

Land Use Change, Fuel Use and Respiratory Health in Uganda

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Abstract

Rural households in developing countries rely heavily on biomass fuels to provide energy for cooking. We explore whether the characteristics of biomass supply and consumption are changing as a result of land use change in western Uganda. We pair remote sensing data of land use change in 18 villages with detailed data for a panel of 455 households on the type, quantity, and source of biomass fuels used in 2007 and 2012. In our study area, where there has been considerable deforestation and forest degradation, we find that there has been a 23 per cent reduction in fuel wood sourced from proximate forests and woodlands and an 18 per cent increase in fuel wood sourced from fallows, agricultural lands and other wild areas with much lower biomass availability than forests. We assume that fuel sourced from these areas is of lower quality than fuel wood sourced from fully stocked forests. We also observe a 5 per cent increase in the use of crop residues. We find that over time the quantity of fuel used by households has increased by roughly 16-17 kilograms per month.

Little is known about how changes in biomass fuel supply affect health outcomes associated with biomass burning. We explore how patterns of biomass fuel consumption are related to the incidence of acute respiratory infection (ARI) using a cross-sectional data set of 1218 women engaged in cooking, and 605 children under 5. We estimate a series of probit regression models to test whether the type, quantity and source of fuels used in the households where our respondents live are determinants of ARI. The effects of fuel supply are most pronounced for children. We find a positive and significant relationship between ARI and the quantity of fuel wood from non-forest areas; a 100 kilogram increase in fuel wood from a non-forest area results in a 2.4 per cent increase in the incidence of ARI for children under 5. We find the inverse effect of increased reliance on crop residues – the corresponding 100 kg increase in the use of crop residues results in a 3.9 per cent decline in the likelihood of ARI for children under 5. Our findings have implications for policies and interventions directed at forest policy, land use change and biomass fuel supplies. As current rates of deforestation and forest degradation continue, biomass fuel portfolios will continue to move away from high quality fuel wood sourced from forests, which may in turn lead to a higher incidence of health problems associated with exposure to biomass burning.

1. Introduction

Fuel and cooking technology choices in the developing world are garnering increased attention in the wake of new research about the health impacts of exposure to smoke from biomass fuels (Smith 2000; Ezzati et al. 2002; Mishra et al. 2004; Fullerton et al. 2008; Sreeramareddy et al. 2011). Similarly, biomass smoke or “black carbon” has been implicated in regional and global climate change (Ramanathan and Carmichael 2008; UNEP and WMO 2011).¹ The Global Alliance for Clean Cookstoves (www.cleancookstoves.org) is one example of a mechanism for increased public investment in addressing fuel use and cooking technology options in developing countries. Public investments directed at reducing household emissions are viewed as potentially generating a ‘double-dividend,’ because actions relating to fuel and cooking technology could have large and immediate impacts on both local health and greenhouse gas pollutants (Kandlikar et al. 2009; Smith and Balakrishnan 2002; Smith et al. 2009).

Between 2 and 3 billion people, or roughly 40 per cent of the world’s population are completely dependent on biomass as their primary fuel for cooking and heating (Vlosky & Smithhart 2011; Openshaw 2011; Grieshop, Marshall & Kandlikar 2011; WHO 2006, Foell et al. 2011). Barnes et al. (2006) estimate that the absolute number of people dependent on biomass fuels will increase through 2030, suggesting that policy makers should be attentive to factors that influence the supply, demand and distribution of biomass fuels. The consumption of biomass fuels is higher in sub-Saharan Africa than in any other region

¹ The terms biomass fuels, solid fuels and traditional fuels are used interchangeably in the literature. These fuels are differentiated from the modern or liquid fuels (e.g. paraffin, kerosene, liquid petroleum gas) which are considered to be more efficient and less damaging to human health.

(Arnold, Köhlin & Persson, 2005; Vlosky & Smithhart, 2011; Bailis, Ezzati & Kammen, 2005; Nkambwe & Sekhwela 2006), and demographic trends, including both population growth and rapid urbanization suggest that demand will continue to grow.² East Africa is particularly dependent on biomass fuels: more than 95 per cent of the populations of Burundi, Ethiopia, Rwanda, Tanzania and Uganda use solid fuels for cooking and heating (WHO 2006). This degree of dependence places the region in sharp focus for investigating the environmental and health impacts of using biomass for energy purposes.

While demand for biomass fuels continues to grow in sub-Saharan Africa, rapid land use change is reducing the supply of high quality biomass and leading individuals to shift collection away from forests toward locations such as farms and fields that typically yield much lower per hectare quantities of biomass (DeFries et al. 2010; Ahrends et al. 2010). Such changes in the supply of locally-available biomass fuels have implications for household fuel use and the exposure of women and children to harmful gasses and particulate matter associated with the incomplete combustion of low-quality biomass. These changes also have indirect effects on how women and children use their time, the number of meals that are cooked, and the types of foods that are prepared. All can affect overall food security as well as health and nutrition outcomes. Nevertheless, how land use change affects the types, quantities and sources of biomass fuels, and how those in turn affect health and welfare outcomes is poorly understood.

This paper focuses on two questions relevant to these global concerns. First, we ask whether changes in forest cover in Uganda are precipitating changes in household fuel

² The Food and Agriculture Organization of the United Nations (FAO) estimates that, in 2008, 6.15 billion square meters of fuel wood were harvested in Africa, more than one-third of which were in East Africa (FAO 2011).

portfolios, i.e. the relative shares of different types of fuels consumed by a household. A typical fuel portfolio in rural Uganda includes fuel wood of varying qualities, charcoal and crop residues. In addition to cataloging the types of fuels being used, we also measure the quantities and identify the sources of these fuels, in particular whether fuels are being collected from forests or elsewhere. We hypothesize that forest degradation and loss may be leading households to substitute fuel from non-forest environments, including fallows and bush land, in place of higher-quality forest-based fuels. We also hypothesize that forest degradation and loss reduce overall household fuel consumption. To test these conjectures we use panel data from 455 households in western Uganda, collected in 2007 and 2012. These data include detailed information about the types, quantities and qualities of biomass fuels consumed, and allow use to measure changes in these features over time.

Our second research question focuses on how patterns of biomass fuel consumption affect health outcomes for women and children. Specifically we test two hypotheses. First we study whether the quantity of fuel used by a household is correlated with the incidence of acute respiratory infection (ARI). Second, we test whether the incidence of ARI is correlated with a shift away from high quality fuel wood (sourced from forests) toward lower quality fuels (sourced outside of forests). For this stage of the analysis we use data from the 2012 wave of our survey which recorded symptoms typical of ARI among children under age 5 and adults – typically women – involved in cooking.³ Our sample includes 1823 women and children that were residing within the 555 households included in our survey. We estimate a series of probit regression models that take into account household-level

³ Ninety-eight per cent of cooks in the sample are female. Henceforth we use the terms “women” and “cooks” synonymously.

characteristics known to influence health outcomes and estimate marginal effects of changes in the quantities and types of fuels used.

Our findings confirm that rapid deforestation is changing the fuel portfolios of rural households. We find evidence of a major shift to fuel wood sourced from non-forest areas including fallows, agricultural plots and bush lands. Crop residues are also increasingly common. We also find evidence of a link between biomass source and the incidence of ARI. Controlling for other characteristics of the household, individuals living in households that sourced their fuel from forests had lower overall rates of ARI, compared with those living in households that are more dependent on fuel from non-forest areas. Our findings confirm that deforestation plays a role in altering household fuel portfolios and suggests that ongoing changes in fuel use have implications for human health.

2. Linking biomass supply to health outcomes

Our analysis rests on a two stage causal pathway. Along the first path, forest quality, forest proximity and overall patterns of land use influence fuel availability and household decisions regarding fuel used for cooking and household chores. Along the second pathway, the types and quantities of fuels used by the household determines respiratory health outcomes for women and children.

(a) Land use and biomass availability

One of the primary tensions in the developing world is the imbalance between a rapidly expanding population and a diminishing resource base. According to one estimate, developing countries occupy 55% of global land area but contain 76% of the population (Openshaw 2011). This disproportionate distribution of natural resources necessitates

careful consideration of how existing resources are used and what effects they have on individuals' livelihoods and on the environment. The acquisition and use of fuel support the basic human needs of cooking and heating, and throughout the developing world the use of different fuel types can have adverse health and environmental consequences.

Predictions of a "fuel wood crisis" in the developing world (e.g. Eckholm 1975) pushed researchers throughout the past several decades to investigate interactions between fuel wood use, deforestation, and energy poverty in developing countries. While dire predictions have largely been dismissed, past warnings informed the structure of many developing nations' energy policies, which remain unchanged today. To some extent, this has hindered progress in sustainable fuel wood management (Zulu 2010). Broadly speaking, research addressing the sustainable harvest of woody biomass and fuel wood fall into two groups. A first school of thought asserts that fuel wood harvesting is a major contributor to global forest degradation and has severe negative environmental ramifications. The second school of thought asserts that the impacts of non-commercial fuel wood harvesting are not necessarily negative, and that harvesting can sometimes even improve environmental robustness (Masera et al. 2006; Openshaw 2011; Arnold, et al. 2005; Nkambwe & Sekhwela 2006; Foley et al. 2005, Naughton-Treves, et al. 2007).

The proposed contribution of woody biomass harvesting to land degradation and its associated negative environmental effects are largely dependent on both the setting and parameters employed to characterize woody biomass stocks. In many rural areas, gathering wood for fuel has been shown to not have a detrimental impact on land, but in more densely populated areas where natural resources are less abundant, the demand for land and resources can lead to higher degree of degradation (Nkambwe & Sekhwela 2006).

Highlighted throughout the literature is the growing disconnect between small-scale harvesting systems put in place by rural and peri-urban communities and national-scale policies designed to ensure the long-term sustainability of forest stocks (Kaburi & Medley, 2011; Hiemstra-van der Horst & Havorka, 2009). Much of this disconnect stems from the inconsistent measures used to determine availability of biomass throughout tropical forests and other landscapes.

Several studies have noted the lack of information available about fuel wood harvesting practices, geography, and dynamics, specifically with respect to woody biomass availability within different land uses (Masera et al. 2006; Smeets & Faaij 2007; Foley 2001; Hiemstra-van der Horst & Havorka 2009). Much of the material like fallen branches, dead wood, and material from shrubs that serve as an important sources of fuel for many rural populations are not necessarily included in overall assessments of biomass stocks. Furthermore, it is difficult to synthesize what information is available due to the range of scopes employed to characterize the stock of woody biomass throughout tropical regions; inventories of this nature rarely take into account biomass stocks outside forest regions (Turyareeba, Drichi & UNEP 2001; Foley 2001; Smeets & Faiij 2007). While one estimate shows that dry tropical woodlands provide as much as 80% of energy needs for urban and rural populations in sub-Saharan Africa (Foley 2001), other landscapes can also serve as important sources of fuel stocks. This literature has largely focused on the hypothesis that biomass fuel harvesting is a driver of deforestation and degradation. However, limited attention has been paid to the role of large scale deforestation—as observed in many places in sub-Saharan Africa—on fuel availability.

(b) Health Impacts of Woody Biomass Burning

Serious health implications can arise when biomass is burned in an enclosed space without proper ventilation. It has been estimated that as much as 76 percent of all global particulate air pollution occurs indoors in developing nations, a figure that can be largely attributed to the burning of biomass for cooking and heating purposes (Fullerton, et al. 2008). The WHO (2006) identifies the most common ailments associated with indoor air pollution as acute infections of the lower respiratory tract, chronic obstructive pulmonary disease, lung cancer, asthma, cataracts, and tuberculosis. ARIs, which can result from inhalation of particulate matter and other toxins, are responsible for as much as 6 per cent of global disease and mortality, predominantly in less-developed nations (Ezzati & Kammen 2001). Women, as the primary cooks and caretakers of most households, are especially vulnerable to the health impacts caused by the inhalation of particulates from biomass smoke. Not only do they bear the largest health burdens associated with emissions from woody biomass, they also lose time and suffer physical consequences from gathering and transporting biomass fuels (Foell et al. 2011).

The health impacts from burning woody biomass in an unventilated indoor environment are considered more harmful than second-hand tobacco smoke or industrial emissions (Dosier, 2004), and have been estimated in some cases to exceed the equivalent of smoking two packages of cigarettes every day (WHO 2006). Exposure can exceed the U.S. Environmental Protection Agency's recommended exposure levels by as much as a hundred times (Bailis, et al. 2009). The World Health Organization (WHO) has estimated that as many as 2.5 million women and young children die prematurely each year from respiratory ailments caused by inhalation of smoke from open biomass-burning stoves,

(Arnold, et al. 2005). It is estimated that in 2000, 51 per cent of child deaths and 63 per cent of adult female deaths in sub-Saharan Africa were attributable to pollution caused by household burning of biomass (Bailis, et al., 2005). Young children exposed to high concentrations of byproducts from biomass burning like carbon monoxide, hydrocarbons, and particulate matter are two to three times more likely to develop acute lower respiratory tract infections than children in households using cleaner fuels. Mothers exposed to these toxins not only run the risk of their own respiratory infection, their children can present with lowered birth weights and nutritional deficiencies that can slow development and even result in stunting (Fullerton, et al. 2008).

While there has been a gradual progression towards cleaner fuels in the past decades with targeted aid programs, these developments have been unable to maintain pace with population growth, leading to an overall increase in the number of individuals who rely on the combustion of solid fuels (WHO 2006). A 2011 study investigating the economic and health benefits of using improved cook stoves indicates that traditional cooking methods, which involve using supports over an open fire and lack any means of emissions capture or combustion control, can be improved in three ways: by increasing thermal energy, by reducing emissions, and by increasing ventilation (Grieshop et al. 2011). The focus that international aid organizations have put on promoting safer-burning cook stoves has not attained the scope necessary to impact public health outcomes on a wide scale in sub-Saharan Africa (Bailis et al. 2009). While many development projects have made a positive overall impact, , the growing dependence on biomass presents a substantial hurdle to scaling up these efforts, and one that is likely to be overcome only through public sector investment (Kees & Feldmann 2011). Zhang et al. (2000) encourage aid organizations to

strive for a balance between greenhouse gas emissions, thermal efficiency of stoves, and health ramifications when considering interventions, rather than just one of the three. Discovering the proper balance in a timely manner is essential, since projections indicate that unless effective interventions are implemented at scale, indoor air pollution may cause as many as 9.8 million premature deaths by the year 2030 (Bailis, et al. 2005).

Research on the determinants of fuel and cooking technology use has been heavily focused on demand side determinants including income, household size and education levels (Heltberg 2004; Chen et al. 2006; Gupta and Kohlin 2006; Kavi Kumar and Viswanathan 2007). Many studies are predicated on the energy ladder hypothesis which states that demand for fuel wood, an inferior good, decreases as income increases, while that for gas and liquid fuels rises with income.⁴ Econometric studies of household fuel wood demand generally find that income elasticities are negative, validating the energy ladder hypothesis (Gundimeda and Kohlin 2008). However, in most studies, the effect appears to be small and statistically weak (Barnes et al. 2002; Arnold et al. 2005; Baland et al. 2010), suggesting that factors other than income may be driving household decisions. A number of case studies include distance to forest, or time spent on fuel collection, and find that this variable is positively related to charcoal consumption and negatively related to fuel wood consumption (Chen et al. 2005; Jumbe and Angelsen 2010). Other meso level variables considered in case studies include altitude and forest area per person (Turker et al. 2001); own and cross price elasticities for different fuels (Gupta and Kholin 2006); presence of community-based institutions focused on sustainable forest management (Jumbe and Angelsen 2010); community coordination and public provision of services

⁴ For example, our own regression results based on nationally representative data from the 2006 Uganda National Household Survey suggest an income elasticity of demand for charcoal of -0.05, compared with 0.36 for liquid fuels.

(Pandey and Yamada 1992; Sinton et al. 2004; Macht et al. 2007; Pattanayak and Pfaff 2009); convenience and reliability of fuel supply (Gupta and Kohlin 2006); perception of pollution (Gupta and Kohlin); credit market access (Edwards and Langpap 2005); and population growth rates (Arnold et al. 2005; Baland et al. 2010). Few studies model a comprehensive set of both the supply and demand side determinants of fuel and technology use, and most studies are focused on relatively small geographic areas, making it difficult to include heterogeneous meso- and macro-level variables. A recent study by Rehfuess et al. (2010) used hierarchical Bayesian spatial models to quantify heterogeneity between regions and districts, and finds that fuel choice in three SSA countries is heavily influenced by neighborhood effects and place. These findings suggest that the sharp focus on household level determinants and case studies provides only a partial picture of the determinants of fuel and technology use. This study aims to develop and test a model that includes meso and micro level variables.

3. Study area, sampling and empirical approach

(a) Study area

The study villages fall within seven districts (Figure 1) in Uganda's west central region. The study area spans a relatively large geographic area with roughly 300 kilometers between the southern and northern most villages. The dominant cropping systems include maize, bananas, and coffee. Rainfall is moderate and altitude ranges from 1000 to 1800 meters above sea level. Smallholders keep cattle, small ruminants and poultry in extensively managed crop-pasture systems (MAAIF 1995; Nzita and Niwampa 1993). Land holdings in the area are relatively small, averaging 2.65 hectares per household. Three land

tenure systems are common: customary, freehold and *mailo*. The Bugoma and Budongo study area have undergone rapid settlement over the past 10 years largely by Bakiga migrants from land scarce Kabale District in southwestern Uganda. Livelihood strategies in the study area fall into five main categories: agriculture, livestock husbandry, collection of forest and wild products, wage labor, and self-employment (i.e. small business). The labor force is relatively stationary, suggesting few opportunities for households to generate remittances.

[Figure 1 here]

Deforestation is well known to be a major environmental issue in both western Uganda. Forests outside of gazetted areas (i.e. national parks and central forest reserves) face serious threat (Nsita 2005). In-migration and land disputes are contributing factors to high rates of deforestation, and degraded forest mosaics are common, particularly in areas with relatively good market access. Clearing forest and establishing perennial agricultural crops including bananas and coffee is the most expedient and reliable way to establish *de facto* property rights (Acworth 2005). A large share of the sawn wood produced for Uganda's domestic timber markets is also sourced from this area, which contributes to forest degradation. Estimates from several forest agency documents suggest that approximately 50 per cent of tropical high forest on private land is degraded, as compared with 17 per cent in protected areas (Nsita 2005).

In Uganda, land cover types and woody biomass were not formally documented until the National Biomass Study in 1996. The biomass study divided land into gazetted and ungazetted areas and provided estimates of total available woody biomass by category of land use. Approximately 36% of Uganda's available woody biomass is found in subsistence

farmlands, 28% in woodlands, 14% in tropical high forests, 11% in grasslands, and the remaining 11% between hardwood plantations, built areas, bush lands, large-scale farmland, softwood plantations, and degraded tropical high forests. However, on a per hectares basis, tropical high forest provides by far the highest amounts of available woody biomass (224 t/ha) (Table 1). Degraded tropical high forest provides approximately half the per hectare woody biomass; subsistence crop land provides only 12.7 t/ha.

[Table 1 here]

(b) Sampling and data collection

The data for this study come from two rounds of a household panel survey conducted in 2007 and 2012. The initial sample was drawn from a randomly selected set of villages in the forest mosaics of west central Uganda (N=18). Within each village a random sample of 30 households was selected to participate in the household interview (N=540). The second round of the panel attempted to follow these households. There was a relatively low rate of attrition from the sample. The balanced panel includes 455 households. The most common reasons for attrition were either death of the household head or out-migration.⁵ The total population of the thirteen sub-counties in which data were collected was 253,587 in 2002 (UBOS 2006). Our sample includes approximately 3,600 individuals, or approximately 1.4 per cent of the total population of the 13 sub-counties.

(c) Remote sensing data and analysis

We obtained freely available data from the online data pool at NASA's Land Processes Distributed Active Archive Center (LP DAAC) where satellite data are classified into land

⁵ Most migrants moved to other rural areas, often within the same district.

cover types at 500-meter resolution with quality control and assurance provided by MODIS Land Evaluation Strategy.⁶ We selected averaged yearly land cover data for three years of interest (2003, 2007, and 2011) corresponding with the time frame relevant to our socioeconomic panel dataset collected in field sites in Western Uganda. The V005 and V051 data set span the temporal range of 2001-2011. Land cover classifications existed for fourteen different land cover types and due to our specific interest in vegetated forest and savanna conversion to cropland- we reclassified the land cover types into broader categories including forest, woody savanna, and savanna to denote varying amounts of biomass availability for household fuel use⁷.

After downloading the land cover type data and reclassifying the forest, woody savanna, and savanna into broader categories, we identified major land cover transitions of interest. Using raster algebra, we were able to identify 500 x 500 m pixels of land that were forestland in year 2003 and track these individual pixels in the subsequent years of our study— 2007, and 2011. By combining raster algebra and the reclassify tool in the Spatial Analyst toolbox, we were able to create new land cover classes. We defined transition classes where a pixel of land that was forest in year_{t-1} and cropland in year_t would join a newly created land cover class, i.e. “Forest->Cropland.” These transitions were created to measure cropland conversion, forest degradation (Forest->Woody Savanna), and areas of limited change. Because the land cover data are closely tied to the panel survey data collected at 18 villages, we then demarcated a 10-kilometer buffer zone circling each village and used the

⁶ MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid. NASA Land Processes Distributed Active Archive Center (LP DAAC). ASTER L1B. USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota. 2001.

⁷ Evergreen Needleleaf, Evergreen Broadleaf, Deciduous Needleleaf, Deciduous Broadleaf, and Mixed forest were all reclassified into general “Forest” land cover type. Open and closed shrublands were reclassified into general “Shrublands” land cover type.

Tabulate Area function in the Spatial Analyst Toolbox to count the number of pixels of each land cover transition class for each village for the following periods—2001-2011, 2001-2003, 2003-2007, 2007-2011, and 2003-2011. We also measured land cover transitions at the district level to convey localized impacts with the broader shifts in forest and cropland.

(d) Analysis

Our first question is aimed at understanding the composition and determinants of fuel use over time. By combining remote sensing analysis with descriptive statistics of the type, quantity and location of harvest of biomass fuels we infer the impact of rapid deforestation and forest degradation on fuel use portfolios. To measure and characterize land use change, we employ remote sensing data as well as data on household-level perceptions of changes in forest cover and quality. We explore the role of rapid land use change on fuel use portfolios between 2007 and 2012. We estimate the volumes of fuel wood, charcoal and crop residues harvested by individual households from forests and non-forest environments, and use these to construct measures of household fuel portfolios. We present descriptive statistics to explore the variation in fuel use across time. We adjust monetary amounts from 2007 to be comparable with 2012 data using the average annual inflation rate between 2007 and 2011 of 10 per cent.

To explore the relationship between biomass fuel use and ARI we estimate a series of probit regression models using 2012 data and individuals at the unit of analysis. The dependent variable in these models is a binary indicator of ARI, which equals one if the individual reported combined symptoms of cough and difficulty breathing and zero otherwise. We estimated three models, one for the full sample of 1823 individuals, a second for only children, and a third model for only adults. The volume of biomass fuels

consumed by the household are the independent variables of interest (i.e. volume of fuel wood from forest, volume of charcoal, volume of fuel wood from non –forest areas, volume of crop residues. In our analysis the maintained assumption is that fuel from forests is of higher quality than fuel from non-forest areas. This assumption in part rests on data presented in Table 1 which highlights the scarcity of biomass fuels in non-forest areas. Our unit of observation is the individual, but we control for a number of household-level characteristics including total income, the role of the individual (first, second or third youngest; primary, secondary or tertiary cook), extent of ventilation in the cooking setting, use of improved stove, household size, and age, gender and education level of the household head. We also include dummy variables for the study site as an indicator of broad differences in regional economic, demographic and biophysical conditions. For each of our models we estimate marginal effects. Descriptive statistics for all variables included in the regression models are summarized in Table 2.

[Table 2 here]

4. Results

(a) Land use change and biomass consumption

Remote sensing data indicating the area of forest (predominantly tropical high forest), woody savannah, savannah, and cropland within a 10 km radius of village centroids are summarized in Table 3. We consider data for two time periods: 2003-2007 representing the time period prior to our 2007 socioeconomic data collection, and 2007-2011 representing the period prior to our 2012 socioeconomic data collection.⁸ Our expectation is that land use trends in the years immediately prior to our socioeconomic data collection

⁸ More recent remote sensing images are not yet available.

will strongly influence the location where fuel is sourced as well as the types and quantities of fuel used.

[Table 3 here]

Our remote sensing analysis reveals considerable changes in land use, with forest cover falling from 43.8 per cent in 2003 to 30.4 per cent in 2011. Our analysis suggests that both deforestation and forest degradation are taking place. Cropland increased by 7.0 per cent between 2003 and 2007, and an additional 6.2 per cent between 2007 and 2011. The increasing presence of woody savannah over time is evidence of forest degradation (i.e. tropical high forest transitioned to forest mosaics that presents as woody savannah). Maps illustrating the extent of land cover change within the village buffers are presented in Figure 2. Our analysis is consistent with other reports in the literature, including Nsita (2005) and Acworth (2005) who observed high rates of deforestation and forest degradation in the years immediately prior to our baseline data collection.

[Figure 2 here]

To corroborate our remote sensing analysis of land use change we asked households about changes in forest cover and quality for two time periods, 2003-2007 and 2007-2012. Respondents indicated major declines in both time periods in general forest cover and specific closed-canopy forest area. They also reported increases in flooding, soil erosion and water availability, which are consistent with observed patterns of deforestation. Indicators of degradation include changes in the diversity of tree, animal and bird species, number of large trees and quality of water. All indicators point to a trend of considerable forest degradation in recent years, particularly for privately-owned and community-managed forests in the study area.

An important question for our analysis is what drives deforestation and degradation in our study area. In particular, to verify our hypothesized causal chain, we need to know that fuel collection by rural households is not a major driver of deforestation or degradation. Both key informant interviews with village leaders and forest officials, as well as data collected in 2007 on area of forest cleared and the motivations for forest clearing verify that agricultural production and timber harvesting (Jagger et al. 2012; other) are the main contributors to deforestation and degradation. We assert that fuel harvesting plays a negligible role in forest degradation in the study area. Technology constraints (i.e. lack of saws) prohibit households from harvesting standing trees for fuel, and charcoal production is largely a by-product of the land conversion process; charcoal is often produced in tandem with land clearing for crop and livestock production (Shively et al. 2011).

We collected data on the type, volume and source (i.e. location of harvest) of biomass fuels consumed by households in 2007 and 2012 (Table 4).⁹ We present data for biomass fuels obtained from forests as well as fuels obtained from non-forest areas including fallows, agricultural lands, bush land etc. Forest fuels include fuel wood and charcoal. Fuels obtained from outside forests include fuel wood sourced from fallows, agricultural lands, bush lands etc., and crop residues.¹⁰ In 2007, 74.2 per cent of fuel wood was sourced from forests as compared with 23.6 per cent sourced from areas outside of forests. When we compare these data with data from 2012 we find that there has been a significant change in where households are sourcing fuel wood from. Roughly half of the fuel wood the

⁹ Data represent one quarter of the year, roughly May-July for the Bugoma and Budongo field sites. The data from the Rwenzori field sites represents household activity for October – December for the Rwenzori site. Data were collected at the same time to avoid issues of seasonal bias in the reporting of volume and value estimates.

¹⁰ Maize cobs, bean husks and millet stalks are the most commonly used crop residues in the study area.

households in our sample use comes from forests, and the share of fuel wood sourced from areas other than forests has increased to 39.8 per cent in 2012.

We do not observe major changes in the quantities of charcoal used by rural households. While charcoal often produced as a byproduct of forest clearing, the majority of charcoal is sold to traders who market it in Kampala or other major urban areas (Khundi et al., 2011; Shively et al., 2011). Finally we observe a significant increase in the use of crop residues as fuels. In 2007, households were using an average of 2.6 kgs of crop residues per quarter. However, by 2012, households were using approximately 30 kgs of crop residues over a three month period, accounting for between 6 and 7 per cent of total fuel use in the household.

[Table 4 here]

We find that total fuel consumption per household has increased from 446 kgs over a three month period, to 500 kgs for the matched sample of households during the same quarter. Fuel wood (forest fuel + non forest fuel) accounts for roughly 12 kgs of the increase, with crop residues explaining the remainder. Finally, we find significant changes in the distance that households travel to the nearest forest. In 2007, the average time to walk to the nearest forest was 34 minutes. By 2012, the average time increased to 45 minutes for the matched sample of households. These findings are consistent with our remote sensing analysis confirming that deforestation is affecting the distance people need to travel to collect high quality fuel wood.

(b) Biomass fuel portfolios and health outcomes

We now turn to the linkage between fuel use and health outcomes. Our hypothesis is that the quantity and quality of biomass fuels used in households may influence health outcomes associated with exposure to smoke from biomass burning. We hypothesize that both quantity and quality are determinants of overall exposure to carbon monoxide and particulate matter, which in turn influence respiratory health outcomes. Our interest in this question is to connect our findings about land use change and fuel supply to health outcomes.

To assess whether individuals experienced acute respiratory infection we collected data on self-reported symptoms of ARI including fever, presence of cough, and difficulty breathing by replicating questions from the Uganda Demographic and Health Survey (DHS) designed to measure indicators of ARI. We collected these data for the three youngest children under 5 years, and for the primary, secondary and tertiary cooks in each household. While these individual indicators are not unique to ARI, when observed in combination they are strongly indicative of ARI. Data for ARI involved recall over the past 14 days. This time frame overlaps with our recall data on biomass consumption which includes all biomass consumed by the household during the past 30 days. We assume that fuel consumed by the household in the several weeks immediately prior to and during the 14 day recall period for health outcomes properly maps fuel consumption patterns to health outcomes.

Our data suggest a relatively high incidence of ARI for children under 5 (34 percent). There is a strong negative correlation between age and presence of symptoms of ARI for children; among youngest children 38 per cent exhibited symptoms of ARI. Reports of ARI

symptoms decreased with age, 30 per cent of second youngest children and 21 percent of third youngest children had symptoms of ARI. In our adult population 7 percent of women reported having symptoms of ARI within two weeks prior to the interview. Primary cooks had the highest incidence (12 per cent) and dramatic reductions in symptoms of ARI were documented for secondary and tertiary cooks (5 and 2 percent respectively).

We are specifically interested in the quantity and source of biomass that households are consuming, and whether consumption of fuels of different types and from different land uses might have an effect on observed health outcomes.¹¹ Our preliminary investigation of the correlation between the volume and type of fuel used at the household level and reports of ARI infection suggests that there are few significant differences between fuel wood sourced from forests, charcoal consumption and ARI outcomes (Table 5). We do observe statistically significant differences between the quantity of non-forest fuel wood and symptoms of ARI, with a particularly strong effect for children under 5. Children in households that use larger quantities of non-forest fuel wood have a higher incidence of ARI. We find the opposite relationship between crop residues and ARI; that is individuals in households that use larger quantities of crop residues are less likely to have symptoms of ARI.

[Table 5 here]

We explore the role of biomass fuels in determining ARI by running a series of probit regression models (Table 6). The primary focus of these models is to identify the effect of different types and quantities of fuels in explaining ARI outcomes when controlling for a

¹¹ Note that by definition crop residues are sources from non-forest lands. All charcoal consumed in the households in our sample was produced from forests or woodlands allowing us to categorize it as forest fuel.

number of important covariates including household income, the role of the individual in the household (i.e. birth order of children under 5; primary, secondary or tertiary cook), the cooking setting (i.e. outdoors, in well ventilated kitchen, in poorly ventilated kitchen), whether the household uses an improved stove, household demographic characteristics (i.e. size of household, age, education and gender of head), and study site.

We find support for our hypothesis that fuel sourced from non-forest areas is associated with a higher incidence of ARI, particularly for children. We estimate that a 100 kg increase in fuel wood from non-forest areas increases the likelihood of ARI by 2.4 per cent for children. To put this number in perspective it takes roughly 5-7 kgs of fuel wood to cook a pot of beans on a three stone fire. One hundred kilograms of fuel wood represents between 15 and 20 cooked meals. Conversely we find a significant negative effect of crop residues on ARI. A 100 kg increase in crop residues is associated with a 3.9 per cent decrease in the likelihood of ARI in children, and a 2.2 per cent decrease in the likelihood of ARI for the full sample of adults and children.

[Table 6 here]

We find a weakly statistically significant positive relationship between income and presence of ARI in children. A possible explanation for this is that better off households have more cooked meals. Thus being a child in such a household suggests increased exposure to biomass smoke. However, we do not find a significant result for adults. Being the youngest child in the household or being the primary cook is a strong determinant of ARI. Second and third youngest children are 6.8 and 16.0 per cent less likely to have ARI than the youngest child. Our explanation for this is that the youngest child spends the most time with the mother, who is frequently the primary cook. We also observe a similar

pattern for secondary and tertiary cook who would have far lower exposure to biomass smoke; they are 6.4 and 8.9 percent less likely to have ARI respectively. Surprisingly we don't find that ventilation or cooking with an improved stove have significant effects on ARI outcomes. Finally, household size plays a significant role as a determinant of ARI. We observe a significant and positive relationship between household size and ARI for the overall sample, and for children. For example, the addition of one person to the household increases the likelihood of ARI in children by 4.6 percent likely due to increased fuel consumption due to more mouths to feed. However, the sign on the squared term suggest that concave relationship with a downward slope as more people or added to the household.

5. Conclusions and recommendations

We highlight two main findings from our analysis. First, we find that deforestation, motivated primarily by clearing land for agricultural production influences the type and source of biomass fuels used by rural households in Uganda. While our study area has experienced rapid deforestation, the rate of forest loss is not atypical of other parts of East Africa where forests are found outside of gazetted or protected areas. Specifically we find that the types of fuel and the source of fuel used by rural households changed substantially between 2007 and 2012. Fuel from non-forest areas and crop residues became more commonly used increasing by 18 per cent and 5 per cent of total fuel supply respectively.

Our second major finding is that the source of biomass appears to be correlated with reported health outcomes. Specifically we find a higher incidence of ARI for households that are more heavily reliant on fuel sourced from non-forest areas, and a lower incidence

of ARI among households that are more reliant on crop residues. Given that differences in total volumes of forest and non-forest fuels are small, we believe differences in fuel quality may be responsible, in part, for influencing negative health outcomes. This finding is particularly important in light of rapid deforestation and associated land use change, and potential constraints on future fuel supply.

These findings suggest several points of entry for health and environmental policy interventions. If one assumes that the availability of modern fuel and cooking technologies in the region will continue to be limited, and that adoption will therefore be slow, our findings provide prima facie evidence in favor of policies to promote the use of higher-quality biomass fuels AND more efficient cooking technologies. Interventions aimed at providing information to households about the differential health impacts of biomass fuels, and supporting efforts to promote the planting of trees that produce high quality fuel wood are likely to result in health and socioeconomic gains for rural households in the short to medium-term.

References

- Arnold, M., Köhlin, G., & Persson, R. (2005). Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives. *World Development*, 34(3), 596-611.
- Bailis, R., Cowan, A., Berrueta, V., & Masera, O. (2009). Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves. *World Development*, 37(10), 1694-1705.
- Bailis, R., Ezzati, M., & Kammen, D. (2005). Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa. *Science*, 308 (5718), 98-103.
- Bruce, N.L., Rehfuess, E., Mehta, S., Hutton, G. & Smith, K. 2006. Indoor Air Pollution. In *Disease Priorities in Developing Countries*, 2nd Edition, Jamison, D.T., Breman, J.G. and A.R. Measham (eds). New York, NY: World Bank and Oxford University Press.
- Demirbas, A. (2009). Biomass Feedstocks. *Biofuels* (pp. 45-85). Heidelberg, Germany: Springer Verlag.
- Dosier, R. (2004). Energy Ladder in Developing Nations. *Encyclopedia of Energy* (Volume 2, pp. 423-435). New York: Elsevier Inc.
- Eckholm, E. P. (1975). *The other energy crisis, firewood*. Washington, D.C.: Worldwatch Institute.
- Ezzati, M., & Kammen, D. (2001). Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *The Lancet*, 358, 619-624.
- Foell, W., Pachauri, S., Spreng, D., & Zerriffi, H. (2011) Household cooking fuels and technologies in developing economies. *Energy Policy*, 39, 7487-7496.
- Foley, G. (2001). Sustainable woodfuel supplies from the dry tropical woodlands. *ESMAP technical paper 013*, 1-94.
- Foley, J., DeFries, R., Asner, G., Barford, C., Bonan, G., Carpenter, S., et al. (2005). Global Consequences of Land Use. *Science*, 309(570), 570-574.
- Food and Agriculture Organization of the United Nations. *The State of the World's Forests 2011*. Rome, 2011.
- Fullerton, D., Bruce, N., & Gordon, S. (2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 102, 843-851.
- Grieshop, A., Marshall, J., & Kandlikar, M. (2011). Health and climate benefits of cookstove replacement options. *Energy Policy* 39, 7530-7542.
- Hiemstra-van der Horst, G. H., & Hovorka, A. (2009). Fuelwood: The "other" renewable energy source for Africa? *Biomass and Bioenergy*, 33, 1605-1616.
- Jagger, P., Shively, G. and Arinaitwe, A. (2012). Circular Migration, Small-scale Logging and Household Livelihoods in Uganda. Forthcoming in *Population and Environment*.

- Kammen, D., & Kirubi, C. (2008). Poverty, Energy, and Resource Use in Developing Countries. *New York Academy of Sciences*, 1136, 348-357.
- Kaburi, S., & Medley, K. (2011). Community Perspectives on Fuelwood Resources in East Africa. *Mountain Research and Development*, 31(4), 315-324.
- Kees, M., & Feldmann, L. (2011). The role of donor organizations in promoting energy efficient cook stoves. *Energy Policy*, 39, 7595-7599.
- Khundi, F., Jagger, P., Shively, G. and Sserunkuuma, D. (2011). Income, Poverty and Charcoal Production in Western Uganda. *Forest Policy and Economics*, 13(3), 199-205.
- Laumbach, R., & Kipen, H. (2012). Respiratory health effects of air pollution: Update on biomass smoke and traffic pollution. *Journal of Allergy and Clinical Immunology*, 129(1), 3-11.
- Masera, O., Ghilardi, A., Drigo, R., & Trossero, M. (2006). WISDOM: A GIS-based supply demand mapping tool for woodfuel management. *Biomass & Bioenergy*, 30, 618-37.
- Masera, O., Saatkamp, B., & Kammen, D. (2000). From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. *World Development*, 28(12), 2083-2103.
- Naughton-Treves, L., Kammen, D., & Chapman, C. (2007). Burning biodiversity: Woody biomass use by commercial and subsistence groups in western Uganda's forests. *Biological Conservation*, 134, 232-241.
- Nkambwe, M., & Sekhwela, M. (2006). Utilization Characteristics and Importance of Woody Biomass Resources on the Rural-Urban Fringe in Botswana. *Environmental Management*, 37(2), 281-296.
- Openshaw, K. (2011). Supply of Woody Biomass, Especially in the Tropics: Is Demand Outstripping Sustainable Supply?. *International Forestry Review*, 13(4), 487-499.
- Shively, G., Jagger, P., Sserunkuuma, D., Arinaitwe, A. and Chibwana, C. (2010). Profits and margins along Uganda's charcoal value chain. *International Forestry Review*, 12(3), 271-284.
- Smeets, E., & Faaij, A. (2007). Bioenergy potentials from forestry in 2050. *Climatic Change*, 81, 353-390.
- Turyareeba, P., Drichi, P, and UNEP Collaborating Centre on Energy and Environment (2001). Plan for Development of Uganda's Biomass Energy Strategy. 1-37. Accessed 02/10/12 at <http://uneprisoe.org/SEAF/PlanDevelopBioEnergyStrategy.pdf>.
- UBOS. (2006). 2002 Uganda population and housing census. Kampala, Uganda: Uganda Bureau of Statistics.
- Utell, M., & Frampton, M. (2000). Acute Health Effects of Ambient Air Pollution: The Ultrafine Particle Hypothesis. *Journal of Aerosol Medicine*, 13(4), 355-359.
- Vlosky, R., & Smithhart, R. (2011). A Brief Global Perspective on Biomass for Bioenergy and Biofuels. *Journal of Tropical Forestry and Environment*, 1(1), 1-13.
- World Health Organization. *Fuel for Life: Household Energy and Health*. Geneva, 2006.

- Zhang, J., Smith, K., Ma, Y., Ye, S., Jiang, F., Qi, W., et al. (2000). Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. *Atmospheric Environment*, 34(26), 4537-4549.
- Zulu, L. (2010). The forbidden fuel: Charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi. *Energy Policy*, 38, 3717-3730.

Table 1: Woody biomass density by land use^{1,2,3}

Land cover (use)	Ungazetted land ⁴ (hectares)	Available (t/ha)
Tropical high forest	174,800	224.0
Tropical high forest (degraded)	175,900	113.0
Woodlands	2,601,800	29.9
Broadleaved plantations	12,200	75.9
Softwood plantations	700	147.1
Large-scale farmlands	66,200	0.0
Subsistence farmlands	7,902,100	12.7
Bush lands	2,755,800	2.5
Grass lands	174,800	177.6

1. All values for air dried wood.
2. Adapted from Turyareeba, Drichi and UNEP (2001).
3. Excludes built up areas, impediments, water and wetlands which have negligible woody biomass.
4. Excludes land under protected area status as national park, game reserve, central or local forest reserve.

Table 2: Descriptive statistics for variables included in probit regression models

Variable	N	Mean	Standard deviation	Minimum	Maximum
Presence of acute respiratory infection, 0=No; 1=Yes	1823	0.16237	0.368891	0	1
Fuel wood from forest (kgs)	1823	272.8725	321.3307	0	1500
Charcoal from forest (kgs)	1823	8.41333	63.9975	0	500
Fuel wood from non-forest (kgs)	1823	194.7065	241.5256	0	1000
Crop residues (kgs)	1823	34.76083	93.38606	0	500
Total income (10,000 UgShs)	1823	153.123	167.117	0	1000
Second youngest child (c.f. youngest child)	1823	0.106418	0.308457	0	1
Third youngest child (c.f. youngest child)	1823	0.030719	0.172602	0	1
Primary cook (c.f. youngest child)	1823	0.302249	0.459359	0	1
Secondary cook (c.f. youngest child)	1823	0.215579	0.411336	0	1
Tertiary cook (c.f. youngest child)	1823	0.150302	0.357465	0	1
Cooking indoors with ventilation (c.f. cooking outdoors)	1823	0.741635	0.437856	0	1
Cooking indoors with no ventilation (c.f. cooking outdoors)	1823	0.094899	0.293155	0	1
Cooking on improved stove (0=No; 1=Yes)	1822	0.179473	0.383853	0	1
Household size (number of people)	1823	5.016456	3.987873	0	20
Age of head (years)	1816	43.07544	15.15886	16	112
Female headed household (0=No; 1=Yes)	1823	0.15469	0.361708	0	1
Education of head (years)	1815	4.59449	3.626099	0	18
Bugoma site (c.f. Rwenzori)	1823	0.224904	0.417634	0	1
Budongo site (c.f. Rwenzori)	1823	0.46407	0.498844	0	1

Table 3: Land use within 10 km radius of village centroids, percent of area in category

	2003	2007	2011	Change between 2003 and 2007	Change between 2007 and 2011
Forest	45.8 (22.3)	33.3 (15.7)	30.4 (19.4)	-12.5	-2.9
Woody savannah	17.6 (14.5)	23.6 (16.2)	20.7 (19.4)	+6.0	-2.9
Savannah	1.0 (1.8)	0.7 (1.3)	0.3 (0.8)	-0.3	-0.4
Cropland	35.0 (16.8)	42.0 (16.1)	48.2 (17.4)	+7.0	+6.2
N	18				

Table 4: Fuel use per household by type and source

	Volume (kgs)			Shares		
	2007	2012	2012	2007	2012	2012
<i>Forest</i>	Full sample	Full sample	Matched Panel	Full sample	Full sample	Matched Panel
Fuel wood	335.1 (327.0)	253.5*** (3.7.7)	263.8*** (310.6)	74.2 (39.8)	51.6 (40.8)	51.2 (39.8)
Charcoal	13.5 (79.8)	8.0 (62.6)	7.6 (60.7)	1.5 (8.8)	1.0 (7.7)	0.9 (7.3)
<i>Non-forest</i>						
Fuel wood	94.8 (196.1)	188.3*** (236.6)	202.5*** (244.5)	23.6 (38.9)	39.8 (39.0)	41.8 (39.0)
Crop residue	2.6 (20.9)	31.6*** (99.8)	26.4*** (82.2)	0.75 (5.2)	7.6 (18.9)	6.1 (17.3)
TOTAL	446.0 (336.5)	481.5* (350.7)	500.3** (356.1)	100	100	100
Distance to forest (minutes)	34.1 (43.3)	43.8*** (42.0)	45.2*** (43.3)			
N	540	555	455			

,* means 2007 and 2012 data are statistically significantly different at the 10%, 5%, and 1% levels respectively.

Table 5: Volume of fuel consumed by household and presence of acute respiratory infection (self or mother reported cough and trouble breathing) during two weeks prior to interview^{1,2}

Volume	All		Children under 5		Adult cooks		
	No ARI	ARI	No ARI	ARI	No ARI	ARI	
Total fuel, kgs	508.1 (247.8)	524.7 (368.6)	506.2 (352.6)	553.9 (355.8)	508.7 (346.2)	457.8 (390.3)	
Fuel wood from forest, kgs	273.4 (322.1)	270.3 (317.3)	280.7 (318.4)	285.9 (317.5)	270.8 (232.5)	234.8 (317.6)	
Charcoal from forest, kgs	8.4 (64.0)	8.4 (64.0)	11.2 (73.7)	7.2 (59.3)	7.4 (60.2)	11.1 (74.1)	
Fuel wood from non-forest, kgs	189.1** (238.8)	223.8 (253.4)	182.5*** (224.7)	238.4 (258.7)	191.4 (243.7)	190.4 (238.8)	
Crop residues, kgs	37.3** (97.6)	22.1 (66.1)	31.8 (92.4)	22.4 (65.2)	39.1* (99.4)	21.5 (687.5)	
	N	1527	296	399	206	1128	90
Shares							
Fuel wood from forest, percent	53.0 (41.3)	51.7 (39.3)	54.5 (40.5)	52.0 (38.7)	52.0 (41.6)	51.0 (40.7)	
Charcoal, percent	1.1 (8.2)	0.9 (6.7)	1.2 (7.9)	0.8 (6.8)	1.0 (8.4)	1.0 (6.6)	
Fuel wood from non-forest, percent	37.6** (38.6)	43.1 (38.5)	37.6 (38.0)	42.6 (38.0)	37.6 (38.8)	44.3 (39.7)	
Crop residues, percent	8.4*** (20.0)	4.3 (12.6)	6.7 (18.1)	4.5 (13.4)	8.9** (20.6)	3.4 (10.5)	
	N	1438	274	378	194	1060	80

1. Standard deviation in parentheses.

2. ARI assumed based upon self-reported presence of cough and trouble breathing.

Table 6: Determinants of acute respiratory infection (ARI) in children under 5 and adults involved in cooking

	All		Children under 5		Adults	
	Estimated coefficient	Marginal effect	Estimated coefficient	Marginal effect	Estimated coefficient	Marginal effect
Fuel wood from forest (kgs)	0.012 (-0.87)	0.00002	0.032* (-1.67)	0.00011	-0.008 (-0.37)	-0.00001
Charcoal from forest (kgs)	-0.005 (-0.07)	-0.00000	-0.054 (-0.59)	-0.00018	0.062 (-0.74)	0.00008
Fuel wood from non-forest (kgs)	0.037** (-2.18)	0.00007	0.071*** (-2.74)	0.00024	0.004 -0.16	0.00000
Crop residues (kgs)	-0.108** (-2.11)	-0.00022	-0.118* (-1.71)	-0.00039	-0.112 (-1.54)	-0.00014
Total income (10,000 UgShs)	0.000 (-1.47)	0.00007	0.001* (-1.72)	0.00018	0 (-0.38)	0.00002
Second youngest child (c.f. youngest child)	-0.201* (-1.71)	-0.07051	-0.198* (-1.65)	-0.0668	-	-
Third youngest child (c.f. youngest child)	-0.490** (-2.46)	-0.16038	-0.504** (-2.44)	-0.15797	-	-
Primary cook (c.f. youngest child)	-0.920*** (-9.12)	-0.26125	-	-	-	-
Secondary cook (c.f. youngest child)	-1.381*** (-10.31)	-0.32645	-	-	-0.454*** (-3.45)	-0.06425
Tertiary cook (c.f. youngest child)	-1.718*** (-9.11)	-0.35213	-	-	-0.777*** (-4.26)	-0.08911
Cooking indoors with ventilation (c.f. cooking outdoors)	0.041 (-0.39)	0.00824	0.092 (-0.62)	0.03055	-0.012 (-0.08)	-0.00161
Cooking indoors with no ventilation (c.f. cooking outdoors)	-0.172 (-1.02)	-0.03475	-0.087 (-0.36)	-0.02890	-0.194 (-0.83)	-0.02534
Cooking on improved stove (0=No; 1=Yes)	-0.06 (-0.53)	-0.12097	0.11 (-0.69)	0.03652	-0.216 (-1.23)	-0.02828
Household size (number of people)	0.085*** (-2.79)	0.01725	0.139*** (-3.1)	0.04614	0.027 (-0.59)	0.00358

Household size x2	-0.008*** (-3.60)	-0.00165	-0.012*** (-3.65)	-0.00392	-0.004 (-1.14)	-0.00055
Age of head (years)	0.004 (-1.52)	0.00089	0.008* (-1.67)	0.00252	0 (-0.13)	0.00006
Female headed household (0=No; 1=Yes)	-0.056 (-0.46)	-0.01128	-0.361* (-1.77)	-0.12010	0.136 (-0.93)	0.01777
Education of head (years)	-0.025** (-2.11)	-0.00505	-0.022 (-1.31)	-0.00745	-0.027 (-1.56)	-0.00348
Bugoma site (c.f. Rwenzori)	0.514*** (-4.49)	0.09464	0.741*** (-4.76)	0.22535	0.255 (-1.52)	0.03209
Budongo site (c.f. Rwenzori)	0.554*** (-4.37)	0.10366	0.893*** (-5.1)	0.27990	0.211 (-1.17)	0.02568
Constant	-0.981*** (-4.17)		-1.657*** (-4.99)		-1.193*** (-3.53)	
	N	1807	598		1209	
	Pseudo R-Squared	0.1805	0.0850		0.0767	
	Log-likelihood/Pseudo log-likelihood	-656.35	-350.56		-295.79	

1. Coefficients for village level dummy variables not reported.
2. Robust standard errors are reported in parentheses.
3. *, **, *** Statistically significant at the 10, 5 and 1 per cent levels respectively.

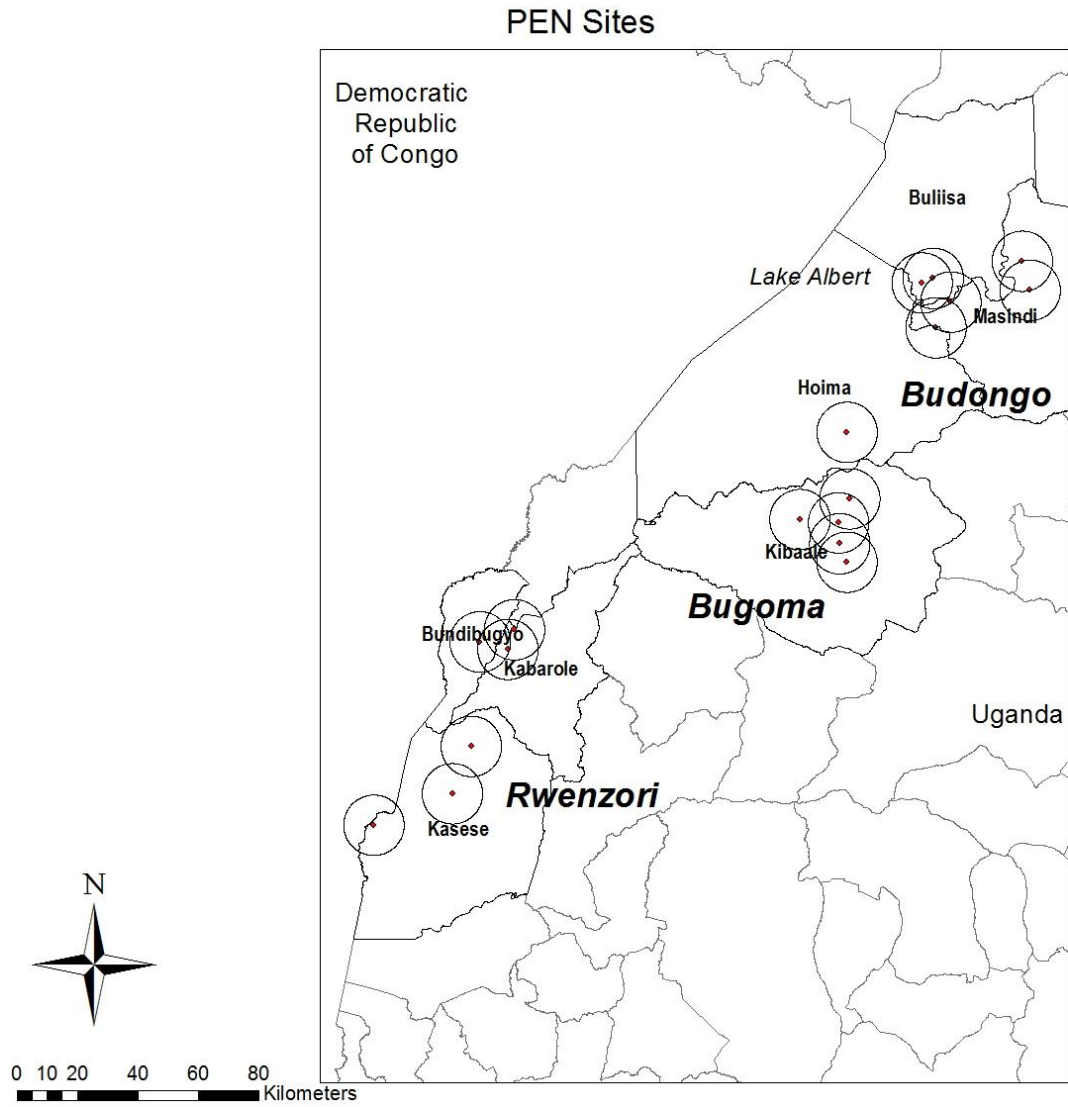
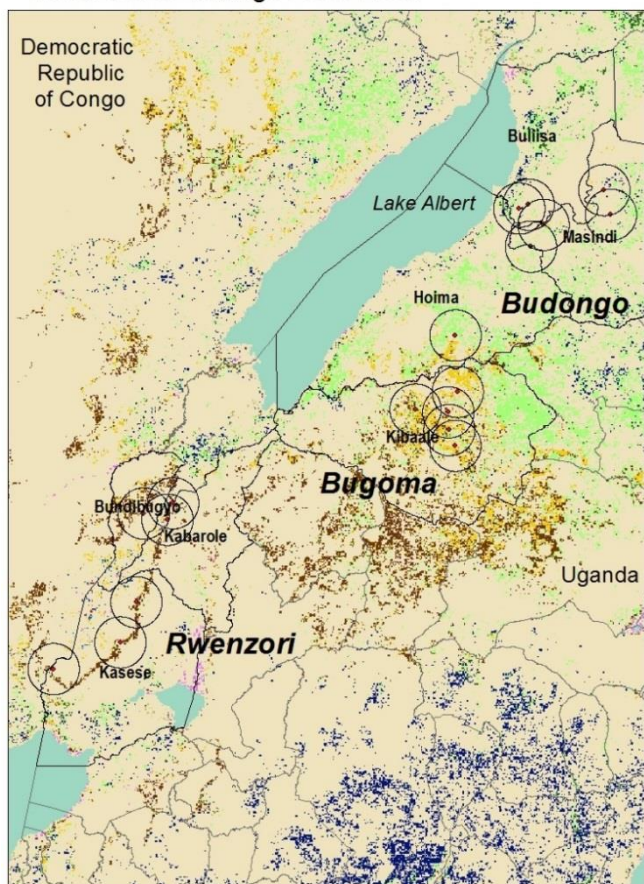


Figure 1: Study sites

Land Cover Change 2003-2007



Land Cover Change 2007-2011



Legend

- No Change
- Water
- Other -> Cropland
- Forest -> Shrubland
- Forest -> Woody Savanna
- Forest -> Savanna
- Woody Savanna -> Savanna
- Forest -> Other
- Forest -> Grassland
- Forest -> Cropland
- Woody Savanna -> Other
- Woody Savanna -> Cropland
- Savanna -> Other
- Savanna -> Cropland
- Grassland -> Cropland

Land Cover Change 2003-2011

