact differences between villages. Where there are discrepancies or differences in observations between villages, these are described but relative to the landcover class trends. The landcover classes were combined into three groups, relative to their potential functional use by village residents to present and interpret this section of the results. Settlement was maintained as a separate entity and Open areas consisted of Parklands and Croplands. Shrubland and Mixed Woodland classes are presented together as woody areas based on the logic that although structurally different, village residents could still extract wood and other non-timber forestry products, NTFP, (Shackleton & Shackleton 2004) although perhaps to varying extents, from both classes.

3.3.6.1 Settlement expansion

Settlements extent increased in both villages; (Figure 3.5, and Figure 3.6); the gain in settlement area in Welverdiend was twice that of Athol by 2009. Settlements tend to gain area or expand into land that was already cleared; from the gains in Welverdiend, 5.88% of landscape area in 2009 was converted to settlement from Croplands and Parklands (Figure 3.5) compared to 3.9% in Athol (Figure 3.6). This accounts for over half the "new" Settlement area being developed from former Cropland and Parklands. These trends verify the spatial patterns of change that were observed (Figure 3.4, Figure 3.5).

3.3.6.2 Open areas: Croplands and Parklands

Croplands showed the lowest net change in Welverdiend and the second largest net change in Athol. There is low persistence in this landcover class; very little of the Cropland in 1965 remained in this class over the study period in both villages. Furthermore Croplands consistently exhibited the greatest degree of swap/conversion from the other classes. This indicates that the change in Cropland area is from losses from other landcover classes. Parklands show the same trend, with very little persistence (3% in Welverdiend and 0.2% in Athol), the gains in area are almost completely due to gains from other landcover classes. Mixed Woodland lost the most area to Croplands and Parklands in 2009 in both landscapes (Figure 3.5, Figure 3.6). Over the study period 25.37% of the landscape in Welverdiend and 20.52% in Athol were cleared from Mixed Woodland to open areas (Figure 3.5, Figure 3.6).

3.3.6.3 Wooded areas: Mixed Woodland and Shrubland

Mixed Woodland cover underwent the biggest net loss in both villages but the bigger Mixed Woodland loss occurred in Welverdiend, which declined from 72% to 26% of the total village landscape in 2009 (Figure 3.5). Most of the area attributed to Mixed Woodland in 2009 in both villages consisted of persistent cover (Figure 3.5, Figure 3.6), with very little gains from the other classes, that is, once Mixed Woodland was converted to another class, there was very little replacement from conversion by the other classes into Mixed Woodland (Figure 3.4). In direct contrast to this Shrubland shows almost no persistence between 1965 and 2009 in both villages (Figure 3.5, Figure 3.6). The net change in this landcover class (Figure 3.4) is predominantly due to gains from other landcover classes, especially in Welverdiend where this class underwent a 20% gain in area on the landscape, of which, most was gained from Mixed Woodland (16.6%, Figure 3.5), indicating woodland degradation resulting in the modification of Mixed Woodland to Shrubland. A similar trend can be traced in Athol although to a lesser degree since there was not as considerable a loss of Mixed Woodland in Athol.

The landcover classes that had low persistence in both villages over the study period, Croplands, Parklands and Shrublands, showed great mobility across the landscape, concurrent with the expansion of the settlement areas- consistently moving outwards and always away from the settlement area across the landscape.

Figure 3.3.3 Transition matrix interpreted in terms of losses in Welverdiend (1965-2009). The number in boldface is the actual percent of the landscape (P_{ij}). The second number in italics is the percent of the landscape one would expect to observe if the loss was random (L_{ij}). The number in circular brackets is the difference between the observed and expected values . If change is random, these values will be 0; non-zero values indicate a process driven change. The final number is the difference relative to the expected value and the magnitude of this value gives the signal as to the degree of systematic transition (Pontius *et al* 2004)

	2009						
1965	**Settlement**	**Cropland**	**Parkland**	**Mixed woodland**	**Shrubland**	**TOTAL 1965**	**Loss**
Settlement	**1.68**	**0.00**	**0.00**	**0.00**	**0.00**	**1.68**	**0.00**
	1.68	*0.00*	*0.00*	*0.00*	*0.00*	*1.68*	*0.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cropland	**3.48**	**2.93**	**3.01**	**1.50**	**2.91**	**13.83**	**10.90**
	1.72	*2.93*	*2.73*	*3.49*	*2.96*	*13.83*	*10.90*
	(1.75)	(0.00)	(0.28)	(-1.99)	(-0.05)	0.00	0.00
	1.02	0.00	0.10	-0.57	-0.02	0.00	0.00
Parkland	**1.88**	**2.28**	**3.09**	**0.32**	**2.77**	**10.34**	**7.25**
	1.18	*1.64*	*3.09*	*2.40*	*2.03*	*10.34*	*7.25*
	(0.70)	(0.64)	(0.00)	(-2.07)	(0.73)	0.00	0.00
	0.59	0.39	0.00	-0.86	0.36	0.00	0.00
Mixed woodland	**5.83**	**11.58**	**13.79**	**24.45**	**16.62**	**72.27**	**47.82**
	8.42	*11.63*	*13.31*	*24.45*	*14.46*	*72.27*	*47.82*
	(-2.59)	(-0.05)	(0.48)	(0.00)	(2.15)	0.00	0.00
	-0.31	0.00	0.04	0.00	0.15	0.00	0.00
Shrubland	**0.11**	**1.15**	**0.63**	**0.00**	**0.00**	**1.88**	**1.88**
	0.31	*0.43*	*0.50*	*0.64*	*0.00*	*1.88*	*1.88*
	(-0.21)	(0.71)	(0.13)	(-0.64)	(0.00)	0.00	0.00
	-0.66	1.64	0.26	-1.00	0.00	0.00	0.00
TOTAL 2009	**12.98**	**17.93**	**20.51**	**26.27**	**22.30**	**100.00**	**0.00**
	13.33	*16.63*	*19.61*	*30.97*	*19.46*	*0.00*	*0.00*
	(-0.34)	(1.31)	(0.90)	(-4.70)	(2.84)	0.00	0.00
	-0.03	0.08	0.05	-0.15	0.15	0.00	0.00
Gain	**11.30**	**15.01**	**17.43**	**1.83**	**22.30**	**0.00**	**0.00**
	11.64	*13.70*	*16.53*	*6.52*	*19.46*	*0.00*	*0.00*
	(-0.34)	(1.31)	(0.90)	(-4.70)	(2.84)	0.00	0.00
	-0.03	0.10	0.05	-0.72	0.15	0.00	0.00

Figure 3.3.4 Transition matrix interpreted in terms of losses per landcover class in Athol (1965-2009). The number in boldface is the actual percent of the landscape (P_{ij}). The second number in italics is the percent of the landscape one would expect to observe if the loss was random (L_{ij}).

	2009						
1965	**Settlement**	**Cropland**	**Parkland**	**Mixed woodland**	**Shrubland**	**TOTAL 1965**	**Loss**
Settlement	**2.62**	**0.00**	**0.00**	**0.00**	**0.00**	**2.62**	**0.00**
	2.62	*0.00*	*0.00*	*0.00*	*0.00*	*2.62*	*0.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cropland	**2.84**	**2.04**	**1.22**	**0.75**	**0.00**	**6.86**	**4.82**
	0.48	*2.04*	*0.41*	*3.67*	*0.26*	*6.86*	*4.82*
	(2.36)	(0.00)	(0.82)	(-2.92)	(-0.26)	0.00	0.00
	4.91	0.00	2.01	-0.80	-1.00	0.00	0.00
Parkland	**1.06**	**0.85**	**0.81**	**0.18**	**0.39**	**3.27**	**2.47**
	0.21	*0.50*	*0.81*	*1.64*	*0.11*	*3.27*	*2.47*
	(0.84)	(0.34)	(0.00)	(-1.46)	(0.27)	0.00	0.00
	3.93	0.68	0.00	-0.89	2.39	0.00	0.00
Mixed woodland	**0.65**	**15.89**	**4.63**	**60.36**	**3.92**	**85.46**	**25.10**
	5.31	*12.47*	*4.48*	*60.36*	*2.84*	*85.46*	*25.10*
	(-4.66)	(3.42)	(0.15)	(0.00)	(1.08)	0.00	0.00
	-0.88	0.27	0.03	0.00	0.38	0.00	0.00
Shrubland	**0.92**	**0.23**	**0.16**	**0.47**	**0.02**	**1.79**	**1.77**
	0.15	*0.35*	*0.13*	*1.15*	*0.02*	*1.79*	*1.77*
	(0.77)	(-0.13)	(0.04)	(-0.68)	(0.00)	0.00	0.00
	5.13	-0.36	0.28	-0.59	0.00	0.00	0.00
TOTAL 2009	**8.09**	**19.00**	**6.82**	**61.76**	**4.33**	**0.00**	**0.00**
	8.77	*15.37*	*5.82*	*66.82*	*3.23*	*0.00*	*0.00*
	(-0.68)	(3.64)	(1.01)	(-5.06)	(1.10)	0.00	0.00
	-0.08	0.24	0.17	-0.08	0.34	0.00	0.00
Gain	**5.47**	**16.96**	**6.02**	**1.39**	**4.31**	**0.00**	**0.00**
	6.15	*13.33*	*5.01*	*6.45*	*3.21*	*0.00*	*0.00*
	(-0.68)	(3.64)	(1.01)	(-5.06)	(1.10)	0.00	0.00
	-0.11	0.27	0.20	-0.78	0.34	0.00	0.00

3.3.7 Change trajectories and systematic transitions amongst landcover classes

The change trajectories of each landcover class are traced over the study period. The relative contributions of each landcover class to the observed changes in a given class are presented holding persistence as a constant (therefore excluded). Thus the proportion of each landcover class to the observed gains and losses in a given landcover class for each time interval in the study. These are presented together with the analyses of systematic change (Pontius *et al* 2004) between landcover classes for 1965 and 2009 (Figure 3.5 and Figure 3.6).

3.3.7.1 Settlement expansion patterns (1965-2009)

If only landcover change between 1965 and 2009 as a single time-interval is considered, it would appear that Settlement growth may be linked to both conversion of open areas and Mixed Woodland clearing (Welverdiend, Figure 3.5). However, the fine-scale temporal analysis shows that Settlement growth in each time interval predominantly occurred from conversion of open areas in both villages (Figure 9). The most notable exception was in Athol during the 1986-1997 interval, when approximately 50% of the total gains were from clearing of woody areas (Mixed Woodland and Shrubland).

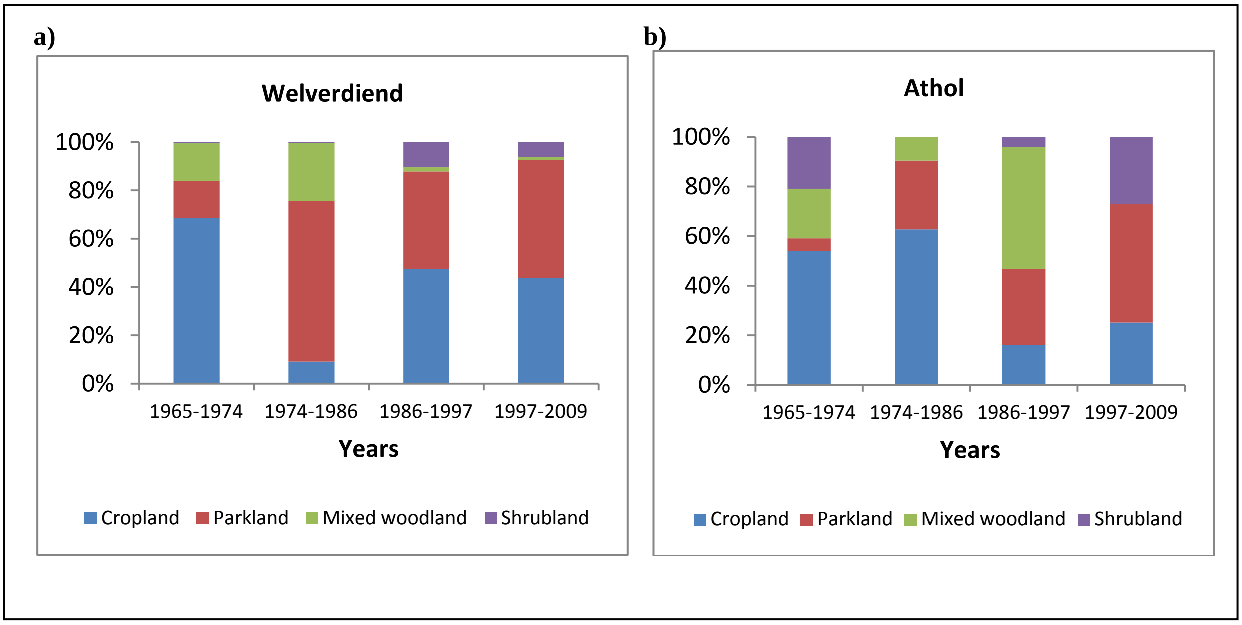


Figure 3.3.9 Pattern of settlement expansion showing the proportion of area gained in the settlement area by conversion from the other landcover classes in each time interval during the study period (1965-2009). For example between 1965-1974 ~70% of the total gain in settlement area was from expansion into (or conversion from) Cropland. Only gains are shown since Settlements did not undergo any losses in area.

3.3.7.2 Landcover transitions in Open areas

There is a significant interchange of cover between Cropland and Parkland (Figures 3, 4, Figure 3.3.10). For example in Welverdiend, since 1974 approximately 50% of all inter-decadal cropland conversions have been to Parkland cover (Figure 3.3.10a) and between 40%-50% of all Parkland cover losses since 1965 have been conversion to Cropland (Figure 3.3.10e). The same trend is apparent in Athol but increasing conversion of Cropland to Parkland (relative to all other Cropland losses) since 1965 (Figure 3.3.10g).The landcover change patterns for Cropland and Parkland gains echo the observations from the respective VLC (Figure 6,7,8). Thereafter the most consistent cover change observations are that the majority of gains in the Cropland and Parkland classes came from Mixed Woodland over the study period, except between 1997 and 2009 in Welverdiend and from 1965 to 1974 in Athol. Between 1965 and 1997 in Welverdiend Cropland gains were predominantly from the conversion of Mixed Woodland cover (Figure 3.3.10b). Thereafter in the last over the last decade there was no clearing of Mixed Woodland and Cropland gains were from clearing of Shrubland and exchange with Parkland cover. However, this coincides with Mixed Woodland clearing (cover loss) in the North-East corner of Morgenzon adjacent to Welverdiend (Figure 8). Cropland and Parkland cover also consistently lost area to the Settlement class in both villages over the study period (Figure 3.3.10 a, c, e, g).

The conversion of open areas to Shrubland and Mixed Woodland has declined steadily over the years (Figure 3.3.10 a, c, e & g), indicating that land that has been cleared may not be allowed to regenerate. This may be due to settlement expansion (Figure 9 a & b) or intensification of use. That is, open areas transition between Cropland and Parkland and were less likely in 2009 to regenerate to Shrubland or Mixed Woodland than in previous years.

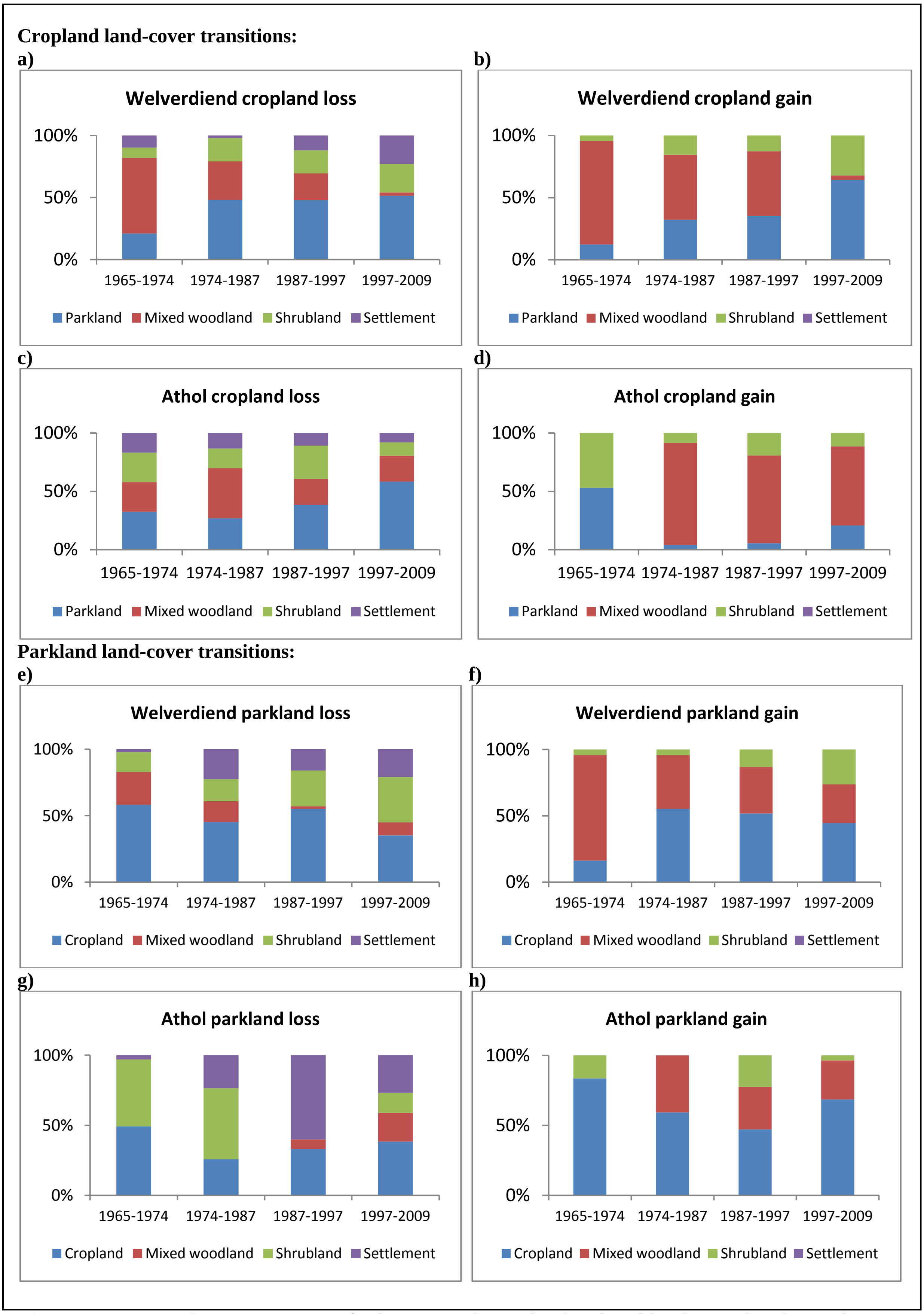


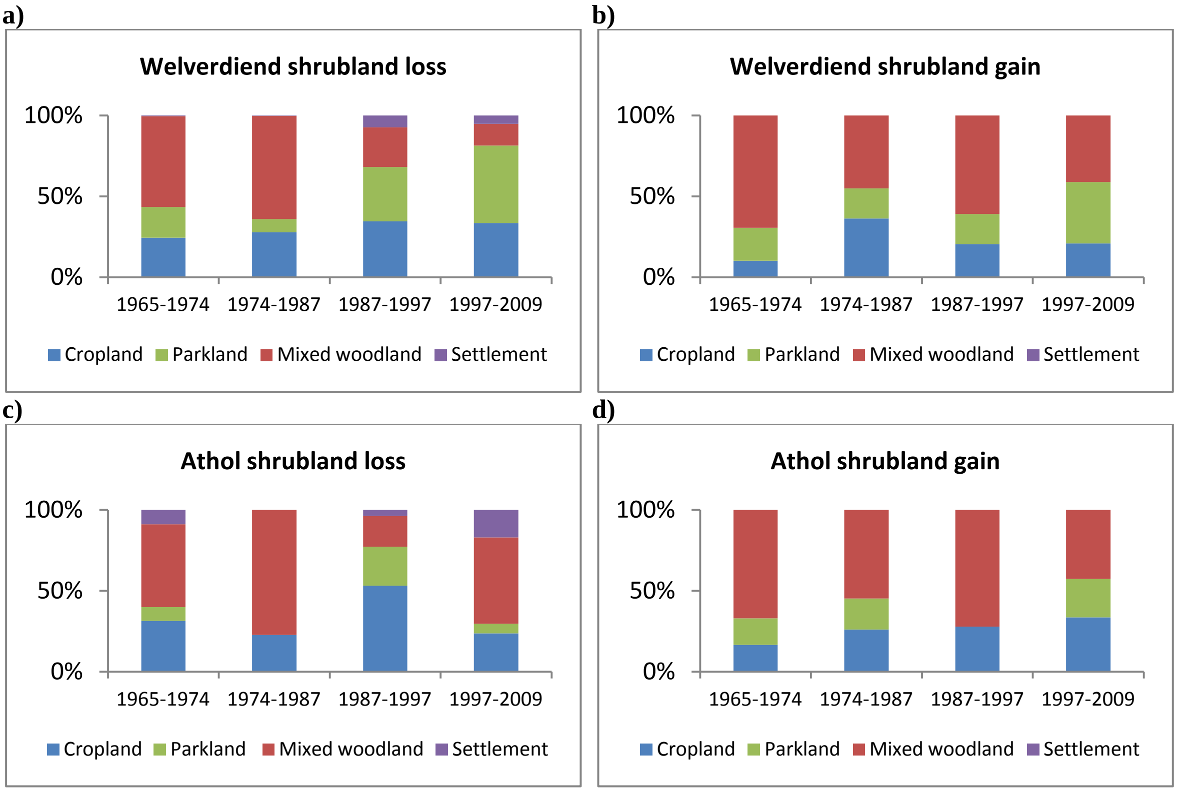
Figure 3.3.10 Landcover transitions for bareground- cropland and parklands. Each column shows the relative contribution (%) of the other landcover classes to gains and losses observed in croplands and parklands during each inter-decadal time-slice (1965-2009).

3.3.7.3 Landcover transitions in woody areas

The most evident pattern of change in the overall wooded areas (Mixed Woodland and Shrubland) was the consistent loss of Mixed Woodland and Shrubland to open areas (Cropland and Parkland) through clearing, during each successive time-period of the study (Figure 3.3.11a, c, e & g). Over the study period (1965- 2009) conversion to open areas accounts for approximately 60% - 80% of all losses of Mixed Woodland cover in Welverdiend (Figure 3.3.11e) and 50% - 90% of the losses in Athol (Figure 3.3.11g). Systematic woodland degradation is evident by assessing the Shrubland gains in both villages (Figure 3.3.11 b & d). Shrublands were consistently predominantly created from Mixed Woodland cover in both villages during each time interval (Figure 3.3.11 b & d); although this was to a greater magnitude in Welverdiend (Figure 3.3.11b) than in Athol (Figure 3.3.11d).

Scrutiny of the Mixed Woodland gains (Figure 3.3.11 f & h) suggests that there is some degree of resilience and regeneration from cleared areas. However the actual gains in Mixed Woodlands translate to a small proportion of the total areas of the respective village landscapes (Figure 3.5 & 6). In general, between 1965 and 2009 the gains in cover of Mixed Woodland from the other landcover classes comprised of such small proportions of the village landscapes, (<2% or <78 ha in Welverdiend and <56 ha in Athol Figure 3.5, Figure 3.6) as to be virtually irrelevant in terms of replacing lost Mixed Woodland area. Nonetheless observed gains in Mixed Woodland during each interval were primarily from regeneration of Cropland, Parkland and Shrubland (Figure 3.3.11).

Shrubland transitions:



Mixed Woodland transitions:

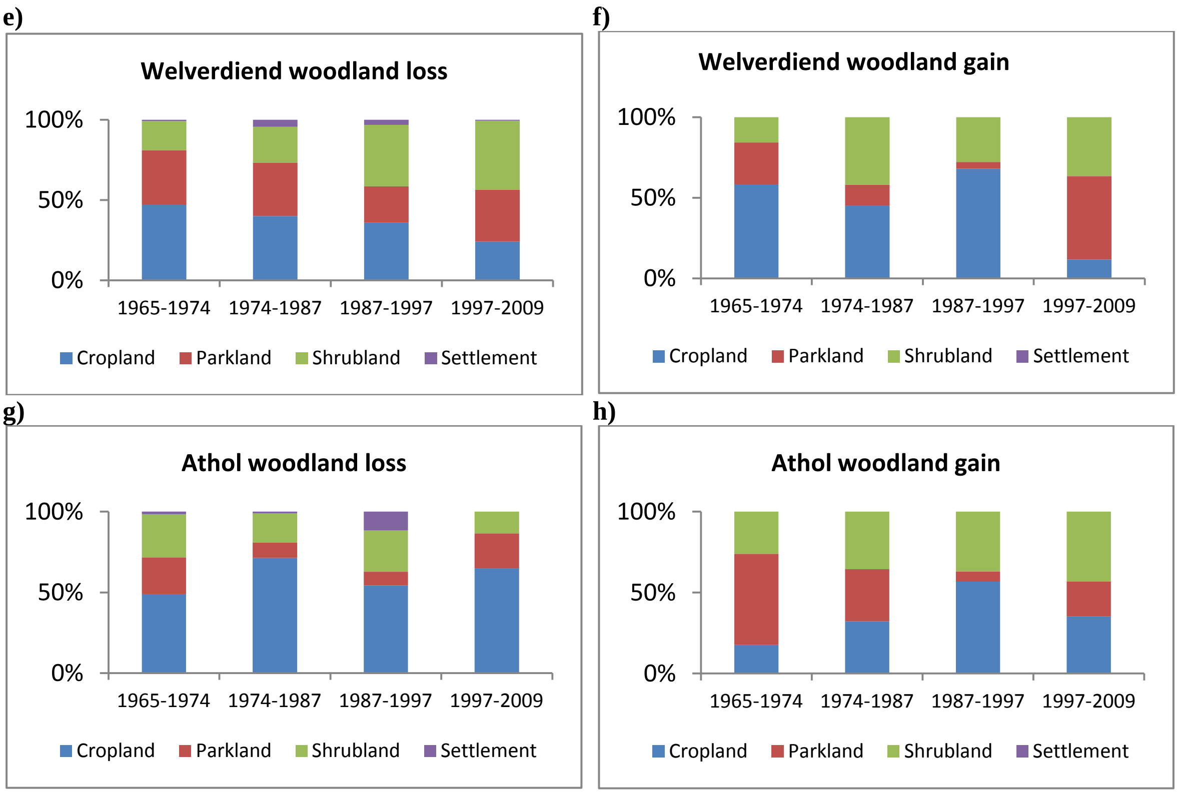


Figure 3.3.11 Landcover transitions in wooded areas, both shrublands and mixed woodlands. Each column shows the relative contribution (%) of the other landcover classes to gains and losses observed in these landcover classes respectively during each inter-decadal time-slice (1965-2009).

3.3.8 Identifying Systematic Landcover transitions between 1965 and 2009

3.3.8.1 Landcover Transitions in Welverdiend

Nearly all of the differences between the observed proportion and the expected proportion (in round parentheses) in the transition matrix for Welverdiend were larger than zero in value. According to Pontius *et al* (2004) this indicates that the observed changes were not due to random error or chance processes occurring in the landscape between the images for 1965 and 2009. The only zero values were observed in the loss of Mixed Woodland to Cropland which is very close to zero in value. However, the temporal trends in Mixed Woodland loss for each successive time interval (Figure 3.3.11) show that this loss is not by random error, it is likely that this result is due to the large degree of transition on the landscape as a whole. This method holds the persistence constant and redistributes the loss equally between the other landcover classes according to the relative cover of each class (Pontius *et al* 2004). In 2009, the landcover classes contributed similar proportions to the landscape (Figure 3.5, Figure 3.3) so at the coarse temporal scale the observed change pattern may mimic a random change pattern, thus weakening the ability to differentiate between systematic Mixed Woodland loss to Cropland and random process. However, this may also indicate that transition to Cropland of wooded areas occurs in already degraded areas first- that is, Mixed Woodland is replaced by Shrubland and there is a strong signal that Shrubland is predominantly converted to Cropland and to a lesser extent Parkland .

3.3.8.2 Landcover transitions in Athol

All observed losses in Athol could be attributed to systematic change, rather than random process or error (no zero values). The signals of systematic transition (Difference divided by expected,) are noticeably stronger in Athol than in Welverdiend. Specifically the transitions to Settlement from Croplands (4.91) Parklands (3.93) which indicate that the transition is systematic occurring at approximately 4.5 times the rate at would if this was random or methodological error. A similarly strong signal of systematic conversion between Parkland and Shrubland is also evident, however, this only accounts for a small proportion of the landscape (0.27) that the strong signal may simply be due to the small size of Shrubland relative to Parkland (Pontius *et al* 2004).

3.4 Discussion

Landcover changes modify the ability of the landscape to provide certain ecosystem services although not all changes result in negative impacts (Leppers *et al* 2005). Therefore the observed landcover changes are discussed relative to potential impacts on ecosystem service delivery, with particular reference to the sustained loss of the Mixed Woodland class in both villages. The implications of the past LUCC trends up until 2009 are discussed in the context of the success of future socio-economic development plans for Bushbuckridge as an ISRDP node as well as an integral part of the K2C Biosphere Reserve.

3.4.1 Communal landscape change trajectories

The landscapes of both villages have followed the same basic trajectory of development over the study period. There has been consistent Settlement expansion and loss of Mixed Woodland in each communal landscape, buffered by a variable, heterogeneous zone of agricultural lands, both active and fallow, cleared open spaces and degraded shrublands lying between those two classes. This spatial pattern conforms to descriptions of disturbance gradients with human utilisation impacts decreasing with distance from residential areas in other communal landscapes (Shackleton *et al* 1994, Fisher *et al* 2012). These trends in landscape development suggest that heavily utilised villages (communal woodlands) begin to lose this gradient and become increasingly homogeneous (Giannecchini *et al* 2007, Fisher *et al* 2012).

The landscape compositions were similar to begin with in 1965 but by 2009, Welverdiend showed a considerably greater degree of transformation. This may primarily be due to the higher rates of landcover change in Welverdiend, consistent in each time-period, implying higher population pressures requiring more space to build homes and arable land, that is, more people settled in Welverdiend compared to Athol. Thus in Welverdiend, as the population grew (as evidenced by the increasing size of the settlement area), the disturbance gradient has become less evident; for example, from 1986, as the Mixed Woodland contracted towards the north-east, south-east and south-west corners of the village extent, the lands lying towards the east and west of the settlement area have become a patchwork of open cropland and parklands (Figure 3.4). Parklands are partially deforested woodland with scattered large trees (e.g. abandoned fields), in some instances this landcover class gained large areas from Mixed Woodlands. Such patterns were observed by Giannecchini *et al* (1997) and this transition was attributed to areas which having been cleared for agriculture had been abandoned but still contained large indigenous fruit trees, such as Marula, (*Sclerocarya birrea*) with some degree of regeneration.

Fuelwood harvesting, in conjunction with agricultural clearing, has also been identified as a major driving force behind woodland degradation and woodland-cover change in other Dryland ecosystems in southern Africa (Bagachwa *et al* 1995, Luoga *et al* 2000, Petit *et al* 2001, Luoga *et al* 2002, Scholes 2009). Selective species harvesting, as is carried out in fuelwood harvesting (Brouwer *et al* 1997) ultimately leads to woodland degradation (Grainger 1999). Not all species are targeted for fuelwood harvesting; some species, such as *Pterocarpus,* are preferentially cut for timber and carving. Deforestation as a result of fuelwood harvesting begins to occur once the resource becomes scarce relative to demand (Shackleton *et al* 1994). However, once harvesters begin to chop live stems, then woodland degradation initially through repeated woodland thinning processes compounded with agricultural clearing (Grainger 1999) will result in the transition patterns displayed in the case-study villages in Bushbuckridge. Thus the interaction between residential and agricultural expansion, wood harvesting and livestock browsing (which has not been accounted for in this study) are direct causes of deforestation in these socio-ecological systems (Grainger 1999, Geist & Lambin 2002, Biggs *et al* 2005, Scholes 2009).

3.4.2 The legacies of past land-use and the influence of social occurrences on landcover change

The most obvious legacy of past land-use patterns is the spatial persistence of the disturbance gradient around each settlement area which follows the proscribed land-use planning system of the Apartheid land Betterment Schemes (McCusker & Ramadzuli 2007). These land-use planning patterns are still being applied in the development of rural settlements in South Africa (McCusker 2004, McCusker & Ramadzuli 2007). However, the extent to which topography mediated what land-use and therefore what land-cover could occur on the landscape needs to be further investigated. Even though a gradient was observed around settlements, the location of fertile clay soils in valleys and sandy soils on hilltops (Venter *et al* 2003) may have influence on the location of fields and parklands in a manner that decouples from classic linear disturbance gradient. The common perception that the severe degradation on communal rangelands should only be attributed to unsustainable use patterns by village residents (de Wet 1987, Scoggings *et al* 1999) should be brought into question, in light of the histories of these areas. The establishment of these villages on former farms forced larger numbers of people than could naturally be supported onto small, restricted parcels of land, with little planning for future population expansion (McCusker & Ramadzuli 2007). Limited infrastructural investment by Apartheid structures and the post-1994 national Government re-enforced livelihood dependence on these lands; creating situations of increasing resource harvesting pressure and inevitable unsustainable systems over time.

Petit & Meyfroidt (2010) identified two levels of human influence on landcover changes. Socio-ecological feedbacks are community-driven, village-level landcover changes that affect ecosystem services provided in the immediate environment. Socio-economic changes operate at a higher decision level and are often not under the control of the proximate communities; they include changes in government development or economic policies (Geist & Lambin 2002, Petit & Meyfroidt 2010). The observed patterns of change within the case study sites fit well within this framework. Rates of landcover change in each village were non-linear and echoed social patterns of change that were occurring in the political domain of South Africa during the first time-period (1965-1974) when the forced resettlements happened and the Bantustans were officially proclaimed. Platzky and Walker (1985) document that hundreds of thousands of people were relocated into the Gazankulu and Lebowa homelands. The second episodic spike in landcover change rate occurred during the third interval (1986-1997) which was concurrent with the significant influx of the Mozambiquan refugees into the area (Twine 2005). During each pulse, rates of landcover change would have been driven by the need to create new space for homesteads, perhaps arable fields as well as building materials (Twine 2005, Giannecchini *et al* 2007). Socio-ecological feedbacks are evident in the expansion of the Welverdiend resource base onto Morgenzon (Figure 7). Initially in response to perceived shortages in woodland resources due to drought but also as space has become limited on Welverdiend farm, for new land for agriculture.

3.4.3 The impact of landcover change on land-based livelihood strategies

Although they are not the primary source of livelihood communal woodlands can contribute up to 30% of household livelihood streams (Dovie *et al* 2005) thus they contribute significantly to mitigating the impacts of poverty and improving human well-being in communal areas. Therefore household livelihood security is linked to secure access to communal woodlands and resources (Cousins 1999, Dovie *et al* 2005). They also provide a cash-saving function to the household, since households access resources at no or little financial cost (Shackleton & Shackleton 2002) and are buffered against environmental and social shock (Arnold & Ruiz-Perez 2001). The high monetary costs associated with monthly tariffs, purchasing and maintaining the technologies that are required to make adequate use of electricity such as stoves, are often prohibitive to these rural households (Williams & Shackleton 2002). For instance the money that households save by using fuelwood rather than electricity for cooking is then available for other households needs such as purchasing food (Madubansi & Shackleton 2006, Shackleton *et al* 2007). Thus the communal woodlands represent a vital cash-saving function, not only to the households but also to the national government. The domestic use of fuelwood represents a saving of approximately R3 billion or just less than R2000 per using household per annum (Williams & Shackleton 2002) or approximately 10% of the average income of households in the case study villages (Matsika *et al*, In Review, Chapter 4). If the trends continue, this implies the transferral of this cost to either the households or to the State to replace the lost fuelwood reserves with viable energy alternatives (Shackleton *et al* 2007). The dependence on natural resources from the communal woodlands will not change over the intermediate future unless either economically viable alternatives (at the household level) can be introduced, or the socio-economic conditions that prevent households from making efficient use of improved infrastructure change (Williams & Shackleton 2002).

In light of this, the rapid conversion of the communal woodlands to settlements represents a negative change in many fronts as it will require households to develop considerable coping strategies to cope and adapt the new regimes (Shackleton *et al* 2007). To secure access to woodland ecosystem goods such as fuelwood, timber, bush meat or medicinal plants, households may cope by walking further distances, investing more time and household labour to access these resources or switch to alternatives (Abbott 1998, Brouwer *et al* 1997). However such coping strategies will only be adequate for as long as the woodlands persist on the landscape. If similar changes are in fact occurring in the other villages in Bushbuckridge, along the same patterns (Coetzer *et al* 2012, Submitted) then it is likely that, either the communal woodlands will disappear completely or be reduced to patches of heavily impacted woodland that are commonly shared by several villages. This has in fact already been observed to varying degrees in other villages in Bushbuckridge (Fisher *et al* 2012). This brings into sharp focus the question of how such communities will cope without the safety net and extensive resources available to them currently from the communal rangelands. The trend of permanent woodland clearing represents a threat to the various income-generating activities from communal lands including collection and sale of various resources such as timber, thatching grass, fuelwood, wild plants and animals for food and traditional medicinal purposes (Twine *et al* 2003, Shackleton *et al* 2001, Shackleton *et al* 2007).

3.4.4 Landscape development, resource shortages and socio-economic development in Bushbuckridge

The basic premise of the ISRDP serves to create conditions under which local Government structures in each of the nodes drive infrastructural development within the area (Harmse 2010). Under this, the Bushbuckridge Municipality created a Spatial Development Framework to guide development activities in the future and identified the lack of infrastructural development in the settlements within the municipality with specific reference to services such as water and electricity (BLM 2010). With reference to the latter, rural communities in Bushbuckridge are predominantly dependent on fuelwood extracted from the woodlands to meet their thermal-intensive energy needs. The extensive electrification programme has had limited success, given that up to 90% of the households with access to electricity still use fuelwood for their main thermal energy requirements (Madubansi & Shackleton 2006, Matsika *et al*, In Review, Chapter 4).

The observed trajectories of change in the case-study villages indicate how landscapes in other villages in Bushbuckridge and other former homeland areas in South Africa have developed, if they were established in the same manner. From the cross tabulation of landcover transitions it is evident that settlements expand outwards into land that has already been cleared for agricultural purposes, leading to new clearing of Mixed Woodland areas to create new croplands for village residents but since space within the village bounds is limited, there is no replacement of Mixed Woodland area. The limited resource-base continues to shrink and move further away from the settlement area as the populations grow. Furthermore, the results suggest that at the fine-scale (village-level) the beginning of disturbance, for example from wood harvesting for fuelwood, within the natural landcover type (Mixed Woodland to Shrubland, Tables 7, 8) acts as a kernel around which systematic transition, from Shrublands to Cropland to Settlement area progresses rapidly, relative to extant population pressures. This echoes trends that were observed in landcover change analyses of transitions at the macro-scale, ecosystem level within the Kruger to Canyons Biosphere Reserve by Coetzer *et al* (submitted).

The results point to two inevitable outcomes, if these trajectories hold true in the future. Space for human settlements could become an issue as villages run out space to expand into, within the land that is available to them. Secondly, as Mixed Woodlands continue to be cleared to make way for settlements and agricultural lands, scarcities of the various ecosystem goods and services upon which the village residents are so dependent are bound to occur with time, irrespective of the seemingly "sustainable" nature of current use-patterns. Such ecosystem goods include fuelwood, poles for construction and fencing, thatching, edible fruits and medicinal plants amongst others (Twine *et al* 2003). As the woodlands contract and the human population increases, the extractive pressure on the communal woodlands per person (or per household) per unit area will increase. The additive effects of increasing pressure on shrinking woodland areas will lead to the collapse of the resource base. Population growth, manifest through settlement expansion is a major driver of change in Bushbuckridge, also observed by Giannecchini *et al* (2007). Even should population growth rates slow, this will not necessarily translate to a decline or reversal of the rates of household creation (and therefore settlement expansion) or the need for agricultural land.

The development considerations in light of these patterns are further compounded by the inclusion of Bushbuckridge within the K2C Biosphere Reserve. The expansion of the Welverdiend resource range into Morgenzon illustrates the desperate need for space and high value of land, as a source of essential ecosystem services and for outward settlement expansion. Similar trends of village range expansion have occurred in Athol during the drought in the early 1990s (Giannecchini *et al* 2007). Furthermore historical resentments and tensions between resource-stressed rural communities and neighbouring commercial conservation enterprises have been previously documented in the area (Pollard *et al* 2003). The annexure of Morgenzon may be a unique, opportunistic social development with respect to Welverdiend, or it may be indicative of potential conflicts to come if the change patterns continue and space and resources in the communal woodlands become increasingly scarce.

The current Spatial Development Framework for Bushbuckridge does not account for any of these observed trends and the almost inevitable future resource shortages that could occur if landcover change processes continue along the same trajectories. Current municipal land-use planning for new settlement areas is still based on the patterns of the Apartheid Betterment Schemes (McCusker 2004, McCusker & Ramadzuli 2007). This ensures the perpetuation of the type of landcover dynamics that are evident now into the future. Greater consideration for the results of past land-use planning on landcover today needs to be taken into consideration in the planning for Bushbuckridge to ensure the creation of sustainable natural-resource based communities.

3.4.5 Methodological considerations

Error may have been introduced into the analysis of landcover change at two points in the methodology- during orthorectification process as well as manual classification. Change detection requires accurate coregistration of successive images to each other so that they have the same geometry and are perfectly aligned (Coppin *et al* 2004). If not comparisons of landcover change between successive images might result in false detections of change. However, the low RMSE value for both village datasets (<3m) indicated that the error in this regard is minimal. Human error may have occurred during the manual classification and digitisation process since the delineation of landcover classes is somewhat subjective but the relatively small areas over which the analyses were performed meant manual photo-interpretation could be applied confidently (Gennaretti *et al* (2011). However, whatever human error that was incorporated through subjective misclassification may be discounted since this was carried out by a single analyst who was very familiar with the landscapes under investigation as a result of extensive field work and data collection in the communal woodlands and settlement areas. Thus whatever human error that may have been introduced was well managed and minimal.

The method proposed by Pontius *et al* (2004) makes use of statistical techniques to identify the most common systematic trends in landcover transformation in a given landscape. Although it is useful to indicate landcover transformation trends that may require management intervention or research focus from a scientific perspective, it has not been widely applied in landscape ecology. As such, there is a lack of comparative studies that could be used to check how accurate the identifications of systematic transition are in real-world landscapes. Furthermore, this method does not account or differentiate for the causal mechanisms of LUCC, through human action or gradual environmental change and this needed to be taken into consideration. For instance, systematic changes from the Mixed Woodland to Shrubland classes indicate some degree of bush encroachment but do not explicitly identify human actions as the causal agents as this could also be as a result of gradual environmental changes, drought or fire all of which are common occurrences in Savanna landscapes (Scholes & Walker 1997). The small scales over which the analysis was carried out and the heavy human presence and influence within these landscapes during the study-period makes it more likely that the observed changes were community-driven and village residents were the agents of change (Petit & Meyfroidt 2010).

3.5 Conclusion

Human societies on cultural landscapes shape and are shaped by their environments in a process of constant change and adaptation through socio-ecological and socio-economic feedback mechanisms operating at various temporal and spatial scales. In the communal landscapes in Bushbuckridge communal land is fast becoming a scarce resource as a result of a combination of historical landcover change dynamics and population growth and settlement expansion and demand for small-scale agricultural spaces. Should these landcover change trajectories continue, then resource shortages, of fuelwood, timber and various other NTFP will be inevitable, irrespective of how "sustainable" current harvesting practices may be in the individual communities. There is an urgent need to investigate the implications of socio-economic development programmes in affecting rural-rural intermigration onto already stressed, vulnerable rural communal livelihood systems (Shackleton *et al* 2001). Environmental resilience and rapid reversals of change are characteristic of such cultural landscapes but where the change is driven from natural cover to a built-up environment, such changes tend to be permanent. Therefore more efficient land-use planning and rural planning systems should be investigated to halt the threat to woodland resources and the communities that depend on them.

Chapter 4

4. The dichotomy of fuelwood depletion VS access to electricity in rural South Africa

Abstract

Energy security is central to achieving sustainable development and reducing poverty worldwide. Over 70% of the population of Sub-Saharan Africa, mostly in the rural areas, depend on wood fuel, as firewood or charcoal, to meet their primary domestic energy requirements. This dependence is projected to increase with population growth in the intermediate future, regardless of the implementation of rural electrification programmes. . Fuelwood shortages occur at the localised village level and are a chronic landscape syndrome, becoming more severe over time, with increasing population pressures and competing land-uses. In the South African context, the provision of electricity to rural households at subsidised rates would be expected to provide a viable alternative to fuelwood under conditions of scarcity. This paper compares the fuelwood consumption strategies of households in a fuelwood-scarce environment against those in fuelwood-abundant environment in order to illustrate the inelastic nature of the demand for fuelwood in rural communities, even in the face of severely depleted wood stocks. We seek to understand the mechanisms that households implement to ensure household fuelwood/energy security and how these responses aggregate at the landscape level to shape landscape dynamics. This will aid better planning of intervention policies in the future.

4.1 Introduction

Household energy security is an essential aspect of poverty reduction amongst the vulnerable populations of less developed nations (Pachauri and Spreng, 2004, Starr, 1996,). It is an essential building block in almost all socio-economic development activities (Zhang and Fu, 2011) and access to efficient affordable energy services is related to an improvement in human societal welfare (Davis, 1998; Leach and Mearns, 1988). The harsh reality is that a large proportion of the populations of less developed countries exist under conditions of energy poverty, lacking access to energy sources that are "adequate, safe and reliable for economic and human development" (Perreira *et al* 2011). For these populations, residing mostly in rural, undeveloped areas, woodfuel either burnt directly as fuelwood or processed to charcoal is the primary source of domestic energy (Karekezi, 2002). In these rural communities household energy is secured at the opportunity cost to the household of time spent by females in fuelwood collection (Dovie *et al* 2004).

Generally, fuelwood is collected from communal woodlands and agricultural fields around the homestead and/or village depending on the settlement pattern. Fuelwood collection is preferentially of dead and dry branches but as demand increases and begins to exceed the available deadwood resources, live woody stems and branches is cut for fuelwood and over time this brings about woodland degradation (Grainger, 1999**).** Concerns about this and the assumption that fuelwood harvesting would result in widespread deforestation, and therefore a gap between demand for fuelwood and the available supply, gave rise to what was referred to as the "Fuelwood Crisis" in the global energy planning arena in the 1970s (Eckholm, 1975; de Montalambert and Clement, 1983). Entire developing nations were projected to have insufficient woodland reserves to meet the needs of their populations as a result of this deforestation (Dewees, 1989). Subsequent and on-going research has shown that fuelwood deficits do not occur at the national level of accounting; rather, fuelwood crises are highly-localised, village-level phenomena (Dewees, 1989; von Maltitz and Scholes, 1995). The definition of a fuelwood crisis is the scarcity of fuelwood of sufficient quality, relative to the needs of the dependent communities (Arnold *et al* 2006). This issue should remain within the focus of global concern because of the high dependence on fuelwood in the developing world, currently and well into the intermediate future (Aron *et al* 1991; Karekezi 2002; Williams and Shackleton 2002).

Fuelwood scarcity in Sub-Saharan Africa is a chronic landscape condition (Brouwer *et al* 1997). This means that it generally becomes worse over time through woodland loss, as a result of rural agricultural and settlement expansion (Petit *et al* 2001) and increasing extractive pressure on the remaining wood stocks for multiple uses (Shackleton and Shackleton, 2000; Twine and Siphugu, 2002). Restricted access to fuelwood implies a loss of societal welfare and the gravity of the situation depends on the ability of households to cope with decreasing levels of fuelwood availability (Arnold *et al* 2006). Underpinning the societal implications of these shortages is the own-price demand for fuelwood which is often expressed through the increased opportunity cost of fuelwood collection time (Baland *et al* 2010; Cooke St Claire *et al* 2002) and financial investment through purchasing wood as harvestable fuelwood stocks decrease by the household (Brouwer *et al* 1997; Twine *et al* 2003). However, rural demand is not very responsive to decreasing fuelwood availability (Arnold *et al* 2006) and this has been attributed to a lack of economically viable energy alternatives (Cooke St Claire *et al* 2002). It is therefore important to understand what factors sustain the demand for fuelwood in situations of scarcity, that is, how and if households adjust their fuelwood consumption strategies to ensure household energy security particularly in economically vulnerable, rural communities. Such coping mechanisms are implemented at the household level, therefore for the purposes of this study, fuelwood consumption was considered to refer to how households access and use fuelwood. The aggregate household responses will determine the impact of the village on the socio-ecological landscape and this depends on a complex interplay of socio-economic conditions, such as local land-use rights, systems of governance (Kaschula *et al* 2005) and available alternatives (Brouwer *et al* 1997**)**.

In South Africa, the post-Apartheid government implemented an accelerated electrification programme to address the historical developmental imbalances in today's rural areas - the former "homelands" of pre-democracy South Africa (DME, 1998). These are economically and socially marginalised areas that were designated for forced resettlement of indigenous black people by the Apartheid government (Thornton, 2002). The electrification programme increased household access to electricity in the general populace from 36% in 1994 to 68% by 2000 (Kotze, 2001**.** However, in the rural areas, the introduction of electricity had little bearing on the demand for fuelwood, as up to 95% of households with access to electricity still use fuelwood as the primary energy choice (Davis, 1998; Madubansi and Shackleton, 2006; Thom, 2000). Rural households incorporate electricity into their domestic energy mix, rather than transition completely (Madubansi and Shackleton, 2006) even though they receive a free basic allowance that results in heavily subsidised electricity tariffs (Davis, 1998; Thom 2000). Even with decreasing fuelwood availability, households still invest limited household resources into purchasing fuelwood rather than electricity in order to meet their domestic energy needs (Davis, 1998; Thom, 2000). This is linked to various socio-economic factors such as the prohibitive costs of monthly tariffs and the purchase and maintenance of the technologies needed to use electricity efficiently (Williams and Shackleton, 2002).

In the context of predicted (Banks *et al* 1996) and proven fuelwood shortages (Madubansi and Shackleton 2007), there is little information in the literature as to the mechanisms that rural households and communities in South Africa are adopting to combat shortages in light of the introduction of electricity as a widely available, “cheap”, subsidised domestic energy alternative. Determining if and how household fuelwood consumption behaviour changes relative to the availability of the resource in the presence of electricity is pivotal to understanding whether similar interventions could be successfully introduced in other rural communities. This study investigated the strategies that rural households engage in to meet their energy needs under conditions of fuelwood scarcity, where electricity has been made available as an alternative. Specifically, fuelwood use in two rural villages in Bushbuckridge rural local municipality in Mpumalanga Province, South Africa was compared. Welverdiend represents a village under conditions of fuelwood scarcity, while Athol represents village with sufficient fuelwood resources, based on predictions made by a previous study focusing on these two villages (Banks *et al* 1996). After comparing the household demographic and socio-economic characteristics of the two villages, we investigated the strategies households used to ensure domestic energy security with respect to use patterns of fuelwood and identify differences related to fuelwood scarcity and access to electricity. We then quantified and compared the characteristics of fuelwood collection and the associated opportunity costs relative to the costs of electricity in each village. In this way we determined whether there is a discernable difference in fuelwood consumption characteristics with loss of fuelwood availability. This paper contributes to the dialogue around why the issue of fuelwood scarcity is still highly topical in rural Sub-Saharan African communities, despite over 30 years of discussion and debate around the relevance of the fuelwood “crisis”.

The choice of study area for this research is significant. Bushbuckridge has been identified as an Integrated Sustainable Rural Development Programme (ISRDP) node by the national government (RSA, 2000) and was specially mentioned by the Presidency as needing special development intervention (Mbeki, 2001). Under the ISRDP the South African government identified 13 high-poverty priority areas that were underdeveloped but had potential for economic growth and facilitated conditions to upgrade infrastructure and investment (RSA, 2000). As a flagship area, the success of such interventions, including the efficacy of household electrification in improving human wellbeing and stimulating socio-economic development, will determine if similar programmes will be rolled out nationwide (Harmse, 2010). The communal lands within the buffer zone are hemmed in by state and private conservation areas. This effectively makes land in the K2C a high-value, limited resource since it restricts the space available for outward village expansion in line with population growth, as well as increasing pressure on the remaining, ever-shrinking communal woodland space, to provide fuelwood and other essential livelihood resources.

4.2 Methods

4.2.1 Study Area

The case-study villages Athol (24° 43’S 31° 21’E) and Welverdiend (24° 36’S 31° 07’E) are located in the Bushbuckridge Municipality of Mpumalanga Province, South Africa (Figure. 1). Economic development is marginalised, unemployment is rife, monetary income is low and human settlements are densely populated with an average range of 150-350 people km^{-2} (Pollard *et al* 1998**;** Thornton, 2002)**.** Subsistence agriculture is widely practised, but unlike rural areas across the rest of Sub-Saharan Africa, this is not the mainstay of livelihoods, shortages of land being one of the main factors. Households rely heavily on remittances from migrant household members and on social grants. The land tenure in the region, as in all former “homelands” is communal; the land falls under the authority of traditional leaders who determine local land use patterns (Shackleton and Shackleton, 2000).Village commons are defined by the boundaries of the original farms upon which the villages were established (Banks *et al* 1996) and are fenced off from other neighbouring villages. The communal land is used by village residents for cultivation, grazing for livestock, and harvesting of a wide range of non-timber forest products. State or privately-owned conservation initiatives are the next most common land use types in Bushbuckridge for nature conservation, commercial game hunting or eco-tourism.

The estimated number of households has more than doubled in both settlements since 1992, although to a greater degree in Welverdiend (Figure 4.1). Information on the number of households in each settlement was extracted from data provided by the Bushbuckridge Municipality. Measurements of the spatial extent of the village area were carried out on 2009 aerial photographs of each village in ArcGIS v9.3. Village area is the total area of the residential settlement and village commons. The communal woodlands are under three times the amount of extractive pressure in Welverdiend than in Athol to provide the entire suite of livelihood requirements per unit area of land, including cropland, fuelwood and medicine.

Table 4.1 The spatial extent of the case study villages as given by the total farm area and the actual extent of the communal rangelands related to the number of households in 2009.

	Households (1992)	**Households (2009)**	**Village area (ha)**	**Total woodland area (ha)**	**Woodland availability (woodland area ha/ household)**	**Woodland extraction pressure (households/ ha)**
Welverdiend	564	1508	3945	2284	1.52	0.67
Athol	292	517	3432	2208	4.27	0.23

4.2.3 Biophysical characteristics

The topography of the region is gently undulating with an average altitude less than 600m above sea level (Shackleton *et al* 1994a). Soils are underlain by granitic gneiss with local intrusions of gabbro. The vegetation is Mixed Lowveld Bushveld and is mostly dominated by tree species of the *Combretum* and *Terminalia* genera (Rutherford *et al* 2006).

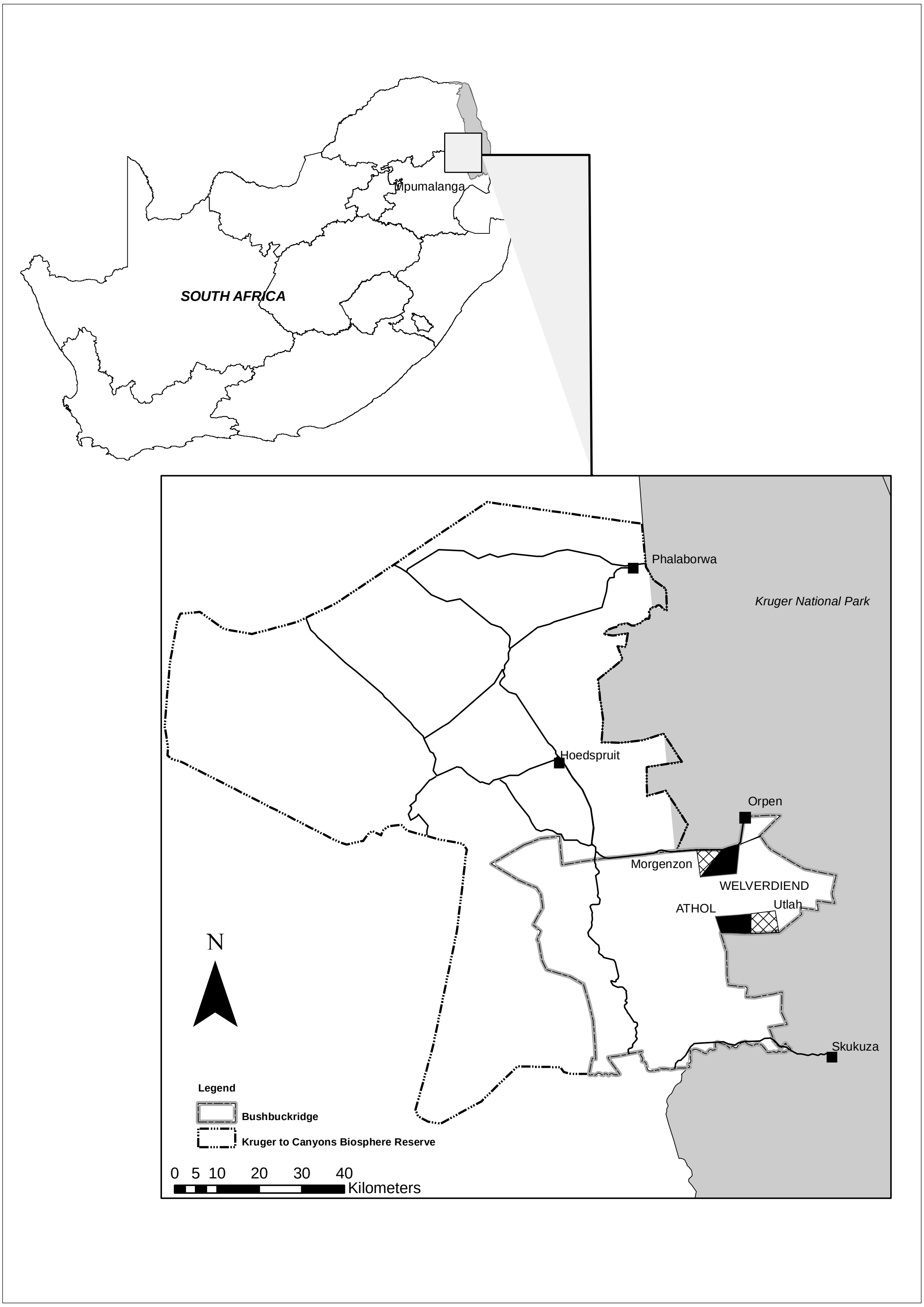


Figure. 4.1 The locations of Welverdiend and Athol villages, relative to the Kruger to Canyons Biosphere Reserve and the Kruger National Park in South Africa. Solid polygons show the extent of the original farm boundaries of each settlement. Hatched polygons are the spatial extent of Morgenzon, adjacent to Welverdiend and Utlah adjacent to Athol

Rainfall is received during the summer season (October to May), mainly in the form of convectional thundershowers and averages 650 mm annum-1 in the west and 550 mm annum-1 in the east along a rainfall gradient and droughts occurring roughly once every decade. Mean annual temperature is 22 ºC; summers are hot, with a mean daily maxima 30 ºC and winters are mild with mean daily maxima of 23 ºC.

4.2.3 Data collection and analysis

The household surveys in both Athol and Welverdiend were conducted as part of a larger research project (The Volkswagen Foundation Biomodels Project) studying woody biomass energy use in southern Africa (South Africa, Zambia and Mozambique). Data collection in South Africa was carried out in 2009 between May and August on a per household basis using a structured and semi-structured interview format (Appendix 1). Participating households were selected randomly using aerial photographs of the settlements. The questionnaires were administered with the aid of local XiTsonga translators from both villages. If household members were not at home or declined to participate in the survey, another randomly selected household was chosen to replace it and enumerators moved on to the next household on the list. In total, 125 (24%) households were interviewed in Athol and 139 households in Welverdiend; however irregularities in the interview process by one of the enumerators reduced the Welverdiend sample size to 120 households (8 % sampling intensity). Generally the adult females of the household were interviewed as they are most often responsible for the daily household chores requiring energy use and household income expenditure. In the case where there were no adult females available or present the person responsible for these tasks was interviewed regardless of gender. During focus group discussions held at the onset of this study, which ran concurrently with field campaigns in Zambia and Mozambique, it became apparent that the locals in all three countries recognised three distinct seasons over the year. A hot, dry season (summer), running from August to October, a hot, wet (rainy) season from November to April and the cold, dry season (winter) from May to July and adjusted their fuelwood consumption strategies in accordance with each season. As such these seasons, rather than the traditional winter and summer seasonal divisions were applied in questions in the survey relating to seasonal use of fuelwood.

The first part of the questionnaire provided information on household demographics and income streams through formal and informal employment, remittances and government social grants. Household fuelwood consumption profiles were determined through data concerning frequency and duration of fuelwood collection trips, harvested species and quantities of fuelwood used and collected daily, making allowance for seasonality. The household member responsible for these tasks was asked to set aside a fuelwood pile that represented daily use and this was weighed by the enumerators using a spring balance and recorded in kilograms, accurate to the nearest 0.1 kg, except where the household had no fuelwood available for measurement. The questionnaire also provided information describing the sources of fuelwood used within the household, whether purchased or collected as well as quantities that were purchased per household; data on the use of alternatives particularly electricity as well as cooking habits were also collected. Fuelwood was measured in kilogrammes. Households described amounts collected in headloads, wheelbarrows, or *vrag* loads, where a *vrag* is the local colloquial term for the load that would be contained within the carry bin of a pick-up vehicle. The weight of a headload was determined to be 14.5 kg (n=40), the weight of a wheelbarrow load 39.6 (n=20) and the weight of a *vrag* was taken to be 532 kg from Twine *et al* (2003), following a study in neighbouring villages within Bushbuckridge. These values were used for all related computations.

Data were captured in Microsoft Excel (MS Excel 2007) and analysed using SAS Enterprise Guide 4.2. For discrete variables the responses were coded and frequency analyses were carried out for each response. Normality of continuous variables was tested using the Kolmogorov-Smirnov test and summary statistics were calculated for all numeric variables; descriptive analyses were carried out for each village separately. Since many of the numeric variables failed the tests for normality the non-parametric Two Sample Wilcoxon tests were used for the comparative analyses of household demographic and fuelwood collection and consumption characteristics between villages. Comparisons of categorical data between the villages were tested for significance using Chi-Squared tests although for ease of interpretation the results were reported in terms of percentage values in each village

Average daily household fuelwood consumption was tested for significant differences between seasons and between villages by Two-Way Analysis of Variance (ANOVA). The annual fuelwood consumption (kg/household/annum) was calculated by summing the daily use values as given for each season. Log-transformation was carried out on the annual household use values and thereafter a 2-way Analysis of Variance (ANOVA) was carried out to test the significance of village and access to electricity on annual fuelwood consumption. Purchasing fuelwood is a characteristic of fuelwood-scarce communities, as is fuel substitution. Thus buying fuelwood and access to electricity were tested for significant effects on annual household fuelwood consumption. This was carried out on the subset of households that purchased fuelwood (as well as collected it) in Welverdiend only, since the sample size in Athol was insufficient to allow statistical comparison.

Household fuelwood collection strategies that were considered were trip duration (hours/trip/household) and frequency (number of trips/week). Frequency of collection trips was collated to the weekly temporal scale since the majority of households do not collect fuelwood daily. The average values were compared between villages at both the weekly and annual time scales. The opportunity cost of fuelwood collection to the household as a unit, incorporates both of these factors (time per collection trip and the frequency of collection trips) into one numerical variable with an intrinsic value attached to it (Rands annum^{-1}). Following Dovie *et al* (2002), the opportunity cost of fuelwood collection was taken as the product of the time spent collecting fuelwood per household annum-1 and the shadow price of casual labour in the area. In South Africa minimum wages are prescribed per sector per area; for the purposes of this study, the shadow price of labour was taken at R6.74/ hour ,the prescribed hourly rate for casual farm labour in the area. Studies in south Asia showed that of the time used in fuelwood collection, when given alternatives- women would use only 50% of the saved time in income-generating activities (Baland *et al* 2010). This value was used a proxy for our study area since no similar studies have been carried out in southern Africa. Thus the actual value of the time spent, or the opportunity cost of collecting fuelwood was calculated based on 50% of the time spent in fuelwood collection activities each year. The opportunity cost of fuelwood collection was calculated for each household as a unit (irrespective of the number of fuelwood collectors). Two-Way ANOVA was used on the log-transformed value of household opportunity costs to compare between villages and household with or without access to electricity. The savings represented by transitioning to electricity were calculated by comparing the actual financial costs paid in electricity bills between households using fuelwood only and those using a mix of fuelwood and electricity, these values were also compared against the fuelwood-use investment costs to the household (opportunity costs and purchase costs).The total economic cost of maintaining household fuelwood supply, where this value includes the cost of purchasing fuelwood, was compared between the two villages to see whether households in Welverdiend invest more to ensure household energy security than those in Athol.

4.3 Results

4.3.1 Household demographics and socio-economic characteristics

There were no significant differences in the demographic profiles between the villages at the household level with respect to the mean number of people living in the homestead as well as the number of men, women and children (Table 4.2). All household characteristics refer to individuals that reside within the household permanently and exclude migrant members. Of the sampled households children (less than 18 years old) make up 44% and 40% of the populations in Athol and Welverdiend respectively, adult men make up 22% and 28% and adult women make up 34% and 32% respectively and the village demographic profiles are not significantly different from each other. (DF=2, X^2=2.1312, p>0.05).

Table 4.2 The household demographic and socio-economic characteristics for Athol and Welverdiend villages; medians with lower quartile and upper quartile using Wilcoxon 2-sample tests.

Socio-economic characteristics	**Athol**	**Welverdiend**	**Results**
Household size	5.0 (4,6)	5.0(4,7)	Z=0.6945, p>0.05
Number of adult males	1 (1,3)	1 (1,3)	Z=3.465, p>0.05
Number of females	1 (1,2)	2 (1,3)	Z=1.429, p>0.05
Number of children	2 (1,3)	2 (1,3)	Z=0.8539, p>0.05
Income (R/annum)	18,060 (6,600-24,240	17,280 (8,640-26,880)	Z= -1.2147, p>0.05

The patterns of employment amongst the adult populations are similar (X^2= 0.8564, DF = 3, p>0.05) with the greater proportion of adults being unemployed (Figure. 2), highlighting the value of alternative income streams such as remittances, government social grants and the informal trade sector within these communities. There is no difference in the average household income (the sum of all cash streams including remittances in R/annum) in both villages (Table 4.2) thus the average annual income (of the pooled dataset) is R18,000± R1,075 annum^{-1}. Based on the total annual household income, 36.4% of households in Athol survive on less than US$1/person/day compared to 17.2% in Welverdiend. However, when remittances are excluded from the income stream then these proportions increase to 42.1% in Athol and to 36.8% in Welverdiend, emphasising local household dependence on remittances from migrant labour.

Figure 4. 2 Income streams amongst the entire adult populations of a) Athol and b) Welverdiend villages respectively. Percentage values are of all adults from the surveyed households

4.3.2 Village household energy consumption patterns

All surveyed households use predominantly fuelwood, electricity or a mix of both to satisfy the entire suite of domestic thermal energy requirements, (Figure 4.3). The fuelwood is either collected or purchased or both (Figure. 4). Gas and paraffin are available as energy alternatives to fuelwood and electricity and are used to supplement the main energy sources, but no households reported using them exclusively, and only one per cent made mention of them for use in cooking only. Of the households that have been connected to the national electricity grid, 91% in Welverdiend and 82% in Athol still use fuelwood as their main source of energy. Significantly more households in Athol than in Welverdiend have transitioned to exclusive use of electricity (X^2=6.6902, DF=1, $p<0.05$). Although the reason for the difference is not clear, the most commonly cited reasons for making the complete transition to electricity in both villages were the high opportunity cost of using fuelwood (too much effort- time and distance, to collect fuelwood) as well as the ready availability of electricity as an alternative. Households in Athol that use fuelwood as well as electricity, spend on average, R600.00±R53.46/annum on electricity, compared against R1200.00±R146.00 for those households that use electricity only (z=2.6515, $p<0.01$). A similar pattern emerges in Welverdiend where households using fuelwood report spending significantly less on electricity (R840±R85.08) than households that have transitioned to exclusive use of electricity (R1200.00±R215.71), (z=2.8041, $p<0.01$). Thus using the pooled village dataset the average household, using electricity only (n=27) spends an average of R1200±R130 pa on electricity (energy) which is significantly more than the households that also use fuelwood, these households spend R600±R52 annum-1, (z=-5.3095, $p<0.0001$).

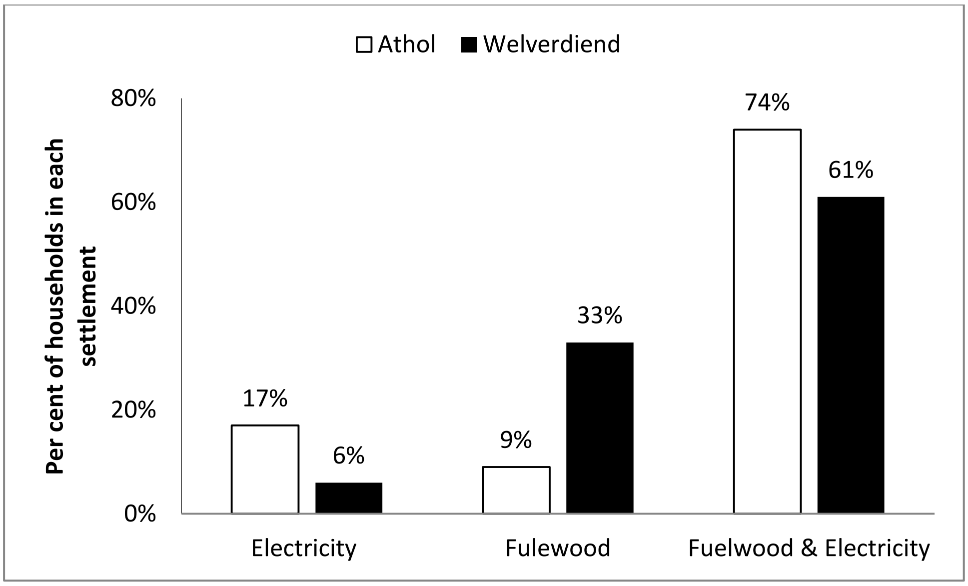
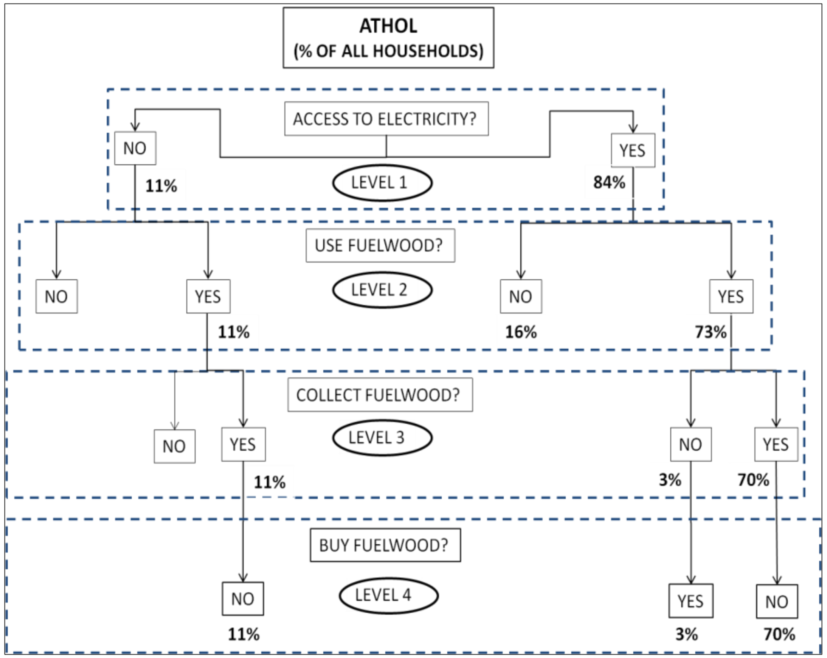


Figure. 4.3 Energy mix characteristics of households in Athol and Welverdiend based on the proportion of all interviewed households mentioning the use of either fuelwood, electricity or both as the main source of energy.

Households in Welverdiend are more economical in terms of one of the uses of fuelwood, cooking significantly fewer meals than households in Athol (Table 4.3) at an average of one cooked meal a day (1±0.05) in Welverdiend compared to two, (2±0.06) cooked meals per day in Athol.

a) 

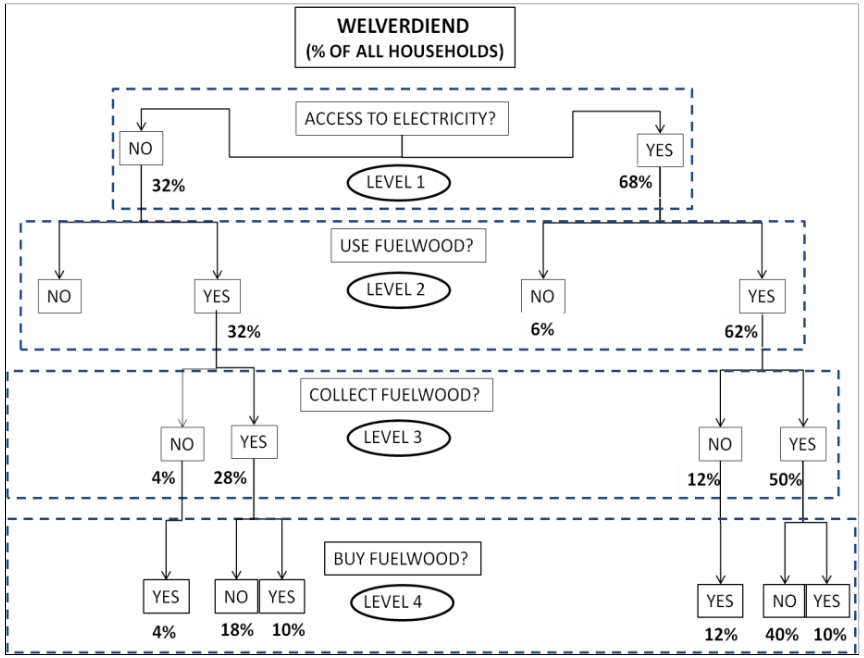
b) 

Figure 4.4 Fuelwood and electricity village-level percentage-use characteristics in 2009 for a) Athol and b)Welverdiend villages; percentage values at each level refer to percentage of all surveyed households.

Table 4.3 The household fuelwood consumption profiles of user households showing collection trip frequency, duration per trip and time and opportunity costs, annual household fuelwood use and the average number of meals cooked for Athol and Welverdiend. Unless otherwise stated all variables refer to the per annum temporal scale.

	Athol (n=97)	Welverdiend (n=88)	Results (W 2-sample test)
Fuelwood consumed (kg)	3193.1±114.9	3285.0±186.2	Z=-0.7780, p>0.05
Number of meals cooked	730±24	365±19	Z=-4.1190, p<0.05***
Fuelwood collected (kg)	3502±362	4154±299	Z= -1.47, p>0.05
Number of trips per household	117.0±5.6	91.0±6.8	Z=-3.3013, p<0.0001***
Length of collection trip (minutes/trip)	180.0±5.9	240.0±14.0	Z= 6.1499, P<0.0001***
Time collecting fuelwood (hours)	312.0±17.5	312.0±30.4	Z=0.0551, p>0.05
Opportunity cost (R)	R1051.44±R55.14	R1095.25±R98.10	Z=0.5217, p>0.05
Household investment cost of fuelwood use (R)	R1051.44±R53.74	R1213.34±R108.76	z=-1.6652, p<0.05***

**** Statistical significance of the Wilcoxon Two Sample test (Wilcoxon 2-sample test)*

4.3.3 Household fuelwood consumption

There is a marked seasonal pattern of fuelwood consumption (kg/day) which is not different between the two villages ($F_{5,546}$ =19.21, $p<0.0001$) with significantly lower consumption during the summer season (7.8±2.8 kg) than both the winter (10.5±4.5 kg) and rainy season (10.2±3.6 kg) daily consumption. Annual household fuelwood consumption does not differ significantly between Athol and Welverdiend (Table 4.3). Whether a household has access to electricity has a significant bearing on annual fuelwood consumption, irrespective of which village the household belongs to ($F_{3,207}$= 4.53, $p<0.01$). Households with access to electricity use less fuelwood annum^{-1} (2898.26 kg ± 130.42 kg) compared to those that do not (3451.45 kg ± 203.70 kg).

Thirty-six percent (36%) of all households in Welverdiend buy fuelwood in order to meet their needs (Figure. 4). They report buying 1,880±232 kg annum^{-1} at an average cost of R800±R144 annum-1. A significantly lower number of households buy fuelwood in Athol (3%, DF=1, X^2=43.6, $p<0.0001$), buying1596±532 kg annum^{-1} at a cost of R705.00±R213.00

annum^{-1}. Households in Athol that buy fuelwood (n=4) have made a deliberate choice not to collect fuelwood as they can afford to buy it instead. In contrast, the most common reasons for buying fuelwood in Welverdiend are insufficient resources within the communal woodlands and fear of being arrested if caught cutting livewood (29%). In Welverdiend, the source of the fuelwood, that is, whether it is bought or collected does not influence annual household fuelwood consumption ($z=-0.1512$, $p>0.05$) as there is no significant difference in the amount of fuelwood consumed by these two groups; households purchasing fuelwood use on average 3651±210.6 kg annum-1 and those that do not, use 3649±192.8 kg annum-1.

4.3.4 Fuelwood collection strategies

Collecting fuelwood from the communal woodlands is the most common method to secure household supply in both villages (Figure. 4). A greater proportion of households in Welverdiend (26%) stated that they could not collect sufficient fuelwood for their needs from the communal woodlands relative to Athol residents (5%) yet household in Welverdiend do not invest more household labour to collect fuelwood. The size of the fuelwood collecting party ranges between 1-4 people (Welverdiend) and 1-5 people (Athol) per household respectively, averaging 2 people in either village ($z=-1.5297$, $p>0.05$). Mostly adult women carry out the bulk of the fuelwood collection duties in both Welverdiend (73%) and Athol (68%) and there is no significant difference in the amounts of fuelwood collected per collection trip (Table 4.3).

4.3.5 Household investment into fuelwood collection

All households that collected fuelwood were included in this analysis, regardless of whether they also buy fuelwood since buying fuelwood had no influence on the duration ($Z= 0.876$, $p>0.05$) nor the frequency ($Z=0.655$, $p>0.05$) of fuelwood collection trips. Households in Welverdiend have consolidated the time they spend collecting fuelwood, making significantly fewer collection trips annum-1 but spending more time per trip than households in Athol (Table 4.2). Harvesters in Welverdiend, although making less frequent trips per week, invest more effort in terms of energy to walk longer distances and/or collect more fuelwood, (Table 4.2). However, when the time per collection trip (hours) and number of trips taken annum-1 were tallied to give the annual time invested per household to collect fuelwood, there was no significant difference between Athol and Welverdiend (Table 4.2) and consequently no difference in the opportunity cost to the household of fuelwood collection either (Table 4.2). The average opportunity cost for households collecting fuelwood (pooled village dataset) is R1051.44±R55.17/annum. However when the cost of buying fuelwood is factored in together with the opportunity cost, giving the total economic cost to the household, it becomes apparent that households in Welverdiend are forced to invest more and bear a greater cost, in terms of their time and money to secure household fuelwood supplies than in Athol (Table 4.3).

Table 4.4 The fuelwood consumption characteristics of the pooled village dataset separated by whether households have been connected to the national electricity grid. All variables are analysed at the per annum temporal scale.

	Electricity (n=160)	**No Electricity (n=49)**	**Results**
Time collecting fuelwood (hours)	280.15±17.9	364±39.2	Z=1.8671, p<0.05***
Opportunity cost (R)	R941.91±R60.47	R1226.65±R131.94	Z=2.9813, p<0.01***
Economic cost of fuelwood use (R)[1]	R1051.44±R61.73	R1676.20±R167.67	Z=-1.6652, p<0.05***

[1] The economic cost incorporates both the opportunity cost and the financial cost of purchasing fuelwood to the household.

However, incorporating the effect of household access to electricity dampens the difference in economic cost of fuelwood between the two villages, the Two-Way ANOVA is significant ($F_{3, 181}$= 4.12, p<0.01) and shows that village in itself is not a significant factor (F=2.43, p>0.05) but that access to electricity is (F=6.24, p<0.05) and the interaction between them is weak (F=3.71, p=0.054). Generally, in these two villages, households that do not have access to electricity spend 30% more time collecting fuelwood (84 hours) and invest up to 60% more in terms of the opportunity and financial costs of securing fuelwood for the household than those household that have access to electricity (Table 4.4).

4.4 Discussion

4.4.1 The dichotomous nature of "sustainable" fuelwood use

In comparing the fuelwood consumption profiles of households in Welverdiend against Athol, we have examples of two villages within the same socio-economic context at different points on the same fuelwood supply-demand trajectory (Banks *et al* 1996). It is conceded thatthe higher unemployment rate in Welverdiend may be a significant driver of fuelwood use. The primary quantifiable difference between these two villages is that the human population of Welverdiend is almost thrice that of Athol; consequently the ecological footprint of Welverdiend residents on their village landscape is greater due to sheer number and the requirements for space for homesteads and subsistence agriculture (Petit *et al*, 2001). Although the total area of communal woodland for both villages is similar, the area of woodland relative to village size differs resulting in a lower ratio of woodland to household in Welverdiend. It is worrying that as the human populations grow in both villages (indeed in many communal areas across southern Africa with similar land tenure), land availability will become the limiting factor, as the demands for space for residential and agricultural needs as well as the multitude of ecosystem services provided by the continuously decreasing communal woodlands, particularly fuelwood grow in parallel with the human population growth (Banks *et al* 1996, Karekezi *et al* 2004). Thus, although the fuelwood use behaviours in Athol are "sustainable", that is, the demand does not appear to be in excess of what the woodlands can supply (Shackleton *et al* 1994), as a result of inevitable village expansion and the consequent woodland loss through landcover conversion, there will come a time when the demand will become unsustainable relative to the ability of the woodlands to supply fuelwood. Unless there is a significant decrease in human population growth and a cessation of residential and agricultural expansion or a dramatic shift in use of alternative energy source (e.g. electricity), this situation is inevitable (Geist and Lambin, 2002).

The direct causes of localised fuelwood scarcity are woodland clearing for agricultural and residential expansion (Arnold *et al* 2006, Dewees, 1989; Geist and Lambin, 2002) and the penetration of market forces (Davidar *et al* 2010). Rural households in conditions of scarcity adjust their immediate fuelwood consumption profiles to mitigate the social impacts on their livelihoods (Dewees, 1989) but these changes are largely cosmetic, rearranging household time and financial budgets and minor substitutions of alternatives into the household energy mix (Brouwer *et al* 1997; Davis *et al* 1998; Madubansi and Shackleton, 200; Thom, 2000; Vermeulen *et al* 2000; White *et al* 1997). On the surface, it appears that the households in

Welverdiend have made the predicted adjustments to their fuelwood consumption profiles in response to scarcity (Arnold *et al* 2006; Brouwer *et al* 1997; Dewees, 1989; Mlambo and Huizig 2004). Welverdiend households invest more of their household resources into accessing fuelwood, have consolidated their fuelwood collection strategies to make it more efficient, purchase fuelwood to supplement that which is collected from the woodlands, cook less often and have incorporated electricity more into their household energy mix (Madubansi and Shackleton, 2006). However, inspite of perceived scarcity in Welverdiend, the demand for fuelwood remains comparable to that of households in Athol where fuelwood is in abundance. That the average annual fuelwood consumption per household is not different between the villages suggests that the other uses of fuelwood such as water heating and space heating may in fact account for more of the household consumption than previously thought.

The actual household demand for thermal energy and therefore fuelwood remains inelastic despite high population pressures and therefore resource shortages. This may be attributed to the multi-use nature of fuelwood and the limited ability of these rural households to make effective use of offered alternatives, such as electricity due to financial constraints (Arnold *et al* 2006; Gundimeda and Kohlin, 2008; White *et al* 1997; Williams and Shackleton, 2002).

Poverty is linked to environmental degradation and is inextricably linked to the use and the unsustainability of fuelwood use across rural landscapes (Geist and Lambin, 2002; Mataya *et al* 2002). The undervaluation of woodland ecosystem services and benefits by these rural communities is associated with poverty (Geist and Lambin, 2002) and unsustainable, resource-poor agricultural practices. This is manifest by over-cultivation leading to over-expansion, to sustain productivity and overharvesting of woodland products leading to woodland deforestation and degradation (Grainger, 1999; Mlambo and Huizig, 2004) and inevitably the development of fuelwood crises (Arnold *et al* 2006, Davidar *et al* 2010).

4.4.2 Adjusting to fuelwood shortages

As fuelwood becomes increasingly scarce, rural households alter their fuelwood collection and use patterns (Dewees, 1989; Brouwer *et al* 1997); beginning with increasing collection effort through more frequent trips and longer collection times, investing more household resources through labour for collecting and the development of fuelwood markets (Abbott, 1999; Brouwer *et al* 1997; Madubansi and Shackleton, 2006). In our study reduced access to wood may also have forced households to become more economical in their use of fuelwood and incorporate more of the available alternative as is economically permissible for them (Brouwer *et al* 1997; Madubansi and Shackleton, 2007). Inspite of the immediate changes in fuelwood collection strategies, the opportunity costs (time) borne by households in Welverdiend and those in Athol are not significantly different. Rather the difference is seen in the total household investment cost as more income is diverted to pay for fuelwood and electricity tariffs where the household is connected. It is therefore ironic that the provision of electricity, which should result in an improvement in wellbeing by freeing household time for other pursuits such as education and income-generating activities, becomes a financial cost. In comparison, time is the one resource that rural households have in abundance and the value of the time saved, although significant, is heavily discounted income and employment opportunities are severely limited. The continued use of fuelwood even when households have electricity represents a tangible saving, allowing money to be invested into other household necessities- such as food and clothing, rather than invested into energy security.

Gupta and Kohlin (2006) cite convenience, price and reliability of supply as being the major attributes influencing the transition of rural households to electricity from traditional woody biomass energy sources which corresponds with answers given by respondents in this study. Despite the observed reduction in average household fuelwood consumption by those households with access to electricity, they still use fuelwood and in some instances even purchase fuelwood rather than transition completely (Welverdiend). In Zimbabwe, where fuelwood reserves are limiting, in the presence of electricity, most households still use fuelwood for the major thermal demands such as cooking and space heating but electricity may take up the load for other requirements such as boiling water for tea and bathing (Vermeulen *et al* 2000), as the technologies are relatively inexpensive and may be easily attainable (Howells *et al* 2003; White *et al* 1997; Williams and Shackleton, 2002). However, the relatively high cost of electricity through monthly tariffs and the need to purchase and maintain such technologies such as stoves, poses a deterrent to financially strained rural households from fully transitioning (Williams and Shackleton, 2002). Thus alternatives to collected fuelwood are used to supplement what can be harvested at relatively lower economic costs (time or cash) to the households, even when the communal woodlands have become so degraded as to be unable to provide adequate fuelwood. This reiterates the notion that wood harvesting is widespread because of it is often free, relatively cheap and easily available in comparison to alternatives such as electricity (Williams and Shackleton 2002). This comparative "abundance makes it reliable" (Davidar *et al* 2010) and sustains rural demand.

4.4.3 Fuelwood markets sustaining household demand

The development of fuelwood markets has been linked to communal woodland degradation and deforestation (Davidar *et al* 2010; Shackleton *et al* 2005; Twine *et al* 2003). Fuelwood markets develop in response to fuelwood scarcity and market responses convert a subsistence activity into an income-generating livelihood strategy (Shackleton *et al* 2006; Twine *et al* 2003). The motivations behind wood extraction for these two activities are different; fuelwood for a commercial market is removed on a larger scale as harvesters often use motor-vehicles and harvest larger, live trees (Shackleton *et al* 2006), often using mechanised equipment such as chainsaws, firewood traders remove larger quantities than subsistence harvesters would to satisfy the market, these resources are not replaced and consistent extraction pressure makes this system unsustainable (Davidar *et al* 2010). This fuelwood is often not harvested from the depleted woodlands but from villages where fuelwood is more abundant (Twine *et al* 2003) thus placing unaccounted-for pressure on other villages woodland resource bases and increasing the likelihood of fuelwood shortages in these areas (exacerbating the syndrome of woodland degradation and fuelwood shortage). Once fuelwood becomes a livelihood option, it becomes increasingly difficult to change the extraction cycle and successfully introduce alternatives (energy and livelihood options) (Davidar *et al* 2010).

4.4.4 Social mobilisation in response to fuelwood scarcity

An unexpected significant result that was not initially part of the investigation into how communities cope with resource shortages came to light in the course of this study. The residents of Welverdiend have coped with this resource shortage in a twofold manner, the creation of a fuelwood market, (this will be discussed further below) and the out ward expansion of their woodland resource base to an adjacent parcel of land named Morgenzon that was lying "unused" (Rex Mnisi, deputy chairman of the Welverdiend Community Development Forum, pers. comm.). This parcel of land was designated as a nature reserve but the animals were removed to the neighbouring Kruger National Park in the late 1980s in response to a severe drought. Consequently Welverdiend residents also listed Morgenzon as a fuelwood collection site along with areas within the original village boundaries. This social response to fuelwood scarcity implies that woodland area availability is the defining factor in determining the sustainability of rural fuelwood use. The issue is that if indeed such processes are occurring concurrently in the many rural villages lying in close proximity to each other within this area, there is potential for great conflict once the land as a resource is no longer available for outward communal expansion. Similar behaviour has been observed in Athol during times of drought when residents expand their cattle grazing and resource extraction area to include the communal land of neighbouring Utah (Figure.   1; Giannecchini *et al* 2007). In this region, the next most available land areas are conservation areas- large tracts of land upon which woodland resources are in abundance due to careful and deliberate management. “Poaching” occurs when local residents are prevented from active involvement in the sustainable use of essential, available resources that they consider vital to securing their livelihoods (Misana *et al* 1996). There is a need for proactive response by conservation managers and practitioners to put in place mechanisms to allow local communities to partake of managed, sustainable harvesting activities for fuelwood or other resources (thatching, medicine etc) before conflicts arise in the future (Williams and Shackleton, 2002).

4.5 Conclusion

The sustainability of traditional resource harvesting practices in rural areas has been eroded over time due to growing populations, market pressures, land and resource shortages and weakening traditional land management institutions and mechanisms (Davidar *et al* 2010; Geist and Lambin, 2002; Kaschula *et al* 2003). With respect to rural energy provision in South Africa, this means that irrespective of seemingly sustainable household fuelwood consumption profiles in the present, the aggregate impacts of the households as a collective community, will in the future result in fuelwood shortage. Without interventions to break the poverty cycles to increase the likelihood of households converting to energy alternatives or landcover-use conversion cycles to mitigate future resource shortages, it is difficult to pronounce the continued dependence of rural households on fuelwood in South Africa as being sustainable. It is this double jeopardy of financial poverty and resource depletion that must be managed in the future with respect to encouraging sustainable fuelwood use in rural

South Africa. The multiple factors involved denote a more holistic, trans-disciplinary approach to solving this issue as it is not primarily an issue of managing fuelwood extraction and consumption behaviours.

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Chapter 5

5. Fuelling demand: the household socio-economic characteristics driving fuelwood use in rural South Africa

Abstract

Energy security is central to the achievement of sustainable development and the reduction of poverty. The national government of South Africa has instituted an intensive national electrification programme since 1994 as part of its poverty alleviation efforts. This included electrification of rural households in areas where fuelwood is the primary source of energy for everyday domestic needs. However, rural households tend not to make the complete transition to electricity from fuelwood, continuing to use fuelwood for thermal energy-intensive tasks such as cooking. This study aimed to investigate the main socio-economic determinants of household fuelwood consumption in rural areas in South Africa in relation to whether or not electricity is available. Household size was a common determinant of fuelwood consumption, although in households with electricity the number of women in the household was very influential in reducing the total amount of fuelwood the household used each year. Households that were aware of a problem with fuelwood availability used less fuelwood. Those households claiming that there was always enough fuelwood, also tended to buy more fuelwood in comparison to others indicating the active role played by fuelwood markets in maintaining high levels of fuelwood consumption. However the awareness of fuelwood scarcity was only an influential factor in households with electricity. Household population was the most influential factor in determining the likelihood of a household switching to exclusive use of electricity.

5.1 Introduction

Rural household access to energy is simultaneously an important driver of economic development to improve societal welfare (Leach 1988, Davis 1998) and a cause of environmental degradation (Trossero 2002, Grainger 1999). In Sub Saharan Africa, national policy interventions to secure rural household access to energy have been geared towards widespread electrification programmes to provide more efficient energy alternatives (Karekezi 2002). These programmes have met with limited success as, even when households are given access to electricity, they will still use fuelwood to meet their main thermal energy requirements (Hosier & Dowd 1987, Vermeulen *et al* 2000) and incorporate electricity into their energy mix rather than transitioning to exclusive use of electricity (Davis 1998, Thom 1998) even under conditions of increasing fuelwood scarcity (Madubansi & Shackleton 2006). Under such conditions, energy poverty and environmental degradation are inextricably linked (Perreira *et al* 2010).

5.1.1 The South African context

The South African context of fuelwood consumption is unique because this nation has developed economy characteristics, set firmly against a developing nation backdrop (Madubansi & Shackleton 2006). It has the highest energy use on the continent and the largest carbon footprint but also has the greatest capability to implement domestic energy policies that can be used as flagship on the African continent, to other emerging economies. Despite the relatively well-developed economy, over 70% of all rural South African households are still directly dependant on fuelwood for cooking and water heating (Eberhard 1992). This situation exists in spite of the implementation of an accelerated national electrification programme by the South African government between 1994 and 1999. The main objective of which was to improve the access of rural and low-income urban households to electricity and redress the past imbalances of Apartheid-era government policies (Davidson & Winkler 2006). Rather than switch to exclusive use of electricity to meet their thermal energy needs (primarily cooking), up to 95% of these households (Madubansi & Shackleton 2006) continued using fuelwood and incorporated electricity as an option into their household energy-source mix (Davis 1998, Thom 1998). Poor infrastructure, lack of access to the appropriate appliances and technologies and the prohibitive costs of electricity tariffs were identified as the main culprits behind the continued dependence on fuelwood (Gaunt 2002, Williams & Shackleton 2002), highlighting the challenges faced by low income households in using electricity effectively.

5.1.2 Governing the fate of fuelwood use in the rural areas of South Africa

Studies have focused on the social and environmental implications of the continued rural household dependence on fuelwood in South Africa (von Maltitz & Scholes 1995, Banks *et al* 1996, Madubansi &Shackleton 2007) but few have considered ensuring the security of fuelwood reserves in the future as a pathway to social and economic development. This is reflected in the absence of national policies in South Africa that explicitly deal with managing the current and future rural household demand for fuelwood. This may be because fuelwood use is associated with poverty, and a policy for rural fuelwood use may be politically unpopular as it could be interpreted as keeping people in poverty. However, it ignores the reality on the ground where access to modern energy sources does not mean that all rural households cease their dependency on fuelwood. The dependence on fuelwood is not likely to decline over the medium term but energy policy papers do not explicitly deal with this issue. The White Paper on Energy Policy (DME, 1998), Renewable Energy Policy (DME, 2003) and the Integrated Energy Plan (DME, 2003) all fail to explicitly account and plan for the continued dependence of the majority of the South African (rural) populace on fuelwood. The White Paper on Energy (DME 1998) recognises a need to mitigate environmental effects of fuelwood dependency stating that targeted interventions in rural areas to manage woodlands for the benefit of rural households is required but do not further elucidate as to how this is to be managed or who in the Government framework is responsible for this. Instead the White Paper on Energy (DME 1998) introduces the concept of "Rural Energisation" as part of an integrated framework that includes rural electrification to address rural energy consumer needs but does not go into detail about the concept itself and what it entails. Nissing & von Blottnitz (2010) present the first comprehensive definition of rural energisation, describing it as a transitional energy delivery process, incorporating the specific, unique energy requirements of a target group and tailored to provide a variety of accessible and affordable alternative energy services (including but not limited to electricity) thus enabling sustainable development and targeted poverty alleviation. To date there is no information within the public domain detailing the incorporation of this concept into South African domestic energy policy. One of the possible benefits of providing a variety of competitive, affordable and accessible energy-source options to rural households in South Africa would be a possible reduction in fuelwood demand and household consumption (Prassad 1996).

5.1.3 The future of rural household fuelwood use

According to the Integrated Energy Plan (DME 2003) “renewable energy formed about 8% of the South Africa’s primary energy supply mostly in the form of firewood in the rural areas” but then goes on to state that there is little accurate and reliable data available. Vermeulen *et al* (2000) challenge the notion that solving the issue of energy security in developing countries is a simple matter of providing households with electricity, even if it is subsidised, as in South Africa where households are provided with a monthly Free Basic Allowance of 50 kWh (ESKOM 2011). Because of the decentralised nature of most rural wood-energy systems and inadequate national capabilities, energy and forestry statistics seldom include the same level of information about fuelwood consumption as about other conventional sources such as electricity (Trossero 2002). The main consequence of which is that “incomplete and misleading energy stats result in distorted national, regional and international energy forecasting scenarios (Trossero 2002). There is therefore a need for accurate information detailing rural household fuelwood consumption characteristics and the household drivers that influence the continued reliance on fuelwood over electricity, where it is available. Understanding the determinants of household fuelwood demand and therefore extraction rates provides important information about the potential impacts of continued fuelwood use on the woodland resources (MacKenzie & Weaver 1986). Furthermore, identifying the determinants of rural fuelwood use informs predictions about the likelihood of households continuing to use fuelwood if competitive, alternative energy-sources are made available to them (MacKenzie & Weaver 1986, Hosier & Dowd 1987).

Bushbuckridge was declared an Integrated Sustainable Rural Development Programme (ISRDP) node by the national government (RSA, 2000). This classified the area as a high-priority area for government intervention, to create conditions that encourage economic development and infrastructural investment in order to relieve rampant poverty (RSA, 2000). Bushbuckridge is one of 13 ISRDP nodes that were identified nationwide. This makes the assessment of the drivers of the continued demand for fuelwood, where there has been such high investment in rural electrification/energisation (DME 1998) highly significant. Assessing the efficacy of such interventions in improving human wellbeing and stimulating socio-economic development in this node could well influence the structure of similar programmes in the future (Harmse 2010).

The aim of this study is to investigate the main determinants of fuelwood consumption in two rural villages in South Africa. Specifically this study addressed the following questions:

1. Does the perception of fuelwood availability by household members influence rural fuelwood consumption?
2. What are the household characteristics that influence fuelwood consumption and do they differ depending on whether the household has access to electricity?
3. How do these household characteristics affect the likelihood of a household switching to exclusive use of electricity if electricity is available?

Earlier studies projecting fuelwood consumption into the future linked fuelwood consumption (demand) directly to per capita consumption and aggregated this to the national (or village) level by multiplying that value by the total human population of each country (Shackleton 1994, Banks *et al* 1996, Arnold *et al* 2006). This was projected into the future by linking it to forecasted human population growth rates (Dewees 1989, Arnold et al 2003, Arnold et al 2006). However, per capita fuelwood demand is "not a static variable" (Dewees 1989) and is tempered by household socio-economic characteristics (Arabatzis & Malesios 2011) such as income, household demographic composition and available labour (Dovie et al 2004)**.** Furthermore, prior static per capita estimation methods may have led to over-estimation of fuelwood consumption over time, as increasing household income and the availability and access to alternative energy-sources moderate fuelwood consumption (Madubansi & Shackleton 2006). However decisions over the use of fuelwood consumption, over available alternative and the amounts of wood burnt are made at the household level (Brouwer *et al* 1997). Therefore in this study models were fitted at the household level and then in order to factor out differences in household sizes models were also fitted based on per capita fuelwood consumption (Twine *et al* 2003a).

5.2 Methods

5.2.1 Study Sites

For this paper we focused on two villages, Athol (24° 43’S 31° 21’E) and Welverdiend (24° 36’S 31° 07’E), located in the Bushbuckridge Municipality of Mpumalanga Province (Figure 5.5.2). Bushbuckridge consists of two former “homeland” areas and still bears the legacy of Apartheid policies in its socio-economic condition: high unemployment, low monetary income, poor economic and infrastructural development and densely populated human settlements, ranging an average of 150-350 people km^{-2} in this specific area (Pollard *et al* 1998**,** Thornton 2002). As a result, many households depend substantially on remittances from household migrant labour and government-issued social grants. Some households cultivate small gardens to supplement household food supplies but agricultural productivity is generally low (Shackleton *et al* 2002). Land tenure type is communal, whereby traditional leaders have authority to apportion local land-use rights and therefore determine land-use patterns (Shackleton *et al* 2002). Communities are heavily dependent on the communal woodlands for a wide variety of non-timber forest products such as wild fruit and vegetable, medicinal plants and fuelwood.

5.2.2 Biophysical characteristics

The terrain consists of gently undulating hills with an average altitude of 600m a.s.l. (Shackleton *et al* 1994a). Soils are underlain by granitic gneiss with local intrusions of gabbro. The vegetation is classified under Mixed Lowveld Bushveld, dominated by trees and shrubs of *Combretum*, *Terminalia* and *Acacia* genera (van Rooyen & Bredenkamp 1996). The climate in the region is described as hot and humid in summer and mild and dry in winter, with mean daily maxima of 30 ºC and 23 ºC respectively. Rain is received mainly in the form of convectional thunderstorms between October and May, with drought experienced approximately once a decade.

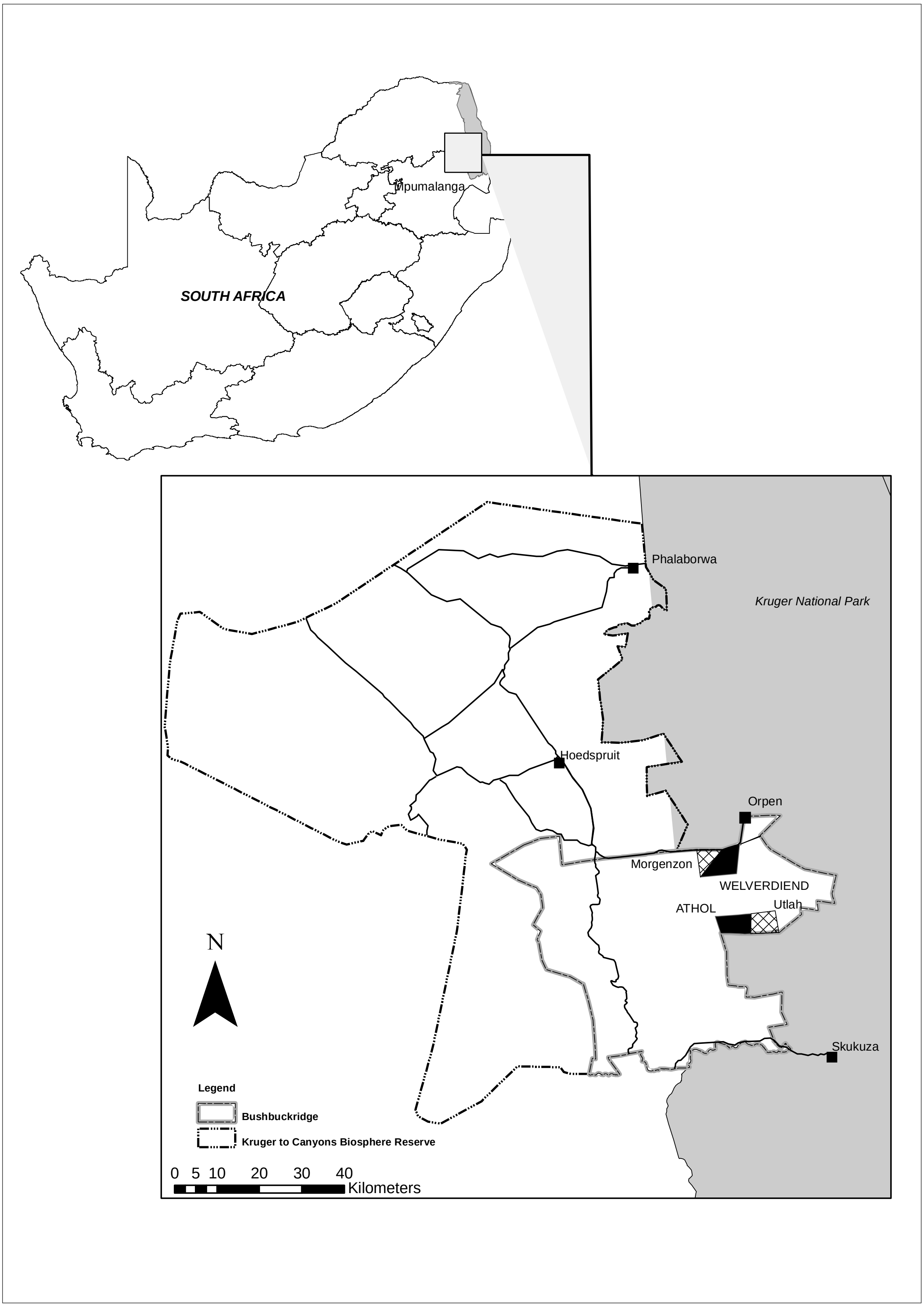


Figure 5.5.1 The locations of Welverdiend and Athol villages, relative to the Kruger to Canyons Biosphere Reserve and the Kruger National Park in South Africa. Solid polygons show the extent of the original farm boundaries of each settlement. Hatched polygons are the spatial extent of Morgenzon, adjacent to Welverdiend and Utlah adjacent to Athol

5.2.3 Data collection

Questionnaires administered at the household level were used for data collection in both Athol and Welverdiend (Appendix 1). These household surveys were carried out between May and August 2009. Aerial photographs of each settlement were used to randomly select participating households. A combined structured and semi-structured questionnaire was administered in the local language xiTsonga at each selected household with the assistance of local translators. A total of 125 households in Athol and 139 households in Welverdiend were interviewed (irregularities by one of the enumerators in Welverdiend reduced this to a sample of 120) representing a sampling intensity of 24% and 8 % after irregular questionnaires were removed. The person or persons most responsible for daily household tasks involving household income expenditure and energy consumption was preferentially interviewed, generally this was carried out by the adult women in the household, except where there were none present.

The first part of the questionnaire provided information on household characteristic and income streams through formal and informal employment, remittances and government social grants. Subsequent sections in the questionnaire gave information on the use of electricity and other alternatives, cooking habits as well as a section detailing household fuelwood collection and consumption patterns. Daily household fuelwood consumption was established by asking the household member responsible for cooking to set aside a fuelwood pile that would typically be used in a day in each season. This bundle was weighed using a spring balance giving a value to the nearest 0.1 kg unless there was no fuelwood available to be measured. This was aggregated to give annual fuelwood consumption in kg annum^{-1} for each household that used fuelwood.

5.2.4 Statistical methods

Matsika *et al* (In Review, Chapter 4) addressed household adaptations to different levels of fuelwood availability by comparing fuelwood consumption and collection patterns between Athol and Welverdiend. Village was not a significant factor in determining how much wood was used by a household annually but access to electricity was. Households that had electricity used significantly less fuelwood in comparison to households that did not have electricity. Furthermore there were no significant differences in household size, composition (the number of men, women and children in the average household) and annual income between the villages. Based on these factors, the datasets for both villages were pooled and then divided according to whether the household had access to electricity (n=164) or not (n=47). Unless otherwise stated, all analyses were carried out on these two data subsets.

Data were captured in Microsoft Excel (MS Excel 2007) and analysed using R. 2.13.0. (R Development Core Team, 2011) All continuous variables were tested for normality using the Kolmogorov- Smirnov test; variables that failed the tests for normality were log-transformed to normalise the variances and the use of multivariate linear regressions to determine relationships   Various regressions were fitted to the data using the Linear Modelling function, lm(), in the Faraway package (Faraway, 2011) and the General Linear Modelling function in the package "car" (Fox & Weisberg 2011).

5.2.4.1 Testing for the effect of household perception of fuelwood availability on consumption

Respondents were asked what their perception of fuelwood availability was. Since the respondents were predominantly the adult women who are primarily responsible for cooking and fuelwood collection, this was taken as a proxy for perception of that household and is hereafter referred to as "perception". The responses fell into three options:

- Always enough fuelwood
- Sometimes difficult to get enough fuelwood
- Never enough fuelwood

The values for total annual household fuelwood consumption were log-transformed and a Two-Way Analysis of Variance (ANOVA) was carried out to test for the significance of village, perception and the interaction between them, if any, on annual household fuelwood consumption. Thereafter ANOVA were carried out to test the significance of household perception on annual fuelwood consumption separately in households that had electricity compared to those that did not. Summary statistics of household characteristics according to perception were calculated and tested for significance using ANOVA.

5.2.4.2 The influence of household characteristics on fuelwood consumption

Multivariate linear regression analyses using Ordinary Least Squares were used to model fuelwood consumption as a means to quantify the relationships amongst the influential drivers of demand and compare them between the two data sub-groups, divided according to access to electricity. Two levels of fuelwood consumption were considered and models were fitted to describe both household and per capita consumption patterns. Per capita fuelwood consumption values were derived by dividing the household consumption value by the number of permanent residents living in the house. AICc values cannot be compared between models with different response variables (Burnham &Anderson 2002), so the R-squared values of the "best" models were used to compare the difference in goodness of fit between models that were fitted using the household consumption values against those that used per capita consumption values.

5.2.4.3 Multivariate linear regression: Explanatory variable selection.

Following the framework suggested by Burnham & Anderson (2002) the selection of the explanatory variables was based on previous theoretical and empirical studies of fuelwood consumption patterns in Bushbuckridge (Banks et al, 1996, Dovie et al, 2004) and field observations in the study area (Matsika *et al*, In Review, Chapter 2). A subset of 4 categories of household characteristics was selected from the questionnaire data (Table 5.1). Dovie *et al* (2004) derived a model of household fuelwood consumption from empirical data collected in a village in Bushbuckridge close to the two case-study villages. They linked household fuelwood consumption to the number of adult women living in the household but included non-significant terms for the number of men and children in the household as they may have contributed to understanding the general household fuelwood consumption behaviour. They also found a positive correlation between household size and annual fuelwood consumption. Household resource-use characteristics are also influenced by gender and household composition (Dovie *et al* 2005). However household size (the total number of people living in the household) and the household composition (individual terms for the number of men, women and children) were collinearly related therefore these terms could not be included in the same candidate model. Thus either household size (HHOLD) or the household composition (HHOLDDEM) were fitted in a model (Table 5.1) and were tested to see the difference of the influence of each parameter on annual fuelwood consumption. The influence of the number of women in the household on fuelwood consumption was of particular interest because this also effectively represents the available labour for fuelwood collection (Dovie *et al* 2004) and served the double purpose of testing the influence of labour availability (using the adult female population as a proxy) on household fuelwood consumption.

Income has been identified as a major determinant of household energy choice and consumption patterns (Hosier & Dowd 1987, Leach & Mearns 1988, Campbell *et al* 2003). With increasing income households tend to transition from complete dependence on fuelwood towards a wider mix of more sophisticated alternatives such as kerosene and electricity (Hosier and Dowd 1987, Campbell *et al* 2003, Ouedraogo *et al* 2006). Household income constraints have also been linked to the inability of rural households to transition to exclusive electricity use as households are unable to afford the monthly tariffs or purchase and maintain electrical appliances, such as stoves and fridges (White *et al* 1997, Williams & Shackleton 2002).

Household perception or awareness of fuelwood scarcity or rather ease of availability may have an influence on the amount of fuelwood consumed as well as the choice of energy source used (Hosier & Dowd 1987, Arabatzis & Malesios 2011). Based on the influence of perception, the response to this question was converted to a binomial yes/no response- based on whether the household was always able to collect enough fuelwood or not. The latter category consisted of both households that stated that sometimes they were unable to get enough fuelwood and those that stated they were never able to collect sufficient fuelwood for their needs. However, the question of perception of fuelwood availability was only asked to households that use fuelwood and therefore the influence of this parameter on the choice to use electricity could not be tested.

The cost of energy-source to the household has an influence on household choice and consumption (Hosier & Dowd 1987). The cost of fuelwood use to the household is manifest through the amount of time spent by the household in fuelwood collection activities each year, at the opportunity cost of other potential income-generating activities (Dovie *et al* 2005). A term for fuelwood collection time (TIME, Table 5.1) was included in the modelling process to test the influence of collection time on fuelwood consumption where households have access to electricity.

Table 5.1 Definition of variables used to model household and per capita fuelwood consumption in the case study villages.

Variable group	Variable Definition
Response variables	
Fuelwood only	Annual household fuelwood use (kg)
	Annual per capita fuelwood use (kg)
Fuelwood & Electricity	Annual household fuelwood use (kg)
	Annual per capita fuelwood use (kg)
Explanatory variables	
HHOLD	Household size (permanent residents)
HHOLDDEM	MEN (number of men)
	WOMEN (number of women)
	CHILDREN (number of children
INCOME	Annual Income (R/ Annum)
PERCEPTION	Household perception of fuelwood availability, Dummy indicating "Always enough" (1,0)
TIME	Time spent collecting fuelwood (Hours/ Annum)

5.2.5 Model selection using the Akaike Information Criteria (AICc)

Based on the variables that were included in the analysis there were a total of 24 possible configurations or candidate models. The same sets of models (combination of household variables) were tested on households that had electricity and those that did not at both household and per capita consumption levels. The Akaike Information Criterion corrected for small sample bias (AICc) was used to select the best models (Equation 1). The AICc is used to select a model that fits well and is parsimonious. The addition of parameters increases the value of the AIC thus in a given set of candidate models, that with the lowest AIC value is specified as the "best" (Burnham & Anderson 2002). The models were ranked from best to worst based on the value of the AICc. Delta AICc (Equation 2) values were used to select a set of confidence models from the 24 candidate models. To be included into the confidence set of models the Delta AICc had to be ≤ 2. Generally a Δ_i that is <2 from the minimum indicates that the model is not competitive with the selected best and can be excluded from consideration (Burnham & Anderson 2002). Although Burnham & Anderson (2002) state that models with Delta AICc up to 10 are plausible, the smaller this value is the better, consequently although it is not inflexible, they suggest a cut-off of Delta AICc ≤ 2 if meaningful inferences are to be made from the candidate models (Burnham & Anderson 2002, pp 48). The Akaike weights (Equation 3) were calculated and used to measure the strength of the evidence of the models relative to each other, since the Akaike weights of all the candidate models should sum to 1(Burnham & Anderson, 2002). Akaike weights are used to show the relative likelihood of each of the models within the candidate set being the best model; the closer the Akaike Weight is to 1 the higher the odds are that it is the best (Burnham & Anderson 2002). Akaike weights were then used to calculate evidence ratios (Equation 4), comparing the other models within the confidence set to the “best” model. Evidence ratios compare to what extent one model is better than another. If more than one model was included in the confidence set of models, then model averaging or multi-modal inference techniques were applied to base the inference on the entire set of candidate models as suggested by Burnham & Anderson (2002). Weighted average estimates were calculated for the parameter coefficients of each model within the confidence set based on the Akaike weight, calculated for only the models within the confidence set. These were summed for each parameter to give a weighted average estimate which was used in the Weighted Average Model. This methodology increases precision and reduces bias and strengthens the inferences that can be made based on the model (Burnham & Anderson 2002).

$$AICc = -2(loglikelihood) + 2K + \frac{2K(K+1)}{(n-K-1)} \qquad \text{Equation [1]}$$

Where n is the sample size and K is the number of parameters.

$$\Delta_i = AICc_i - min\ AICc \qquad \text{Equation [2]}$$

$$w_i \quad = \quad \frac{\exp\,(-\frac{1}{2}\Delta_i)}{\sum_r^R \exp\,(-\frac{1}{2}\Delta_r} \qquad \text{Equation [3]}$$

5.2.5.1 Household characteristics that influence energy-use choice for cooking

Fuelwood is used primarily for cooking in rural households (Hosier and Dowd 1987) as such I investigated the likelihood of the household switching to the use of electricity rather than fuelwood for cooking. This analysis was carried out using data from all households that had access to electricity and divided according to the energy source they used for cooking. Logistic regression analysis was used to model the likelihood of a household using only electricity for all cooking purposes rather than fuelwood. Logistic regression is the most appropriate methodology for fitting models with the binary response variable (Hosmer & Lemeshow 2000), that is, use/no-use of electricity for cooking as used in this analysis. The logistic regression models the logit or the log-odds ratio of an event occurring based on the combination of independent variables. The odds of the modelled outcome can be calculated by taking the exponential of the logit value. The model parameter coefficients can also be transformed back to odds ratio values and measure the contribution of each explanatory variable to the response variable (Agresti 1996). Models using Maximum Likelihood non-linear estimates were fitted to the data. In this way the influence of household size, annual household income, and the household expenditure on electricity and fuelwood collection time on the likelihood of household making use of electricity only for cooking were tested, individually and in relation to each other (Agresti 1996). The best, most parsimonious model was selected using the AICc and Delta AICc values as described in the previous section. This model was used to determine which household variables influence transition to electricity use as well as to estimate the probability of a household that has access to electricity switching to the use of electricity for all of thermal energy requirements.

5.2.5.3 Logistic regression: Explanatory variable selection

The choice of household variables to include in the logistic regression (Table 5.2) was informed by the results of the linear regression for the determinants of annual household fuelwood consumption in households with electricity. Household Annual Income was one of the variables tested for influence on the likelihood of a household switching to electricity (Table 5.2). Households with higher incomes have more energy options available to them since they are often in a better position to access the appropriate appliance and pay the connection fees and monthly tariffs (Davis 1995, Davis 1998, Thom 2000). Since energy choice is influenced by the cost to the household of a given energy-source (Hosier & Dowd 1987, Brouwer *et al* 1997, Dovie *et al* 2005) both the annual cost of electricity (COST) to the household and the time spent collecting fuelwood were included as potential explanatory variables in this analysis. The influence of each explanatory variable, alone and in conjunction with other variables was tested and the best model was selected using the AICc.

Table 5.2 Definition of variables included in the logistic regression analysis. Only households that had electricity were included in this analysis.

Variable Definition	Variable definition	Frequency
Response variables		
Electricity only	Yes	31
	No	132
	Total sample size	N = 163
Explanatory variables		
HHOLD	Household size (permanent residents)	163
COST	cost of electricity	
TIME	time collecting fuelwood	163
INCOME	Annual Income	163

Because the question concerning perception was only asked to households that use fuelwood, it could not be included as a variable in the logistic modelling process. As such atest for association between perception of scarcity and the use of electricity could not be carried out; it was only incorporated into the modelling process for households that use fuelwood.

5.3 Results

5.3.1 Characteristic of households according to energy-mix used

Of the households that had access to electricity in the household only 14% had transitioned to exclusive use of electricity for all their domestic energy needs. These households tended to be smaller in size (fewer people permanently living in the house) and there was no discernible difference in annual income when compared to households that used fuelwood for cooking, or even households that did not have access to electricity (Table 5.3). As expected, these households spent significantly more money on electricity (DF=185, t=2.88, $p<0.05$) each year, spending approximately R395 or 33% more than households using fuelwood to cook (Table 5.3). Of the households that used fuelwood to cook, households that had electricity used less fuelwood and also tended to buy less fuelwood each year (Table 5.3.), possibly highlighting the use of electricity as a back-up or secondary choice fuel for cooking.

Table 5.3 Household characteristics of the pooled village datasets sub-divided according to the main fuel that is used to cook. The first level of sub-division gives information about whether electricity is available in the house and the next level shows which fuel is primarily used to cook. Tests for significance were carried out on the log-transformed values; significant differences are highlighted in bold and asterisk.

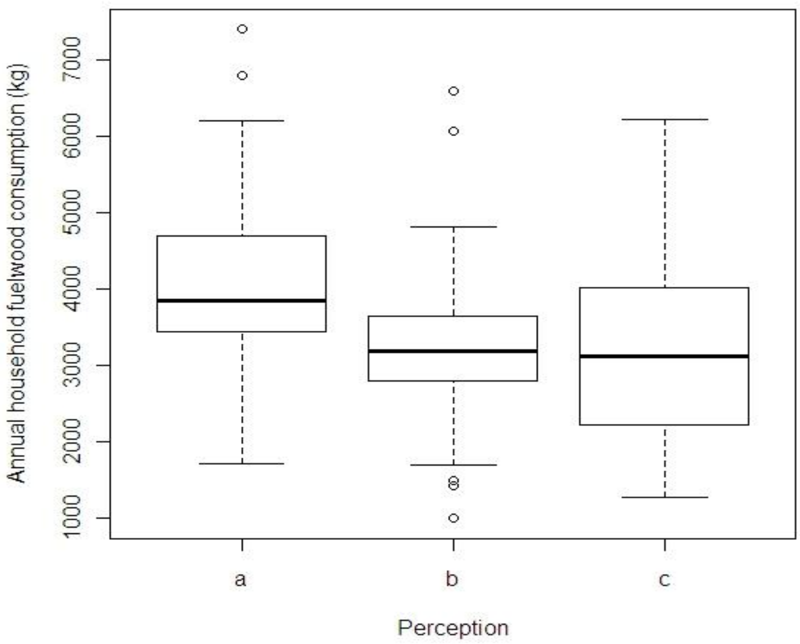
	Electricity available		**No Electricity**	
Main fuel used to cook	**Electricity (N=27)**	**Fuelwood (N=164)**	**Fuelwood (N=47)**	
Variable	**Mean±SE**	**Mean±SE**	**Mean±SE**	**Significance**
Household size	4*± 0.28	5.5± 0.18	4.89± 0.33	**0.0037**
Adult females	1.5± 0.15	1.8± 0.08	1.7± 0.16	NS
Adult males	1± 0.16	1.4± 0.10	1.2± 0.15	NS
Children	1.7± 0.17	2.2± 0.11	2.5± 0.21	NS
Annual Income (R/ annum)	22017.78± 2726.65	21414.75± 1408.52	20146.53± 2112.04	NS
Electricity cost (R/annum)	1182.22± 130.44	786.75± 51.87		**<0.0001**
Total bought fuelwood (kg/ annum)		748.28± 184.77	1019.39± 250.05	NS

5.3.3 Perception of fuelwood abundance (Awareness of scarcity)

The 2-Way ANOVA of Village and User perception was significant overall ($F_{7, 164}$= 3.28, p<0.01) and confirmed that Village had no significant effect on annual household fuelwood consumption (F=2.49, p>0.05) but that the household perception of fuelwood availability did (F_3=4.74, p<0.01) and there was no significant interaction (F_3=0.71, p>0.05). Therefore I proceeded to test the effect of user perception on household fuelwood consumption on the data divided by access to electricity.

User perception of fuelwood availability had a significant effect on household fuelwood consumption (kg annum^{-1}) only if the household had access to electricity (F_2=9.74, p<0.0001). Households that replied in the affirmative, that they were always able to collect enough, used significantly more fuelwood annually than those households that indicated that they had a problem with availability, that is, sometimes they couldn't get enough fuelwood or they could never collect enough fuelwood (Figure 5.5.2a, Table 5.6,). Perception of fuelwood availability did not have an effect on the amount of fuelwood used annually for household that did not have electricity (Figure 5.5.2b, F_2=0.77, p>0.05).

a)



b)

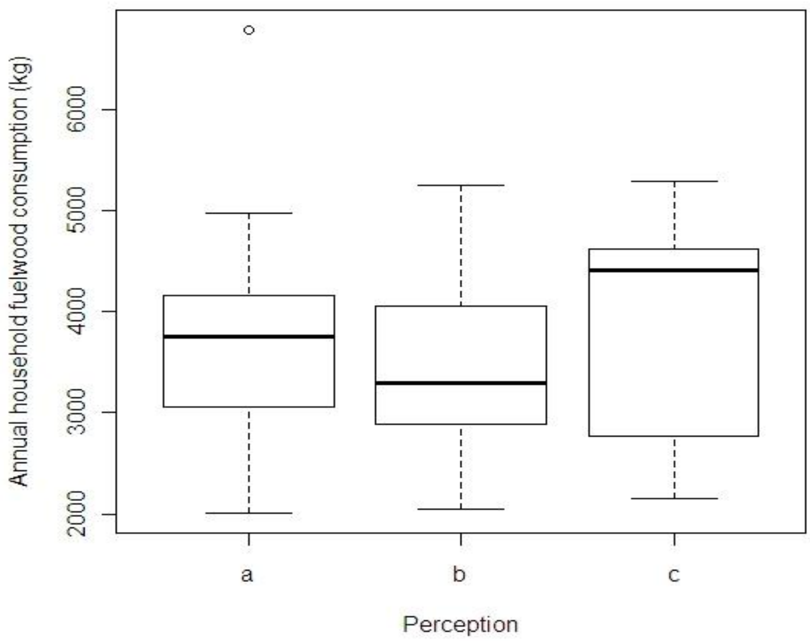


Figure 5.2 The effect of household perception of fuelwood availability on the amount of fuelwood used per annum compared for households a) with access to electricity and b) without access to electricity. Perception of availability (x-axis) was divided into 3 categories: a- always enough fuelwood; b-sometimes difficult to collect enough; c- never enough fuelwood from the communal woodlands.

Households that indicated no problem with fuelwood availability had the lowest average annual income and spent significantly less time collecting fuelwood than households in the other categories (Table 5.4). The values of the average amount of bought fuelwood suggest that these households tend to buy almost double the amount of fuelwood in comparison to the other households, although this figure is highly variable and not statistically significantly different amongst the three categories of perception. There is no association between the education level of the household head and the perception of fuelwood availability (Chi-Square X^2=0.936, DF=4, p>0.05).

Table 5.4 Household characteristics relative to household perception of fuelwood availability for the pooled dataset of households with access to electricity. Significant differences in household characteristics are presented in bold. Tukey HSD tests were carried out to identify the source of the differences; values followed by the same letter do not differ significantly.

Household characteristics	Always enough (a) ± std.err (n=37)	Sometimes insufficient fuelwood (b) ± std.err (n=82)	Never enough (c) ± std.err (n= 20)	DF	F	Significance
Fuelwood used (kg/annum)	**4163*±211 (a)**	**3216±99 (b)**	**3245±294 (b)**	**2**	**6.14**	**0.0002**
Electricity cost (R/annum)	960±132 (a)	617±144 (a)	762±124 (a)	2	1.88	NS
Household size	6±0	5±0	5±0	2	0.22	NS
Annual Income (R/annum)	**15012*±1879 (a)**	**21527±1586 (b)**	**19832±3100 (b)**	**2**	**9.02**	**0.0132**
Collecting time (hours/annum)	**239*±45 (a)**	**352±20 (b)**	**334±49 (b)**	**2**	**16.54**	**<0.0001**
Bought fuelwood (kg/annum)	1034±341 (a) (n=26)	574±228 (a) (n=16)	567±287 (a) (n=15)	2	0.77	NS

Since there were no statistical differences between Groups b and c (Table 5.4), they were merged into a single group as households perceiving insufficient fuelwood availability. Thus for the regressions there were two categories of household perception of fuelwood availability: “always enough” and “not enough”. These were coded into the dummy variable PERCEPTION (Table 5.1) where 1 indicated “always enough” and 0 indicated “not enough”.

5.3.4 Model selection based on the selected explanatory variables

5.3.4.1 No Electricity: Household fuelwood consumption

The combination of household composition (men, women and children) and annual income were the primary determinants of fuelwood consumption. Based on the Delta AICc values model 1 and model 2 (Table 5.5) were the best models for this dataset; Model 1, which had the lowest AICc values is almost 3 times more likely to be the best fit model than Model 2. Models that consisted of only either men or women as explanatory factors did not receive substantial statistical support. The models of children and income whilst plausible (Delta AICc <10) were considerably less robust than Model 1, which was 10 and 100 times more likely than the CHILDREN only and INCOME only models respectively. Models which incorporated the time spent by each household collecting fuelwood were plausible (Model 3, Model 7) with Delta AIC between 3 and 7 (Burnham & Anderson 2002) but based on the Akaike weights there was little support to choose these Models over the top two. Household perception of fuelwood availability did not seem to influence fuelwood consumption at all; generally there was no statistical support for models incorporating perception as an explanatory variable, with less than 0.1% chance (from Akaike weights) and Delta AICc >10.

The results of the model averaging between Model 1 and Model 2 are presented in Table 5.8, giving the weighted average parameter estimates for the "best" model of household fuelwood consumption. All of the parameters in the final model, (MEN, WOMEN, CHILDREN, INCOME) were found to be significant predictors of fuelwood consumption (R^2 =0.3819). The coefficients of the final model suggest that the number of women and income have a negative impact on household fuelwood consumption. Whilst the numbers of both men and children in the household increase the amount of wood used, the number of children in the household has a greater influence (Table 5.6).

5.3.4.2 No Electricity: Per capita fuelwood consumption

Per capita consumption was most influenced by household size in conjunction with annual income (Model 1, Table 5.7), rather than the actual household composition as was the case with the models at household level (Table 5.6). Models incorporating household composition or the individual variables as MEN, WOMEN or CHILDREN were not supported, generally these models had Delta AICc >35 (Table 5.7). Models incorporating perception did not have substantial statistical support either- although Model 5, which incorporates perception, falls within the Delta AICc < 10 category and would be considered plausible (Burnham & Anderson 2002) but it has a 1% chance of being the best model (Akaike weight) and Model 1 is 40 times more likely to be the best explicatory model than Model 5 (Evidence ratio, Table 5.9).

The confidence set of models (Model 1 and Model 2) incorporated these two factors and the results of the model averaging are presented in Table 5.5.10. All parameters in the weighted model of per capita consumption were significant, with an R^2=0.7873.

Table 5.5. Annual household fuelwood consumption as a function of household characteristics in households without access to electricity, variables were standardised. Best model indicated by AICc value

#	Model parameters	LL	K	AICc	Delta AICc	Akaike weights	Evidence ratio
1	HHOLDDEM+INCOME	**5.49**	**5**	**3.35**	**0**	**0.55**	**1**
2	HHOLDDEM	**3.11**	**4**	**5.41**	**2.06**	**0.20**	**2.80**
3	HHOLDDEM+INCOME+TIME	**5.64**	**6**	**5.92**	**2.57**	**0.15**	**3.61**
4	CHILDREN	-0.73	2	8.06	4.71	0.05	10.54
5	HHOLD+INCOME	-0.78	3	10.61	7.26	0.01	
6	HHOLD	-2.46	2	11.54	8.19	0.01	
7	HHOLD+INCOME+TIME	-0.72	4	13.06	9.71	0.00	
8	INCOME	-3.33	2	13.27	9.92	0.00	
9	WOMEN	-3.48	2	13.57	10.22	0.00	
10	HHOLD+TIME	-2.34	3	13.74	10.39	0.00	
11	PERCEPTION*HHOLD+PERCEPTION*INCOME	3.11	9	13.78	10.43	0.00	
12	MEN	-3.77	2	14.15	10.8	0.00	
13	TIME	-4.09	2	14.79	11.44	0.00	
14	PERCEPTION	-3.68	3	16.42	13.07	0.00	
15	PERCEPTION*HHOLD+PERCEPTION*INCOME+ PERCEPTION*TIME	4.43	12	17.142	13.792	0.00	
16	HHOLDDEM+TIME	3.4	5	18.76	15.41	0.00	
17	PERCEPTION*HHOLD	-0.97	6	19.14	15.79	0.00	
18	PERCEPTION*INCOME	-1.26	6	19.73	16.38	0.00	
19	PERCEPTION*TIME	-1.55	6	20.29	16.94	0.00	
20	PERCEPTION*INCOME+PERCEPTION*TIME	1.25	9	24.38	21.03	0.00	
21	PERCEPTION*HHOLD+PERCEPTION*TIME	0.55	9	25.78	22.43	0.00	
22	PERCEPTION*HHOLDDEM+PERCEPTION*INCOME	12.84	15	27.24	23.89	0.00	
23	PERCEPTION*HHOLDDEM	5.48	12	27.59	24.24	0.00	
24	PERCEPTION*MEN+PERCEPTION*CHILDREN+ PERCEPTION*WOMEN+PERCEPTION*INCOME+ PERCEPTION*TIME	13.38	18	44.28	40.93	0.00	

Table 5.6 Annual household fuelwood consumption; model averaging of parameter estimates for households without access to electricity

PARAMETER	MODEL1	MODEL2	WEIGHTED AVE
INTERCEPT	8.2368	7.9864	**8.1709**
MEN	0.1845	0.1693	**0.1805**
WOMEN	-0.1935	-0.2217	**-0.2009**
CHILDREN	0.2523	0.2353	**0.2478**
INCOME	-0.0333		**-0.0333**

Table 5.7 Per Capita consumption modelled as a function of household characteristics of households without access to electricity.

#	Model parameters	LL	K	AICc	Delta AICc	Akaike weights	Evidence ratio
1	HHOLD+INCOME	**-2.33**	**3**	**13.71**	**0**	**0.42**	**1**
2	HHOLD	**-3.83**	**2**	**14.27**	**0.56**	**0.31**	**1.32**
3	HHOLD+INCOME+TIME	**-2.15**	**4**	**15.93**	**2.22**	**0.14**	**3.03**
4	HHOLD+TIME	**-3.58**	**3**	**16.21**	**2.5**	**0.12**	**3.49**
5	PERCEPTION*HHOLD	-1.95	6	21.1	7.39	0.01	40.25
6	PERCEPTION*HHOLD+PERCEPTION*INCOME	2.11	9	22.67	8.96	0.00	
7	PERCEPTION*HHOLD+PERCEPTION*TIME	-0.59	9	28.06	14.35	0.00	
8	PERCEPTION*HHOLD+PERCEPTION*INCOME+ PERCEPTION*TIME	3.11	12	32.34	18.63	0.00	
9	HHOLDDEM	-18.97	4	49.56	35.85	0.00	
10	HHOLDDEM+INCOME**	-18.77	5	51.87	38.16	0.00	
11	HHOLDDEM+TIME	-18.84	5	52.01	38.3	0.00	
12	HHOLDDEM+INCOME+TIME	-18.67	6	54.55	40.84	0.00	
13	WOMEN	-24.02	2	54.66	40.95	0.00	
14	PERCEPTION*HHOLDDEM	-9.49	12	57.53	43.82	0.00	
15	PERCEPTION*HHOLDDEM+ PERCEPTION*INCOME	-8.89	15	70.72	57.01	0.00	
16	CHILDREN	-32.77	2	72.17	58.46	0.00	
17	INCOME	-34.63	2	75.87	62.16	0.00	
18	MEN	-34.73	2	76.08	62.37	0.00	
19	TIME	-35.11	2	76.83	63.12	0.00	
20	PERCEPTION	-34.12	3	77.28	63.57	0.00	
21	PERCEPTION*INCOME	-31.01	6	79.22	65.51	0.00	
22	PERCEPTION*MEN+PERCEPTION*CHILDREN+ PERCEPTION*WOMEN+PERCEPTION*INCOME+ PERCEPTION*TIME	-5.29	18	81.62	67.91	0.00	
23	PERCEPTION*TIME	-33.83	6	84.87	71.16	0.00	
24	PERCEPTION*INCOME+PERCEPTION*TIME	-30.61	9	88.21	74.5	0.00	

Table 5.8 Per capita model, averaging parameter estimates for households without access to electrity

PARAMETER	MODEL1	MODEL2	WEIGHTED AVE
INTERCEPT	8.8584	8.6028	**8.748**
HHOLD	-1.101	-1.1178	**-1.108**
INCOME	-0.031		**-0.031**

5.3.4.3 Electricity available: Household fuelwood consumption

Household fuelwood consumption is influenced by the number of people residing in the house, the amount of time spent collecting fuelwood and the household perception of fuelwood availability. The best model incorporated all three variables (Model 1, Table 5.9) and the next best variable incorporated all except for the influence of collection time. Perception of fuelwood availability has a strong influence on annual household fuelwood consumption since the subset of plausible models (Delta AICc<10) consisted only of models that incorporated a term for household perception (including the PERCEPTION only model, Model 7, Table 5.9). Although models incorporating income fall within the subset of plausible models (Models 4, 5, 10), the evidence ratios suggest that they are unlikely to be the best explanatory models relative to Model 1 (Table 5.9). In direct contrast to households without electricity, models incorporating the actual household composition (numbers of men, women and children) as explanatory variables do not have any statistical support.

Models 1 and 2 (Table 5.9) were selected as the best models. The parameters and coefficients of the weighted average model are shown in Table 5.10. Perception of fuelwood availability had the strongest influence on household fuelwood consumption compared to the other variables. As shown previously, the perception that the household was always able to get enough fuelwood was associated with higher annual fuelwood consumption (Figure 5.5.2, Table 5.10) but these households also spent less time collecting fuelwood per annum (Table 5.3, Table 5.10). This model had a low R-squared value (R^2=0.2173), reflecting the high variability in household fuelwood use and the complexity of the factors that influence this value. The low R-squared value may also indicate that there is some other variable that was not assessed that influences fuelwood consumption. This variable may be a range of wood (species) preferences and wood (species) harvesting behaviours based on individuals' knowledge of differences in wood density, differences in smoke density and wood chemistry.

Table 5.9 Annual household fuelwood consumption modelled as a function of various household socio-economic characteristics in households with electricity

#	Model parameters	LL	K	AICc	Delta AICc	Akaike weights	Evidence ratios
1	PERCEPTION*HHOLD+PERCEPTION*TIME	**-31.52**	**6**	**77.05**	**0**	**0.51**	1.00
2	PERCEPTION*HHOLD	**-34.24**	**4**	**78.92**	**1.87**	**0.20**	2.55
3	PERCEPTION*TIME	**-34.42**	**4**	**79.31**	**2.26**	**0.16**	3.10
4	PERCEPTION*HHOLD+PERCEPTION*INCOME	**-34.18**	**5**	**82.36**	**5.31**	**0.04**	14.22
5	PERCEPTION*HHOLD+PERCEPTION*INCOME+ PERCEPTION*TIME	**-31.5**	**8**	**82.4**	**5.35**	**0.03**	14.51
6	PERCEPTION	**-38.21**	**2**	**82.59**	**5.54**	**0.03**	15.96
7	PERCEPTION*INCOME+PERCEPTION*TIME	**-34.36**	**6**	**83.57**	**6.52**	**0.02**	26.05
8	PERCEPTION*INCOME	**-37.93**	**4**	**86.32**	**9.27**	**0.00**	103.03
9	HHOLD	**-41.85**	**2**	**89.89**	**12.84**	**0.00**	
10	PERCEPTION*HHOLDDEM	**-35.69**	**8**	**90.76**	**13.71**	**0.00**	
11	HHOLD+TIME	**-41.46**	**3**	**91.23**	**14.18**	**0.00**	
12	HHOLD+INCOME	**-41.56**	**3**	**91.42**	**14.37**	**0.00**	
13	PERCEPTION*MEN+PERCEPTION*CHILDREN+ PERCEPTION*WOMEN+PERCEPTION*INCOME +PERCEPTION*TIME	**-31.62**	**12**	**92.15**	**15.1**	**0.00**	
14	HHOLD+INCOME+TIME	**-41.15**	**4**	**92.75**	**15.7**	**0.00**	
15	PERCEPTION*HHOLDDEM+PERCEPTION*INCOME	**-34.91**	**10**	**93.9**	**16.85**	**0.00**	
16	TIME	**-46.28**	**2**	**98.72**	**21.67**	**0.00**	
18	MEN	**-46.67**	**2**	**99.5**	**22.45**	**0.00**	
19	WOMEN	**-45.38**	**2**	**99.57**	**22.52**	**0.00**	
20	CHILDREN	**-46.7**	**2**	**99.57**	**22.52**	**0.00**	
21	INCOME	**-46.75**	**2**	**99.68**	**22.63**	**0.00**	
22	HHOLDDEM (men, women, children)	**-44.97**	**4**	**100.39**	**23.34**	**0.00**	
23	HHOLDDEM+TIME	**-44.65**	**5**	**101.93**	**24.88**	**0.00**	
24	HHOLDDEM+INCOME**	**-44.91**	**5**	**102.45**	**25.4**	**0.00**	
25	HHOLDDEM+INCOME+TIME	**-44.58**	**6**	**104.01**	**26.96**	**0.00**	

Table 5.10 Parameter estimates for the linear models for households with electricity

PARAMETER	MODEL1	MODEL2	WEIGHTED AVE
Intercept	7.4141	7.7378	**7.516**
HHOLD	0.1181	0.1639	**0.131**
TIME	0.0718		**0.0718**
PERCEPTION	0.4323	0.086	**0.4166**
PERCEPTIONA*HHOLD	0.1235	0.0827	**0.112**
PERCEPTIONA*TIME	-0.0754		**-0.0754**

5.3.4.4 Electricity available: Per capita fuelwood consumption

Three models were selected as the best models from amongst the candidate models (Models 1-3, Table 5.11), the parameters that were supported as influencing per capita consumption were household size, annual income and time spent collecting fuelwood. The importance of household perception is clear at the per capita level, with all plausible models containing a term that incorporates perception. There is support for the influence of income, in conjunction with other household characteristics, on per capita fuelwood consumption (Models 2-4, Table 5.11). Models incorporating household characteristics were not supported in this dataset.

The weighted-average model parameters were significant with moderate explanatory power, R^2=0.5892, (Table 5.12). Household size has a strong negative influence on per capita consumption; as do the interaction terms between household perception and collection time, as well as household perception and income. Household perception of fuelwood availability has a strong positive (additive) influence on per capita annual fuelwood consumption; this trend was also observed in the model fitted for household consumption.

Table 5.11 Per Capita fuelwood consumption as a function of various household socio-economic characteristics in households where electricity is available

Model parameters	LL	K	AICc	Delta AICc	Akaike weights	Evidence ratios
PERCEPTION*HHOLD	-41.46	4	93.65	0	0.37	1.00
PERCEPTION*HHOLD+PERCEPTION*INCOME	-39.45	6	93.76	0.11	0.35	1.06
PERCEPTION*HHOLD+PERCEPTION*TIME	-40.25	6	95.35	1.7	0.16	2.34
PERCEPTION*HHOLD+PERCEPTION*INCOME +PERCEPTION*TIME	-38.34	8	96.08	2.43	0.11	3.37
HHOLDDEM+INCOME+TIME	-44.58	7	104.01	10.36	0.00	177.68
HHOLD	-49.31	2	104.8	11.15	0.00	263.75
HHOLD+TIME	-48.74	3	105.79	12.14	0.00	432.68
HHOLD+INCOME	-49.27	3	106.85	13.2	0.00	735.10
HHOLD+INCOME+TIME	-48.72	4	107.88	14.23	0.00	1230.28
PERCEPTION*HHOLDDEM	-67.16	9	153.72	60.07	0.00	
HHOLDDEM (men, women, children)	-73.16	4	156.76	63.11	0.00	
HHOLDDEM+INCOME**	-72.6	5	157.84	64.19	0.00	
PERCEPTION*HHOLDDEM+PERCEPTION*INCOME	-66.92	10	157.91	64.26	0.00	
HHOLDDEM+TIME	-72.02	6	158.89	65.24	0.00	
PERCEPTION*MEN+PERCEPTION*CHILDREN+ PERCEPTION*WOMEN+PERCEPTION*INCOME +PERCEPTION*TIME	-66.78	12	162.48	68.83	0.00	
WOMEN	-86.56	2	179.29	85.64	0.00	
MEN	-87.88	2	181.94	88.29	0.00	
CHILDREN	-99.15	2	204.48	110.83	0.00	
PERCEPTION	-99.88	2	205.94	112.29	0.00	
INCOME	-100.37	2	206.92	113.27	0.00	
TIME	-100.89	2	207.95	114.3	0.00	
PERCEPTION*TIME	-99.12	4	208.68	115.03	0.00	
PERCEPTION*INCOME	-99.44	4	209.33	115.68	0.00	
PERCEPTION*INCOME+PERCEPTION*TIME	-98.88	6	212.62	118.97	0.00	

Table 5.12 Model averaging for per capita consumption models for households with electricity

PARAMETER	MODEL 1	MODEL 2	MODEL 3	WEIGHTED AVE
Intercept	8.148	7.7041	7.906	**7.9274**
HHOLD	-0.9632	-0.9957	-0.9974	**-0.9823**
TIME			0.0537	**0.0537**
PERCEPTION	0.2261	0.6671	0.4825	**0.4481**
INCOME		0.0522		**0.052**
PERCEPTIONA*HHOLD	0.0158	0.0477	0.0469	**0.034**
PERCEPTIONA*TIME			-0.0559	**-0.0559**
PERCEPTION*INCOME		-0.0517		**-0.0517**

5.3.4.5 The influence of household characteristics on the likelihood of transition to exclusive use of electricity

The global model incorporating all of the household variables was selected as the best model amongst all the candidate models. Model 1 (Table 5.13) had the lowest AICc as well as the highest Akaike weight. The evidence ratio showed that Model 1 is 11 times more likely to be the best model than the next best contender, Model 2.

Table 5.13 Candidate models of the likelihood of a household continuing to use fuelwood to cook when electricity is available in the home.

Model parameters	LL	K	AICc	Delta AICc	Akaike weights	Evidence ratio
HHOLD+INCOME+TIME+COST	-34.15	5	80.85	0	0.87	1.00
HHOLD+INCOME+TIME	-37.65	4	85.68	4.83	0.08	11.19
HHOLD+TIME	-39.15	3	86.54	5.69	0.05	17.20
TIME	-44.75	2	95.64	14.79	0.00	1627.82
INCOME+TIME	-44.32	3	96.9	16.05	0.00	
HHOLD+COST+INCOME	-55.66	4	121.69	40.84	0.00	
HHOLD+COST	-56.92	3	122.09	41.24	0.00	
COST	-63.12	2	132.39	51.54	0.00	
COST+INCOME	-62.84	3	133.94	53.09	0.00	
HHOLD+INCOME	-63.84	3	135.94	55.09	0.00	
HHOLD	-64.93	2	136	55.15	0.00	
INCOME	-69.74	2	145.64	64.79	0.00	

The test of the full model against the intercept only model was significant indicating that the parameters and coefficients included in the model are significant (Likelihood ratio test, X^2=101.72, DF=4, p<0.0001). The Hosmer-Lemeshow Goodness of Fit test indicated that the model predictions do not differ significantly from the observed values (X^2=1.817, DF=8, p<0.05).The prediction success of the model was 97.1% for households switching to electricity from using fuelwood to cook. Household investment into obtaining energy, either in the guise of collection time of fuelwood, or money spent to pay for electricity had weak effects on the likelihood of a household switching completely to electricity (Table 5.14). The Wald criterion showed that all parameters except for annual income had a significant impact on the odds of a household using electricity only (Table 5.14). The number of people living in the household had the strongest effect on the likelihood of a household making the transition (Table 5.14), generally the more people resident in the household, the less likely a household was to switch to using electricity only. Holding all other parameters constant, each additional person residing in the house reduces the likelihood of this transition by 48% (Table 5.14). This may explain the weak negative influence of fuelwood collection time on the odds of the household using electricity only, presumably the more people there are residing within a house, the greater the thermal energy demand for cooking, resulting in slight more time being invested in collecting fuelwood. Contrary to expectation, household income did not have any influence on the likelihood of a household transitioning to electricity for cooking (Table 5.14), the confidence interval of the odds ratio for this parameter includes 1, meaning that the odds of a household transitioning are even and a higher or lower household income had no bearing on this behaviour.

Table 5.14 The parameters included in the logistic regression based on the AICc parameter selection process. The binary dependent variable was the likelihood of a household switching from fuelwood to electricity (modelled for only households that had electricity). Coefficients for each parameter included in the GLM with the lowest AICc. Odds-ratio and Confidence Intervals indicate which parameters contribute to the likelihood of a household switching to electricity.

PARAMETER	PARAMETER ESTIMATE	ODDS RATIO	CONFIDENCE INTERVAL (95%)	
			Lower limit	Upper limit
INTERCEPT	1.9831	-	-	-
HHOLD**	**-0.6625**	**0.516**	**0.332**	**0.801**
INCOME	0.000039	1	1	1
TIME*	-0.0186	0.982	0.974	0.989
COST*	0.00108	1.001	1	1.002

5.4 Discussion

Rural households tend to make use of a variety of energy-sources to meet their basic energy needs (Hosier & Dowd 1987, Vermeulen *et al* 2000, Madubansi & Shackleton 2006). However, households within this study area tend to use primarily either fuelwood or electricity for cooking purposes, as the primary or secondary fuels and although other options such as gas and kerosene (paraffin) are available, they are used as back-up energy options to combat erratic electricity or fuelwood availability (Madubansi & Shackleton 2006) (Figure 5.3). Only four households (2%) of the households included in the survey mentioned using those two fuels, and only as third choice fuels for cooking and boiling water. As such their use was not considered or assessed and the discussion focuses on the use of either fuelwood or electricity as the first-order energy options in the case-study villages. This paper sought to establish links between household characteristics and fuelwood consumption, however any discussion of the results must be tempered by the acknowledgement of the difficulty of establishing, quantifying and proving such cause and effect pathways. It may be that there are other variables that were not included in this analysis, such variables may include the influence of species preference on fuelwood collection times, where harvesters may invest more time to access the preferred species, such as demonstrated by Nantel et al (1996). Other variables that may influence fuelwood consumption behaviour include education levels of the women collecting fuelwood or the health and age of the fuelwood collectors as these may influence consumption and collecting behaviour.

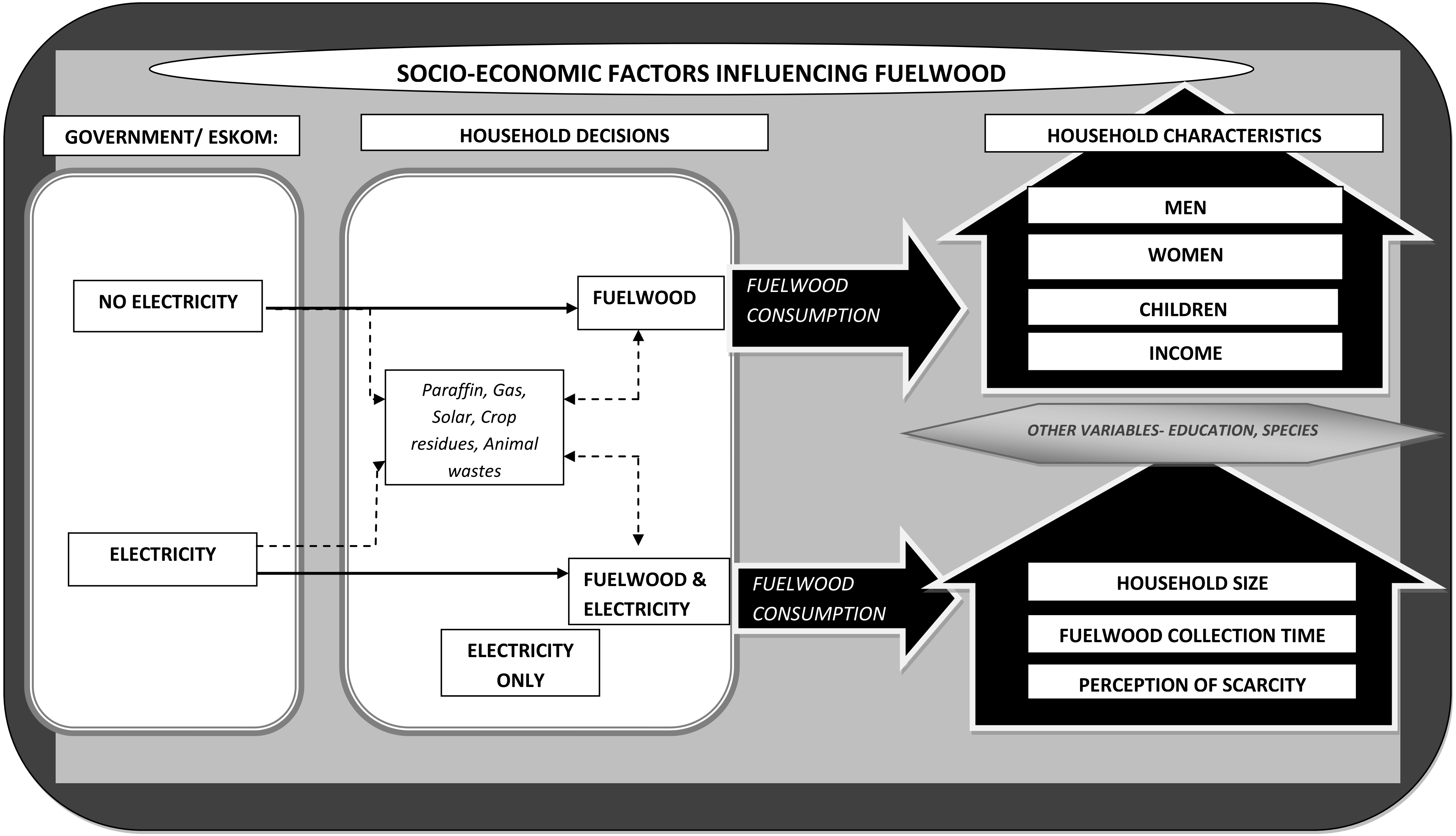

SOCIO-ECONOMIC FACTORS INFLUENCING FUELWOOD
GOVERNMENT/ ESKOM:
HOUSEHOLD DECISIONS
HOUSEHOLD CHARACTERISTICS
NO ELECTRICITY
FUELWOOD
FUELWOOD CONSUMPTION
MEN
WOMEN
CHILDREN
INCOME
Paraffin, Gas, Solar, Crop residues, Animal wastes
OTHER VARIABLES- EDUCATION, SPECIES
ELECTRICITY
FUELWOOD & ELECTRICITY
FUELWOOD CONSUMPTION
HOUSEHOLD SIZE
FUELWOOD COLLECTION TIME
PERCEPTION OF SCARCITY
ELECTRICITY ONLY

Figure 5.3 Flow diagram of the energy choices that are available to households within the study area that influence whether they use electricity or fuelwood or a combination of both and the household characteristics which influence the annual fuelwood consumption (1,2).

5.4.1 Drivers of rural household fuelwood consumption

The flow diagram (Figure 5.5.3) provides a visualisation of how the variables that were measured influence fuelwood consumption. Households have limited control of whether they have access to electricity or not, the largest hurdle being the provision of adequate infrastructure by the national government through ESKOM, it s implementing agency. Households do however have to pay a connection fee once that that infrastructure is in place, and in such situations, the available disposable household income becomes the first hurdle to whether households will choose electricity or continue using fuelwood (Davis 1995, Davis 1998, Thom 1998). Thereafter households that have access to electricity consume far less fuelwood than those that have no other energy alternative (Chapter 4). The socio-economic household characteristics that drive the different fuelwood consumption patterns differ between households based on access to electricity (Figure 5.5.2). Household population size is a clear driving factor behind the total amount of fuelwood used by a household in a year whether electricity is available or not. The difference is that in electrified households the driver is the total number of people living in the house, and in fact, holding all other variables constant, the likelihood of a household switching to electricity decreased by 48% with each additional person living within the home. This is consistent with other studies that showed that larger households use more fuelwood and are more likely to remain primarily dependent on fuelwood for cooking and other thermal energy-intensive needs, even where other energy sources are available (Hosier & Dowd 1987, Davis 1995, Ouedraogo 2011, Arabatzis & Malesios 2011). In contrast, the exact composition (number of men, women and children) was more important in houses without electricity (Figure 5.5.3).

Davis (1995) and Madubansi & Shackleton (2007) suggest that household composition and the social structures and power relations within the household influence household fuel choice and patterns. In this study, a negative relationship between the number of women in the household and the amount of fuelwood used was found. This may imply that the presence of women results in more economical (less) use of fuelwood. This contrasts with Dovie *et al* (2004) who were able to trace a positive relationship between total annual fuelwood consumption and the number of women within the house. Fuelwood collection and cooking activities are predominantly the responsibility of adult women within the household, meaning that they make the every-day household decisions on how much fuelwood is used daily. These decisions are influenced by the cost of fuelwood which is borne by the household as time spent collecting fuelwood (Baland *et* al 2009). On average, households within the study area are spending increasing time per collection trip as fuelwood is becoming increasingly scarce (Madubansi & Shackleton 2007). As the time spent in fuelwood collection increases, it is possible that women will change use patterns and make more economical use of the limited fuelwood resources (Davis 1995), particularly where there are no other options.

The question for future consideration is whether household size is indeed the main driver of fuelwood consumption within the study area, or whether it is an indicator of other social conditions characteristics of the region.

Based on the AICc values and the method used to choose the best linear regression of household characteristics driving annual fuelwood consumption annual income (R/annum) was only supported as a good predictor of consumption in households that did not have electricity. This is surprising because the influence of income on fuelwood consumption is linked to the "Energy Ladder" hypothesis, that increasing income increases the energy options available to a household and households will tend to lessen their dependence on woody biomass to more sophisticated "cleaner" energy alternatives (Hosier & Dowd 1987, Leach & Mearns 1988). In reality, households tend to make use of a wider variety of energy-sources with increasing income (Masera *et al* 2000, Campbell *et al* 2003, Madubansi & Shackleton 2006). It is interesting that the relationship between income and fuelwood consumption was not as strongly supported during model selection, in households with electricity as an alternative to fuelwood. Linear regression models including income were supported somewhat although based on the interpretation of the Akaike weights and Evidence Ratios they were not as plausible (Burnham & Anderson 2002).

Household income has consistently been identified as a major determinant of household fuel-switching in other studies (Hosier & Dowd 1987, MacKenzie &Weaver 1987, Davis 1998, Thom 1998, Ouedrago 2006, Arabatzis & Malesios 2011). The costs of electrical appliances and monthly tariffs to the household have been cited in the literature as significant stumbling blocks to low-income households, preventing them from depending on electricity exclusively

(Thom 1998, Davis 1998, Williams & Shackleton 2002, Nissing & von Blottnitz). Thus the expectation was that the likelihood of households using electricity for cooking instead of fuelwood would increase with income but the results of the logistic regression modelling suggested that income was not a significant determinant (the odds were even). Furthermore, the logistic regression testing the influence on income alone on the likelihood of households with electricity switching from cooking with fuelwood was over 1000 times less supported as a sole determinant than the best selected model (Table 5.5.16). However the apparent non-significance of household income in this study does not necessarily indicate that it is not an important factor as this has consistently been revealed in other studies in this area (Madubansi & Shackleton 2006).Rather, this result may reflect the overarching socio-economic context that the study was carried out in, where low employment levels translated to generally low household incomes with little variation between households using either fuelwood or electricity for cooking. Of the households that have electricity, there was no significant difference in mean annual household income between households that use electricity to cook and those that choose to use fuelwood. Furthermore, of this group, the ranges in income were similar for households using electricity to cook (R2, 8880-R54, 120 per annum) and those using fuelwood (R2, 880 –R76, 560 per annum), meaning there was no clear differentiation between them in this respect. Generally, 75% of the households in each subset earned less than R28, 000 per annum (R27, 360 ± R2, 469 for households cooking with electricity and R26, 760 ± R1, 167 for households cooking with fuelwood). This may partially explain why income as a factor has no effect on the likelihood of a household using electricity rather than fuelwood. However this may also point to the need for a larger sample size in future studies in this regard, stratified for greater representation of households that choose to cook with electricity. There is definitely a need for more studies investigating fuel-switching in relation to electricity over fuelwood. This is particularly relevant in the context of Bushbuckridge as a flagship ISRDP node where there has been special Government intervention and investment into improving household access to electricity and the supporting infrastructural networks (BLM, 2010).

5.4.2 Perception of fuelwood abundance as a determinant of household fuelwood use

Few studies have incorporated how households perceive fuelwood abundance or availability (through ease of access) as determinants of fuelwood use. Hosier & Dowd (1987) found that households perceiving fuelwood to be easy to access tended not to switch away from fuelwood use to other energy alternatives as they felt fuelwood was abundant. In this study, the perception of fuelwood abundance only had an influence on consumption rates where an alternative option, electricity, was available. In this group, the perception that fuelwood was scarce or difficult to collect, was linked to lower annual fuelwood consumption rates. The tendency of households that did not perceive fuelwood to be difficult to collect to use more fuelwood was consistent with behaviour described by Hosier & Dowd (1987); where wood is generally perceived to be in abundance, households will not change or lessen their consumption patterns. However, whilst making the household consumption of fuelwood more economical, the perception that fuelwood was difficult to collect resulted in these households spending more time collecting fuelwood per annum, a commonly cited household response to scarcity (Brouwer *et al* 1997, Abbott & Homewood 1999, Madubansi & Shackleton 2007). The perception that there was no problem with fuelwood availability is possibly being supported at the household level by the thriving fuelwood trade industry in the study area (Twine *et al* 2003). These households purchased almost twice as much fuelwood as households that indicated difficulty in getting enough fuelwood, indicating that their perception and higher consumption rates were being maintained because of the ease of access to purchased fuelwood. This behaviour is not linked to higher household income as this was also the lowest income group (Table 5.5.3). The role of the fuelwood trade industry is an important factor in assessing the sustainability of continued household fuelwood use; yet there is little information about the sources of purchased fuelwood or harvesting behaviour of fuelwood traders (Twine *et al* 2003). Households indicated that they were unaware of the source of the fuelwood they purchased, as in most cases the vendors were from neighbouring villages- the *modus operandi* being that one placed an order to a trader via a phone-call and the delivery was made directly to the home, in some instances fuelwood could be bought directly from the home of traders within the village. This has broader-scale implications, with respect to the source of the fuelwood. If the purchased fuelwood is harvested from "else-where" this indicates an externalisation of the costs of fuelwood use and an artificial reprieve from the effects of fuelwood scarcity within the immediate village environment. If the source is from within the village communal woodlands then this adds pressure to the fuelwood reserves. Furthermore this decreases the effectiveness of energy policy interventions that promote a move away from the use of fuelwood because this trade is now a livelihood strategy, providing an essential stream of income (Barbier *et al* 2010).

Perceptions of fuelwood abundance or ease of collection had no effect on consumption rates in households that were wholly dependent on fuelwood.   The difference in the effect of perception on fuelwood consumption indicates the potential role in lessening the dependence on fuelwood in the future of ensuring households have access to viable energy-source options (Madubansi & Shackleton 2006). The factors influencing perception of scarcity should be investigated further in the future, the question being whether this is driven by an actual scarcity which drives reduced consumption or through awareness of the potential for excessive fuelwood consumption to create scarcity. Such information would contribute to the effectiveness of interventions to introduce alternative energy sources or encourage sustainable fuelwood use behaviours.

5.4.3 Household *versus* Per capita fuelwood consumption patterns

The linear regressions of fuelwood consumption were carried out on the subset of households that used fuelwood and split into those that have electricity and those that do not. It is evident that in both groups, fromthe negative coefficients in the per capita regressions, that larger households use fuelwood more efficiently per capita even as they use more fuelwood than smaller households. Furthermore using per capita consumption as the dependent variable vastly improved the fit of the models for predicting consumption of fuelwood (kg per capita per annum) in comparison to those modelling household consumption. This indicates that the high variability in household size, ranging from 1-14 permanent residents, has a powerful dampening effect on predicting fuelwood consumption and should always be controlled for by creating predictive models at per capita level (Twine *et al* 2003).

5.4.4 Planning for the future: rural energisation and sustainable fuelwood use in Bushbuckridge

The results of this study have direct input into the application of future rural "energisation" programmes in Bushbuckridge as a flag-ship ISRDP node. Household population size is the primary determinant of fuelwood consumption, determining consumption rates (amount used in kg per household per annum) as well as significantly decreasing the likelihood of households switching to electricity for cooking purposes. This may be linked to high thermal energy load that could be associated with cooking for a larger household populations and the high costs that would be associated with substituting free fuelwood with electricity to meet this need. Furthermore, the importance of environmental awareness or the perception of fuelwood availability has been shown to be a critical determinant of household fuelwood consumption patterns (Hosier & Dowd 1987). The role played by the fuelwood trade industry, in maintaining perceptions of high fuelwood abundance in Bushbuckridge should be further investigated. The subject is highly sensitive in this region. Livewood harvesting without permission from local traditional authorities is prohibited (Twine *et al* 2003); these social conditions resulted in fuelwood vendors in Welverdiend being very reluctant to participate in a survey on fuelwood collection patterns. However this information is critical if the medium to long-term sustainability of such rural domestic wood-energy systems is to be assessed. Therefore, successful energy interventions within this area should possibly focus on providing energy alternatives that can be easily substituted for fuelwood for cooking but do not necessarily require expensive or complicated technology or appliances (Nissing & von Blottnitz 2011) so as to remain economically competitive with fuelwood (Prassad 2006). Furthermore, more cognisance needs to be taken of household perceptions in introducing energy alternatives. The household perception that fuelwood is difficult to access resulted in lower consumption rates in comparison to the perception of abundance and Arabatzis & Malesios (2011) identified a similar trend in Greece. Perhaps a more holistic approach to managing the rural energisation process is required to promote household uptake of introduced alternatives. Such an approach should involve changing user perceptions of fuelwood abundance to encourage lower consumption rates; such awareness campaigns could be targeted at women, since they shape household decisions around fuelwood use and collection (Dovie *et al* 2005) and their presence within the household results in more economical use of the resource.

5.4.5 Household fuelwood consumption and environmental degradation

There is a need to forecast how rural fuelwood consumption rates will change in the future and to do this we need models that can be used to test the effectiveness of intervention policies. Woodland degradation as a result of livewood harvesting for fuelwood sets in once the resource becomes scarce- there is a need to be able to project future extraction needs- as a means to calculate the carrying capacity of those communal woodlands with respect to their ability to continue to provide fuelwood in the future. This environmental aspect has also developed new facets since the recognition of climate change as a global threat and the various international treaties such as the Kyoto Protocol that have since been declared and signed. For example, countries participating in the United Nations Reduced Emmissions from Deforestation and Forest Degradation programme, REDD, must be able to monitor and account for emissions from forest carbon stocks and one of the proposed methods builds upon the understanding of carbon up-take by forest (tree) growth and carbon release through anthropogenic activities such as timber and fuelwood harvesting and sub-canopy fires (Kohl *et al* 2009). Most carbon cycle studies in Africa leave out domestic emissions from wood-harvesting, particularly fuelwood (Williams et al 2007), yet deforestation and degradation are major sources of carbon release (Denman 2007) and fuelwood is by far the most commonplace forest/woodland product in developing countries (Kohl *et al* 2009). This may contribute to inaccurate underestimate of carbon sinks and sources (Williams *et al* 2007).

5.4.6 The on-going global fuelwood "problem"

Concerns about the continued dependence of rural households on fuelwood in Developing Countries revolved around the perceived social, development and environmental problems of future supply shortages linked to unsustainable fuelwood harvesting practices (Dewees 1989, Arnold *et al* 2003). Reviews of the initial forecasts of the Fuelwood Crisis showed that fuelwood harvesting resulted in woodland degradation rather than deforestation (Grainger 1999) and that the predicted national fuelwood shortages were not forthcoming, leading to reduced focus on this issue (Dewees 1989, Karekezi 2002). In reviewing this phenomenon that was the Fuelwood Crisis Arnold *et al* (2006) suggested that the marked "downgrading of both research and forestry interventions" may have been a mistake leading to the neglect of this important issue. This is apt, given that issues around rural energy security, social and economic concerns about fuelwood availability and the sustainability of rural wood-energy systems are still on the agendas of the governments of many countries on the African continent.

One of the main barriers to effective planning is the lack of reliable information about fuelwood demand and the socio-economic factors driving the use of fuelwood, even where households have access to alternative energy sources such as electricity, kerosene or gas (DME 2003, Karekezi 2002). These are important given the projections of continued dependence on fuelwood by rural domestic households in South Africa (Williams & Shackleton 2002). Putting this in context, information about household consumption rates and the factors that influence them is necessary from a policy development perspective to allow adequate planning with respect to securing rural energy access as part of the energisation process (Nissing & von Blottnitz). Questions have been raised around the effectiveness and the appropriateness of the national electrification programme as a means to ensure household energy security in low-income rural areas (Gaunt 2003). Broad-scale domestic electrification is not financially viable at the national level and as a means of improving well-being by improving access to energy it is biased against low-income households as its use and benefit is tied to using costly appliances that are often out of the financial reach of most rural households to purchase and maintain (Gaunt 2003 unpublished data, Davis 1998, Williams & Shackleton 2002, Madubansi & Shackleton 2006).

5.6 Conclusion

Without an extensive improvement in the local infrastructure and socio-economic conditions in much of rural South Africa, it is not likely that households will move away from using fuelwood as the main household energy-source. An alternative pathway to sustainable rural energy security in South Africa should be considered. The continuing dependence on fuelwood in rural areas needs to be explicitly acknowledged and planned for. Complementary to attempting to move households up the energy ladder through national electrification programmes, programme frameworks that incorporate the socio-ecological contexts and specific domestic energy needs of rural communities need to be developed.

Chapter 6

6. Synthesis

6.1 Introduction

This research was necessitated by the recognition that the marked global reduction in research and forestry interventions in response to changing views about the Fuelwood Crisis (Dewees 1989) may have been too extreme, leading to the overall neglect of this important livelihood and environmental issue (Arnold *et al* 2003). Over 30 years since the Fuelwood Problem was first described (Eckhom 1975) and the first forestry intervention programmes were created (FAO 1981), fuelwood remains the dominant source of domestic energy in rural Sub-Saharan Africa (MEA 2005). The dependence on fuelwood is expected to increase parallel to human growth into the intermediate future (Karekezi *et al* 2004) in spite of the provision of electricity, especially in South Africa. Lack of access to electricity and/or clean, reliable sources of energy, adequate for household needs, is a major impediment to achieving sustainable development and reaching the Millenium Development Goals in many developing countries in Sub-Saharan Africa (UNDP & WHO 2009). However, as a result of changing paradigms about the nature and severity of the Fuelwood Crisis over the years (de Montalambert & Clement 1983, Dewees 1989, von Maltitz & Scholes 1995, Arnold *et al* 2006) there have been sporadic national and global investments into research and forestry interventions about the sustainability of fuelwood-based rural energy system. This has created a situation where current and up-to-date information about current household fuelwood consumption patterns, socio-economic factors driving demand the physical availability of fuelwood from the rural woodland resource base is not available to enable adequate policy development and planning (Karekezi 2002, Shackleton *et al* 2007).

This study has contributed to the body of knowledge about fuelwood-based rural energy systems in South Africa (since charcoal is not widely used), specifically investigating the interactions between the two components of these coupled human-environment systems. A multi-disciplinary approach was used to meet the individual objectives, using diverse techniques to trace the developments of rural communal woodlands as primary fuelwood resource bases and household adaptations to changes in the biophysical aspects. The overall aim was to investigate the dynamics of fuelwood supply and demand, in space and time, around selected rural communities in a South African savanna woodland. The broad objectives of the research were split into three categories:

Changes in the fuelwood resource base:

1. Establish the woody biomass stock potential in the communal woodlands and evaluate model predictions made about the sustainability of fuelwood harvesting in the rural communities within the study area (addressed in Chapter 2)

2. Investigate the spatial dynamics of communal woodlands in the study area over time (1965-2009) (addressed in Chapter 3).

Human fuelwood use patterns according to fuelwood availability

3. Investigate the strategies employed by rural households to secure access to fuelwood where electricity is available (addressed in Chapter 4)
4. Investigate the main determinants of household fuelwood consumption characteristics (addressed in Chapter 5)

Sustainability considerations

5. Based on the outcomes of the research, create a conceptual framework to explore strategies for the sustainable utilisation of communal savanna rangelands as a continued source of fuelwood in the study area (addressed in Chapter 6).

Chapters 2 and 3 were concerned with quantifying changes in the fuelwood resource under the influence of human use in the study sites. The combined results show that woodland clearing is primarily driven by landcover conversion to make space for residential and agricultural lands as the villages have grown over time (Chapter 3). The knock-on effect of which is that as the populations in each settlement have increased, the area of the communal woodland resource base has decreased, with a corresponding increase in harvesting pressure and impacts on woodland vegetation structure and stem species composition (Chapter 2). In Welverdiend, where there is a higher human population, these impacts are more severe than in Athol. The methods used in Chapter 2 and 3 respectively enabled the quantification of changes in diversity and the spatial arrangement of woodland resources at two temporal scales, over 17 years and 44 years respectively thereby providing an insight into how other settlements in Bushbuckridge could potentially develop in the future and/or the development pathways they have taken in the past since the forced relocations which created them (Chapter 3).

Changes in fuelwood demand patterns in response to differing fuelwood availability where traced through comparison between Welverdiend and Athol, on the premise that in all other aspects, aside from fuelwood availability and human population the two villages were identical and could be used as examples of villages on the same timeline of woodland degradation. The results indicate that the demand for fuelwood is relatively inelastic in relation to fuelwood availability in the communal woodlands of each village (chapter 4), however the high demand for fuelwood in Welverdiend, where the greatest impact in terms of low fuelwood availability was shown, was sustained by the development of a thriving fuelwood trade as well as the expansion of the effective woodland resource base to include Morgenzon. Thus it well might be that with further degradation, even onto Morgenzon, which was shown to be occurring already (Chapter 3), fuelwood demand will become elastic and households will begin to reduce their consumption in response to declining fuelwood availability, or even switch to electricity should the financial costs of buying fuelwood become comparable to those of using electricity (Chapter 5).

Ultimately, the assessment of how the components of the studied socio-ecological systems evolve in light of the continuing high dependence on fuelwood points to a discussion about the sustainability of these rural wood-energy systems. In this chapter a synthesis of the main findings from each objective is presented to provide perspective of how they interact and can be used to indicate the future of fuelwood-use in similar socio-ecological systems.

Fuelwood supply-demand systems are complex and site-specific (DeWees 1989, Bhattarisai *et al* 1997, Arnold *et al* 2003). This limits the broad-scale applicability of this set of results for use as indicators of the sustainability of rural fuelwood-energy systems in different socio-economic and ecological contexts. However, many countries in southern Africa share similar social and political histories, often inheriting the land-tenure and land-use practices, as well as interlinked land-based livelihood strategies similar to those in the study area, from their common colonial pasts (Adams *et al* 1999, UNECA 2003). The main difference is that in the study sites there is a relatively high availability of electricity in South Africa in comparison to other African countries (IEA 2010). These results and conclusions may still be used to indicate how coupled rural fuelwood-based human-environment systems in other African countries could develop and respond to intensive rural electrification programmes such as there have been in South Africa (Madubansi & Shackleton 2006, IEA 2010). The potential contribution of this research towards informing rural energy policies is explored. Furthermore, I discuss the contribution of this study to the knowledge about the energy and energy-technology requirements and choices made by low-income, rural villages in southern Africa.

6.1.2 Advancing the understanding of rural fuelwood supply-demand dynamics

The choice of case-study villages were influenced by the extensive work and availability of a long-term database for woodland structure as well as records of unchanging demand patterns over the study period (1992- 2009). The predictions made by Banks *et al* (1996) of sustainable harvesting in one village wood-energy system (Athol) and not the other (Welverdiend) immediately lead to the question of what is the difference between these two villages? Answering this question required an investigation into the village characteristics to identify whether there were differences in population size relative to the resource base, levels of income and unemployment and resource governance that could account for any observed differences in fuelwood consumption characteristics. Banks *et al* (1996) suggested population growth as the primary factor pushing unsustainable harvesting rates and indeed, this study has shown that population size at the household level is a highly influential factor of how much fuelwood is used by a household each year. Predictions of the different biophysical expressions of fuelwood harvesting were correct although, they significantly underestimated the regenerative capacity of the savanna woodlands through the coppice response of most savanna tree species (Higgins *et al* 1999) as seen in Welverdiend (Chapter 2).

The resilience of the communal woodlands to disturbance from fuelwood harvesting is partially expressed by their ability to recover from human disturbance by selective harvesting through coppicing (Chapter 2) and also through the ability to regenerate from clear cut cultivated lands to woodland cover over a decade (Giannecchini *et al* 2007). The latter however only applies where the woodlands are cleared and allowed to regenerate but with higher population pressures, cleared agricultural land is more likely to be converted to residential land as space becomes premium (Chapter 3). Figure 6.1 shows the location of the sampled plots in the communal rangelands of Athol, illustrating how with time if the landcover change trends continue, in the future these plots may well be located in fields or in residential stands, as is clear in the north-west corner.

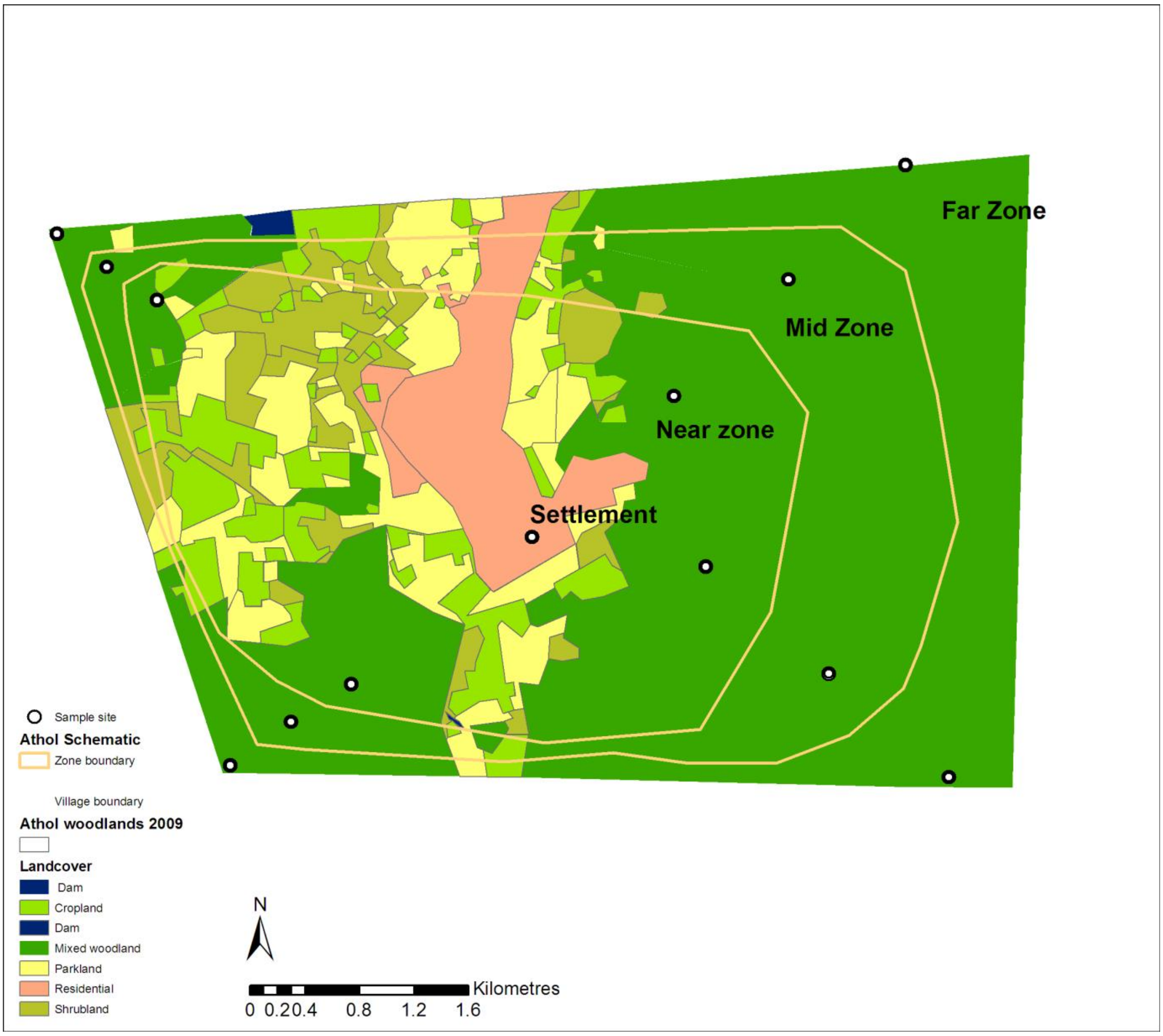


Figure 6.1 Landcover map of Athol village in 2009, overlain with the location of the woody biomass assessment sample plots used to asses standing woody stocks (fuelwood availability).

The initial logic to compare the villages used by Banks *et al* (1996) against each other and assess the socio-economic differences that may have led to either sustainable or unsustainable harvest patterns. However there were no real differences in socio-economic characteristics or annual fuelwood consumption patterns between the two villages (Chapter 4), inspite of the different levels of fuelwood availability (Chapter 2, 3). Although there were differences in the immediate arrangement of household time allocations to fuelwood resources- as was expected- fuelwood collection times per trip were significantly longer in Welverdiend, households also went less frequently to collect fuelwood, and when aggregated the actual annual opportunity cost was not different between the two villages.

The two most important drivers of fuelwood consumption were local fuelwood shortages and households access to electricity (Chapter 4, Chapter 5). Households in Welverdiend are forced to purchase more fuelwood to meet their needs for fuelwood and demand has remained fairly inelastic inspite of the added financial cost where fuelwood is usually accessed at no monetary cost (Chapter 4). Household access to electricity makes a significant difference in annual household fuelwood use (kg per annum) with households that have electricity using less fuelwood annually (Chapter 5). Furthermore, the perception by household members, particularly adult women, of fuelwood abundance or availability shaped fuelwood consumption patterns, and this perception was not linked to the village in which the household was located (Chapter 5). In other words, the observed environmental realities of woodland degradation, in terms of fuelwood production, are not as important as the perception of fuelwood abundance by the users of the resource in changing fuelwood consumption behaviour. This is supported by a study carried out by the International Labour Organisation that found that household fuelwood users (women) were not as concerned with the availability of fuelwood with respect to shortages, or in improved cooking efficiency: for the most part when asked, they were looking for a simple solution to meet their immediate energy needs for cooking (Cecelski 1987). There is a clear gap in the knowledge about what factors shape perception or the awareness of fuelwood availability by household members It was not related to household income level or the education level of the household head (Chapter 5). The results of Chapter 5 indicated the important role that fuelwood markets have played in maintaining high household consumption levels and the perception of high fuelwood abundance. Households where the respondents indicated that there was no problem with fuelwood availability in the woodlands had the highest fuelwood consumption (Chapter 5), even though they bought significantly more fuelwood than households that stated that there was a problem with fuelwood availability.

6.1.3 Domestic energy security & the rural household as an agent of change in communal woodland landscapes

The household as a unit is the agent of change driving the observed woodland dynamics. Decisions about fuelwood consumption patterns, that is, the amounts of fuelwood used and purchased, number of meals cooked, collection times, labour allocation etc are made at the household level (Brouwer *et al* 1997). Fuelwood collection is carried out by individualswho make decisions on fuelwood harvesting patterns, such as cutting livewood, target species or harvest site, so that they obtain maximum benefit from the fuelwood collection trip in light of the cost to them of their time and energy (MacDonald et al 1998, Sankhayan & Hofstad 2001, Namaalwa et al 2007). These decisions define the impacts of fuelwood use on the communal woodlands and are driven by the need to satisfy household energy demand for cooking and heating. Furthermore, policy interventions to improve energy security and the sustainability of fuelwood supply-demand system were formed to address household-level concerns with respect to improved cookstoves, access to energy alternatives or the creation of fuel woodlots (Dewees 1989, Davis 1998, Arnold *et al* 2006). I present a conceptual framework, based on observations from this study, to summarise how the rural household acts to satisfy its domestic energy demand requirements and how these actions aggregate at the village level to influence communal woodland dynamics (Figure 3.1). This framework also serves to illustrate how the results of this study advance the knowledge about rural wood-energy systems and the sustainability thereof in South Africa.

6.2 Unpacking the conceptual framework: the role of the household within the rural wood-energy system

Rural household access to electricity is determined by the actions of the national Government, by instituting appropriate policies and allocating adequate resources to enable the expansion of electricity network infrastructure and maintenance protocols in place (Alam *et al* 1998, DME 2003, DoE 2010). The South African government has committed to universal access to electricity for all households by 2014 (DoE 2010) and Bushbuckridge has benefitted from intensive investment into household electrification under the accelerated national electrification programme (DME 1998) as well as its designation as an ISRDP node (RSA 2000, Harmse 2010). In spite of this, at the time of the study not all households in both Welverdiend and Athol had access to electricity.

6.2.1 Rural electrification and household access to electricity

The availability of electricity within the household had a direct influence on the amount of fuelwood used annually predominantly for cooking and boiling water (Chapter 4, 5, Hosier & Dowd 1987, Campbell *et al* 2003). Rural households are more likely to use a mix of energy-sources to meet their thermal energy needs rather than immediately switch to the exclusive use of electricity (Davis 1998, Thom 2000, Madubansi & Shackleton 2006). This is indicated by the dashed arrows in the conceptual framework (Figure 3.1) under household choices of energy carriers. It was not possible to quantify this behaviour as there were very few instances of households mentioning alternative energy-carriers such as Kerosene (Parrafin), Gas or Crop residues as the main fuels used for cooking. These alternatives were mentioned as back-up fuels- used when there was no fuelwood or electricity in the household- hinting at the importance of the availability of alternatives as a diversification strategy to ensure the household energy needs can always be met and minimise risk and household cost (Soussan 1987). Thus these households use a wide-variety of energy-carriers for some energy-needs such as lighting but tend to maintain their use of fuelwood as the primary energy source for cooking (Chapter 4, Davis 1998, Masera *et al* 2000, Vermeulen *et al* 2000, Campbell *et al* 2003, Brouwer & Falcao 2004, Madubansi & Shackleton 2006).

6.2.2 Household choice of energy-carriers: fuelwood *versus* electricity

In this study, I found that households used either fuelwood or electricity primarily for cooking and, depending on access to electricity, followed one of three energy-use pathways (Figure 6.2), each with different influences on annual fuelwood consumption (Chapter 5). Households without electricity used significantly more fuelwood annually (Pathway 1, Figure 3.1), irrespective of the village in which the household was located than households with electricity (Pathway 2, Figure 3.16.2, Chapter 4). Access to electricity does not guarantee that

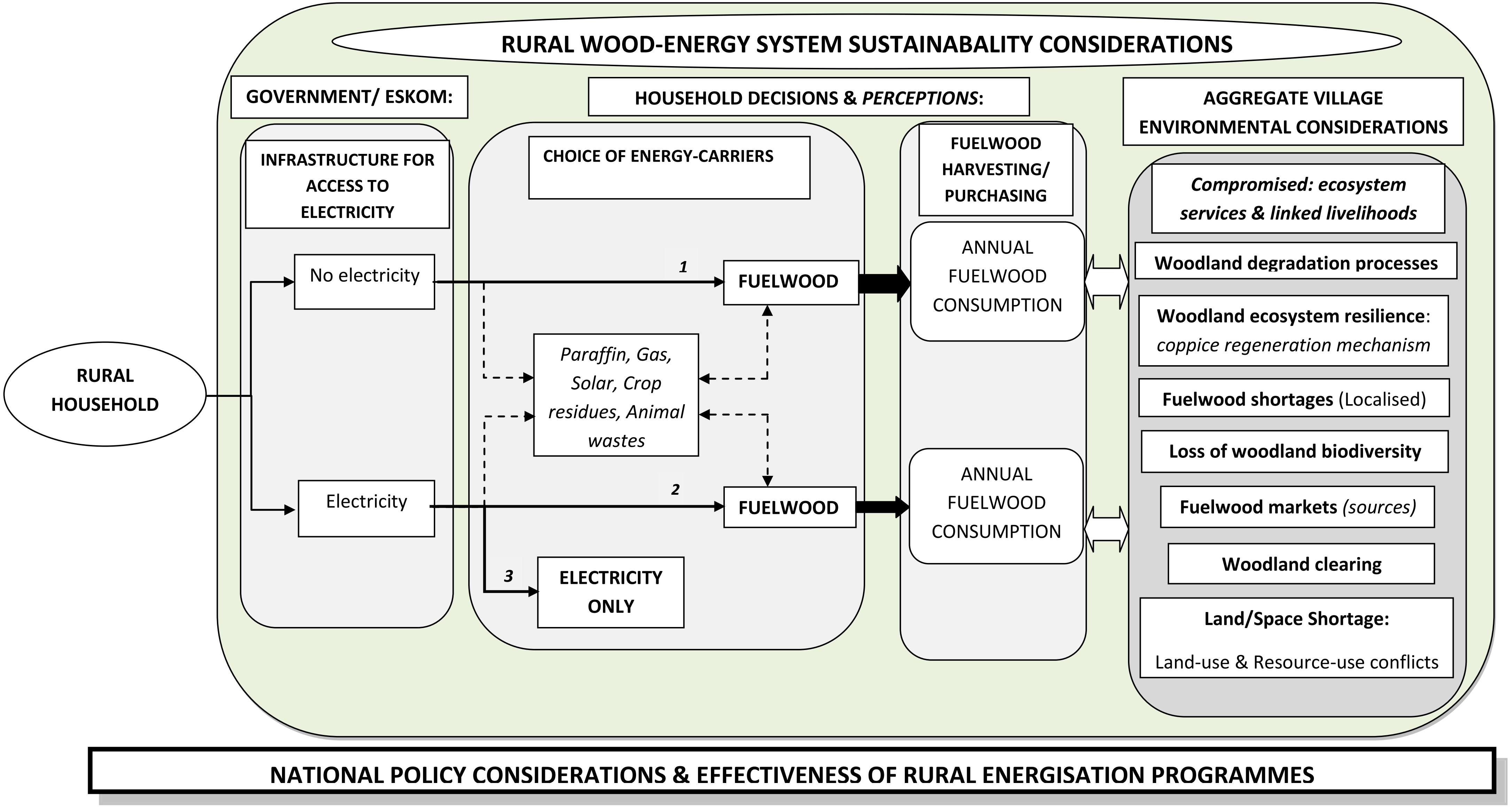


Figure 6.2. A conceptual framework of the implications of results from the study of the fuelwood supply and demand dynamics in Bushbuckridge and the flow of actions. Taking the household as the basic unit, each subsection has implications for the sustainability of the rural wood-energy system. Government action determines access to

electricity. Household decisions are moderated by household characteristics. Harvesting or use decisions have impacts at the village level. Solid lines indicate the household energy pathways that were investigated, dashed arrows and italics indicate pathways that need further investigation.

households will shift to using electricity exclusively to meet all their energy needs (Davis 1995, Thom 2000, Madubansi & Shackleton 2006). The household decision to use electricity in combination with fuelwood (Pathway 2, Figure 6.2) or exclusively (Pathway 3, Figure 3.1) in the household energy-mix is moderated by a range of household specific characteristics (Chapter 5). The likelihood of a household switching to electricity increased in direct relation to the amount of time (hours per annum) invested in fuelwood collection (Chapter 5). Furthermore the importance of household size in fuel-choice became apparent; the higher the number of people living in the house was, the less likely a household was to use electricity as it primary energy source for cooking (Pathway 3, Figure 6.2, Chapter 5). The influence of household size is probably linked to the high thermal-energy requirement for cooking for larger numbers of people and possibly the financial cost implications if this need were to be met by electricity only.

The household size (permanent residents) was an important determinant of total annual fuelwood consumption whether electricity was available or not, although expressed as household composition (numbers of men, women and children) for households without electricity (Chapter 5). The strong influence of adult females in moderating household fuelwood consumption was only apparent in households that were completely dependent on fuelwood with no access to electricity (Chapter 5). In contrast permanent household size, irrespective of gender composition was the major determinant of total annual fuelwood use where electricity was available (Chapter 5). Cecelski (1987) proposes that fuelwood use is linked to the time spent on cooking and fuelwood collection and that this is directly linked to the women in the household, since it is their time at stake. This effect may be dampened by the availability of electricity as an accessible alternative, since electricity reduced household fuelwood use (Chapter 4).

A major difference between fuelwood-using households following either Pathway 1 or Pathway 2 (Figure 6.2) was the importance of household perception of fuelwood availability (ease of access) in influencing household consumption (Chapter 5). Where electricity was available (Pathway 2), then households that indicated that they faced some level of difficulty in accessing sufficient fuelwood lessened their annual fuelwood consumption. Households that had no other primary energy alternative (Pathway 1) did not or could not moderate their use accordingly. The influence of perception in household fuel-switching to electricity bears further investigation. It was surprising that the perception of fuelwood availability/ease of access was not associated with the village (Chapter 5), considering the degraded nature of woodlands in Welverdiend compared to Athol (Chapter 2). This may be one of the reasons why no clear difference in household fuelwood consumption behaviour could be traced between the villages (Chapter 4). I expected that perceptions of scarcity would be determined by village, as a direct reflection of the biophysical condition of the village communal woodlands (Chapter 2). In other words, in Welverdiend, where there was high woodland degradation in comparison to Athol, there would be a greater degree of household adaptation to meet household demand for fuelwood, similar to patterns commonly cited in the literature (Brouwer 1989, Brouwer *et al* 1997, Arnold *et al* 2006). Although Welverdiend households adapted their immediate behaviour, spending longer times in fuelwood collection per collection trip, they also went less frequently to collect fuelwood, furthermore, household demand (annual consumption) was not lower in comparison to Athol but more households purchased fuelwood to meet their energy need (Chapter 4). This means that although the households' methods of fuelwood acquisition changed, with households in Welverdiend rearranging their time budgets and buying more fuelwood, the actual demand for fuelwood remained the same between the two villages. The perception of high fuelwood abundance (always enough fuelwood) was linked to household fuelwood purchasing (Chapter 5); these households bought more fuelwood to satisfy their fuelwood needs than households that were aware of potential fuelwood shortages (Chapter 5). This is interesting, given that purchasing fuelwood is often seen as an indicator of fuelwood scarcity (DeWees 1989, Arnold *et al* 2003). The factors that determine household environmental awareness and perception of fuelwood availability, with respect to shaping fuelwood consumption patterns, need further investigation as they may hold the key to success for future woodland resource management plans.

Household income has been identified in other studies as the main stumbling block preventing low-income (mostly rural) households from switching to electricity or making greater use of electricity as they can neither afford to buy electrical appliances nor pay monthly tariffs (Hosier & Dowd 1987, Davis 1998, Williams & Shackleton 2002). The fact that income was not selected as a major determinant influencing fuelwood use in all households except where there was no access to electricity was unexpected (Chapter 5) and contrary to other studies in the region (Twine et al 2003a,, Madubansi &Shackleton 2006). This may in fact reflect the generally low household incomes of the households that were included in the village surveys (Chapter 4) rather than the alternative which is that income has no bearing on fuel-choice. The cost-saving benefit of fuelwood use for cooking is implicit in the differences in observed household expenditure on energy between households that use only electricity and those with access to electricity but using fuelwood to cook (Chapter 4).

6.2.3 The environmental impacts of household decisions on the village communal woodland dynamics

In complex, socio-ecological systems, such as in Welverdiend and Athol, the overarching interactions between government policies, poverty and land-based livelihood strategies and control of access to resources (land-use rights and land-tenure) are a crucial component of the suite of variables influencing woodland change (Chapter 3, Adams *et al* 1999, Shackleton *et al* 2007, Scholes 2009). The geographical histories of these landscapes as former homeland areas are still evident in the manner in which households access and use their village communal woodlands (McCusker & Ramadzuli 2007**.** Customary communal land-tenure systems and weakening traditional institutions that are unable to control community resource exploitation have been linked to unsustainable woodland use and degradation (Adams *et al* 1999, UNECA 2003, Kirkland *et al* 2007). The breakdown in the traditional structures that formerly managed woodland exploitation in Bushbuckridge has created situations of poor resource management, over-exploitation and woodland degradation (Twine 2005). Differences in resource governance by traditional leadership in the two villages were not explicitly investigated as there is adequate evidence that traditional authorities in the study region are essentially ineffective in regulating harvesting (Twine *et al* 2003b, Kirkland *et al* 2007). The break-down in traditional institutions and mechanisms of regulation encourages the creation of individualistic resource use-patterns whereby the household as a unit benefits from free access to woodland resources, such as fuelwood, but the total costs of over-harvesting, woodland degradation and fuelwood shortage are borne by the village as a whole (Adams *et al* 1999).

Increasing population pressures result in outward expansion of the village settlement area into areas that have already been cleared for agriculture, which necessitates more woodland clearing and deforestation to replace the lost land, as well as to cater for the small-scale gardening needs of the newly created households (Chapter 3). In each of these village landscapes, space for outward residential and agricultural expansion is limited. This means that over time, as the total woodland area shrinks (Chapter 3), the resource extraction pressure per household per unit area of remaining woodland will inevitably increase and begin to manifest as intense woodland degradation (Chapter 2, Chapter 4). Woodland degradation manifests initially as changes in species composition as favoured fuelwood and timber species disappear and changes in woodland structure as demand for fuelwood outstrips the sustainable woodland off-take through livewood harvesting (Chapter 2, Shackleton 1994, Scholes 2009). Over-harvesting and the associated degradation through conversion to shrubland is often a pre-cursor to woodland land-cover change, through deforestation/clearing for agricultural purposes and ultimately settlement expansion (Chapter 3, Scholes 2009).

6.3 Environmental considerations for the future

6.3.1 Landscape dynamics and ecosystem services

If the observed trends in landcover change hold true, the result in these rural landscapes is that fuelwood shortages are inevitable. This is not necessarily as a result of "unsustainable" harvesting practices in isolation (Banks *et al* 1996) but a result of the compound effects of the financial inaccessibility of electricity as a household energy alternative, inelastic household demand for fuelwood and increasing human population extractive pressures on shrinking woodland areas. The factors that shape perception of fuelwood (resource) availability need also to be investigated. Almost two-thirds of the households were aware of a problem with fuelwood availability but of those households, only those households with electricity and therefore access to an energy alternative were able to modify their behaviour accordingly. Unless there is a change in the local socio-economic systems, the patterns of resource use will not change. Even as resources become increasingly scarce, although households may make more economical use of their time in collecting resources such as fuelwood, ultimately the need for the resources does not decline. Unless households have viable, affordable and economically accessible alternatives to substitute for these essential ecological services, they are unable to adapt their behaviour/use patterns accordingly. In the case of household fuelwood consumption, without adequate redress this will not change no matter how aware they are of the changing environmental conditions or how physically accessible alternatives such as electricity are.

These factors point to the feedback loops between environmental degradation and economic and in this case energy poverty. Human population growth is driving woodland loss but communities have no viable energy alternatives and continue harvesting fuelwood, until it begins to result in degradation of the remaining woodland patches. This in turn creates shortages for fuelwood and other ecosystem goods and services and a decline in the well-being of these communities as they are forced to expand their resource extraction range in order to maintain their livelihoods (Shackleton & Shackleton 2004, MEA 2005, Shackleton *et al* 2007).

This research focused on fuelwood as one of the goods provided by savanna woodland ecosystems to dependent rural communities in South Africa. However, the range of ecosystem services provided by these woodlands that are affected by the changes described, that is, changes in woodland structure, species composition and spatial coverage extend far beyond the scope of this research. The implications for the other goods that the rural communities obtain from the woodlands such as wild fruit and medicinal plants run parallel to those for fuelwood and are easily quantifiable. However as woodland loss and degradation continue other important ecosystem services that support these communities, albeit indirectly may also be affected. Regulating services such as flood and erosion control will be compromised as woodland cover is cleared for agriculture and becomes degraded through harvesting (Biggs *et al* 2004).For example, the village-level relative woodland cover conversion rates in both villages, ranging from less than 0.01% to 9% annual relative woodland area loss since 1965 (Chapter 3) shows that there is a consistent decline in woodland cover with time. This has culminated in an overall woodland cover loss of 48% in Welverdiend and 26% in Athol. The trend in declining woodland cover have been observed at the aggregate landscape level in the same area over a shorter time-period by Coetzer *et al* (2010). Woodland cover declined by approximately 7.3% between 1993 and 2006 and degraded vegetation areas increased by approximately 6.8% over the same time period (Coetzer *et* al, 2010). The knock-on effects are that there are implications for groundwater availability and quality, since as run-off rates increase less water filters down into the water table (Biggs *et al* 2004). Ultimately past, present and future trends in landscape cover dynamics must be incorporated into natural resource management and socio-economic development plans because of the implications on the availability of ecosystem goods and services to the dependent human populations living on them.

6.3.2 Sustainable fuelwood use through coppice regeneration?

Many savanna woodland species are able to regenerate from the root stock or stem after mechanical damage to the main stem, for example through cutting for fuelwood (Shackleton 2000). The importance of the coppice regeneration response to the persistence of the communal woodlands was evident in the high proportion of coppice stems in Welverdiend which had the higher impact with respect to negative changes in woodland structure and species composition (Chapter 2) and woodland loss (Chapter 3). Manipulating coppice regrowth of valuable savanna species has been suggested as a possible management technique to allow continued harvesting from savanna woodlands for fuelwood and construction (Shackleton 1993, Kennedy 1998, Shackleton 2000, Shackleton 2001).

It has been noted that coppice regrowth of semi-arid savanna tree species is resistant to the effects of drought, pests, disease and nutrient-poor soils (Kennedy 1998). Coppice shoots have a faster growth rate than seedlings (Chidumayo 1993, Grundy et al 1993) and due to strong apical dominance grow in the desired shape for fuelwood and construction naturally and attain the desired size faster than seedlings. Shackleton (2000) found that the harvesting techniques used in terms of stem size and cutting height influenced the coppice response of widely used savanna species (*Terminalia sericea)*. In terms of woodland management Kaschula *et al* (2005) found that the coppice regrowth response of savanna species to harvesting depends on the target species and is influenced by catenal position of the harvest sites (soil type and nutrient availability) as well as the harvesting techniques that are used (also Neke *et al* 2006). Manipulation of these factors could also maximise the woody biomass productivity of coppice shoots and provide a sustainable source of fuelwood and construction timber (Kaschula *et al* 2005). There is still a dearth in knowledge about the growth rates of coppice shoots (Kaschula 2003, Neke 2004); information which would allow us to establish the “recovery time” of savanna species. There is also little information about the long term sustainability and survival of coppice woodland stands that are continuously harvested.

This study has shown that coppice stem diameter thickness is declining over time, with continued harvesting pressure, which indicates that the coping mechanism may not be adequate in the long-term. Continuous coppice harvesting affects long term woodland sustainability by not allowing new seed production. If stems are being harvested before they reach pole size (4 – 10cm, Luoga *et al* 2004) like in Welverdiend, there are few stems surviving to become seed-bearing trees; this has implications for the genetic diversity of woodland vegetation population. This could leave the woodlands vulnerable to environmental stochasticity, there should be some environmental shock, such as intense fire, heavy drought or pest attack that the coppice stems were not resistant to. Such an event could ultimately bring about the collapse of the woodland resource base without the back up of seedling reserves.

6.3.3 The role of fuelwood markets in buoying household fuelwood demand

Fuelwood shortages occurring at the village level spawn the development of fuelwood markets and increase the value of fuelwood as an income-generating livelihood strategy, further entrenching the use of fuelwood within these societies (Twine *et al* 2003, Shackleton *et al* 2006, Davidar *et al* 2010)**.** The source of the traded fuelwood remains highly topical but unclear (Twine *et al* 2003b). The origin of the fuelwood supplying the markets remains unclear as fuelwood vendors were unwilling to participate in the survey process, partially as a result of the criminalisation of livewood harvesting and trading without permits from the local traditional authorities. Some commercial wood-harvesting is legal, such as that derived from bush-clearing contracted to local entrepreneurs but for the most part fuelwood vendors remained wary about revealing the source and methods used to harvest the traded fuelwood. Households were likewise ignorant of the source of fuelwood (Chapter 5) as it is often delivered to the home by the fuelwood vendors who harvest on a customer-to-customer basis. Due to the trade in fuelwood, these socio-ecological systems are open systems, that is, fuelwood is brought into the villages from further afield and wood from some village commons is also trucked out. This complicates modelling and managing these systems. Madubansi & Shackleton (2006, 2007) showed that rural households are more likely to spend the limited household income to purchase fuelwood, rather than on electricity. As such, this knowledge is essential for any attempts to understand the role of the fuelwood trade in the continued use of fuelwood in the future, if demand is being sustained by the availability of purchased fuelwood (Chapter 5).

6.4 Predicting future sustainability: modelling coupled rural fuelwood supply-demand systems

Models allow us to explore the sustainability of rural fuelwood-based energy systems based on our current understanding of the relationships and interactions between the human and environment components. In attempting to model such a system one requires well assimilated and integrated data about fuelwood production and consumption within that particular area (Sankhayan & Hofstad 2001). What should be clear is that in the context of savanna systems, these models describe woodland degradation processes occurring as a result of human activities (Grainger 1999). Such a model would primarily be concerned with fuelwood collection but there are other activities that cause woodland degradation and these should be captured as well.

Communal savanna rangelands are subject to deforestation for residential and agricultural expansion (Chapter 3) and degradation through selective harvesting mostly for fuelwood (Chapter 2) and timber, (Grainger 1999, Sankhayan & Hofstad 2001). There are two options available to describe these processes. One may either choose to represent spatial degradation and deforestation either by changes in woodland area and tree density (Grainger 1999, Namaalwa *et al* 2007) or by changes in woody biomass (Grainger 1999, Sankhayan & Hofstad 2001). The latter encompasses changes in tree density and overcomes the problems that arise with incorporating changes in woodland aerial quantities (Grainger 1999). Similar modelling approaches were used by Sankhayan & Hofstad (2001) and later refined by Namaalwa *et al* (2007) to model fuelwood-use systems in West Africa.

The indications from the research suggest that this approach could be applied in communal landscapes similar to Bushbuckridge. Such models are built at the village level, whereby each village and its associated communal rangelands and woodlands are considered a unit.

Assuming that village residents use the communal woodlands so as to guarantee maximum utility (Namaalwa *et al* 2005) then, land use is economically optimal and this could be determined by topo-edaphic characteristics and the distance from the village, offset by the travel costs to the site of a given land use from the village centre. Those activities that bring about woodland degradation, that is, fuelwood harvesting would then be linked to household fuelwood consumption characteristics based on the economic cost to the household of collecting and using fuelwood (Chapter 5, Namaalwa *et al* 2005) using behavioural, structural and accounting equations.

The challenge would be in incorporating the coppice response of felled trees into the biomass regrowth aspect of such a model. One of the main shortcomings of previous biomass supply models was that they overlooked the resprouting response of savanna species after felling (Eberhard 1992, Abott & Homewood 1999). Yet this is a key attribute of savanna species that contributes to ecosystem resilience and productivity (Shackleton 2001). Gambiza *et al* (2000) suggest that stage class matrix models allow for the modelling of the coppice mechanisms as coppicing individuals revert to lower stage classes. Namaalwa *et al* (2005) incorporated a matrix model of the tropical woodlands in Uganda in their application of the Sankhayan & Hofstad (2001) model. However, this requires longitudinal data of the changes in woodland structure with almost annual measurements of growth rates, survivorship and mortality (Osho 1991, Owen- Smith 2007). Such data are not widely available across much of Sub-Saharan Africa. The only other option is to use changes in woody biomass in the communal woodlands as the dependant variable (Grainger 1999). Thus although the conceptual model would be spatial in nature, the actual predictive model would not indicate the location of degradation. Rather, woodland degradation will have occurred when woody biomass removal exceeds the sustainable yield, indicated by a reduction in biomass density per unit area However spatial information about where and how degradation is occurring in the landscape is an essential prerequisite to identifying and prioritising where remedial action should be implemented. The data constraint in modelling wood-energy systems is valid only if this approach is followed but spatial models operating at various organisational scales but based on village-level data are needed for long-term effective planning.

6.5 Fuelwood supply-demand balance assessments and issues of scale

Village level fuelwood supply-demand balance assessments are critical to understand the sustainability of fuelwood use at the greater landscape level, beyond the village-level of the two case study sites, to Bushbuckridge Municipality level or within the Kruger to Canyons Biosphere Reserve itself. Villages covering a spectrum of fuelwood availability and woodland deforestation and degradation and therefore fuelwood availability are located adjacent to each other within the municipality and hemmed in by conservation areas within the K2C Biosphere Reserve (figure 6.3). If similar processes are occurring in other rural villages within this area with respect to fuelwood consumption and the observed environmental impacts, then it becomes even more critical to identify the sources of traded fuelwood, as contributors to the rural "woodshed" (Drigo &Salbitano 2008). The concept of a rural "woodshed" is analogous to a watershed and is used for regional or district energy planning to define and visualize the territory needed for the sustainable supply relative to the demand for fuelwood in dense human settlements (Drigo &Salbitano 2008).

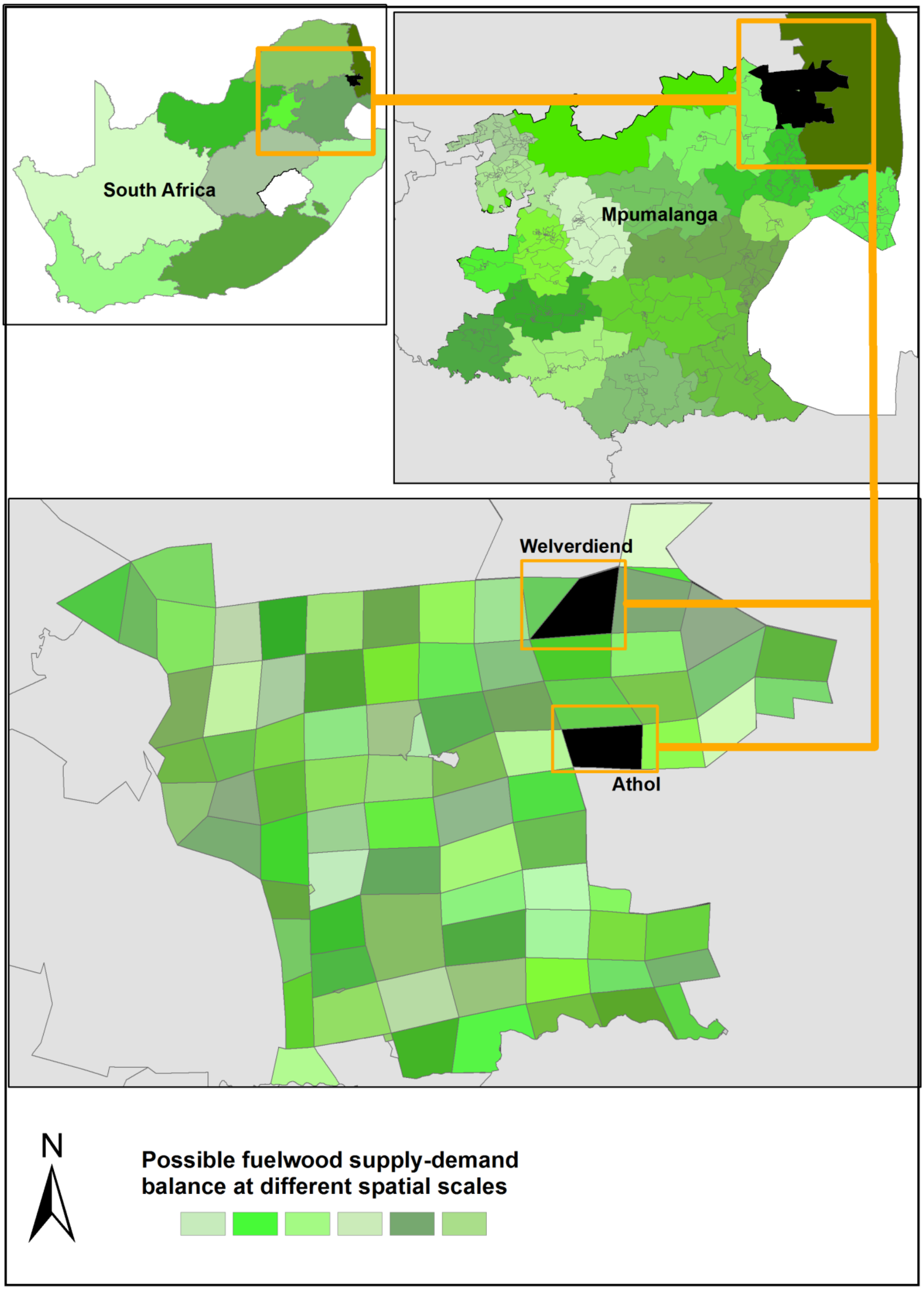


Figure 6.3. Conceptual illustration of the output of a spatially-orientated fuelwood supply-demand assessment system based on the Woodfuels Integrated Supply/Demand Overview Model WISDOM, Masera *et al* (2000). This map illustrates the issues of scale involved in using the case-study approach, in extrapolating such data to the national level as well as the value in sampling across a wider variety of rural landscapes. Such a framework allows the representation of balance assessments at varying planning levels.

Fuelwood shortages occur at the local village or municipal scale (von Maltitz & Scholes 1995). The blanket approach that was used to assess national fuelwood supply-demand balances did not adequately account for the spatial heterogeneity of potential fuelwood supply relative to demand centres (von Maltitz & Scholes 1995, Masera *et al* 2003, Top *et al* 2006). Therefore a new generation of spatially explicit fuelwood balance models were created to account for this but still provide accurate assessments of the sustainability of fuelwood-based energy systems at various scales (Drigo *et al* 2003, Masera *et al* 2003, Gilhardi *et al* 2007). The Woodfuels Integrated Supply/Demand Overview Mapping methodology developed by the FAO (Drigo *et al* 2003) has been successfully applied to assess and identify fuelwood hotspots on the national landscape in Mexico, West Africa and East Africa (Masera *et al* 2006). There is need for the application of such methodologies and generation of this information in southern Africa where fuelwood use remains particularly high (UNDP & WHO 2009).

Spatially explicit information, incorporating data such as has been generated in this research but which also allows for the display and identification of fuelwood crisis areas or hotspots is essential for efficient planning and channelling of resources. Because such methods work at different scales, the information generated may be used at different levels of planning be it municipal, provincial, national or regional (Masera *et al* 2006). The next step would be integrating the results of this study, and more studies like it into spatial fuelwood supply-demand assessment frameworks, across varying scales (figure 6.3). However more research is required to assess modern fuelwood use supply-demand dynamics in different vegetation types using remote sensing technology to create spatial information and quantify the fuelwood supply potential of communal woodland resource bases (Fisher *et al* 2012). The availability of new technologies such as Light detection and ranging (LiDAR) sensors allows for the creation of accurate mapping of three-dimensional vegetation structure in communal rangelands. Such data can be used to assess the spatial patterns of fuelwood availability and harvesting impact (Fisher *et al* 2012) as well as accurately quantify fuelwood (woody biomass) standing stocks within the communal woodlands (Lefsky *et al* 2002). Investigations at provincial, national and regional levels would be required, in order to be able to identify scientifically robust social and ecological indicators of rural wood-energy systems in crisis specific to the southern African context.

6.6 National sustainable energy, health, development & the fuelwood "problem"

Rural household energy insecurity and all the environmental manifestations of the "fuelwood problem" explored in this study ultimately relate to the issues of energy poverty, sustainable development and the challenges faced by developing economies in meeting the Millenium Development Goals (MDG). The concept of energy poverty refers to the lack of choice in access to modern energy services that are "adequate, safe and reliable for economic and human development" (Perreira *et al* 2010). The International Energy Agency, IEA, recognises two indicators of energy poverty at the household level, the lack of access to electricity and the consistent use and dependence on woodfuels for cooking (IEA 2010). Of the 1.5 billion people without access to electricity, 567million live in Sub-Saharan Africa (IEA 2011). This lack is now apparent in that the issue of energy security is seriously putting the achievement of the MDGs at risk especially in Sub-Saharan Africa (UN Secretary General's Advisory Group on Energy and Climate Change, AGECC, 2009).

The South African national government strategy to addressing energy poverty partially involves an intensive national electrification programme that aims to achieve universal access to electricity for all formal households by 2012 and informal households by 2014 (DoE 2010). South Africa has amongst the highest electrification rates in southern Africa; according to the IEA (2009) 55% of the rural population and 88% of the urban population (giving an average of 75% of the total population) had access to electricity by 2008. However, physical household access to electricity through a connection to the national grid does not ensure household use, beyond the monthly Free Basic Allowance which allows for lighting and a few other minor energy uses (Chapter 4, Davis 1998, Thom 2000, Pachauri & Spreng 2004, Madubansi &Shackleton 2006). The continued dependence on fuelwood for cooking and the low likelihood of households switching to electricity have been well illustrated in this and other studies (Chapter 4, 5, Hosier & Dowd 1987, Davis 1998, Thom 2000, Vermeulen *et al* 2000, Campbell *et al* 2003, Madubansi & Shackleton 2006, IEA 2010). The lack of rural households switching to electricity from fuelwood is not unique to sub-saharan Africa and reflects the documented rational behaviour of rural households from China (An *et al* 2002, He *et al* 2009) to South America (Taylor 2005).

The associated woodland/environmental degradation, compounded by the effects of deforestation driven by human population growth, has severe and potentially wide-reaching implications for environmental sustainability (Chapter 2, 3). These “syndromes of Dryland degradation” become progressively worse with time (Chapter 3, Scholes 2009). The consequences are harsh and threaten the sustainability of the multiple land-based livelihood strategies employed by most South African rural households for survival (Arnold *et al* 2006, Shackleton *et al* 2002, Shackleton *et al* 2007). There are also multiple hreats to large-scale ecosystem functions which are beyond the scope of this study (Karekezi 2002, Brouwer & Falcao 2004, MEA 2005, Arnold *et al* 2006).

The issue of continued household fuelwood use has far-reaching socio-economic and environmental consequences, yet to date there are limited and uncoordinated national interventions and programmes in place to deal with this (DME 2000, DME 2003, DoE 2010, DAFF 2010). The Integrated Sustainable Rural Development Strategy, ISRDS, mentions that with respect to energy the national “objective is to increase access to affordable energy services” through increasing household electrification (RSA 2000, DME 2003). The strategic plan of the Department of Energy (2010/11-2012/13) mentions the harvesting of renewable energy sources such as solar and wind energy and reducing the retail price of LP Gas as alternatives to fossil-fuel generated electricity but does not address the role of traditional biomass energy at the household level (DoE 2010). There are two programmes that deal indirectly with satisfying the need for fuelwood for the majority of the South African rural populace. The Working for Energy Programme (WFE) is run jointly by the Department of Energy and the South African National Energy Research Institute (SANERI). This programme evolved out of the Working for Water programme, as a means to channel the woody biomass wastes that were a by-product of clearing of alien invasive species into a resource that could feed into a renewable energy solution (WFE, 2012). It is primarily a job-creation vehicle structured, like the Working for Water programme, as a Public/Private Sector Partnership to encourage employment in rural areas through various renewable energy projects, including fuelwood from invasive alien plant clearing amongst other biofuel-orientated projects (WFE 2012).The Department of Agriculture, Forestry and Fisheries, DAFF strategic plan (2010) makes mention of the Forestry Livelihoods Programme as the main vehicle to support the growth of rural forest-based economies. This programme aims to tackle poverty by ensuring the sustainability of forest-based livelihood systems and the conservation of the associated ecosystem services therein such as fuelwood provision (DAFF 2010). In these instances ensuring household access to a secure supply of fuelwood is a secondary outcome of the actions of these programmes. The common perception that fuelwood use is associated with poverty may act as a deterrent in the development of national policies focusing on managing the continued use of fuelwood in rural areas as it could be interpreted as keeping people under conditions of hardship and poverty. However, it ignores the reality on the ground where access to electricity does not mean the rural households cease their dependency on fuelwood.

The cost of electricity is a major deterrent preventing many rural households from completely switching to electricity from fuelwood (Williams & Shackleton 2002). The question that needs to be answered from a policy perspective is, at what price (cost per unit of electricity) will rural households become switch to electricity? This could be answered in part by carrying out a modelling exercise on the impacts of national energy pricing policy on household fuelwood/energy consumption behaviour. An et al (2002) carried out a similar study in China and showed that a reduction in electricity price by 0.05 RMB (± R0.06 ZAR) per KWh would result in a significant increase in the number of households switching to electricity. Bushbuckridge would be ideal as a study area for a modelling exercise on the impacts of national energy pricing policy on household fuelwood/energy consumption. Particularly given the extensive historical database of knowledge that exists as a result of the various studies carried out in this area, including this study (Griffin *et al* 1993, Banks *et al* 1996, Shackleton & Shackleton 2004, Twine *et al* 2003b, Twine 2005, Madubansi & Shackleton 2007). As an ISRDP node Bushbuckridge would also be the ideal site to test the efficacy of increased energy cost subsidies in promoting the switch to electricity.

Respiratory diseases are known to be a major problem in South Africa and particularly in Bushbuckridge (Maredza *et al* 2011). An in-depth investigation into the linkage between this and fuelwood use was outside the scope of this study. However, from a national policy perspective, it is important to recognise that any discussion about reducing electricity costs or increasing national energy subsidies for low-income rural households must acknowledge the greater cost to the nation of health subsidies and reduced production due to respiratory illness that are inherent with the continued use of biomass as a primary energy source (UNDP & WHO 2009, Po *et al.*, 2011). With regards to this, policy-makers can not afford to discount the health costs of fuelwood use and there is need to consider this as motivation to reduce the costs of electricity to levels that encourage rural household switch.

6.7 Recommendations

The lack of reliable and current data is a prohibitive factor in the formulation of relevant and effective strategies that deal with the reality of fuelwood use in rural and, to a smaller extent, urban households, inspite of national efforts to enable household access to electricity (Shackleton *et al* 2007). The research objectives as stated in Chapter 1 have all been met; this study contributes to the knowledge about the current state of affairs around rural fuelwood use patterns and the associated environmental impacts. The possible future development of these coupled human-environment wood energy systems with respect to the potential for fuelwood shortages indicates the need for the development of co-ordinated national interventions that deal specifically with the issue of fuelwood.

A holistic integrated approach is required targeting:

- Future studies modeling annual household fuelwood consumption should endeavour to include the species and wood preferences of fuelwood users as explanatory variables (mentioned in Chapter 5). Such preferences are influenced by local traditional knowledge of physical (and therefore quantifiable) characteristics of the preferred species, such as wood density, which determines the burning quality of the wood. For example, aside from the cultural taboo of harvesting *Sclerocarya birrea,* the density of *Combretum imberbe* wood (1200 kg/m^3) is more than double that of *S birrea* (560 kg m^{-3}) translating to a longer burning coal and making it a targeted. species for fuelwood, Other qualities include differences in smoke quality, with species that produce almost smokeless fuel, such as *Combretum* being preferred for fuelwood and other specific tasks such as smoking fruit over those producing acrid smoke(Cunningham 2001). Models for different fuelwood harvesting behaviours, similar to Nantel *et al* (1996) should be developed to reflect the selective harvesting, for example through longer distances walked to satisfy the demand for particular species. This knowledge of selective targeting for specific end-uses should also be incorporated into the assessment of harvesting intensity, as not all incidences of live-wood cutting are due to harvesting for fuelwood. There is a need to disaggregate fuelwood cutting from that for other purposes in order to derive a more accurate picture of the impact of fuelwood consumption.

- The assessments of fuelwood availability should be refined in future studies. Given that not all tree species within the communal woodlands represent potential fuelwood resource base, future assessments of fuelwood supply should take different vegetation types into account in terms of their dominant tree species and recovery times. A similar methodology has been applied to model fuelwood collection in the Upper Yangtze catchment in China (He *et al* 2009) but is yet to be applied to sub-Saharan Africa.
- The role of environmental factors in affecting the sustainability of fuelwood use needs further investigation. It may be that the results of this study would have been substantially different had it been conducted in villages with different climates- for example higher or lower rainfalls, or different soils- all of which would affect initial resource availability as well as regenerative capacity of the vegetation. These factors should be included in future
- The implication of national health costs of fuelwood use, through widespread respiratory disease, increased child and adult mortality as a result of increased exposure to indoor pollution (smoke inhalation) and the impact on the labour force should be researched further. The health aspect of fuelwood use needs to be incorporated into discussions about fuelwood and energy use but more research is required to inform such discussions
- The pre-emptive identification of fuelwood hotspots, based on spatial-assessments of fuelwood-based systems (similar to the WISDOM approach) would enable efficient channelling of government financial resources before problems of resource scarcity become apparent.
- Further research is required to understand the role played by the fuelwood trade in maintaining household and therefore community fuelwood demand. There is a need

to identify the sources of traded fuelwood in order to trace the spatial extent of the ecological footprint of fuelwood use on rural landscapes. This has implications for the broader scale, long-term sustainability of the continued household dependence on fuelwood and will allow better environmental planning and management. This is particularly relevant in the context of Bushbuckridge as a part of the greater Kruger to Canyons Biosphere Reserve.

- Current communal land-use systems may need to be reviewed to encourage more efficient use of limited woodland spaces as multi-use landscapes and also to lessen any negative environmental impacts accruing over time. Perhaps encouraging the development of agro-forestry systems of land use, adapted specifically (in this case) to semi-arid savannas or the natural vegetation and incorporating multi-use indigenous species which could be fuelwood sources. This would need extensive investment in agro-forestry extension programmes.
- A change in current land tenure practices by transferring communal rights to individuals should be further investigated; this might arrest the patterns of spatial expansion and woodland degradation. Secure property rights have been shown to encourage more sustainable resource use practices including higher household investment in tree planting, soil and water retention (Maxwell & Wiebe 1998, in UNECA 2003). Processes have been put in place to begin this process in South Africa. The creation of community awareness drives in identified fuelwood hotspots to create or improve household perception or awareness of actual fuelwood availability within their resource base. Further research is required to understand the factors that shape household perception of fuelwood abundance in fuelwood-stressed environments
- The role of women, as the people who are most involved with fuelwood use and collection, in determining household fuelwood use should be incorporated into targeted intervention programmes with respect to improved cook-stoves or lessening household dependence on fuelwood.

Universal household access to electricity is an essential necessary aspect of beating energy poverty, improving household energy security and ultimately moving towards national sustainable development. At the same time the reality is that rural households will continue to depend on fuelwood for thermal energy-intensive domestic tasks for the intermediate future. Contingencies at the national level need to be in place to manage and deal with the social and environmental fall-out, both at present and potentially in the future based on the complex and inter-twined interactions between the social and environmental systems as hinted at and revealed in this research.

Appendix 1

BIOMODEL HOUSEHOLD FUEL USE AND SUPPLY

QUESTIONNAIRE 2008

DETAILS OF THE HOUSEHOLD

Date of the Interview ……………………………………………..

Name of Head of Household ………………………………..

(Headman) …………………………………………………………..

Chief ……………………………………………………………..……

Time of Arrival ………………………………………….……….

Time of Departure ………………………………………………

Name of Interviewer ……………………………………………..

Language of the Interview …………………………………..

Indicate if Translation was used:……………………………

Province ……………. District ……….. Village ………..

Country code………………….……….

RSA1 (Alison), RSA2 (Ruwa), RSA3 (Norma), RSA4 (Ruwa 2) ZAM(Mtumbi), Moz(Ibra)

Questionnaire No

FIELD SUPERVISOR'S COMMENTS:

INSTRUCTIONS:

1. Introduce yourself to the interviewees and briefly explain that this questionnaire has been developed for a study being undertaken by PhD students in South Africa, Mozambique and Zambia. The study aims to better understand how households use different fuels, how easy or difficult it is for households to access fuels according to where they live and their income resources. The study focuses on the collection and use of biomass by households. The study is being undertaken so that policies that make access and use of energy easier can be explored. We will be also be asking you a few questions on household income and expenses.
2. Highlight to them how long the interview will take and ask them if they are willing and ready to be interviewed
3. Explain that data collected will remain confidential and will not be communicated to anyone outside the research team
4. During the interview, *ask each question exactly as it is written on the questionnaire* and record the answers as accurately *and as legibly* as you can. *Also probe when necessary to make sure that an answer is as complete as possible;*
5. If there is an answer you are not sure you and the interviewee cannot shed more light on this answer, please make a note against this answer, and discuss this issue with the Field Supervisor;
6. Remember to remain objective and neutral in your conduct at all times. Do not appear, in your conduct or speech, to be biased and speaking for the interviewees or the client. This will affect the quality of responses that you get. Avoid as much as possible, rendering your opinion on the issues addressed in this questionnaire;
7. Be respectful in your manner at all times

1. In concluding the interview, extend your gratitude to the interviewees for their time and cooperation;

2. See Protocol matrix overleaf (list of which **SECTION** to ask in which Country)

SECTION A		**SECTION D**	
SECTION B		**SECTION E**	
SECTION C		**SECTION F**	

SECTION A: HOUSEHOLD ROSTER

In this first set of questions, we will ask about your household, household members and economic activities

A01 What is your first name? ……………………………………………………………

TABLE 1: Members of Household

A02 First name Write name of respondent in row a.	A03 Sex *Male [1]* *Female[2]*	A04 Age group *Toddler under 6 years [1]* *Preteen [2]* *Teenager [3]* *Adult [4]* *Elder [5]*	A05 Relationship with the household head Choose from the list below: *Self [0]* *father or mother [1]* *brother or sister [2];* *grandfather or grandmother[3]* *uncle or aunt [4]* *great-grandfather or great-grandmother[5]* *brother-in-law or sister-in-law[6]* *cousin [7]* *Child [8]* *Other (specify)………*	A06 What is the highest level of education she/he has completed? Choose from the list below: *No schooling [0]* *Literacy courses [1]* *Completed primary school [2]* *Some primary school [3]* *Completed secondary school [4]* *Some secondary school [5]* *Vocational (e.g. Technical) [6]* *Some vocational [7]* *Completed Tertiary [8]* *Some tertiary [9]* *Other (specify)………*	A07 What is her/his employment circumstances? Choose from the list below: Employment fulltime [1] Employment part time [2] Employment casually (piece jobs) [3] Self-employed [4] Pensioner/retired [5] Disabled [6] Student (including school children) [7] Housewife/home maker [8] Unemployed [9] Other (specify)………..	A08 Where does he/she live most of the time? Choose from the list below: *Always in this house [1]* *Only visits this house on weekends [2]* *Only visits this house during holidays[3]* *Other (specify)* ………………………
Example: Priscilla	F	35	22		4	1
a.						
b.						
c.						
d.						
e.						
f.						
G						

HOUSEHOLD ECONOMIC ACTIVITIES

Household income

We would like to ask about all the sources of income for your household

A09. Over the past year, can you estimate how much income, and at what frequency the household has received income from the following?

	Amount	How often?
From employment, full time, part time or casual		*Monthly*
		every second month
		twice a year
		infrequent
From social grants? (pension, disability, child grant)		*Monthly*
		every second month
		twice a year
		annually
from selling agricultural produce? (crops, forest products, livestock)		*Monthly*
		every second month
		twice a year
		annually
Money received from others? (remittances)		*Monthly*
		every second month
		twice a year

Household expenditure

A10. What does the household spend in a month and a year on the following?

Use the box below for calculations. Where there is no expenditure, write "none"	Indicate average monthly or yearly amount.	
	Monthly	Yearly
TOTAL		
a. Food and groceries (excluding fuels)		
b. Clothes		
c. Transport		

d. Repayment of loans		
e. Savings including saving clubs, including stokvel		
f. Church contributions		
g. Burial society		
h. Water		
i. Furniture, appliances		
j. Medical expenses		
k. School / tertiary education fees		
l. Telephone (mobile)		
m. Labour (home help, gardeners, cooks etc)		
n. Eating / drinking outside the home		
Other (specify)e.g. lawyer, remittances…………………..		

AGRICULTURAL ACTIVITIES AND FOOD SECURITY

A11. Does your household *grow crops*? Yes ☐ No ☐

If No, go to A16.

A12. what crops does your household grow?

Maize ☐

Cassava ☐

Sorghum ☐

Millet ☐

Sweet Potatoes ☐

Vegetables ☐

Groundnuts ☐

Beans ☐

Others (specify) ____

A13 Does the household sell any of crops? Yes ☐ No ☐

If No, go to A16

A14 Which of these does the household sell?

Maize	
Cassava	
Sorghum	
Millet	
Sweet Potatoes	
Vegetables	
Groundnuts	
Beans	

Others (specify) ____

A15. Where does the household sell these crops?

*In this **Village***	
*In neighboring **Village***	
In villages or towns far away	
In other provinces	

Others (specify)
____LIVESTOCK DETAILS

____

A16. Does the household own any livestock? Yes [ ] No [ ]

If No, go to A20

A17. What type of livestock does the household own and how many?

Livestock	**Number**
Cattle	
Goats	
Pigs	
Chickens	
Pigeons	
Guinea Fowls	
Ducks	
Rabbits	

Others (specify) ____

A18 Does the household sell any of these livestock? Yes ☐ No ☐

If **No** go to **A20**

A19. **How many of these livestock does the household sell each year?**

Livestock	**Number**
Cattle	
Goats	
Pigs	
Chickens	
Pigeons	
Guinea Fowls	
Ducks	
Rabbits	

Others (specify) ____

Main Woodland activities

____

A20. **Does the household collect any of the following from the bush?**

Timber (e.g. poles)	
Thatch	
Firewood	
Wood to make charcoal	
Mushrooms/wild vegetables	
Fruits	
Honey	
Medicinal Herbs	

Others (specify) ____

If all answers **No** go to **A24**

A21. **Does the household sell any of these?** Yes ☐ No ☐

If **No,** go to **25,** If **Yes,** go to **A24**

A22. Which of these products does the household sell?

Timber (e.g. poles) ☐

Thatch ☐

Firewood ☐

Wood to make charcoal ☐

Mushrooms/wild vegetables ☐

Fruits ☐

Honey ☐

Medicinal Herbs ☐

Others (specify) ____

***A23*. Who is normally involved in these activities**

List the names of household members that sell what has been collected in the bush

....

....

Your house

A24. Do you own or rent your house or are you provided with accommodation?

Own ☐

Rent ☐

Home provided ☐

A25. Do you have an indoor kitchen which is separate to your house? Yes ☐ No ☐

A26. How many separate buildings make up your house/dwelling excluding separate toilet(s) but including separate kitchen(s)? ....

A 27 Which of the buildings that make up the house or dwelling, excluding the toilet, have ceilings?

Main building ☐

Second building ☐

Third building ☐

Kitchen ☐

SECTION B: INFORMATION ABOUT ENERGY USE AND APPLIANCES

COOKING PRACTICES

B01. Which fuels are used most often for cooking in this household?

Main fuel	
Second fuel	
Third fuel	

B02. Which of the following appliances are used for cooking?

Wood open fire	
Wood stove	
Charcoal Stove	
Coal brazier	
Paraffin Primus	
Paraffin wick	
Gas stove	
Gas ring	
Electric stove	

Others (specify) ……………………………………………………………………………………………………..

B03. What are the 2 most important factors influencing the household choice of (the main fuel) for cooking?

Easy to get hold of	
Easy to use	
Safe to use	
Produces good heat	

Other reasons (specify) ……………………………………………………………………………………………..

B04 What is the main reason for using the 2nd fuel ?

First fuel not available	
Weather	
Safe to use	
Produces good heat	
Easy to get hold of	

Easy to use

Other reasons (specify) ………………………………………………………………………………………………….

B05. Which are the 4 most important factors influencing your choice of your energy devices?

Easy to move to different locations

Can use several fuels

Heat produced can easily be adjusted

Easy to get hold of

Food tastes better

Tradition

Easy to use

Aware of it

other(specify)..

B06. Do you close the pot with a lid when you are cooking? Yes No

B07. Do you close the pot with a lid when you are boiling water? Yes No

B08. How many times per week does the household cook breakfast, lunch and supper?

Season	**Times per week**		
	Breakfast	Lunch	Supper
November to April (rainy season)			
In Winter (May thru to July)			
August through October			

B09. if Breakfast is cooked, How long does it take to cook breakfast?

B10. if Lunch is cooked, How long does it take to cook lunch?

B11. if Supper is cooked, How long does it take to cook supper?

B09	Less 0:30		0h:30-1h:00		1h:00-1h:30	
B10	Less 0:30		0h:30-1h:00		1h:00-1h:30	
B11	Less 0:30		0h:30-1h:00		1h:00-1h:30	

B12 What food do you eat/cook most often for

breakfast…………………………………..lunch……………………………………….supper......................................?

Do you drink a hot drink at (Y= yes, N=no)

breakfast…………………………………..lunch……………………………………….supper......................................?

How many kg of (the main starch) do they buy/eat in a month?___________________kg

B13. Do you cook dry beans? Yes [ ] No [ ]

If No go to B17

If yes, how many kg of beans do they buy/eat in a month _______________________kg

B14. How many times per week do you cook beans?

Season	**Times per week**
November to April (rainy season)	
In Winter (May thru to July)	
August through October	

Other (specify)..

B15. How long does it take to cook?

Less 0:30		0h:30-1h:00		1h:00-1h:30	

B16. Do you pre soak the beans prior to cooking? Yes [ ] No [ ]

B17. How often do you add water to the pot when boiling a meal?

Top up Frequently	
Only when the water is completely running out	
I don't know	

B18. Do you extinguish your fire immediately after you have finished cooking?

Yes With water?		*Yes With sand?*		*No*	

If the answer to **B18** is **NO** ask **B19** if **Yes** go to **B20**

B19 why do you not extinguish your fire immediately after you have finished cooking?____

B20. Is the cooking area sheltered? Yes [ ] No [ ]

BATHING

B21. Which fuels are used most often for heating water in this household for bathing?

Main fuel	
Second fuel	
Third fuel	

B22. Which of the following appliances are used for water heating for bathing?

Wood open fire	
Wood stove	

Charcoal Stove	
Coal brazier	
Paraffin Primus	
Gas stove	
Gas ring	
Electric stove	
Other (Specify)	

B23 How much water is heated for the household for bathing each day?..........................(litres)

HEATING THE HOUSE

B24. Do you heat your house when it is cold? Yes ☐ No ☐

If **B24** is **NO** skip to **B30**

B25. Which fuels do you use most often to heat your house when its cold?

Main fuel	
Second fuel	
Third fuel	

B26. Which of the following appliances do you use within your house to keep warm?

Wood open fire	
Wood stove	
Charcoal Stove	
Coal brazier	
Paraffin Primus	
Electric heater	
Gas stove	
Gas ring	
Electric stove	
Other (specify)	

B 27 Which months does the household heat the house?

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec

B28 For how many hours a day does the household heat the house during those months?..

B29 How many days a week does the household use the second fuel for heating during those months?....................................

B 30 If the household does not heat their home, why not___________________________________ _

B31. Do members of the household ever heat themselves outside the house, for instance in a separate kitchen when it is cold? Yes [ ] No [ ]

If B**31** is **NO,** go to **B35**

B32. Which of the following appliances does the household use outside your house or perhaps in your separate kitchen for heating when it is cold?

Wood open fire		f. Electric heater	
Wood stove		Gas stove	
c. Charcoal Stove		h. Gas ring	
d. Coal brazier		Electric stove	
e. Paraffin Primus		Other (specify)	

B33 Which months does the household heat themselves outside the house or in your separate kitchen?

Jan	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**

B34 For how many hours a day does the household heat themselves outside the house during those months? ______________________(*hours)*

B35 If the household does not use any heating outside the home, why not______________________

____

LIGHTING

B36. Which fuels do you use most often for lighting in this household?

Main fuel	
Second fuel	
Third fuel	

B37. How many rooms in the household do you light with the following sources, please include all buildings?

Source	**Number of rooms**	**How long**
Candles		
Paraffin lamps		
Electricity		
firewood		
Others (specify)		

SECTION C: FIREWOOD USE, SUPPLY AND PURCHASE

FIREWOOD USE AND SUPPLY

C01. Does the household use firewood? Yes ☐ No ☐

*If **NO**, goto C02 and then move on to **Section D**. If **YES** go to **C03.***

C02. Why does the household NOT use firewood?

Not enough wood around this village ☐

It takes too much time or effort to collect ☐

Don't have transport for wood ☐

Electricity or paraffin easier to use ☐

Other (specify) ………

C03. How does the household get firewood?

Only collect firewood ☐

Only buy firewood ☐

Collect and buy firewood ☐

Other (specify) ………

C04 If the household does not purchase firewood, Why does the household not purchase firewood?

Can collect enough firewood around the village ☐

Firewood is expensive ☐

Enough labour to collect ☐

Prefer to buy other fuels ☐

Not possible to buy ☐

Other (specify) ………

*If they **buy firewood** goto **C04**, if they only collect the goto **C13**.*

C05. Why does this household purchase firewood?

Not enough wood around this village ☐

Too far to collect ☐

It takes too much time to collect ☐

Don't have transport for wood ☐

Other (specify) ………

C06. How often do you buy firewood and how much you do you buy each time?

How often		Amount	Local unit for firewood
November to April (rainy season)	*Every day*		
	Every 7 days		
	Every 30 days		
In Winter (May thru to July)	*Every day*		
	Every 7 days		
	Every 30 days		
August through October	*Every day*		
	Every 7 days		
	Every 30 days		

Other (specify)..

C07. How much does it cost?....................................per bundle/wheelbarrow/donkey cart/Vrag/(other)…………………………………….

Firewood Suppliers

C08. Where do you buy your firewood from?

In this ***Village***	
In neighboring ***Village***	
In villages or towns far away	
In other provinces	

Other (specify)…………………………………………………………………………………………....

C09 Do you have to travel to buy your firewood? Yes ☐ No ☐

C10. If Yes, how long does it take to get to your firewood supplier? ....hours

If they can not give time in hours ask this question:

What time do you leave to buy firewood?.......................

What time do you come back?..........................

C11 How do you travel to your firewood supplier? ……………………………….

C12. Does your household pay for transport to get to your suppliers? Yes ☐ No ☐

C13. If Yes, How much does the household pay for the return journey including the transport of firewood?

Amount in local money……………………………………………………

Collecting Firewood

If they DO collect firewood, ask the following questions:

C14. What type of trees do you use for firewood at the present time? Please list them in order of the type of trees you like to use the most. *(Fill in scientific name at a later stage)*

	Local name	**Scientific name**
a		
b		
c		
d		
e		

C15. Who normally collects firewood? *(If appropriate remind them that the answers are confidential)*

List the names of household members that collect firewood

....

....

....

....

C16. How do they carry the firewood back home?

Head	
Bicycle	
Wheelbarrow	
Motor vehicle	
Ox cart	

Other (specify) ……………………………………………………………………………………………………

C17. Please make a bundle of wood that you would collect when you go to get firewood *(tie with string and measure with spring balance)*

…… …………………… kgs

C18. Please make a bundle of wood that you would use in a day in each season *(tie with string and measure with spring balance)*

November to April (rainy season) …………………… kgs

In winter (May thru to July) …………………… kgs

August through October .... *kgs*

C19. How many bundles do you collect each time you go to collect firewood in each season?

November to April (rainy season) …………………… *bundles/wheelbarrows/donkey carts/*………….

In winter (May thru to July) …………………… *bundles/wheelbarrows/donkey carts/*……………

August through October .... *bundles/wheelbarrows/donkey carts/*………….

C20. How often do you go to collect firewood?

November to April (rainy season) ……………………*Times*/Week

In winter (May thru to July) …………………… *Times*/Week

August through October .... *Times*/Week

C21. What time do you leave to collect firewood?..............................

What time do you come back from collecting firewood?........................

Fill in appropriate number of hours……………………………………

C22. I would like to see how big the branches you collect are, may I measure a few that you have collected?

Measure 5 stems and average the circumference…………………………….*cm*

C23. What is more important when choosing a tree used for firewood?

a. Tree or branch size		**b. Species**	

C24. Where do you normally collect firewood from? *(If appropriate remind them that the answers are confidential)*

Around this homestead	
Bush around this village	
Bush around other villages	
Commercial forest land	
Protected areas & reserves	
Agricultural fields	

Other (specify) ……………………………………………………………………………………………………….

C25 Is the household able to collect or buy enough wood during the year?

Always [1]	
Mostly yes [2]	
Mostly no [3]	
No [4]	

Harvesting practices

C26. How do you collect your firewood? *(If appropriate remind them that the answers are confidential)*

- Collect from ground ☐
- Cut dry branches ☐
- Cut green/fresh branches ☐
- Cut dry trunks ☐
- Cut green/fresh trunks ☐
- *Other (specify) …….*

C27 Do you cut down trees for firewood? Yes ☐ No ☐

C28 When you cut down trees do you take the roots as well for firewood? Yes ☐ No ☐

C29. What tools do you use to collect the firewood?

- Break off by hand ☐
- Cutting knife/ Panga ☐
- Hand axe ☐
- Hand saw ☐
- Power saw ☐
- *Other (specify)……………………………………………………….*

C30. What size tree do you normally cut from?

- Lower than your waist [1] ☐
- Between waist and head [2] ☐
- Taller than your head [3] ☐

C31. Do you gather firewood from trees that have been previously cut and new shoots are regrowing from the cut stem? Yes ☐ No ☐

C32. Does it cost you any money to collect firewood? Yes ☐ No ☐

C33. If Yes, what are the associated costs? *(Fill in any other costs)*

Items	Cost
transportation	
labour	
Other (specify)	

Selling Firewood

C34. Does your household sell firewood? Yes ☐ No ☐

If the answer is ***NO****, go to section D*

If the answer is YES please proceed to FIREWOOD TRADERS QUESTIONNAIRE, (C36) and then continue with SECTION D.

C35. How much firewood sold per week in each season and for what price?

Season	Bundles		wheelbarrows		truckload/vrag	
	unit	price	unit	price	Unit	price
November to April (rainy season)						
In Winter (May thru to July)						
August through October						
Don't know						

SECTION E: ELECTRICITY SUPPLY, PURCHASE, USE AND APPLIANCES

E01. Does the household have an electricity connection? Yes ☐ No ☐

E02. If not, why not?...

If not, go to Section F

E03. In Bushbuckridge ask what the meter number is *meter number***……………………………………………. or note the GPS coordinates…………………………………………………………………….**

E04 How much does your household spend on electricity in a month?...

E05 Do you spend more on electricity in winter than in summer? Yes ☐ No ☐

E06 Over time has the household increased its spending on electricity? Yes ☐ No ☐

E07 How long does it take you to go and buy electricity?………………………………………*minutes/hours*

E08. In the event of power failures, what does the household use for lighting?

Diesel or petrol ☐ *d. Gas* ☐

Candles ☐ *e. Fuelwood* ☐

Kerosene (Paraffin) ☐

Other (specify) ....

E09. Does the household own any of the following electrical appliances?

	Number working	Number broken
Electric hot plate		
Electric stove with oven		
Fridge/freezer		
Microwave		
Heating the house		
Cooling the house e.g. fan		
Kettle		
Radio/hi fi		
TV		
Iron		
Cell Phone		

Other (specify) ....

E10 If the household has an electric fridge, Would you mind if I have a look at your fridge, I want to see how much energy it takes to run the fridge?_______________________________(comment size)

SECTION F: OTHER ENERGY SOURCES

KEROSENE (PARAFFIN) USE, SUPPLY AND PURCHASE

F01. Does the household use kerosene (paraffin) at any time of the year? Yes ☐ No ☐

F02. If yes, does the household use kerosene for any of the following? Indicate Yes or No

Make polish	
Run a fridge/freezer	
Selling for profit	
Ironing	

Other (specify) ....

F03.How much kerosene (paraffin) does the household buy in a month?

Amount in litres……………………………….

F04. How much kerosene (paraffin) does the household use in a month? (in litres)

Lighting	
Cooking	
Heating	
Floor polish	
Sell to others	

Other (specify) ....
....

F05. Where do you buy your kerosene (paraffin) usually?

*In this **Village***	
*In neighboring **Village***	
In villages or towns far away	
In other provinces	

Other (specify) ....

F06. How far from home are your usual suppliers? *Specify the distance in time ………………….……. (h)*

CAR BATTERY USE, SUPPLY AND PURCHASE

The car battery in this section refers to the exclusive use for operating household appliances – not for motor vehicles, motor cycles etc.

F07. Does the household use car batteries at any time of the year to operate household appliances? Yes ☐ No ☐

If **NO** go to **F14**

F08. Does the household own any of the following battery operated appliances?

Lights ☐

TV ☐

Radio/music centre ☐

Others (specify). ………………………………

F09. How much does your household pay for a car battery? *Amount in local money………………………*

F10. How many car batteries does your household own? ....

F11. How much does your household spend on charging car batteries per month?

Amount in local money…………………………………………

F12. How often does your household take the car battery for recharging?

Every day ☐

One or two days per week ☐

One or two days per month ☐

Other (specify) …………………………………………………………………

CANDLES USE, SUPPLY AND PURCHASE

F13. Does your household use candles at any time of the year? Yes ☐ No ☐

If **No** go to **F18**

F14 How many candles does the household buy each month?...

F15 How much does the household pay for candles each month?...................................

F16 How many candles does the household use each month for

Lighting ☐

Floor polish ☐

F17. Does the household sell any candles Yes ☐ No ☐

If **No** go to **F20**

F18 how many candles does the household sell in a month…………………………………

F19. How far from home are your usual suppliers? *Specify the distance in time ……………………*

APPLIANCES WORKING FROM A GENERATOR

F20. Are generators available in your immediate area? Yes ☐ No ☐ *Don't know* ☐

F21. Does your household own a generator? Yes ☐ No ☐

F22. *If yes*, how much per month do you pay for diesel?

Amount in local money……………………………

F23. Do you get power from a generator of a neighbour? Yes ☐ No ☐ **F24.**

How much per month do you pay for using the generator?

Amount in local money……………………….

F25. Does your household operate any appliances from a generator? Yes ☐ No ☐

F26. *If yes*, Specify 3 ones do you have.

1. Specify...
2. Specify...
3. Specify...

Thank you

END

FOR THE INTERVIEWER:
PLEASE ANSWER THESE QUESTIONS AS SOON AS POSSIBLE AFTER LEAVING THE HOUSEHOLD

(i) How well were you received by the person interviewed?

Excellent [1] Good [2] Not very well [3] With hostility [4] ☐

Other (Specify)... ....

(ii) Overall, how well did the interview go? ☐
Excellent [1] Good [2] Not very well [3] Badly [4]

Other (Please add your comments)

(vi) How well do you think the person interviewed understood the questions ? ☐

Very well [1] Not very well [2] With great difficulty [3]

(vii) Please add any other comments you think are relevant to the study.

Bibliography

- Abbott, J.I.O & Homewood, K. (1999) A History of Change: Causes of Miombo Woodland Decline in a Protected Area in Malawi. *The Journal of Applied Ecology*. 36:422-433.
- Adams, A.M., Cekan, J. & Sauerborn R. (1998) Towards a conceptual framework of household coping: reflections from rural West Africa. *Journal of the International African Institute* 68:263-283
- Adams M., Sibanda S. & Turner S. (1999) Land tenure reform and rural livelihoods in southern Africa. *Overseas Development Institute: Natural Resources perspectives* **39** URL: http://www.odi.org.uk/resources/docs/2883.pdf accessed online on 02/02/2012
- AGECC (The Secretary- General's Advisory Group on Energy and Climate Change) (2010) Energy for a Sustainable Future, *Report and Recommendations*, New York, United States of America
- Agresti, A. 1996. An Introduction to categorical data analysis. NY: John Wiley
- Antrop, M. (2005). Why landscapes of the past are important for the future. *Landscape and Urban Planning,* 70(1–2): 21–34.
- An, L., Lupi, F., Liu, G., Linderman, M.A, Huang, J.Y. (2002). Modelling the choice to switch from fuelwood to electricity: implications for giant panda habitat conservation. *Ecological Economics*, 42(3):445-457.
- Arabatzis G., & Malesios Ch. (2011) An econometric analysis of residential consumption of fuelwood in a mountainous prefecture of Northern Greece. *Energy Policy,* doi: 10.1016/j.enpol.2011.10.003, accessed online on 02/12/2011
- Arnold J.E.M. & Ruiz-Perez M. (2001) Can non-timber forest products match tropical forest conservation and development objectives? *Ecological Economics* 39:437-447
- Arnold M., Kohlin G., Persson R. & Shepherd G. (2003) Fuelwood revisited-what has changed in the last decade? Center for International Forestry Research (CIFOR), Occasional Paper No. 39
- Arnold, M., Kohlin, G. & Persson, R. (2006) Woodfuels, livelihoods and policy interventions: changing perspectives. *World Development* 34: 596-611
- Aron, J., Eberhard, A.A. & Gandar, M.V. (1991) Fuelwood deficits in rural South Africa. *Biomass and Bioenergy* 1: 89-98.

- Azar, C., Holmberg, J. & Lindgren, K. (1996) Socio-ecological indicators for sustainability, *Ecological Economic*, 18:89-112
- Bagachwa M.S.D., Sechambo F., Sosovele H., Kulundwa K., Naho A. & Gramwell E. (1995). Structural Adjustment and Sustainable Development in Tanzania. University of Dar es Salaam Press: Dar es Salaam.
- Baland, J.M., Bardhan, P., Das, S., Mookherjee, D., Sarkar, R. (2010) The Environmental Impact of Poverty: Evidence from Firewood Collection in Rural Nepal. *Economic Development and Cultural Change*, 59(1): 23–61.
- Banks, D.I., Griffin, N., Shackleton, C.M., Shackleton, S.E., Mavrandonis, J. (1996) Wood supply and demand around two rural settlements in a semi-arid savanna, South Africa. *Biomass and Bioenergy,* 11:319-331.
- Barbier, E.B., Burgess, J.C. & Grainger, A. (2010) Land Use Policy The forest transition: towards a more comprehensive theoretical framework. *Land Use Policy* 27: 98-107.
- Bhattarisai *et al* (1997). RWEDP, Regional Wood Energy Development Programme, (1997).. Regional study on wood energy: today and tomorrow in Asia. Field Document No. 50. Regional Wood Energy Development Programme in Asia GCP/RAS/154/NET. Bangkok, Thailand: FAO;
- Biggs R., Bohensky E., Desanker P.V., Fabricius C., Lynam T., Misselhorn A.A., Musvoto C., Mutale M., Reyers B., Scholes R.J., Shikongo S. & van Jaarsveld A.S. (2004). *Nature supporting people: the southern African Millenium Ecosystem Assessment- integrated report*. CSIR, Pretoria
- BLM, Bushbuckridge Local Muncipality. (2010) Spatial Development Framework. Bushbuckridge, Mpumalanga Province, South Africa.
- Botha H. & Donaldson R. (2000) Using a combination of digital aerial photography and satellite remote sensing to assist temporary restructuring in an urban area of South Africa. *GeoCarto International* 15:53-62
- Bradley, P.N. & Campbell, B.M., (1998) Who plugged the gap? Reexamining the woodfuel crisis in Zimbabwe. *Energy and the Environmment.* 9:235-255
- Broadhead, J., Bahdon, J. & Whiteman, A. (2001) Past Trends and future prospects for the utilisation of wood for energy: Annexes 1 and 2. *Global Forest Products Outlook Study Working Paper No. GFPOS/WP/05.* Rome, FAO

- Brouwer ID, Hoorweg JC & van Liere MJ., (1997). When households run outh of fuel: responses of rural households to decreasing fuelwood availability, Ntcheu district, Malawi. *World Development*. 25: 255-266
- Burnham, K.P. and Anderson, D.R. 2002. Model Selection and Multimodel Inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York. Bushbuckridge Spatial Development Plan, 2010)
- Butler, J., Rotberg, R.I. & Adams, J. (1978) *The Black Homelands of South Africa: The Political and Economic Development of Bophuthtswana and Kwa-Zulu.* Berkeley: University of California Press, http://ark.cdlib.org/ark:/13030/ft0489n6d5/ accessed on 18/01/2012
- Campbell B.M., Vermeulen S.J., Mangono J.J. & Mabugu R. (2003) The energy transition in action: urban domestic fuel choices in a changing Zimbabwe, *Energy Policy*, 31:553-562
- Carr E. & McCusker B. (2009) The co-production of land use and livelihoods change: implications for development interventions. *GeoForum,* 40:568-579
- Carter M.R. & May J. (1999) Poverty, livelihood and class in rural South Africa. *World Development* 27:1-20
- Cecelski E. (1984) The rural energy crisis, women's work and family welfare: perspectives and approaches to action. International Labour Organisation, Geneva, Switzerland.
- Chidumayo EN. (1993) Zambian Charcoal Production: miombo woodland recovery. In Energy Policy SPECIAL ISSUE Vol.21 (5)
- Chidumayo, E.N. (1993) Zambian Charcoal Production: miombo woodland recovery. In *Energy Policy* SPECIAL ISSUE Vol.21 (5)
- Chidumayo, E.N. (1997). *Miombo Ecology and Management: An introduction*. Practical Action Publishing
- Cline-Cole, R.A., Main, H.A.C. & Nichol, J.E. (1990) On Fuelwood Consumption, Population Dynamics and Deforestation in Africa. *World Development* 18(4): 513-527.
- Coetzer, K.L., Erasmus, B.F.N., Witkowski, E.T.F. & Bachoo A.K. (2010) Land-cover change in the Kruger to Canyons Biosphere Reserve (1993-2006): A first step towards creating a conservation plan for the subregion. *South African Journal of Science* 106(7/8): :1-10 doi 10.4102/sajs.v106i7/8.221

- Cooke St. Clair, P., Hyde, W.F., Köhlin, G. (2002) "A Woodfuel Crisis: Where and For Whom?", Fuelwood-Crisis or Balance? Workshop Proceedings, Marstrand June 6-8, 2001, Environmental Economics Unit, Department of Economics, Göteborg University, Sweden. http://www.hgu.gu.se/files/nationalekonomi/eeu/publications/cifor/chapter2.pdf. Accessed 05/06/2011
- Coppin P., Jonckheere I., Nackaerts K. & Muys B. (2004). Digital change detection methods in ecosystem monitoring: a review. *International Journal of Remote Sensing* 25:1565-1596
- Cousins B. (1999) Invisible capital: the contribution of communal rangelands to rural livelihoods in South Africa. *Development Southern Africa* 16: 299–318
- Cunningham, A.B. (2001). *Applied Ethnobotany: people, wild plant use and conservation.* Earthscan, London.
- Davidar, P., Sahoo, S., Mammen, P.C., Acharya, P., Puyravaud, J., Arjunan, M., Garrigues, J., Roessingh, K. (2010) Assessing the extent and causes of forest degradation in India: Where do we stand? *Biological Conservation*, 143: 2937-2944.
- Davidson O., & Winkler H. (1996) Energy Policy. In: Winkler H. (ed.) *Energy Policies for Sustainable Development in South Africa: Options for the Future.* Energy Research Centre, University of Cape Town, South Africa
- Davis M. (1995) Fuel choice in rural communities. *Energy for Sustainable Development*, **2(3):**45-48
- Davis, M. (1998) Rural household energy consumption: the effects of access to electricity—evidence from South Africa. *Energy Policy*, 26:207–217.
- de Montalambert MR & Clement J., (1983). Fuelwood supplies in the developing Countries. Forestry Paper No. 42. Rome: FAO; 1983
- De Wet C. (1995) *Moving together, drifting apart: betterment planning and villigisation in a South African homeland.* Witwatersrand University Press, Johannesburg, South Africa.
- DeFries R. S., Foley J. A., & Asner,G. P. (2004). Land-use choices: balancing human needs and ecosystem function. *Frontiers in Ecology and the Environment,* 2(5):249–257.
- Denman K.L. (2007) Couplings between changes the climate system and biogeochemistry. Climate Change 2007: the physical science basis. Contribution of

Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom

- Department of Agriculture, Forestry and Fisheries (DAFF) (2010). Strategic plan for the Department of Agriculture, Forestry and Fisheries 2010/11. DAFF, Pretoria, South Africa
- Department of Energy (DoE) (2010). Strategic Plan for the Department of Energy 2010/11 -2012/13. DoE, Pretoria, South Africa
- Department of Minerals & Energy (DME) (1998) White Paper on Energy Policy for South Africa. Department of Minerals & Energy Affairs, Pretoria, South Africa.
- Department of Minerals & Energy (DME) (2003) Integrated Energy Plan for the Republic of South Africa, DME, Pretoria, South Africa.
- Department of Minerals & Energy (DME) (2003) White Paper on Renewable Energy for South Africa. Department of Minerals & Energy, Pretoria, South Africa.
- Dewees PA., (1989). The woodfuel crisis reconsidered: Observations on the dynamics of abundance and scarcity. *World Development*. 17:1159-1172.
- Dovie D.B.K., Witkowski E.T.F & Shackleton C.M. (2005) Monetary valuation of livelihoods for understanding the composition and complexity of rural households. *Agriculture and Human Values* 22:87–103
- Dovie DBK, Witkowski ETF, Shackleton CM. (2004). The fuelwood crisis in Southern Africa- relating fuelwood use to livelihoods in a rural village. *GeoJournal*.60: 123-133
- Dovie, D.B.K. (2003) Rural economy and livelihoods from the non-timber forest products trade. Compromising sustainability in southern Africa? *International Journal of Sustainable Development and World Ecology* **10:** 247–262.
- Dovie, D.B.K., Shackleton, C.E., Witkowski, E.T.F. (2002) Direct-use values of woodland resources consumed and traded in a South African village. *International Journal of Sustainable Development and World Ecology*. 9: 269-283
- Drigo R. and F. Salbitano. (2008) WISDOM for Cities. Analysis of wood energy and urbanization aspects using WISDOM methodology. FAO Forestry Department. Urban forestry – Wood energy. FAO URL: http://www.fao.org/docrep/010/i0152e/i0152e00.htm accessed on-line 28/01/2012
- Drigo R., O.R. Masera and M.A. Trossero (2002). Woodfuel Integrated Supply/Demand Overview Mapping – WISDOM: a geographical representation of woodfuel priority areas. Food and Agricultural Organisation (FAO), Rome, Italy

- Eberhard, A.A. (1990) Energy consumption patterns and supply problems in underdeveloped areas of South Africa. *Development Southern Africa* 7: 335–346
- Eberhard, A.A. (1992) Shifting paradigms in understanding the fuelwood crisis: policy implications for South Africa. *Journal of Energy Research and Development in South Africa*, 3:19–25.
- Eckholm, E.P. (1975) The Other Energy Crisis: Firewood. Worldwatch Paper 1. Worldwatch Institute, Washington DC.
- ESKOM. (2011) Customer network business: Distribution division: *Free Basic Electricty*, www.http://financialresults.co.za/2011/eskom_ar2011/cnb_distribution02.php accessed on 21/02/2012
- FAO (Food and Agriculture organisation) 2003. Sustainable wood energy systems. http://www.fao.org/forestry/foris/webview/forestry2/index.jsp?siteId=3741&langId=1&sitetreeId=11477
- Faraway J.(2011) faraway: Functions and datasets for books by Julian Faraway. R package version 1.0.5. http://CRAN.R-project.org/package=faraway
- Farina A. (2000) The cultural landscape as a model for the integration of ecology and economics. *BioScience* 50: 313-320
- Fisher J.T., Witkowski E.T.F., Erasmus B.F.N., Van Aardt J., Asner G.,P., Wessels K., Mathieu R. (2012). Human-modified landscapes: patterns of fine-scale woody vegetation structure in communal savanna rangelands. *Environmental Conservation pages*
- Food and Agriculture Organisation (FAO). (1981) Map of the Fuelwood Situation in the Developing Countries. FAO, Rome, Italy.
- Fox J. & Weisberg S. (2011) An R. companion to applied regression, second edition. Thousand Oaks, California: Sage, United States of America. http://socserv.socsci.mcmaster.ca/jfox/Books/Companion
- Fox J., Krummel J., Yarnasam S., Elasingh M. & Podger N. (1995) Land-use and landscape dynamics in Northern Thailand: assessing change in three upland watersheds. *Ambio* 24:328-334
- Frost, P. & Chidumayo, E. (1996) Population biology of miombo trees. In Campbell, BM (Ed), *The miombo in transition: Woodlands & Welfare in Africa*. Centre for International Forestry Research (CIFOR), Bogor, pp 11-57

- Frost, P. (1996) The ecology of miombo woodlands. In Campbell, BM (Ed), *The miombo in transition: Woodlands & Welfare in Africa*. Centre for International Forestry Research (CIFOR), Bogor, pp 11-57
- Frost, P.G.H., Medina, E., Menaut, J.C., Solbrig, O., Swift, M. & Walker, B. (1986) Responses of savannas to stress and disturbance. *Biology International* (Special Issue) 10:1-78
- Gambiza J, Bond W, Frost P & Higgins S (2000).   A simulation model of miombo woodland dynamics under different management regimes.   *Ecological Economics* **33**:353–368
- Gaugris, J.Y. & van Rooyen, M.W. (2010) Woody vegetation structure in conserved versus communal land in a biodiversity hotspot : A case study in Maputaland, South Africa. *South African Journal of Botany* 76(2): 289-298
- Gaunt C.T. (2002) Electricity supply basics to meet the challenges of distribution. Technical report, 19th Association of Municipal Electricity Undertakings, Technical Meeting, Upington, South Africa
- Gaunt C.T. (2003) Electrification technology and processes to meet economic and social objectives in Southern Africa. Ph.D thesis, Department of Electrical Engineering, University of Cape Town, South Africa
- Geist, H.J. & Lambin, E.F. (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *Bioscience,* 52:143-150
- Geist, H.J. & Lambin, E.F. (2006) What drives Tropical Deforestation? A meta-analysis of the proximate and underlying causes of deforestation based on subnational case study evidence. *LUCC Report Series No. 4,* Louvain-la-Neuve
- Gennaretti F., Ripa M.N., Gobattoni F., Boccia L. & Pelorosso R. (2011) A methodology proposal for land cover change analysis using historical aerial photos. *Journal of Geography and Regional Planning,* 4(9):642-556
- Ghilardi, A., Guerrero, G.   & Masera, O. (2007) A GIS-based methodology for highlighting fuelwood supply/demand imbalances at the local level: A case study for Central Mexico.   *Biomass & Bioenergy* **33:**957-972
- Giannecchini, M., Twine, W.   & Vogel C.   (2007) Landcover Change and human-environment interactions in a rural cultural landscape in South Africa.   *The Geographic Journal* **173:**26-39
- Gill, J. (1987) Improved stoves in developing countries: a critique. *Energy Policy,* 15(2):135-144

- Grainger, A. (1993) Rates of deforestation in the humid tropics: estimates and measurements. *The Geographic Journal*.159: 33-44
- Grainger A. (1999). Constraints on Modelling the Deforestation and Degradation of Tropical Open Woodlands. *Global Ecology and Biogeography*, 8:179-190.
- Griffin., N.J., Banks, D.I., Mavrandonis, J., Shackleton, C.M., Shackleton, S.E. (1993). Fuel use in six rural settlements in Gazankulu. *Journal of Energy in South Africa*. 4:68-73
- Grundy IM, Campbell BM, Balenereho S, Cunliffe R, Tafangenyasha C, Fergusson R and Parry D., (1993). Availability and use of trees in Mutanda resettlement area, Zimbabwe. *Forest Ecology and Management*. **56**: 243-266.
- Gundimeda, H., Köhlin, G. (2008) Fuel demand and elasticities for energy and environmental policies: Indian sample survey evidence. *Energy Economics*, 30:517-546
- Gupta, G., Köhlin, G. (2006) Preferences in urban domestic fuel demand: The case of Kolkata, India. Ecological Economics, 57:107-121
- Haggith, M., Praben, R., Mudavanhu, H., Matose, .F, Mutimukuru, T., Nyirenda, R. & Standa-Gunda, W. (2003) The Challenges of effective model scoping: A case study from the Mafungautsi Forest margin, Zimbabwe. *Small-scale Forest Economics, Management and Policy*. 2(2):155-169
- Hall, D.O. (1994) Introduction, Summary and Conclusions. In Hall DO & Mao YS (Eds). *Biomass Energy and coal in* Africa. Afrepen and Zed, London.
- Harmse A., (2010). Node Selection for the Integrated Sustainable Rural Development Programme in South Africa. *Development Southern Africa*, 27(3):429-445.
- Harrington, R.A. & Fownes, J.H. (1995) Radiation interception and growth of planted and coppice stands of four fast-growing tropical trees. *Journal of Applied Ecology* 32: 1–8.
- Hartter, J. & Boston, K. (2007) An integrated approach to modelling resource utilisation for rural communities in developing countries. *Journal of Environmental Management* 85:78–92
- He, G., *et al*. (2009). Spatial and temporal patterns of fuelwood collection in Wolong Nature Reserve: implications for panda conservation. *Landscape and Urban Planning*. 92:1-9
- Hegan, R.L., Hauer, G. & Luckert, M.K. (2004) Is the Tragedy of the Commons Likely? Factors Preventing the Dissipation of fuelwood Rents in Zimbabwe. *Land Economics* 79:181-197

- Higgins, S., Shackleton, C.M. & Robinson, E.R. (1999) Changes in woody community structure and composition under contrasting landuse systems in a semi-arid savanna, South Africa. *Journal of Biogeography*, 26: 619-627
- Horgan, G.P. (2002) Wood energy economics. *Unasylva* 211 (53): 23-29
- Hosier, R.H., Dowd, J., 1987. Household fuel choice in Zimbabwe: an empirical test of the energy ladder hypothesis. *Resources and Energy* 9: 347–361
- Hosmer, D.W. and Lemeshow, S. 2000. Applied logistic regression. John Wiley &Sons Inc. New York
- Howells, M.I., Alfstad, T., Victor, D.G., Goldstein, G. & Remme, U. (2003) An Energy Model for a Low Income Rural African Village. Working Paper number 18. Energy Research Centre, University of Cape Town
- International Energy Agency (IEA) (2000). *World Energy Outlook.* IEA, Paris
- International Energy Agency (IEA) (2002). *World Energy Outlook.* IEA, Paris
- International Energy Agency (IEA) (2003). *World Energy Outlook.*IEA, Paris
- International Energy Agency (IEA) (2009) *World Energy Outlook*, Paris, France
- International Energy Agency (IEA) (2010) *World Energy Outlook*, Paris, France
- International Energy Agency (IEA) (2011) *World Energy Outlook*, Paris, France
- Kaimowitz, D. & Angelsen, A. (1998) Economic models of tropical deforestation – a review, Center for International Forestry Research (CIFOR), BOGOR, Indonesia.
- Karekezi, S. (2002). Poverty and energy in Africa- A brief review. *Energy Policy*, 30:915-919.
- Karekezi, S., Lata, K. & Coelho, S.T. (2004) Traditional Biomass Energy: improving its use and moving to modern energy use. Thematic background paper for the International Conference for Renewable Energies, Bonn 2004
- Karekezi, S., Mapako, M. & Teferra, M. (2002) Guest Editorial. *Energy Policy* 30: 909-913
- Kaschula S. (2003). Integrating indigenous and ecological perspectives on harvesting and coppice response of three savanna fuelwood species in the Limpopo province. MSc thesis, unpublished. University of the Witwatersrand, South Africa.
- Kaschula S., Twine W. & Scholes M.C. (2005) Coppice Harvesting of fuelwood Species on a South African Common: Utilizing Scientific and Indigenous Knowledge in Community Based Natural Resource Management. *Human Ecology* 33:387-418

- Kaschula, S., Twine, W.C., Scholes, M.C. (2005) The effect of catena position and stump characteristics on the coppice response of three Savanna fuelwood species. *Environmental Conservation*. 32:76-84
- Kennedy AD., (1998). Coppicing of *Tarconanthus camphorates* (Compositae) as a source os sustainable fuelwood production: an example from the Laikipia Plateau, Kenya. *African Journal of Ecology*. **36:** 148-158
- Khorram S., Biging G. S., Chrisman N. R., Colby D. R., Congalton R. G.,Dobson J. E., Ferguson R. L., Goodchild M. F., Jensen N, J. R. & Mace T. H.(1999) Accuracy assessment of remote sensing-derived change detection. *ASPRS Monograph*. Bethesda, Md.
- Kindt, R. & Coe, R. (2005) Tree diversity analysis. A manual for common statistical methods for ecological and biodiversity studies. [WWW.document] URL: http://www.worldagroforestry.org/treesandmarkets/tree_diversity_analysis.asp
- King B. (2011) Spatialising livelihoods: Resource access and livelihood spaces in South Africa. *Transactions of the Institute of British Geographers* 36(2):297-313.
- Kirkland T., Hunter L. & Twine W. (2007) "The Bush is No More:" Insights on natural resource availability from the Agincourt Field Site in Rural South Africa. *Society and Natural Resources* **20(4)**:337-350
- Kohl M, Baldauf T., Plugge D & Krug J. (2009) Reduced emissions from deforestation and forest degradation (REDD): a climate change mitigation strategy on a critical track, *Carbon Balance and Management*, **4:**10 doi:10.1186/1750-080-4-10 accessed online on 15/11/2011
- Kotze, A.I. (2001) The South African Electrification programme: past lessons and future prospects. Pretoria; Department of Minerals and Energy Affairs, Pretoria, South Africa.
- Lambin E.F. & Meyfroidt P. (2010) Land-use transitions: Socio-ecological feedback *versus* socio-economic change, *Land Use Policy*, 27(2):108-118.
- Lambin E.F. (1999) Monitoring Forest Degradation in tropical regions by remote sensing: some methodological issues, *Global Ecology and Biogeograph*, 8: 191-198
- Lambin E.F., Baulies X., Bocksteal N., Fischer G., Krug T., Leemans R., Moran E.F., Rindfuss R.R., Sato Y., Skole D., Turner II B.L. and Vogel C. (1999) Land use and land cover change: implementation Strategy. IGBP Report No. 48 and IHDP Report No. 10 International Geosphere-Biosphere Programme and the Human Dimensions of Global Environmental Change Programme, Stockholm

- Lambin E.F., Geist H.J. & Lepers E. (2003) Dynamics of land use and cover change in tropical regions. *Annual Review of Environmenta and Resources,* **28:**205-241.
- Lambin E.F., Turner B.L., Geist H.J., Agbola S.B., Angelsen A., Bruce J.W., Coomes O.T., Dirzo R., Fischer G., Folke C., George P.S., Homewood K., Imbernon J., Leemans R., Li X., Moran E.F., Mortimore M., Ramakrishnan P.S., Richards J.F., Skanes H., Steffen W., Stone G.D., Svedin U., Veldkamp T.W., Vogel C. & Xu J. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*. 11:261–269
- Lambin, E.F. (1999) Monitoring Forest Degradation in tropical regions by remote sensing: some methodological issues. *Global Ecology and Biogeography.* 8: 191-198
- Leach M & Mearns R., (1988). Beyond the woodfuel crisis: people, land and trees in Africa. London: Earthscan Publications; 1988.
- Lefsky, M.A., Cohen, W.B., Harding, D.J., Parker, G.P., Acker, S.A. & Gower, S.T. (2002) Lidar remote sensing of above-ground biomass in three biomes, *Global Ecology & Biogeography*, 11:393-399
- Lepers E., Lambin E.F., Janetos A.C., DeFries R., Achard F., Ramankutty N. & Scholes R.J. (2005) A synthesis of information on rapid land-cover change for the period 1981-2000, *BioScience*, 55(2):115-124
- Lipton, M., F. Ellis, and M. Lipton (eds.) (1996). Land Labor and Livelihoods in Rural South Africa, Vol. 2: KwaZulu-Natal and Northern Province. Durban, South Africa: IndicatorPress.
- Low, A.B. & Rebelo, A.G. (1996) *Vegetation of South Africa, Lesotho and Swaziland*, Department of Environmental Affairs and Tourism, Pretoria
- Lu D., Mausel P., Brondizio E. & Moran E. (2003) Change detection techniques. *International Journal of Remote Sensing* 25:2365-2407
- Luoga E.J., Witkowski E.T.F. & Balkwill, K. (2000). Economics of charcoal production in miombo woodlands of eastern Tanzania: some hidden costs associated with commercialization of the resources. *Ecological Economics* 35: 243-257.
- Luoga, E.F., Witkowski, E.T.F. & Balkwill, K. (2002) Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania. *Forest Ecology and Management*. 164: 15-30
- Luoga, E.F., Witkowski, E.T.F. & Balkwill, K. (2004) Regeneration by coppicing (resprouting) of miombo (African Savanna) trees in relation to land use. *Forest Ecology and Management*, 189: 23-35

- Lykke, A.M. (1998) Assessment of species composition change in savanna vegetation by means of woody plants' size class distributions and local information. *Biodiversity Conservation* 7: 1261-1275.
- MacDonald DH, Adamowicz WL, Luckert MK. (1998). Valuing Fuelwood Resources Using a Site Choice Model of Fuelwood Collection. Staff Paper 98-01, Department of Rural Economy**,** Faculty of Agriculture, Forestry and Home Economics,University of Alberta, Canada
- MacDonald, D.H., Adamowicz, W.L. & Luckert, M.K. (2001) Fuelwood collection in North-Eastern Zimbabwe: valuation and caloric expenditures. *Journal of Forest Economics* 7:29–52.
- MacKenzie J. & Weaver T.F. (1986) A household production analysis of fuelwood demand in Rhode Island. *Northeaster Journal of Agricultural and Resource Economics,* **15:**53-60
- Madubansi M & Shackleton C.M. (2006). Changing Energy Profiles and consumption patterns following electrification in five rural villages, South Africa. *Energy Policy*. 34:4081-4092
- Madubansi M & Shackleton C.M., (2007). Changes in fuelwood use and species selection following electrification in the Bushbuckridge loweveld, South Africa. *Journal of Environmental Management.* 83:416-426
- Maredza M, Hofman K, Tollman SM., (2011) A hidden menace: cardiovascular disease in South Africa and the costs of an inadequate policy response. *SA Heart* 8(1):48-55
- Masera O, Ghilardi A, Drigo R & Trossero MA (2006). WISDOM: A GIS-based supply and demand mapping tool for woodfuel management. *Biomass and Biomass energy* **30:**618–637
- Masera O., Drigo R., Trossero M.A. (2003). Woodfuels Integrated Supply/Demand Overview Mapping (WISDOM): a methodological approach for assessing woodfuel sustainability and support wood energy planning. FAO–EC Partneship Programme; Wood Energy Programme—FAO Forestry Department. Rome: FAO
- Masera, O.R., Saatkamp, B.D. & Kammen, D.M., (2000) From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model for rural households, *World Development*, 28(12):2083-2103.

- Masera, O.R., Saatkamp, B.D. & Kammen, D.M., (2000) From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model for rural households, *World Development*, 28(12):2083-2103.

- Mataya, C., Gondo, P. & Kowero, G. (2002) Evolution of land policies and legislation in Malawi and Zimbabwe: implications for forestry development. *Zimbabwe Science News,* 36:18–27

- May J. (2000) The structure and composition of rural poverty and livelihoods in South Africa, in Cousins B., *At the Crossroads: Land and Agrarian Reform in South Africa into the 21st Century,* Programme for Land and Agrarian Studies, University of the Western Cape, 21-34.
- Mbeki T. (2001) Address of the President of South Africa at the Opening of Parliament. Delivered by the State President at the Houses of Parliament, February. The Presidency, Cape Town, South Africa.
- McCusker B. & Ramudzuli M. (2007) Apartheid spatial engineering and landuse change in Mankweng, South Africa: 1963-2001. *The Geographic Journal* 173(1):56-74
- McCusker B. (2004) Land-use and landcover change as an indicator of transformation of recently redistributed farms in Limpopo Province, South Africa. *Human Ecology* 32:49-75
- Mertens, B. & Lambin, E. F. (2000) Land-cover change trajectories in Southern Cameroon. *Ann. Assoc. Am. Geogr.* 90 (3): 467–494
- Millenium Ecosystem Assessment (MEA) (2005). *Ecosystems and Human Well-being: Biodiversity Synthesis.* World Resources Institute, Washington, DC. United States of America
- Misana, S., Mung'ong'o, C. & Mukamuri, B. (1996) Miombo woodlands in the wider context:macro-economic and inter-sectoral influences, in: Campbell, B. (Ed.), *The Miombo in Transition: Woodlands and Welfare in Africa*. Centre for International Forestry Research, Bogor, Malaysia, pp. 73-98.
- Mlambo, D. & Huizig, H. (2004) Household responses to fuelwood scarcity: a case study of two villages in Zimbabwe. *Land Degradation and Development*. 15: 271-281

- Mlambo, D. & Huizig, H. (2004) Household responses to fuelwood scarcity: a case study of two villages in Zimbabwe. *Land Degradation and Development,* 15:271-281

- Muetzelfeldt, R. & Massheder, J. (2002) The Simile visual modelling environment. *European Journal of Agronomy.* 18(3/4):345-358

- Murphy C. (1995) Implications of poverty for black rural women in KwaZulu-Natal. Report prepared for the South African Participatory Poverty Assessment, Institute for Natural Resources, Pietermaritzburg, South Africa.
- Mwavu E.N. & Witkowski E.T.F. (2008) Land-use and cover changes (1988-2002) around Budongo Forest Reserve, NW Uganda: Implications for forest and woodland sustainability. *Land Degradation & Development* 19:606-622
- Namaalwa J, Sankhayan PL & Hofstad O. (2007). A dynamic bio-economic model for analyzing deforestation and degradation: An application to woodlands in Uganda. *Forest Policy and Economics* 7:479-495
- Namaalwa, J., Eid, T. & Sankhayan, P.L. (2005) A multi-species density-dependent matrix growth model for the dry woodlands of Uganda. *Forest Ecology and Management.* 213:312– 327
- Nantel, P., Gagnon,D. & Nault, A. (1996) Population vianility analysis of American ginseng and wild leek harvested in stochastic environments. *Conservation biology,* 10(2):608-621
- Neke K.S., Owen-Smith N., Witkkowski E.T.F. (2006). Comparative resprouting response of Savanna woody pland species following harvesting: the value of persistence. *Forest Ecology and Management*. 232:114-123
- Neke KS. (2004). The regeneration ecology of savanna woodlands in relation to human utilisation. PhD thesis. Unpublished. University of the Witwatersrand, South Africa.
- Netshiluvhi, T.R. & Scholes, R.J. (2001) *Allometry of South African woodland trees*. CSIR, Division of Water, Environment and Forest Technology, Pretoria.
- Niehaus I. (2002) Ethnicity and the boundaries of belonging: Reconfiguring Shangaan identity in the South African Lowveld, *African Affairs,* 101:557-583
- Nissing C. & von Blottnitz H. (2010) Renewable energy for sustainable urban development: redefining the concept of energisation. *Energy Policy*, 38(5):2179-2187
- Obiri, J., Lawes, M. & Mukolwe, M. (2002) The dynamics and sustainable use of high-value tree species of the coastal Pondoland forests of the Eastern Cape Province, South Africa. *Forest Ecology and Management* 166: 131-148.
- Osho, J.S.A. (1991) Matrix model for tree population projection in a tropical rain forest of south-western Nigeria. *Ecological. Modeling.* 59: 247–255
- Ouedraogo B.(2006) Household energy preferences for cooking in urban Ougadougou, Burkina Faso, *Energy Policy*, **34(18)**:3787-3795

- Owen-Smith, N. (2007) Introduction to Modeling in Wildlife and Resource Conservation. Wiley Publishing.
- Pachauri, S., Spreng, D., 2004. Energy Use and Energy Access in Relation to Poverty. Economic and Political Weekly, 39 (3), 271-278.
- Paradzayi C. (2012) *Polarimetric Synthesis Aperture Radar (PolSAR) Above-ground Biomass Estimation in Communal African Savanna Woodlands*, unpublished PhD Thesis, University of Johannesburg, South Africa.
- Pattanayak SK, Sills EO & Kramer RA (2004). Seeing the forest for the fuel. *Environment and Development Economics* 9: 155–179
- Pereira H.M. & Cooper H.D. (2006) Towards the global monitoring of biodiversity change. *TRENDS in Ecology and Evolution*, 21:123-129
- Pereira, M.G., Sena, J.A., Freitas, M.A.V. & da Silva, N.F. (2011) Evaluation of the impact of access to electricity: A comparative analysis of South Africa, China, India and Brazil. *Renewable and Sustainable Energy Reviews*, 15:1427-1441
- Petit C., Scudder T. & Lambin E. (2001) Quantifying processes of land-cover change by remote sensing: resettlement and rapid land-cover changes in south-eastern Zambia. *International Journal of Remote Sensing*, 22:3435-3456.
- Petit C.C. & Lambin E.F. (2001) Integration of multi-source remote sensing data for land cover change detection. *International Journal of Geographic Information Science*, 15(8):785-803
- Petit, C., Scudder, T. & Lambin, E. (2001) Quantifying processes of land-cover change by remote sensing: resettlement and rapid land-cover changes in south-eastern Zambia. *International Journal of Remote Sensing*. 22:3435-3456
- Platzky L & Walker C for the Surplus Peoples Project. (1985) *The Surplus People: Forced Removals in South Africa*, Ravan Press, Johannesburg, South Africa.
- Po, J.Y. et al. (2011). Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis. *Thorax*. 66:232-239.
- Pollard S., Shackleton C.M. & Carruthers J. (2003) Beyond the Fence: People and the Lowveld Landscape. . In: *The Kruger Experience: Ecology and Management of Savanna Heterogeneity*. eds J.T. du Toit, K.H. Rogers & H.C. Biggs, pp. 83-129. Island Press Washington
- Pollard SR, Perez de Mendiguren JC, Joubert A, Shackleton CM, Walker P, Poulter T, White M., (1998). Save the Sand Phase 1. Feasibility study: the development of a

proposal for a catchment plan for the sand river catchment (Mpumalanga/Northern Province). Report submitted by AWARD to the Department of Water Affairs and Forestry, Pretoria

- Pollard, S.R., Shackleton, C. & Carruthers, J. (2003) Beyond the Fence: People and the Lowveld Landscape. In: *The Kruger Experience: Ecology and Management of Savanna Heterogeneity*. eds J.T. du Toit, K.H. Rogers & H.C. Biggs, pp. 422-446. Island Press Washington
- Pontius R.G., Shusas E. & McEachem M. (2004) Detecting important categorical land changes while accounting for persistence. *Agriculture, Ecosystems and Environment* 101:251–268
- Prassad G. (2006) Social issues, Energy Policies for Sustainable Development in South Africa, Options for the Future. Energy Research Centre, University of Cape Town, South Africa
- R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org
- Regional Wood Energy Development Programme (RWEDP). (1997) Regional study on wood energy: today and tomorrow in Asia. Field Document No. 50. Regional Wood Energy Development Programme in Asia GCP/RAS/154/NET. Bangkok, Thailand: FAO
- Republic of South Africa (RSA). (2000) The Integrated Sustainable Rural Development Strategy (ISRDS). Office of the Deputy President, 17 November. www.info.gov.za/otherdocs/2000/isrds.pdf. Accessed 13/06/2011
- Robinson, E.J.Z, Albers, H.J. & Williams, J.C. (2006) Spatial and Temporal Modeling of Community Non-Timber Forest Extraction. Report CSAE WPS/2006-03. Centre for the study of African Economies, University of Oxford, England
- Rutherford, M., Mucina, L., Lotter, M.C., Bredenkamp, G.J., Smit, J.H.L., Scott-Shaw, C.R., Hoare, D.B., Goodman, P.S., Bezuidenhout, H., Scott, L., Ellis, F., Powrie, L.W., Siebert, F., Mostert, T.H., Henning, B.J., Venter, C.E., Camp, K.G.T., Siebert, S.J., Matthews, W.S., Burrows, J.E., Dobson, L.N., Schmidt, E., Winter, P.J.D., Ward, R.A., Williamson, S. & Hurter, P.J. (2006) Savanna Biome, in: *The vegetation of South Africa, Lesotho and Swaziland*, Eds. Mucina, L. & Rutherford, M.C., pp. 439-539, Pretoria, Strelitzia19. South African National Biodiversity Institute

- Rutherford, M.C. (1979) Above-ground biomass sub-division in woody species of the savanna ecosystem project study area, Nylsvley. South African National Science Programme report no 36. CSIR. Pretoria
- Sankhayan PL & Hofstad O., (2001). A village-level economic model of land clearing, grazing,and wood harvesting for sub-Saharan Africa: with a case study in southern Senegal.
- Scholes R.J. (2009). Syndromes of Dryland degradation in Southern Africa. *African Journal of Range & Forage Science* 26:113 — 125
- Scholes, R.J. & Archer, S.R. (1997) Tree-Grass Interactions in Savannas. *Annual Review of Ecology and Systematics*, 28:517-544
- Scholes, R.J. & Walker, B.H. (1993) *An African savanna, synthesis of the Nylsvley Study*. Cambridge, UK: Cambridge Univ. Press
- Shackleton, C.M. (1993) Demography and dynamics of the dominant woody species in a communal and protected area of the Eastern Transvaal lowveld. *South African Journal of Botany*. **59:**569-574.
- Shackleton, C.M. (1997) The prediction of woody plant productivity in the Savanna biome, South Africa. PhD thesis, University of the Witwatersrand, Johanesburg.
- Shackleton, C.M. (2000a) Stump size and the number of coppice shoots for selected Savanna tree species. *South African Journal of Botany* **66:** 124-127
- Shackleton, C.M. (2000b) Comparison of plant diversity in protected and communal lands in Bushbuckridge lowveld savanna, South Africa. *Biological Conservation*, 94:273-285
- Shackleton, C.M. (2001) Managing regrowth of an indigenous Savanna tree species (*Terminalia sericea*) for fuelwood: the influence of stump dimensions and post-harvest coppice pruning. *Biomass & Biomass energy*. 20: 261-270
- Shackleton C.M., Griffin N., Banks D.I., Mavrandonis J.M., Shackleton S.E. (1994). Community structure and species composition along a disturbance gradient in a communally managed South African savanna, *Vegetatio*, 115:157-168.
- Shackleton, C.M. & Shackleton, S.E. (2000) Direct use values of secondary resources harvested from communal savannas in the Bushuckridge Lowveld South Africa. *Journal of Tropical Forest Production*. 6:28-47
- Shackleton C.M, Shackleton S.E. & Cousins B. (2001) The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry

and natural resource harvesting in communal areas in South Africa. *Development Southern Africa* 5:581-604

- Shackleton C.M., Shackleton S.E., Ntshudu M. & Ntsebeza J. (2002) The role and value of savanna non-timber forest products to rural households in the Kat River valley, South Africa. *Journal of Tropical Forest Products* 8:45-65
- Shackleton C.M. & Shackleton S.E. (2004) The importance of non-timber forest products in rural livelihood security and as safety nets: a review of evidence from South Africa. *South African Journal of Science* 100:658-664
- Shackleton, C.M., Guthrie, G. & Main, R. (2005) Estimating the potential role of commercial over-harvesting in resource viability: a case study of five useful tree species in South Africa. *Land Degradation and Development*. 16:273-286
- Shackleton, C. M., McConnachie, M., Chauke, M.I., Mentz, J., Sutherland, F., Gambiza, J. & Jones, R. (2006) Urban fuelwood demand and markets in a small town in South Africa: Livelihood vulnerability and alien plant control. *International Journal of Sustainable Development and World Ecology*, 13:481-491
- Shackleton C.M., Shackleton S.E., Buiten E. & Bird N. (2007) The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics* 9:558-577
- Shackleton C.M., Buiten E., Annecke W., Banks D., Bester J., Everson T., Fabricius C., Ham C., Kees M., Modise M., Phago M., Prasad G., Smit W., Twine W., Underwood M., von Maltitz G. & Wenzel P. (2007b) Exploring the options for fuelwood policies to support poverty alleviation policies: evolving dimensions in South Africa. *Forests, Trees and Livelihoods*, **17:**269-292
- Shackleton, S.E. (Ed.) (1995). Adaptive Strategies of the Poor in Arid and Semi-arid Lands: In Search of Sustainable Livelihoods. A Case Study of the Bushbuckridge District, Eastern Transvaal, South Africa
- Shackleton S.E., Shackleton C.M., Netshiluvhi T.R., Geach B.S., Ballance A. & Fairbanks D.H. (2002) Use patterns and value of savanna resources in three rural villages in South Africa. *Economic Botany*. 56:130-146
- Skarpe, C. (1991). Impact of grazing in savanna ecosystems. *Ambio* 20: 351-356.
- Skarpe, C. (1992). Dynamics of Savanna Ecosystems. *Journal of Vegetation Science*. 3: 293-300.

- Soussan J. (1987) Fuel transitions within households. In *Transitions between Traditional and commercial energy in the third worlds,* Surrey Energy Economics Centre Discussion Paper series no 35, University of Surrey, United Kingdom.
- Starr, C. (1996) Sustaining the Human Environment: the Next Two Hundred Years. *Daedalus*. 125(3), 235-253. http://www.jstor.org/sTable/20027378. Accessed: 03/06/2011
- Taylor, M.J. (2005). Electrifying rural Guatemala; central policy and rural reality. *Environment and Planning C: Government and Policy*. 23(2):173-189.
- Thom, C. (2000) Use of grid electricity by rural households in South Africa. *Energy for Sustainable Development*, 4(4):36-43
- Thompson M. (1996) A standard land-cover classification scheme for remote-sensing applications in South Africa. *South African Journal of Science* 92:34-41
- Thornton R. (2002). Environment and Land in Bushbuckridge, South Africa. University of the Witwatersrand, South Africa.
- Top N, Mizoue N, Ito S and Kai S., (2004). Spatial analysis of woodfuel supply and demand in Kampong Thom province, Cambodia. *Forest Ecology and Management* **194:**369-378
- Tothmeresz, B. (1995). Comparison of different methods for diversity ordering. *Journal of Vegetation Science 6: 283-290.*
- Trossero M.A. (2002) Wood energy: the way ahead, *Unasylva* **211(53):**3-12
- Turner M.G. (1987) Spatial simulation of landscape changes in Georgia: a comparison of three transition models. *Landscape Ecology* 1:29-36
- Twine W. (2005) Changing socio-economic factors influence vegetation change in the communal rangelands of the South African Lowveld. *African Journal of Range and Forage Science* 22:93-100
- Twine, W. & Siphugu, V. (2002) “There’s a hole in my bucket”: Increased harvesting of resources by outsiders in rural areas of the South African Savanna lowveld. Proceedings of the Natural Forests and Savanna Woodlands Symposium III, 2002.
- Twine W., Moshe D., Netshiluvhi T. & Siphugu M. (2003a) Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a

semi-arid area of Limpopo province, South Africa. *South African Journal of Science* 99:467-473.

- Twine W., Moshe D. & Siphugu M. (2003b) Harvesting of communal resources by "outsiders" in rural South Africa: a case of xenophobia or a real threat to sustainability? *International Journal of Sustainable Development and World Ecology* 10:263-274
- United Nations Development Programme & World Health Organisation (UNDP & WHO) (2009) The Energy Access Situation in Developing Countries- A review focusing on least developed countries and SSA. *Sustainable Energy Programme Environment and Energy Group Report*.
- United Nations Economic Commission for Africa (UNECA). (2003) *Land tenure systems and sustainable development in southern Africa.* UNECA Southern Africa Office, Lusaka, Zambia
- United Nations Educational, Scientific and Cultural Organization (UNESCO). (1996) Biosphere reserves: The Seville strategy and the statutory framework of the world network. UNESCO; Paris, France
- United Nations Educational, Scientific and Cultural Organization (UNESCO) (1996) Biosphere reserves: The Seville strategy and the statutory framework of the world network. UNESCO; Paris, France.
- van Horen C. & Eberhard A. (1995) Energy, environment and the rural poor in South Africa. *Development Southern Africa* 12:197-211.
- van Rooyen N & Bredenkamp G. *(1996) Mix*ed Lowveld Bushveld. In: *Vegetation of South Africa, Lesotho and Swaziland*, eds A.B. Low & A.G. Rebelo, Department of Environmental Affairs and Tourism. Pretoria, South Africa.
- Vanclay, J.K., Sinclair, F.L. & Prabu, R. (2003) Modelling interactions amongst people and forest resources at the landscape scale. *Small-scale Forest Economics, Management and Policy*. 2(2):117-120
- Venter F.J., Scholes R.J. & Eckhardt H.C. (2003) The abiotic template and its associated vegetation pattern. In: *The Kruger Experience: Ecology and Management of Savanna Heterogeneity*. (Eds) J.T. du Toit, K.H. Rogers & H.C. Biggs, pp. 83-129. Island Press Washington
- Vermeulen, S.J., Campbell, B.M., Mangono, J.J., 2000. Shifting patterns of fuel and wood use by households in rural Zimbabwe. Energy and Environment, 11, 233–54.
- von Maltitz, G.P. & Scholes R.J. (1995) The burning of fuelwood in South Africa: when is it sustainable? *Environmental Monitoring and Assessment*, 38:243-251

- Walker, B.H. (1976) An approach to the monitoring of changes in the composition and utilisation of woodland and Savanna vegetation. *South African Journal of Wildlife Resources*. 6: 1-32
- White, C., Bank, L., Jones, S. & Mehlwana, M. (1997) Restricted electricity use among poor urban households. *Development Southern Africa*, 14:413–30
- Williams A.& Shackleton. C.M., (2002). Fuelwood use in South Africa: where to in the 21st century? Southern *African Forestry Journal*, 196:1–7.
- Williams C.A., Hanan N.P., Neff J.C., Scholes R.J., Berry J.A., Denning A.S. & Baker D.F. (2007) Africa and the global carbon cycle. *Carbon Balance and Management,* **2:**3 doi:10.1186/1750-0680-2-3 http://www.cbmjournal.com/content/2/1/3 accessed on-line on 15/11/2011
- Working For Energy (WFE) (2012), *About WFE,* URL: http://www.wfe.org.za/index.php/about-us accessed on-line 15/02/2012
- World Bank. (2012) Country and Lending Groups. http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Upper_middle_income accessed on-line on 15/02/2012)
- Zhang, S. & Fu, L. (2011) Exploring an integrated approach to utilize indigenous renewable energy to improve energy self-sufficiency and emission reduction. *Renewable and Sustainable Energy Reviews*, 15:827-832.