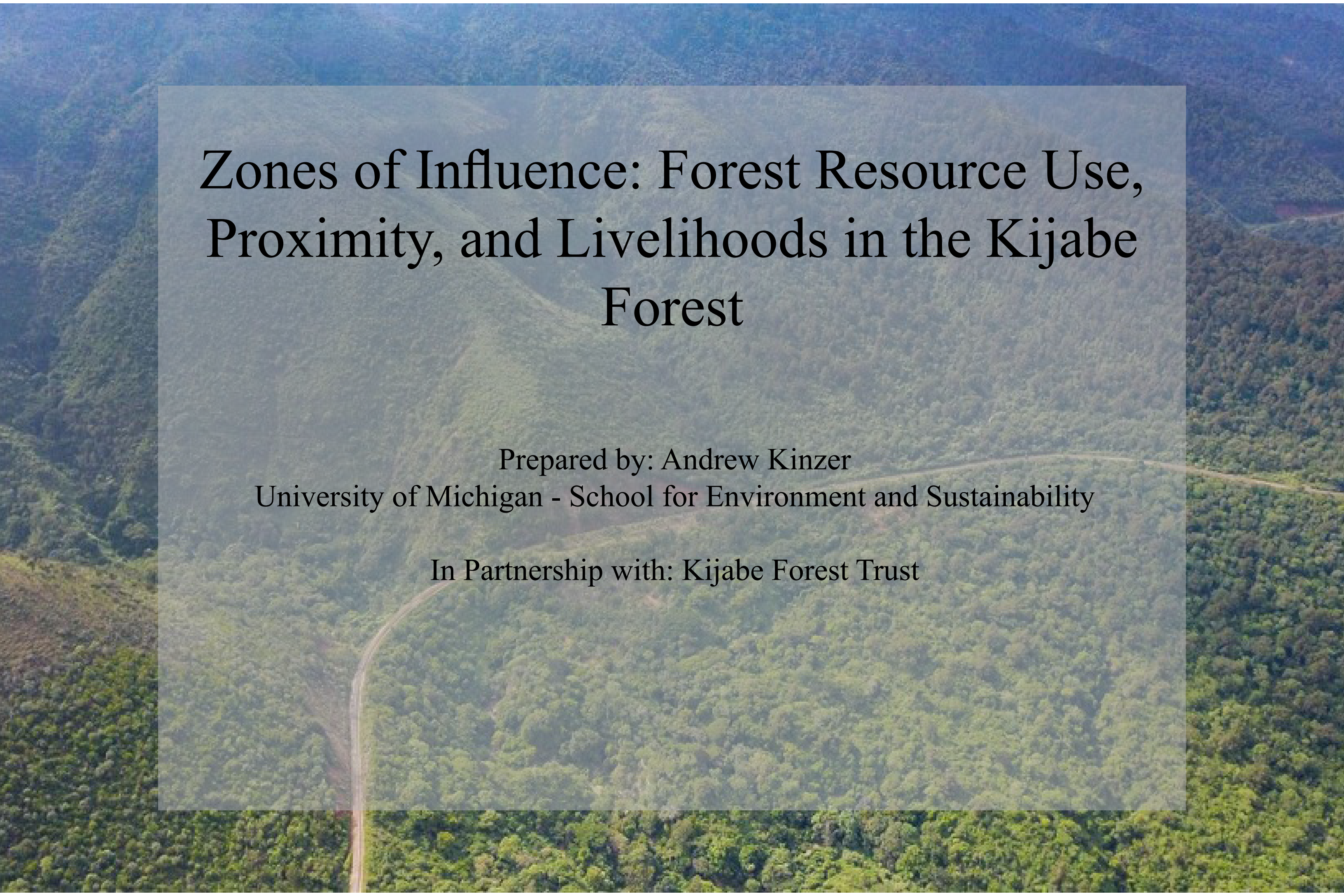

Zones of Influence: Forest Resource Use, Proximity, and Livelihoods in the Kijabe Forest

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In Partnership with: Kijabe Forest Trust

Table of Contents

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Abstract

The factors influencing forest dependence have been examined extensively using both spatial and social variables. While these studies have created valuable insights about forest dependence, a more complex picture that considers the physical distribution of both the resources being depended on and the households depending on them, as well as the social characteristics of those households is needed. This allows us to treat the forest as an agent that is capable of exerting influence over households that changes based on spatial and social factors. This study examined the zones of influence of a 5,500 hectare Afromontane highland forest in central Kenya. It examined the zones of influence of charcoal, firewood, and all the used forest products combined, on the households in the communities around the forest. Furthermore, it examined if that influence changed as a function of distance, household economic characteristics, and household demographic characteristics. The results show that when spatial and social variables are considered together, the zones of influence of each of the forest resources changed, both in which social variables were significant, as well as the magnitude of their significance. Households living close to the forest were not inherently more likely to use any of the forest resources examined, but rather the predicted probabilities changed based on a household's distance from certain forest types, as well as a household's unique economic and demographic characteristics. This highlights the importance of recognizing that forests exist as agents in complex social-ecological systems, and that understanding the relational dynamics between them and the coommunities living around them is the only way we can hope to manage forest resources to meet the difficult goals of conserving biodiversity, restoring degraded landscapes, and meeting the livelihood needs of people.

Keywords: Forests, Zone of Influence, Livelihoods, Agency

Introduction

Current work on forest dependence focuses on what makes a person dependent on forests, and what goods and services forests provide. Forest dependence can be broadly defined as deriving benefits from forests in some way, and forest dependence has been the focus of significant interest and studied extensively by people within academic, development, and conservation fields (Newton et al. 2016). Studies have examined what social and spatial characteristics make a person or community dependent on forests and have developed robust datasets examining the contributions of forests to subsistence or income-generation (Hajjar et al. 2016).

“What makes a person or household dependent on forests?” is an important question to ask, and the studies answering that question examine the relationship between forests and dependence from the perspective of the household relying on them. Forests provide ecosystem services and act as havens for biodiversity. They also serve as safety nets for the poor, provide cultural homes, fuel, income, medicine, etc. (Chazdon et al. 2016). Understanding forest dependence is difficult because not all households value and utilize the forest in the same way, and the resources that are valued and relied on are not evenly distributed throughout the forest. Failing to incorporate the physical and cultural context of a given forest only allows us to develop a coarse understanding of how people depend on the forest.

This study strives to develop a fine-grain understanding of dependence that does justice to both the forest’s ecology as well as how people depend on specific forest resources. It begins by examining each forest resource in its own right; examining their distribution throughout the forest. It then considers where the households that depend on those resources are located and examines their economic and demographic characteristics. This perspective assesses how one

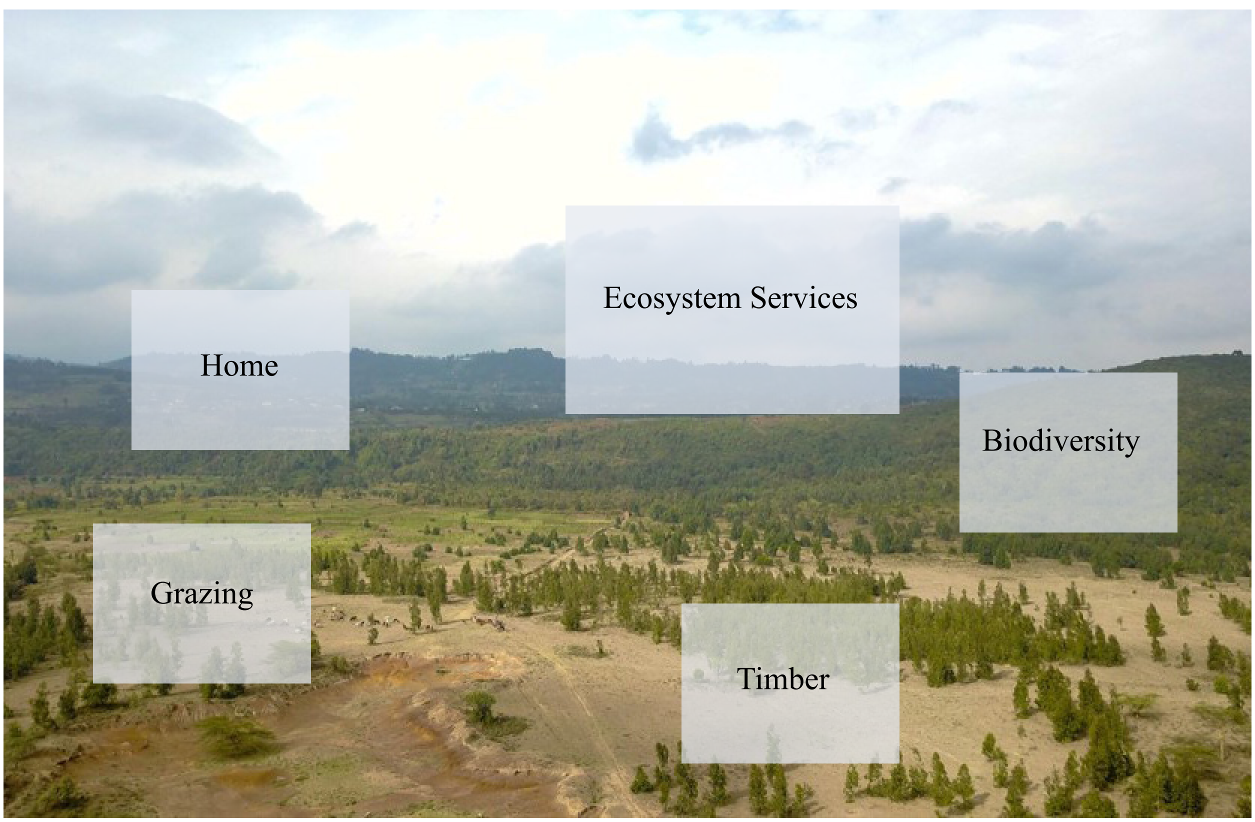


Figure 1: The same forest landscape can be valued for many different purposes, depending on an individual’s needs. None of these are mutually exculsive, and households could prioritize these values differently. In order to truly understand forest dependence, we need to understand the ecology of the forest, as well as the different ways the community values the forest.

can construct zones of influence based on products that forests provide, and their relationships to people's livelihoods.

Research Question

Do different forest products exert different levels of influence over a household?

Does that influence change with:
1. Distance
2. Houshold Economic Characteristics
3. Household Demographic Charactersitics

Examining the zones of influence of specific forest products within the forest changes the question of forest dependence from "How important is this product to a household?" to "What types of households does this forest product influence?". It treats the forest as an agent that is capable of influencing the behavior of people. This draws from current work in Actor-Network Theory (ANT) and melds well with understanding forests as complex social-ecological systems (Bohle et al. 2009).

Agency has traditionally been defined in the social sciences as the capacity for an agent to influence broader social relations, or to actively control an entity that is capable of exerting influence on the people and communities surrounding it (Lister 2004; Brown & Westaway 2011). Traditionally, agency has been applied to humans, but as Dwiartama and Rosin (2014) point out, ANT gives us a way to of understanding agency that extends beyond human intentionality.

A critical component of ANT is the understanding that things (people, institutions, resources, etc.) do not act by themselves, but are connected to the people, institutions, resources, etc. that are around them (Law 1994; Siakwah 2017). Thus, ANT helps us gain a better understanding of how these relational systems work by examining the ways these resources mold and are molded by the individuals and/or institutions to which they are connected (Siakwah 2017). This thinking moves us past considering only human relationships with each other, and includes the relationship that humans have with their environment and the relationship environmental factors have with each other. This acknowledges the ability of any entity, human or otherwise, to make itself vital to its relationship with others. In the case of this study, the relationship examined was between different forest products, and the households that are using them.

Zones of Influence

Traditionally, forest dependence has been looked at through two main lenses, a spatial lens and a social lens. The spatial zone of influence of a forest or forest product has been traditionally measured primarily through distance. A household would be considered within the zone of influence of a forest based on how far away from the forest they lived. Dash et al. (2016), Omotayo (2002), Robinson et al. (2008), Pattanayak et al. (2004), Mbuvi & Boon (2009), and Martínez Romero et al. (2004) found that where a household was located changed the way households depend on forest resources. Generally, households close to the forest would be assumed to be within the forests zone of influence, and the amount of influence would decrease as a household's distance from the forest increased.

The social zone of influence of a forest has been tied to household-level economic or demographic characteristics. An economic sphere of influence would quantify the economic markers of households depending on a certain forest product in the communities living around the forest. Forests play important roles in rural households in preventing, and reducing poverty (Meilby et al. 2014; Fisher 2004; Shackleton et al. 2007), and poor households tend to be more directly dependent on forest resources than wealthy households. Economic characteristics such as the sources of income, total expenses, the existence of a savings account, or having loans (Dash et al. 2016; Meilby et al. 2014) have all been shown to be related to dependence on forest products.

A demographic zone of influence would assume that households with certain demographics would be more dependent on forest products than others. For example, whether the household head is male or female, whether they own the land they live on, the number of years of education of the household head, etc., have all been shown to affect how households depend on forest resources (Agarwal 2009; Dash et al. 2016; Mbuvi & Boon 2009; Sharaunga et al. 2015).

ANT gives a more complex way of thinking about zones of influence through one of its key components: hybridity. Hybridity is the understanding that distance can be conceptualized differently across different dimensions (Latour 1993; Young 2006). Depending on the natural, technological, or social dimensions present in a system, "distance" from an object may look different. This idea treats distance as more than spatial location, but the combination of location and social factors. For example, a household living close to the edge of a forest may be considered within the zone of influence of that forest, but perhaps there are household characteristics that make the use of that forest unnecessary, or institions that are restricting access to use of that forest. While the physical distance may be small, the social "distance" may weaken the zone of influence over that particular household (see zone of influence example below). To construct an accurate zone of influence of a particular resource both spatial and social characteristics need to be considered.

If each forest product's zone of influence over different households can be determined, more appropriate decisions can be made when thinking about development interventions, making governance decisions about forest resource use, and how to prioritize restoration activities based on appropriate ecological knowledge, use preferences, and community needs.

Zone of Influence Example: Charcoal

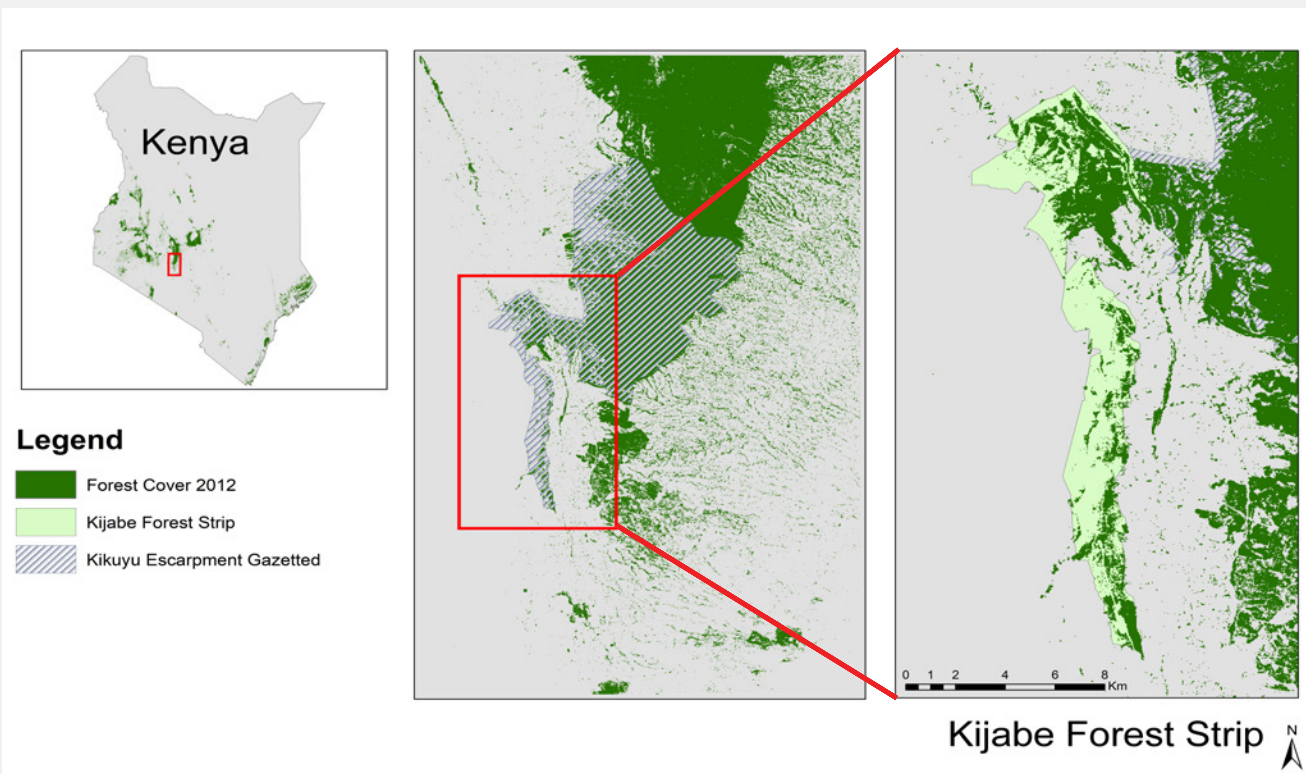
A conservation and development agency is concerned about deforestation and the amount of people that are using charcoal as a cooking fuel. They are interesetd in finding a more sustainable solution for meeting people's cooking needs, and have embarked on a study to determine which households to target, as they have limited funding, but want to make as large an impact as possible. Charcoal is a fairly costly product to both purchase and make, and past research has shown that there are household ecnomic and demographic charactersitics that increase the likelihood that a household is relying on charcoal.
The organization gathers the household demographic and economic information, as well as how close the households are living to the forest, and determine that 150 households should be targetted for an intervention.

Although thorough, the organization is still missing a part of the picture and taking a course view of forest dependence. A fine view of forest dependece would recognize that not all trees produce the same quality charcoal, and recognize that trees favorable for producing charcoal are not evenly distributed across the forest. Considering the distribution of the species used for charcoal and the household characteristics, the organzation wouls be able to more effectively map the zone of influence that charcoal has over housholds.

Site History

The Kijabe Forest strip is a ~5,500-hectare segment of Eastern Afromontane forest located in central Kenya (0˚ 57.815'S, 36˚ 36.110'E) (Map 1). Eastern Afromontane forest is a biodiversity hotspot with globally significant levels of biodiversity and endemism (Mittermeier et al. 2015). The forest was once connected to the larger Kinale/Uplands Forest, gazetted in 1943 under the colonial government(Forest Conservation and Management Act 2016). While human settlement, deforestation, and land use conversion has led the Kijabe Forest strip to become geographically isolated from the Kinale/Uplands Forest, the forest still falls under the Kinale/Uplands Forest management plan. The Kijabe Forest strip has been largely neglected by the Kenya Forest Service, which has led to unchecked deforestation, illegal timber harvesting, and charcoal production.

The Forest Act of 2005 created the opportunity for increased co-management of forests through establishing Community Forest Associations (CFAs). This act did not officially transfer



Map1: The location of the Kijabe Forest strip, located in the central highlands of Kenya. Gazetted as the Kikuyu Escarpment Forest by the Kenya Forest Service, it has become geographically separated and has been minimally managed or protected.

governance from the state to communities, but it did create opportunities for CFAs to work with the government institutions in in charge of those resources. CFAs were formed in both Kereita and the Uplands forests, but the geographic isolation of the Kijabe Forest strip meant that the activities of those CFAs were primarily restricted to those areas and did not extend into the Kijabe Forest strip. Illegal harvesting of timber and firewood, as well as charcoal production continued unabated, and the integrity of the ecosystem continued to be compromised.

The effects of these activities were not confined to ecological degradation, but also had negative effects on the human communities living around the forest. In May of 2013 there was a catastrophic landslide in the Kijabe Forest, sending 80-foot-tall trees and thousands of pounds of mud and boulders careening down the Kijabe escarpment (Figure 2). Railroad tracks, water pipes, roads, bridges, and homes were destroyed, and two children lost their lives. In response to the absence of a management plan for the forest, and the resulting threat to their livelihoods and well-being, community members formed the Kijabe Forest Trust (KFT). The mission of KFT is to organize community efforts to sustainably manage the Kijabe Forest strip, including restoration of degraded areas, and to facilitate access to opportunities for alternative livelihoods, increasing overall forest biodiversity and resilience, and reversing the trend of deforestation and degradation (Anon n.d.).

KFT is concerned with the forests ecological integrity and the well-being of the communities living around it. Because of this, the mission statement of the trust is an appropriate way to

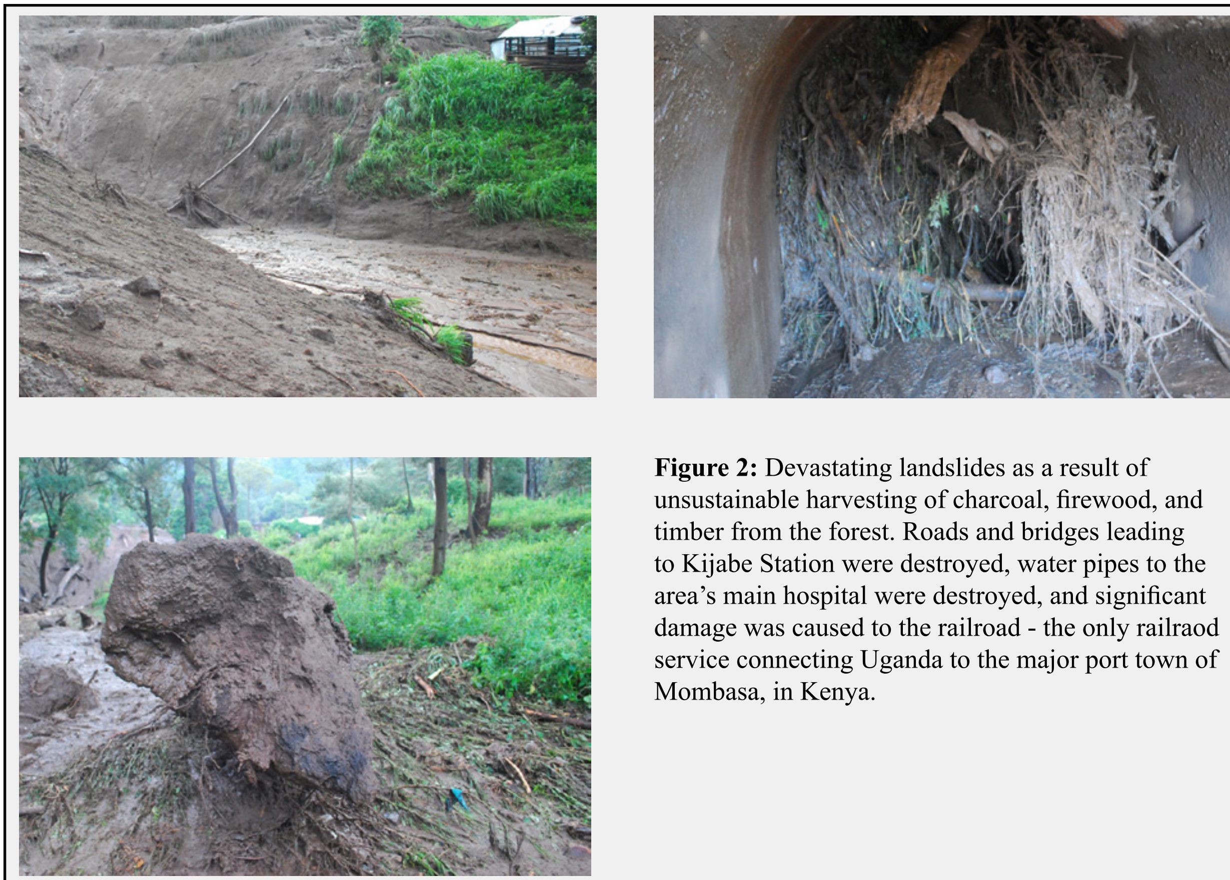


Figure 2: Devastating landslides as a result of unsustainable harvesting of charcoal, firewood, and timber from the forest. Roads and bridges leading to Kijabe Station were destroyed, water pipes to the area's main hospital were destroyed, and significant damage was caused to the railroad - the only railraod service connecting Uganda to the major port town of Mombasa, in Kenya.

examine the relationship between the forest and the communities. It is necessary to include a community element in defining and classifying the forest, as well as classifying it by its ecological characteristics. Failing to incorporate both would give an incomplete picture of the zone of influence of the forest and the way that communities interact with it.

Methods

Forest Sampling

Forest sampling was carried out in the three forest types identified in the Kijabe Forest Strip: Primary, Secondary, and Degraded. Primary forest (Figure 3) was defined as areas of closed canopy forest with little to no human use or degradation. Secondary forest (Figure 4) was defined as areas of forest regularly used by people, but where the canopy is still somewhat intact and there is evidence of active regrowth of dominant canopy species. Degraded forest (Figure 5) was

Figure 3: Primary Forest: Closed canopy forest with little to no human use or degradation and showing evidence of a clear overstory and understory.

Figure 4: Secondary Forest: Areas of forest regularly used by people, but where the canopy is still somewhat intact and there is evidence of active re-growth of dominant canopy species.

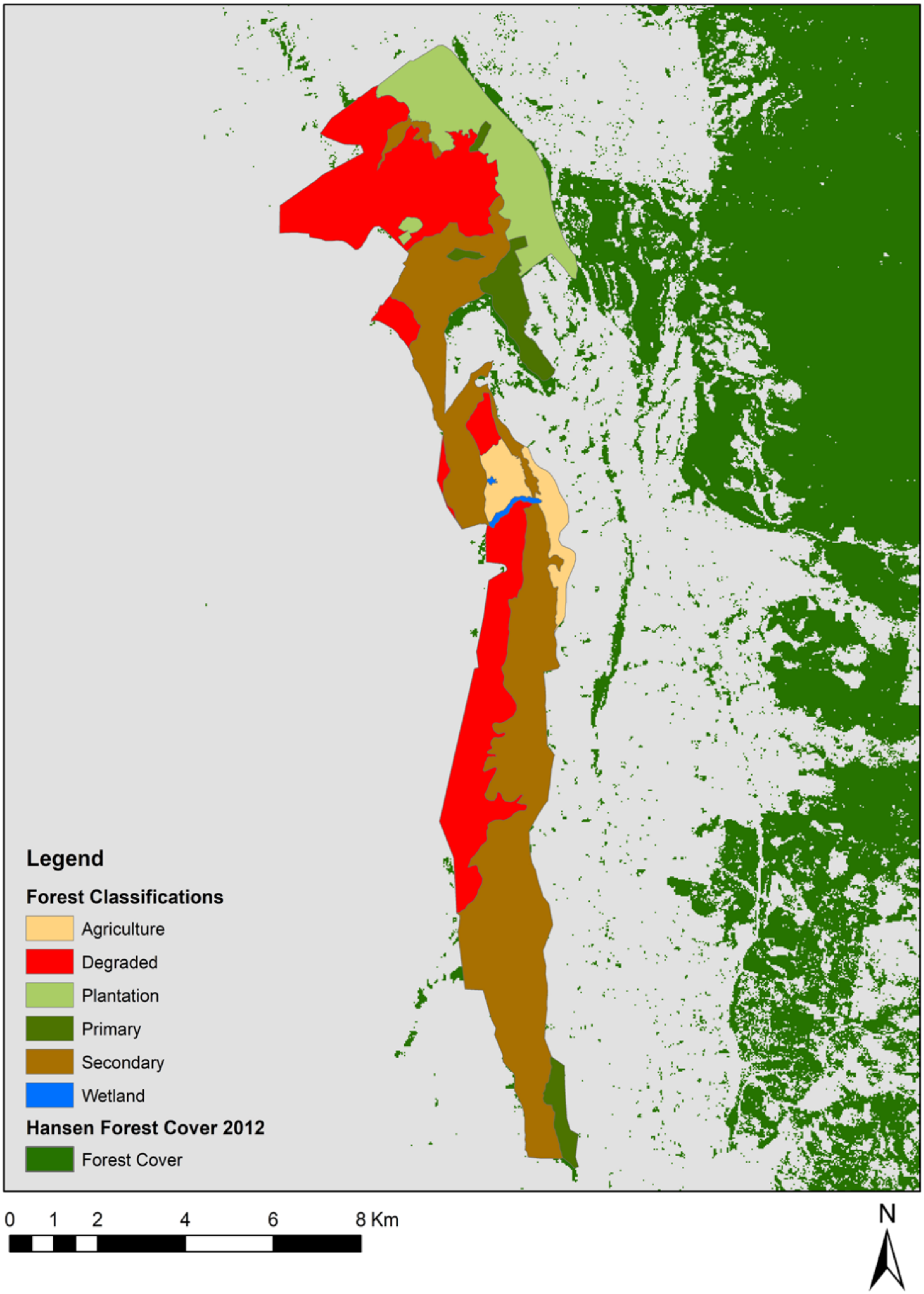
Figure 5: Degraded Forest: Areas that have been heavily used by people, and where dominant canopy species are almost entirely absent.

defined as areas that have been heavily used by people, and where dominant canopy species are almost entirely absent. The forest was classified using a mix of Google Earth satellite imagery (Kijabe Forest 2018), the open-source mapping software Quantum GIS, ground truthing, and community resource mapping. Once classified, standard forest ecology sampling techniques from the work done in Kenyan forests by Glenday (2006) and Cuni-Sanchez et al.(2017). When possible, all trees were identified in the field to the species level. On the occasion a positive *in situ* identification was not possible, a sample was collected for later identification. On the occasion a species was identified by its local name, but no corresponding scientific name was found, the local name was recorded and reported. For the sake of accurate Shannon Diversity Index calculations, if a species was unidentified, but was confirmed as a unique species, it was included in the diversity calculations labeled by its sample number.

Forest Classification

Initially, the forest was manually classified using high resolution imagery from Google Earth that was brought into QGIS using the OpenLayers plugin (QGIS Development Team 2018). Upon arrival at the site, two (2) participatory resource mapping workshops were conducted adapting methods developed by Kalibo and Medley (2007). Participants were asked to map out the location of important landscape features, and to identify parts of the forest they considered to be primary, secondary, or degraded, using the definitions above. The maps were then digitized and used to edit the map originally produced using Google Earth. Ground-truthing was done on foot, and by drone, and the map was adjusted accordingly (Map 2).

Figure 6: Community natural resource mapping workshop where community members and KFT rangers mapped the resources of the forest and classified the forest into different forest types.



Map 2: Forest type classification map showing the results of the collaborative mapping workshops, and ground-truthing by foot and by UAV. Included in the map is sattelite derived forest cover data developed by Hansen et al (2012).

Plot Layout

Plots points were randomly generated and selected in each main forest type. The circular sampling plots were 20 meters in diameter and divided into quarters.
In each plot, site biodiversity, stand composition and structure, and above ground biomass were measured. The center of each plot was marked with a GPS and a permanent metal stake was driven into the ground, so it could be re-visited and re-measured for long-term monitoring in the future.

Tree Measurements

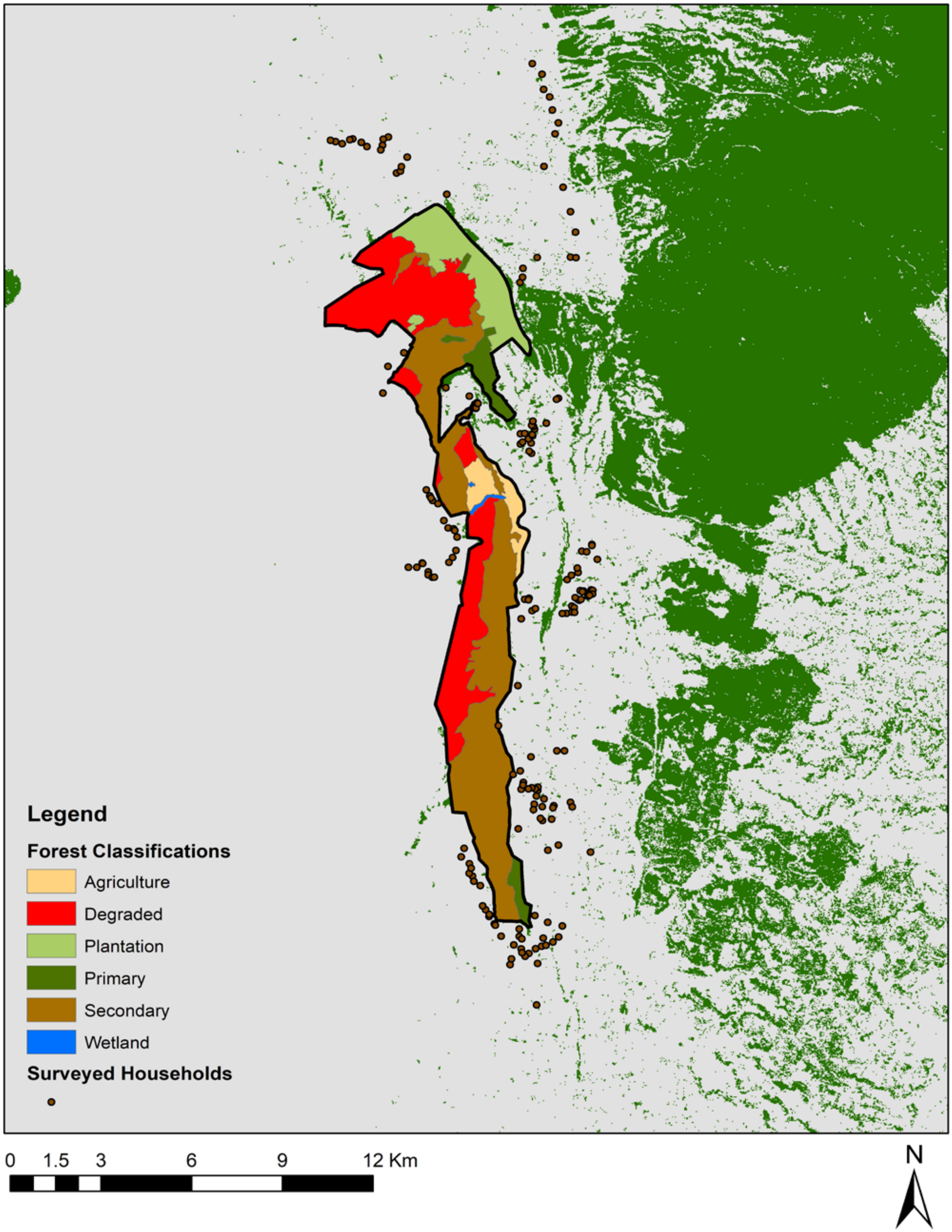
The diameter at breast height (dbh=1.3 meters from the ground) was measured for each tree located within the sample plot using a dbh tape. For multi-stemmed species, each stem was measured and the total dbh was calculated by summing the dbh of all the stems. For trees located on a slope, the dbh was measured on the uphill side of the slope. Additionally, if the tree had a deformity, or branched right at dbh, the measurement was taken immediately above the deformity and/or each stem and branch was measured. For trees that were leaning over, or had multiple stems that were leaning over, only branches or stems that were leaning less than 45 degrees from verticle were measured.

The height of each tree in the sample plot was measured using a Nikon Forestry Pro Laser Rangefinder and Hypsometer.The height and dbh of trees or other woody plants with a dbh >= 10 centimeters were measured within the entire 20-meter diameter circle. Trees or shrubs with a 10 cm>dbh>=2.5 cm were measured within a randomly selected quarter of the total 20-meter diameter plot.

Trees were classified as adults (dbh > 20 cm) or saplings (dbh = 2.5-20 cm). These classifications are taken from other literature on forest stand and structure measurement studies in Kenya (Glenday 2006).In addition to traditional forest structure measurements, cut stumps were also measured in each plot. The diameter at cut height (dch), whether it was coppicing, and the species (where possible) was recorded.

Household Livelihood Surveys

Household level livelihood and forest resource use surveys were conducted in 297 households in the eleven towns located around the Kijabe Forest Strip. The survey was developed by the International Forestry Resources and Institutions (IFRI) research group to measure forest dependence by gathering information on household economics, demographics, forest resource use, and subjective well-being. Surveys were loaded onto tablets and administered by trained enumerators. As census lists were unavailable, houses were randomly selected using the criteria laid out by the Poverty Environment Network survey guidelines (2007). Both a main street and a minor street were selected, and the enumerator surveyed the head of the household (or most senior member if the head of the household was absent) at every third house along the right side of the street. If nobody was home, or if they refused to participate, the enumerator would visit the



Map 3: Forest classification and the location of the households surveyed

neighboring house. A total of 297 households were surveyed, and after the data were cleaned and points were excluded due to missingness, the final sample size used for analysis was 246.

A generalized linear model was used to analyze the data. A nested approach was taken to build the models, and final model selection was based on Akaike Information Criteria (AIC). Six different models were run. Three were run with only social characteristics as independent variables, then the same models were run again with distance included in the indepedent variables. Household forest product use (regardless or product type), household firewood use, and household charcoal were used as the response variables (ex: Model 1: forest product use ~ social variables. Model 2: forest prodcut use ~ social + spatial variables).

Maps showing the zones of influence of each forest product were produced by creating a splined surface using the calculated predicted probabilities that each household was relying on a particular forest product.

Results

Forest Sampling

Species abundance and diversity, stem density, tree height, dbh, above ground biomass (agb), and the number of cut stumps were measured across the three forest types in the Kijabe Forest Strip. Differences in forest structure characteristics were compared across forest types using Analysis of Variance (ANOVA). A Tukey Honest Significant Differences (TukeyHSD) test was run post-hoc to determine which forest types differed from each other. The Shannon Diversity Index was used to measure both the diversity and the evenness of the species at each location. Across the three forest types, there were differences between primary and degraded forest and between secondary and degraded forest, but there were very few differences between primary and secondary forest, with the exception of total AGB and the number of cut stumps (Table 1).

	Forest Type			**ANOVA (p-values)**		
	Primary	*Secondary*	*Degraded*	*Primary-Secondary*	*Primary-Degraded*	*Secondary-Degraded*
Stem Density (ha)	743 ± 1	769 ± 1	390 ± 2	0.98	0.08	0.05*
Tree Height (meters)	12.8 ± 0.17	10.8 ± 0.18	3.33 ± 0.36	0.07	0.00*	0.00*
DBH (cm)	28.4 ± 0.17	23.9 ± 0.18	14.8 ± 0.36	0.24	0.004*	0.09
AGB (mg/ha)	38.1 ± 0.17	17.1 ± 0.18	4.62 ± 0.36	0.01*	0.01*	0.56
Cut Stumps (ha)	180 ± 1	775 ± 1	452 ± 2	0.02*	0.64	0.18
Shannon Diversity Index	1.96 ± 0.17	1.98 ± 0.18	1.19 ± 0.36	0.81	0.00*	0.00*

Table 1: When comparing the differences in forest structure across forest types primary and secondary forest showed very few statistically significant structural differences, while there was a clear difference between the degraded forest and both other forest types.

Bray-Curtis Dissimilarity Index was used to compare the species composition across the three forest types. Structurally there is only a difference between degraded and primary forest and degraded and secondary forest, when looking at species composition, there are clear differences between the three types (Figure 7). In the primary forest we recorded 27 difference species, of which ~50% were made up of *O. europaea ssp. africana* (25.5%), *V. simplicifolia* (13.9%), and *J. procera* (10.2%). In the secondary forest we recorded 35 different species, of which ~50% were made up of *J. procera* (15.9%), *A. schimperi* (14.6%), *S. compactum* (11.6%), and *E. divinorum* (9.1%). In the degraded forest we recorded 12 different species, of which ~50% were made up of *T. camphoratus* (24.1%), Munyama (20.7%), and *D. viscosa* (10.3%). See Appendix I for full species lists of each forest type.

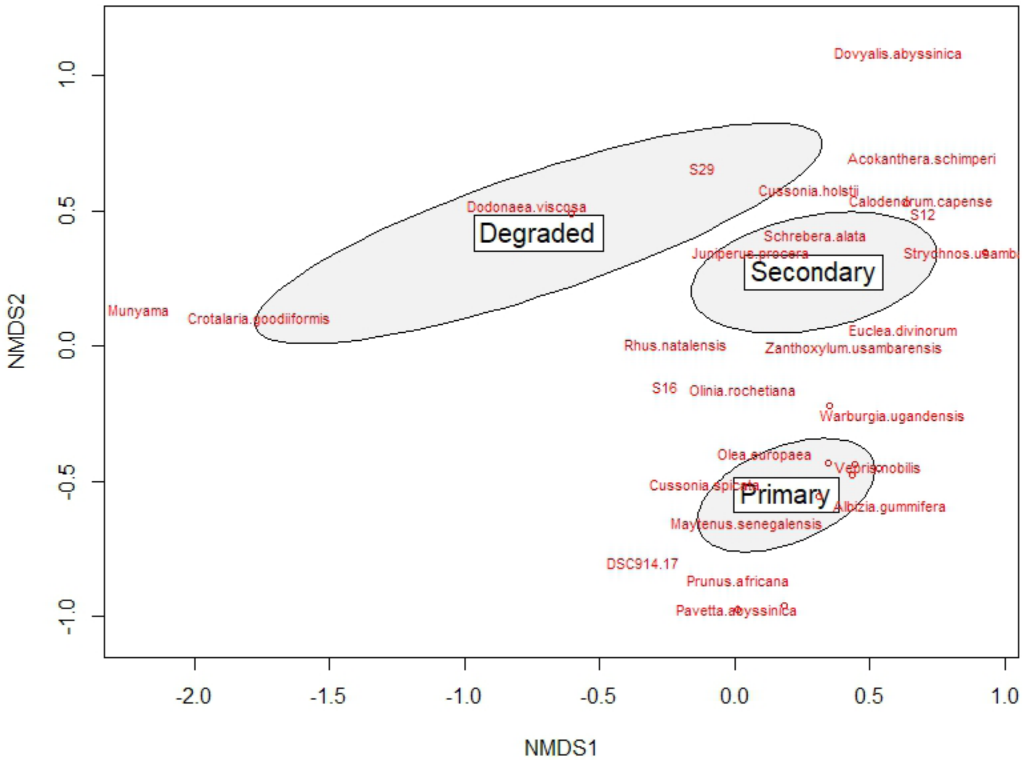


Figure 7: Bray-Curtis Dissimilarity Index showing the difference in species composition between the Primary, Secondary, and Degraded forest.

Community Use Preference

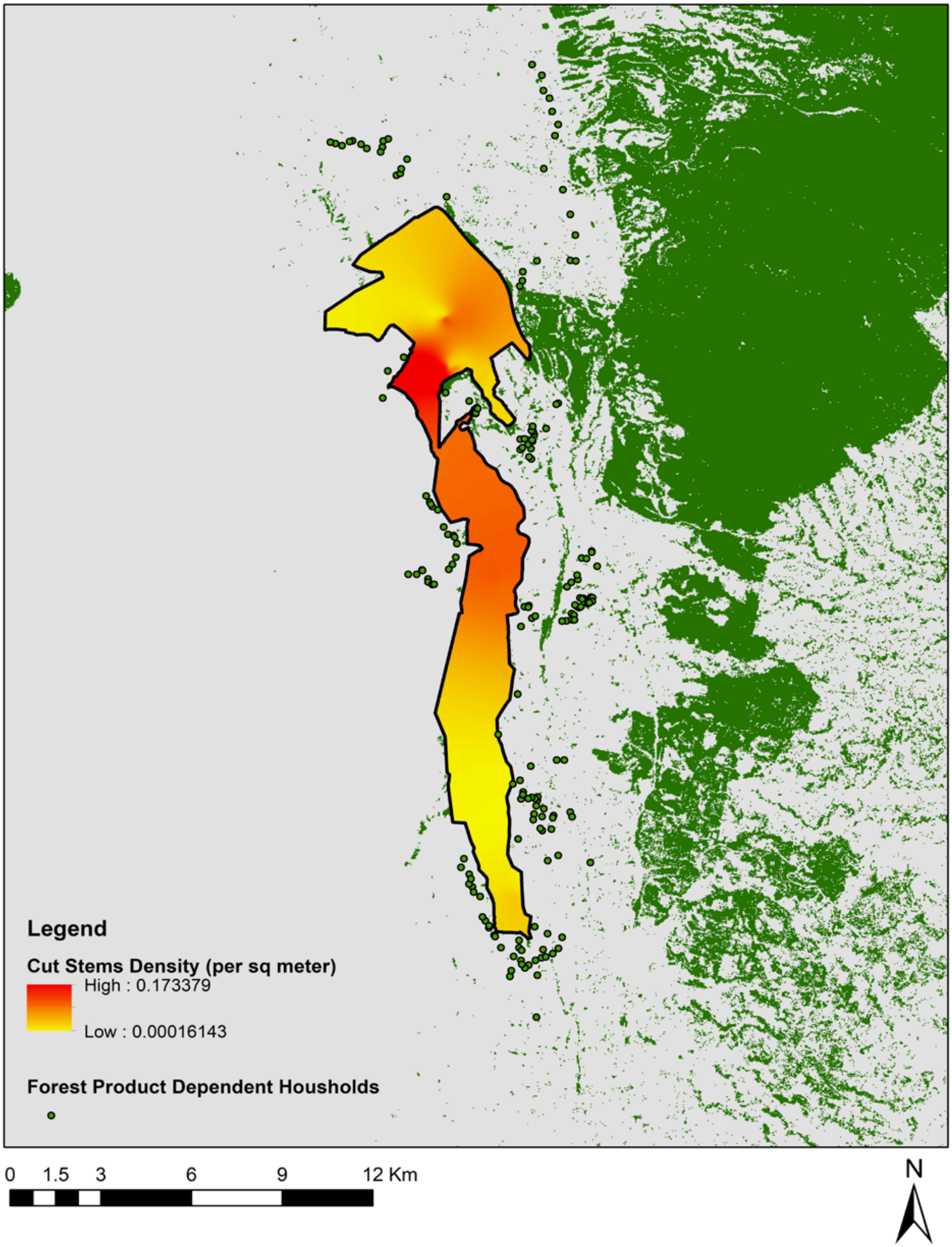
The number of cut stems, species, and whether a stump was coppicing (re-growing) was recorded across all three major forest types. A total of 294 cut stems were recorded in the sample plots, with *Olea europaea ssp. africana* (African olive), *Juniperus procera* (African pencil cedar), and *Euclea divinorum* accounting for 61.8% of the total stems cut (Table 2).

In addition to the species and the number of cut stumps in each quadrat, whether or not the species was coppicing was recorded. Two of the top three harvested species showed signs of coppicing (57.9% of *O. europaea ssp. africana*, and 92.1% of *E. divinorum),* but none of the *J. procera* showed signs of coppicing. When the total number of cut stems per habitat type was calculated, the only significant difference was between the primary and secondary forest (p=0.02) (Table 1). There was no significant difference between either secondary or primary forest and degraded forest.

Species	*Count*	*Percent of Total*	*Coppice*	*Coppice(%)*
Olea europaea ssp. africana	95	32.4	55	57.9%
Juniperus procera	48	16.4	0	0.0%
Euclea divinorum	38	13	35	92.1%
NA	24	8.2	4	16.7%
Tarchonanthus campnoratus	23	7.8	22	95.7%
Calodendrum capense	11	3.8	6	54.5%
Schrebera alata	10	3.4	10	100.0%
Vepris simplicifolia	8	2.7	8	100.0%
Eleodendron buchananii	5	1.7	3	60.0%
Acokanthera schimperi	3	1	3	100.0%
S29	3	1	3	100.0%
Maytenus undata	2	0.7	1	50.0%
Munyama	2	0.7	1	50.0%
Trichocladus ellipticus	2	0.7	2	100.0%
Pavetta abyssinica	2	0.7	1	50.0%
Rhus natalensis	2	0.7	0	0.0%
Watha	2	0.7	1	50.0%
Celtis africana	1	0.3	1	100.0%
Darajaa	1	0.3	1	100.0%
Maytenus senegalensis	1	0.3	1	100.0%
Mubiribiri	1	0.3	0	0.0%
Mukeu	1	0.3	1	100.0%
Murigithati	1	0.3	0	0.0%
Mwathatia	1	0.3	0	0.0%
Olinia rochetiana	1	0.3	1	100.0%
Prunus africana	1	0.3	0	0.0%
Psiadia punctulata	1	0.3	1	100.0%
S13	1	0.3	1	100.0%
Vangueria volkensii	1	0.3	1	100.0%
Warbergia ugandensis	1	0.3	1	100.0%

Table 2: Species preferences as indicated by the number of stumps of each species found across the sample plots. Species making up a higher percentage of the total are assumed to be preferred over the others. The table also shows the number of stumps that were coppicing and naturally regenerating. The scientific names are in italics, and any unidentified species, or species only identified by their local name are not in italics.

However, large sections of the degraded forest had been cut and subsequently burned, which would have contributed to the low stump count in the degraded areas. There were also sections where stumps had been dug out, most likely for charcoal. Interviews with Kijabe Forest Trust rangers and community members confirmed that in areas where there were no more suitable trees for timber, firewood, or charcoal, stumps were often collected as a last resort. An interpolated map showing the density of cut stems across the entire forest strip (Map 4) further illustrates cutting hotspots.



Map 4: The density of cut stems (per m2) across the Kijabe Forest Strip, with yellow showing low levels of cutting, and red high levels of cutting

Forest Use by Species and Forest Type

The preferred use of each species was recorded both by interviews with community members as well as through a search of the literature. The forest types were quantified in terms of their use value by calculating the proportion of species in each forest type that were preferred for a given use (Figure 8). The main uses for the species found in the forest were: charcoal, firewood, firewood and charcoal, timber, multiple (a combination of all previously listed uses), and other (poles, medicine, fodder, thatching material, etc.).

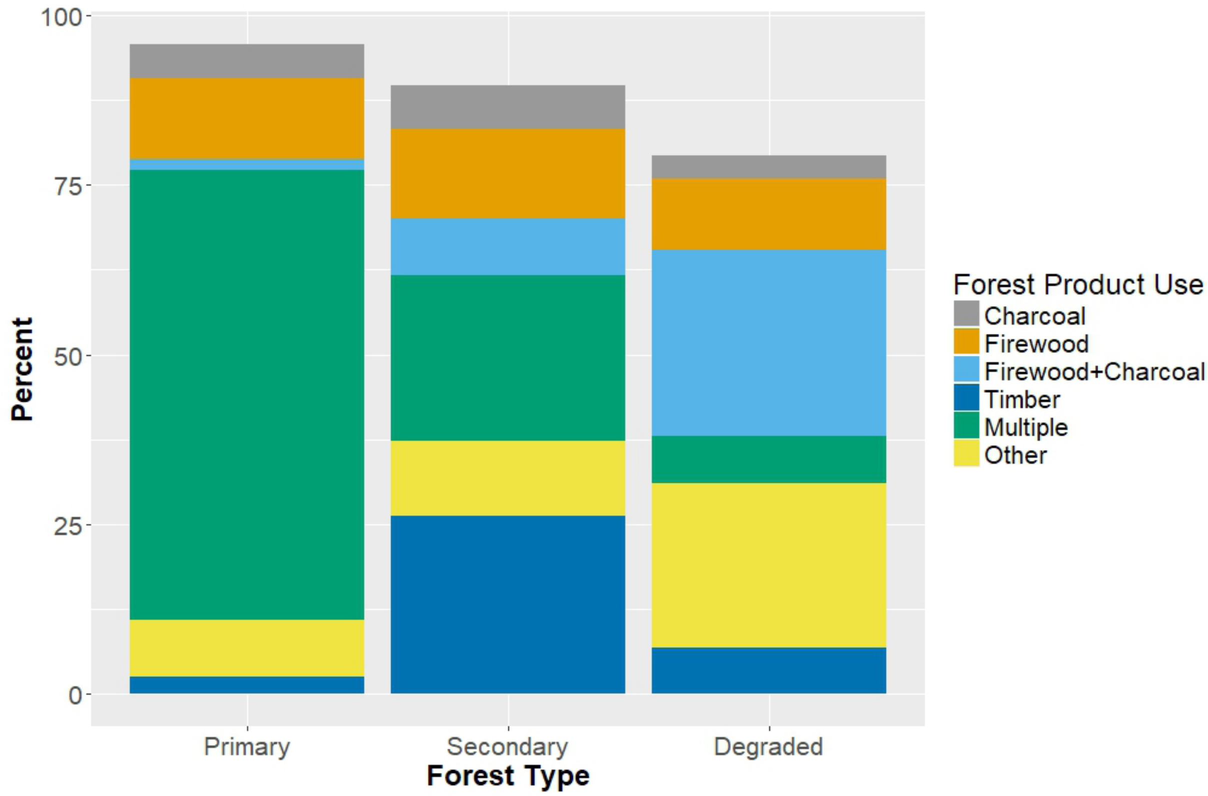


Figure 8: Forest type characterized by the proportion of species preferred for a specific use. This shows that primary forest contains a higher percentage of multi-use species and has relatively few species that are only valued for timber. Secondary forest has a high percentage of species valued as timber, and a much lower percentage of species that are used for multiple purposes. Degraded forest was made up of species mainly valued for charcoal and firewood and had a very low percentage of species used for multiple uses.

Household Surveys

Of the household's surveyed, 79.2% reported using products from the forest. Firewood and charcoal accounted for the majority of use (48.4%) while a combination of both firewood and charcoal accounted for the third most reported use (17.5%) (Table 3). It should be noted that the reporting rate for both timber and poles is not truly representative of their use by households. This is likely because poles and timber are illegally harvested, as permits for harvesting them are difficult to obtain. Anecdotal evidence, informal interviews, and the number of stumps of species exclusively used for timber (*J. procera*) confirm that these values are artificially low.

Because charcoal and firewood are the forest products most frequently used, the remaining analysis focused on establishing the zone of influence for those two forest products. To ensure that the products being used were being sourced from the Kijabe Forest, respondents were asked where they obtained the forest products they were using. As the Kijabe Forest is the largest and most accessible government forest in the area, the assumption is that if a household reported harvesting products from a government forest, the Kijabe Forest is the source. Of the 119 households using firewood or charcoal, the majority reported government forest, in this case the Kijabe Forest, as their primary source of both firewood and charcoal (85.7% and 95.8% respectively) (Table 4).

Forest Product Use	*Number of Households*
Firewood	119
Charcoal	119
Firewood and Charcoal	43
Fodder	5
Poles	2
Timber	2
Leaf	5
Chew-sticks	1
Bamboo	0
Medicinal Plants	0
Honey	0
Thatch	0
Fruit	0
Nuts	0

Table 3: The number of households using each of the forest products included in the survey. Firewood, charcoal, and a combination of the two accounts for the highest use. Values reported for timber and building pole use are likely artificially low.

Source of Harvesting	*Firewood*	*Charcoal*
Cultivated Trees on Farm	8	0
Government Forest	102	114
Market	9	5

Table 4: The primary sources for forest products reported by households. The majority of forest products being used are coming out of the government forest, the closest and most accessible of which is the Kijabe Forest.

A generalized linear model (GLM) was used to examine which household demographic and economic variables increased the probability that a household was harvesting and using forest products. Three iterations of the same model were used. The first examined the characteristics of households that were using any forest product, regardless of the type of forest product (Table 5). The second examined characteristics of households using only firewood (Table 6). The third examined characteristics of households using only charcoal (Table 7). The initial three models did not include a variable examining household location and distance from the forest, but instead defined what could be described as the social zone of influence of charcoal and firewood, as well as the forest as a whole.

When examining general forest product use, the only variable that was statistically significant was if the head of the household was male. If the head of the household was male, it increased the probability that the household was using forest products by 96.9%. Three variables (salary earned off-farm, female head of household, and if the head of household had a loan) were approaching significance. The more money earned from an off-farm salary, the lower the probability the household was using forest products, while having a loan increased the probability the household was relying on forest products. The social zone of influence of the combined resources of the forest is strongest in households that have a household head that is male, that have a low percentage of their income earned from off-farm labor and that have loans.

	Forest Product			
	Estimate	*Standard Error*	*z-value*	*Pr(>|z|)*
Annual Cash Earned (1000 KSHS)				
Crops	-0.004	0.003	-1.291	0.197
Livestock	0.001	0.020	0.043	0.966
On-farm Wages	0.016	0.029	0.550	0.582
Off-farm Wages	-0.004	0.004	-1.001	0.317
Off-farm Salary	-0.005	0.003	-1.701	0.0890.
Off-farm Business Income	0.001	0.004	0.262	0.793
Remittances	-0.030	0.027	-1.112	0.266
Total Annual Expenses (1000 KSHS)	-0.000	0.000	-1.156	0.248
Total Livestock (#)	-0.009	0.013	-0.702	0.483
Savings Account				
No	20.790	1455.000	0.014	0.989
Yes	20.100	1455.000	0.014	0.989
Loan	2.214	1.223	1.810	0.0702.
Male	0.969	0.332	2.920	0.0035*
Female	0.532	0.310	1.717	0.0859.
Age	0.008	0.025	0.298	0.765
Occupation				
Employee	-0.556	0.982	-0.566	0.571
Farmer	-1.348	1.031	-1.308	0.191
Other	18.080	1455.000	0.012	0.990
Trader	-1.454	1.277	-1.139	0.255
Years of Education	-0.131	0.126	-1.038	0.299
Depedence Ratio	-0.001	0.005	-0.111	0.912
Land Ownership and Use				
Owns Land	-0.152	0.750	-0.203	0.839
Cultivates Land	1.109	0.939	1.182	0.237
Total Area of Land (ha)	1.270	0.798	1.591	0.112

Table 5: Results from a generalized linear model showing the household characteristics that were examined to see if they impacted the likelihood a household was harvesting or using any forest product from the forest.
* signifies a statistically significant variable at a 95% confidence level.
. signifies a variable that is approaching statistical significance at a 95% confidence level.

When examining household firewood use, having a loan, owning larger amounts of land, off-farm wages, off-farm business income, and years of education of the household head were all significant predictors. Having a loan increased the probability of using firewood by 315% and each additional hectare of land increased the probability of using firewood by 194%. For every increase in 1000 KSHS (~10 USD) in off-farm wages or off-farm business income, the probability of using firewood decreased by ~1% and 4% respectively. For every additional year of education, the probability decreased by 20.5%. Firewood exerted the strongest social zone of influence over households that have loans, owned larger areas or land, had household heads that attended school for a fewer number of years than others, and had little to no income from off-farm wages or off-farm business.

	Firewood			
	Estimate	*Standard Error*	*z-value*	*Pr(>|z|)*
Annual Cash Earned (1000 KSHS)				
Crops	0.001	0.004	0.397	0.691
Livestock	0.015	0.016	0.962	0.336
On-farm Wages	0.007	0.008	0.882	0.378
Off-farm Wages	-0.008	0.004	-2.140	0.032*
Off-farm Salary	-0.006	0.004	-1.536	0.125
Off-farm Business Income	-0.043	0.021	-2.059	0.039*
Remittances	-0.101	0.074	-1.373	0.170
Total Annual Expenses (1000 KSHS)	0.000	0.000	0.922	0.356
Total Livestock (#)	-0.010	0.014	-0.732	0.464
Savings Account				
No	13.980	1455.000	0.010	0.992
Yes	12.520	1455.000	0.009	0.993
Loan	3.154	0.929	3.396	0.0007*
Male	0.398	0.214	1.858	0.063.
Female	0.405	0.208	1.948	0.0519.
Age	0.019	0.021	0.895	0.371
Occupation				
Employee	0.876	0.864	1.014	0.310
Farmer	-0.598	0.688	-0.870	0.384
Other	-12.860	1455.000	-0.009	0.993
Trader	0.686	1.299	0.528	0.597
Years of Education	-0.205	0.102	-2.011	0.044*
Depedence Ratio	-0.004	0.004	-0.937	0.349
Land Ownership and Use				
Owns Land	-1.089	0.670	-1.626	0.104
Cultivates Land	0.961	0.729	1.317	0.188
Total Area of Land (ha)	1.942	0.631	3.078	0.002*

Table 6: Results from a generalized linear model showing the household characteristics that were examined to see if they impacted the likelihood a household was harvesting or using firewood from the forest.

* signifies a statistically significant variable at a 95% confidence level.

. signifies a variable that is approaching statistical significance at a 95% confidence level.

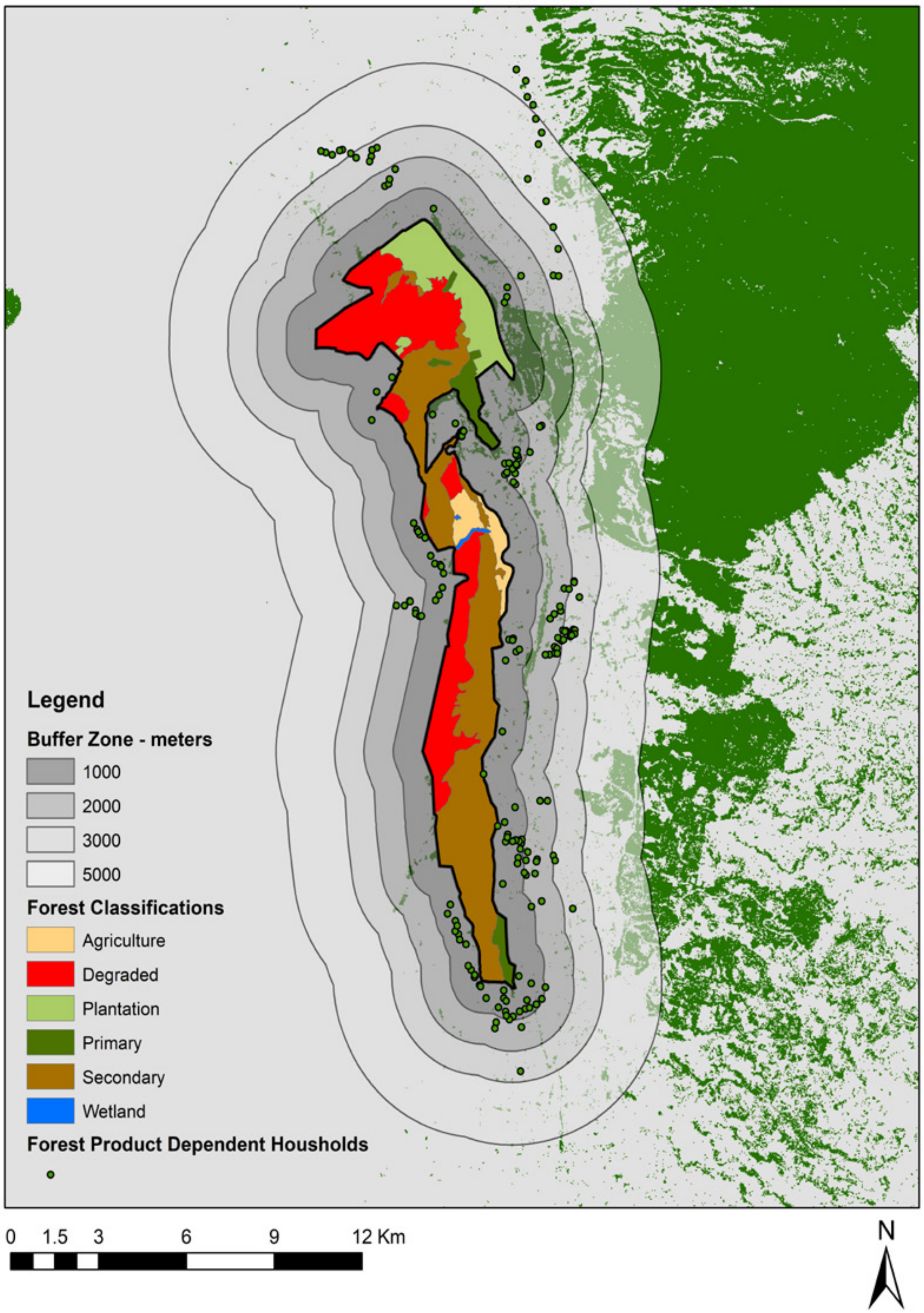
When examining household charcoal use, the only significant variable was the head of household gender. If the head of the household is male it increases the probability that the household is relying on charcoal by 43.8%. However, it should be noted that the amount of annual cash earned from crops, if you work as an employee, and if you are a farmer are approaching significance, and those variables decrease the probability that a household is relying on charcoal. Charcoal's social zone of influence extends to households that have household heads that are male, but has weaker influence over households that farm and have high income from their farms, or are off-farm employees.

	Charcoal			
	Estimate	*Standard Error*	*z-value*	*Pr(>|z|)*
Annual Cash Earned (1000 KSHS)				
Crops	-0.011	0.006	-1.905	0.057.
Livestock	-0.001	0.012	-0.050	0.960
On-farm Wages	-0.008	0.005	-1.502	0.133
Off-farm Wages	-0.004	0.003	-1.241	0.215
Off-farm Salary	-0.003	0.003	-1.068	0.285
Off-farm Business Income	0.001	0.004	0.303	0.762
Remittances	-0.007	0.025	-0.295	0.768
Total Annual Expenses (1000 KSHS)	0.000	0.000	1.093	0.275
Total Livestock (#)	0.006	0.016	0.395	0.693
Savings Account				
No	16.710	1455.000	0.011	0.991
Yes	17.330	1455.000	0.012	0.991
Loan	-0.781	0.689	-1.135	0.257
Male	0.438	0.193	2.262	0.024*
Female	0.251	0.172	1.459	0.145
Age	-0.025	0.019	-1.330	0.184
Occupation				
Employee	-1.224	0.693	-1.766	0.077.
Farmer	-1.218	0.638	-1.911	0.056.
Other	16.390	1455.000	0.011	0.991
Trader	-1.477	1.013	-1.458	0.145
Years of Education	0.064	0.085	0.757	0.449
Depedence Ratio	-0.006	0.004	-1.454	0.146
Land Ownership and Use				
Owns Land	0.188	0.524	0.359	0.720
Cultivates Land	0.827	0.640	1.292	0.196
Total Area of Land (ha)	0.027	0.382	0.071	0.943

Table 7: Results from a generalized linear model showing the household characteristics that were examined to see if they impacted the likelihood a household was harvesting or using charcoal from the forest.
* signifies a statistically significant variable at a 95% confidence level.
. signifies a variable that is approaching statistical significance at a 95% confidence level.

Forest Product Zone of Influence - Spatial

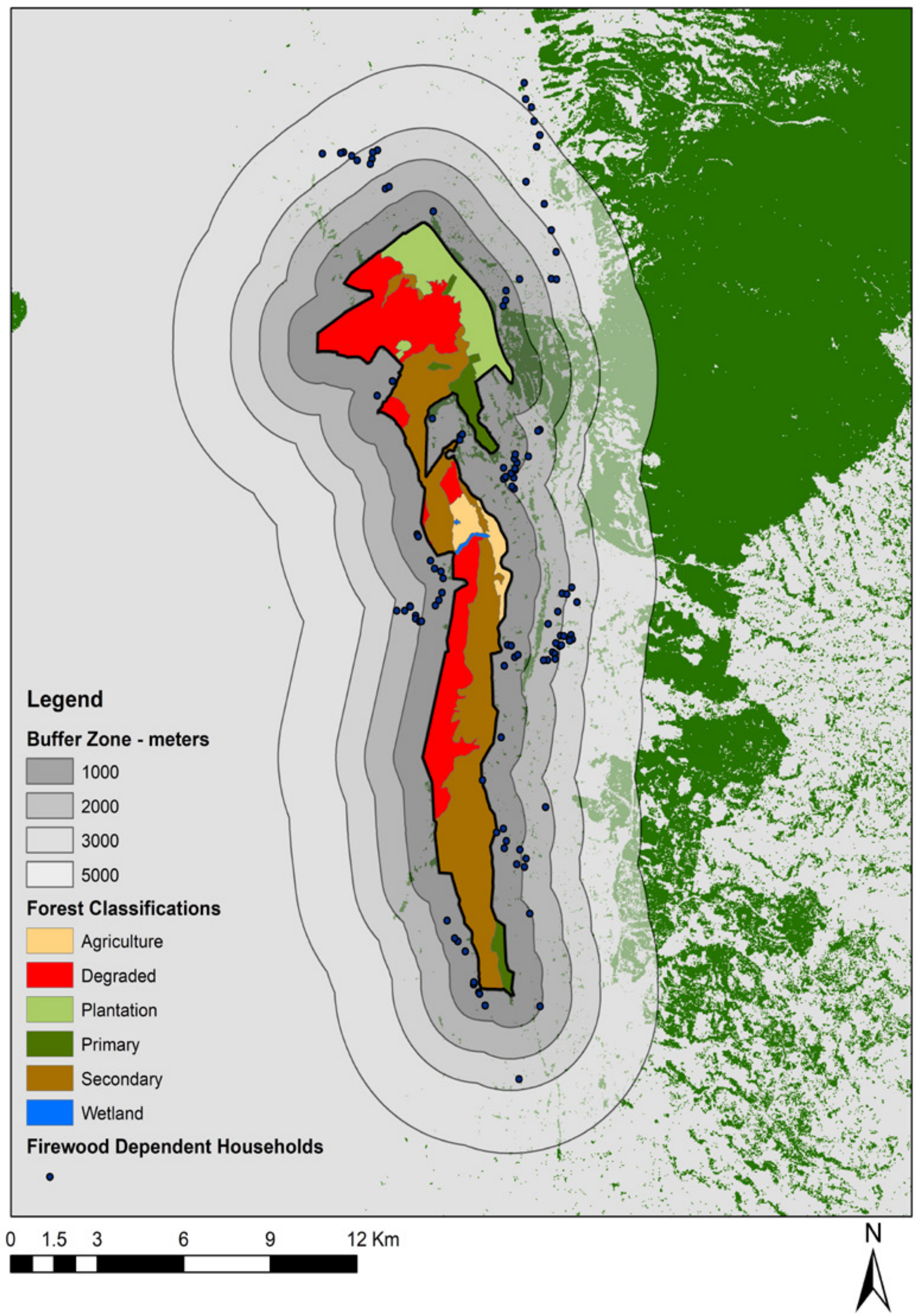
The traditional spatial zone of influence shows that the majority of the households that depend on forest resources are within one kilometer from the forest edge (Map 5).The households are not evenly distributed around the edge of the forest, but the majority that reported using any forest products are located within a kilometer of the edge.



Map 5: The spatial zone of influence of the forest as a whole. The influence is strongest with a higher number of households closer to the forest in the darker areas of the buffer zone, with the influence and total numbers diminishing as you move further away.

Firewood Zone of Influence - Spatial

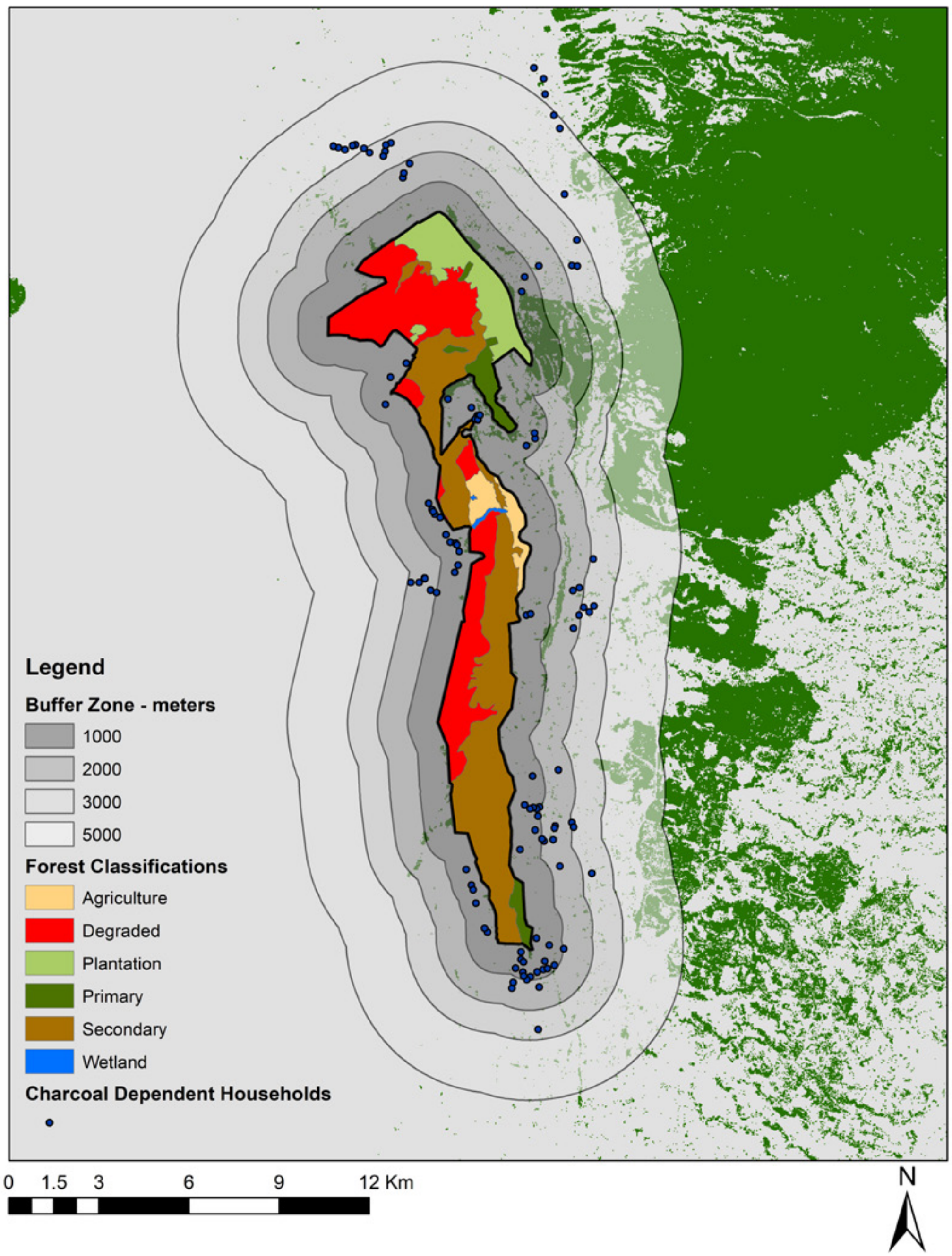
The traditional spatial zone of influence shows the majority of the households that depend on firewood from the forest are within the first two kilometers of the forest edge (Map 6). Similar to the forest product map, the households are not evenly distributed around the edge of the forest, but the majority that reported using firewood are located within a couple kilometers of the edge.



Map 6: The spatial zone of influence of firewood. The influence is strongest where you see the higher number of households closer to the forest in the darker areas of the buffer zone, with the influence and total numbers diminishing as you move further away.

Charcoal Zone of Influence - Spatial

The traditional spatial zone of influence shows the majority of the households that depend on charcoal from the forest are within one kilometer of the forest edge (Map 7). Similar to the other forest product maps, the households are not evenly distributed around the edge of the forest, but the majority that reported using charcoal are located within one kilometer of the edge.



Map 7: The spatial zone of influence of charcoal. The influence is strongest with the higher number of households closer to the forest in the darker areas of the buffer zone, with the influence and total numbers diminishing as you move further away.

These maps seem to confrm the traditional way a spatial zone of influence is constructed. The closer to the forest, the stronger the influence of the forest, with the influence getting weaker and influencing fewer households the farther away you get.

To build a more complex zone of influence, the social and spatial zones of influence were combined by including a distance variable in the models. Becaues different forest types had different species compositions and different preferred uses, household distance from each of the different forest types were included. When these distances were included, the variables that were predictive of forest product use, firewood use, and charcoal use changed, as did their coefficients.

	Forest Product			
	No Distance		Distance	
Variable	*Estimate*	*Pr(>|z|)*	*Estimate*	*Pr(>|z|)*
Male	0.969	0.0035*	1.1	0.002*
Female	0.532	0.0859.	0.563	0.085.
Off-farm Salary	-0.005	0.0890.	-	-
Total Annual Expenses	-	-	-8.56E-6	0.037*
Loan	-	-	2.47	0.052.
Distance from Secondary Forest (km)	-	-	0.823	0.032*

Table 8: A comparison of the variables that were significant predictors of forest product use when the model was run including the distance each household was from the primary, secondary, and degraded forests.
* signifies a statistically significant variable at a 95% confidence level.
. signifies a variable that is approaching statistical significance at a 95% confidence level.

For households that use any forest product from the forest, the household's total annual expenses, if they had a loan, and the distance from secondary forest became significant (Table 8).
When the household location was considered, if the household had a male household head increased the likelihood more than before (evidenced by the change in the variables estimate value). Annual expenses became an importanct factor, but not in the expected direction. Distance seems to have a mitigating effect on expenses, which could indicate that there may be families that have higher expenses who live closer to the forest, yet do not have to depend on forest products to fill any household needs. Additionally, proximity to secondary forest is significant in overall forest product use.

For households that use firewood, there were fewer variables that were significant when distance was included. The significant household characteristics are off-farm wages, if the household head had a loan, years of education of the household head, if the land is owned by the household head, and the distance from secondary forest. The off-farm business income earned and the years of

	Firewood			
	No Distance		Distance	
Variable	*Estimate*	*Pr(>|z|)*	*Estimate*	*Pr(>|z|)*
Off-farm Wages	-0.008	0.032*	0.463	0.042*
Off-farm Business Income	-0.043	0.039*	-	-
Loan	3.154	0.0007*	3.19	0.001*
Years of Education	-0.205	0.044*	-0.242	0.033*
Total Area of Land (ha)	1.942	0.002*	-	-
Male	0.398	0.063.	-	-
Female	0.405	0.0519.	-	-
Owns Land	-	-	-1.60	0.032*
Distance from Secondary Forest (km)	-	-	0.570	0.023*
Distance from Degraded Forest (km)			-0.260	0.096.

Table 9: A comparison of the variables that were significant predictors of firewood use when the model was run including the distance each household was from the primary, secondary, and degraded forests.
* signifies a statistically significant variable at a 95% confidence level.
. signifies a variable that is approaching statistical significance at a 95% confidence level.

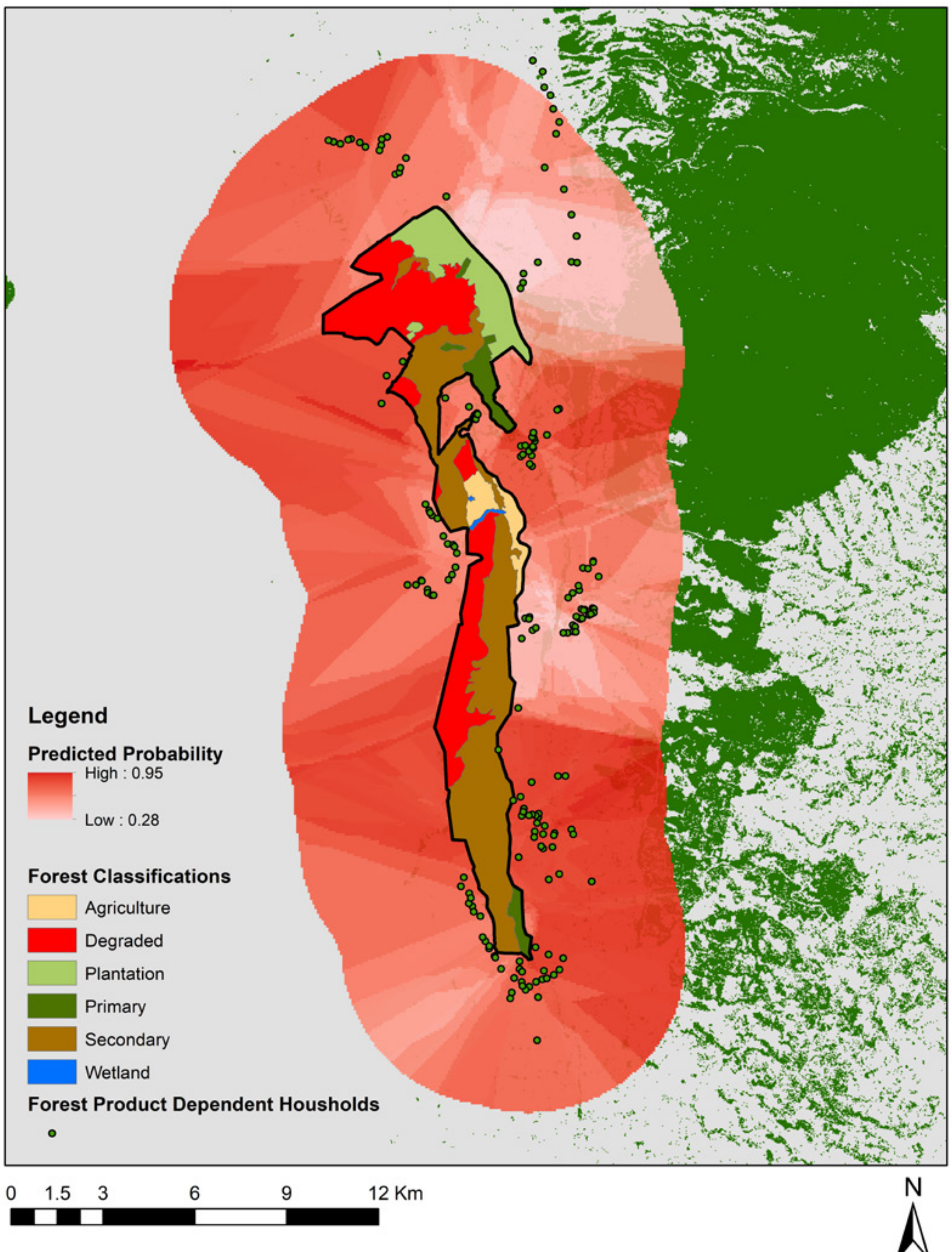
education of the household were no longer significant once distance was considered (Table 9). Similar to general forest product use, it is the distance from secondary forest that is significant. For households that use charcoal, a greater number of household characteristics became significant predictors when distance was considered (Table 10). Which variables were significant predictors also changed. Without distance, it only mattered if the household head was male, but considering distance, charcoal seems to influence both male and female headed households. Additionally, when consdering where the household is located, the income earned from crops also becomes significant. Similar to both firewood and forest product use, the distance the household was located from secondary forest is significant.

	Charcoal			
	No Distance		Distance	
Variable	*Estimate*	*Pr(>|z|)*	*Estimate*	*Pr(>|z|)*
Male	0.438	0.024*	0.436	0.035*
Female	-	-	0.369	0.046 *
Annual Cash Earned - Crops	-0.011	0.057.	-0.014	0.048*
Employee	-1.224	0.077.	-	-
Farmer	-1.218	0.056.	-	-
Employee	-	-	-1.36	0.063.
Trader	-	-	-2.05	0.059.
Distance from Secondary Forest (km)	-	-	0.585	0.005*

Table 10: A comparison of the variables that were significant predictors of charcoal use when the model was run excluding the including the distance each household was from the primary, secondary, and degraded forests.
* signifies a statistically significant variable at a 95% confidence level.
. signifies a variable that is approaching statistical significance at a 95% confidence level.

Forest Product Zone of Influence - Spatial and Social

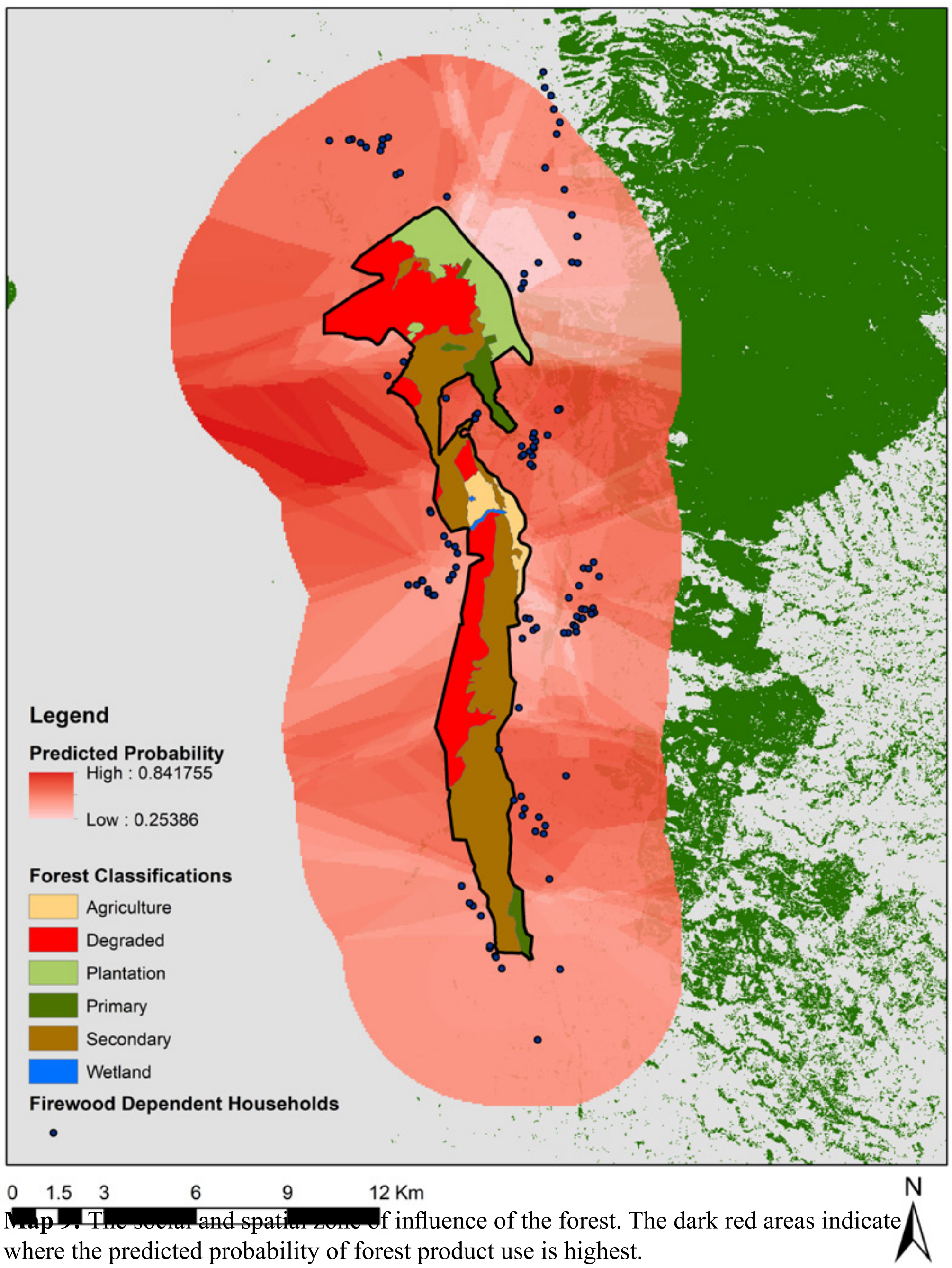
When the predicted probabilities of each household were mapped, one sees a more nuanced picture of the zone of influence of the forest (Map 8). It becomes apparent that there are certain areas where forest products exert more influence than others, and that while some households living close to the forest are still within the forest's zone of influence, the predicted probabilities are not always as closely linked to proximity as one might first expect. For example, on the eastenr edge of the forest there is a cluster of households relatively close to the forest edge, but who are not being strongly influenced by the forest and its products.



Map 8: The social and spatial zone of influence of the forest. The dark red areas indicate where the predicted probability of forest product use is highest.

Firewood Zone of Influence - Spatial and Social

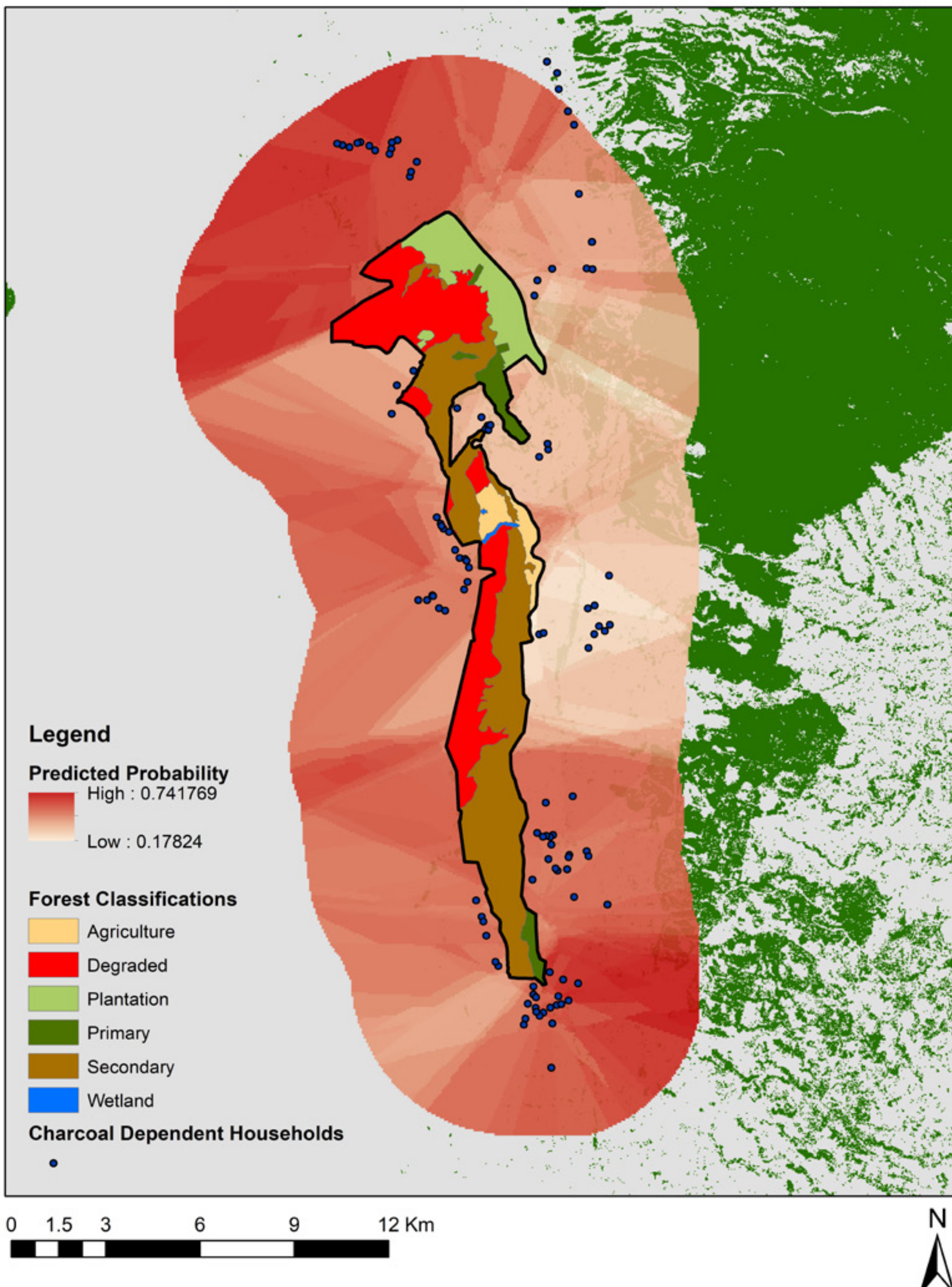
When the predicted probabilities of each household were mapped, one can see a more nuanced picture of the zone of influence of the firewood (Map 9). It is evident that the zone of influence is much stronger around secondary forest towards the center/northern part of the forest, while households living close to the plantation section (NE) of the forest are not being heavily influenced by firewood, although they are living in qiute close proximity to the forest.



[redacted] The [redacted] and spati[redacted]f influence of the forest. The dark red areas indicate where the predicted probability of forest product use is highest.

Charcoal Zone of Influence - Spatial and Social

The zone of influence of charcoal is strongest on the SE and NW ends of the forest (Map 10). It is interesting to note that even though the households on the NW side are not as clost to the forest as some of the others, they have a high predicted probability to be using charcaol.



Map 10: The social and spatial zone of influence of charcoal. The dark red areas indicate where the predicted probability of forest product use is highest.

For all three models; forest product use, firewood use, and charcoal use, the inclusion of distance from a given forest type changed not only which social variables were significant in predicting forest product use, but in some instances changed the coefficients as well. This, in turn, affected the predicted probability that a housheold was dependent on a particular forest product.

Discussion

Forests, and the species or goods they contain, are important to the communities living around them. Each resource play different but important roles in shaping the communities that rely on them. Their influence is not evenly distributed across the people living in those communities, and also changes depending on which resource is being considered. Forests need to be treated as system-forming entities, as they have the capacity to influence the decisions that are made by community members which then continues to shape the ecology of the forest itself. Dwiartama and Rosin (2014) argue that there is a need to consider the "particularities and contingencies" that are introduced into these systems when we recognize non-human components as being agents in these systems.

Examining these particularities and contingencies helps us develop a fine-grain approach in looking at forest dependence in the context of the Kijabe Forest. We can see that there were differences in species composition and distribution across the forest and that those species and forest types were valued for different things by different households. Extraction of these resources was concentrated both by location as well as by species. We also saw that charcoal, firewood, and the forest as a whole exert different zones of influence in the communities living around the forest.

Ecologically, there was very little difference between the primary and secondary forest when we examined forest structure and species diversity, but there was a difference in species composition. Composition turned out to be important because not all species are equally preferred by community members and the community members used different forest types in different ways. Primary forest contains species that are used for firewood, charcoal, and timber. Secondary forest contained species used primarily for timber and charcoal, with some species that are used for timber, firewood and charcoal. Degraded forest contains species that are used for other uses such as fodder, etc, but also contains species that are used for both firewood and charcoal.

These differences are important because it indicates different zones of influence of each forest type, and in return has ecological significance as certain species are harvested more than others, and species regeneration potential (which we measured through coppicing of the stumps) vary by species. Understanding these dynamics allow managers, in this case KFT, to understand how people are using the different types of forest, and how to approach managing those resources for their sustainable use.

Of the top ten most harvested species (Table 3), nine species have coppicing rates >50%, with five of those species having a coppicing rate >90%. Coppice re-sprouting is an important factor to consider in forest regrowth, and studies from Tanzania and Ethiopia show that allowing coppicing to take place as a reforestation strategy encouraged a diverse and healthy understory of native species, even when in exotic tree plantations (Lemenih & Bongers 2010; Lemenih 2006; Senebeta et al. 2002). Knowing where the harvesting hotspots are, what is harvested the most, and the regeneration potential for each species can inform appropriate use of resources in making reforestation plans.

Planting strategies and seedling procurement decisions can be made knowing what species are important to households, and knowing if those species coppice, or need to be replanted. For example, *J. procera* is the second most harvested tree and is a very valuable timber tree, but does not coppice, so would need to be replanted. Similarly, secondary and degraded forest patches exerted a significant influence over household dependence on firewood and charcoal, which can give insight into prioritizing reforestation activities in those areas.

Typically, households living closer to the forest depend more on forest products, both timber and non-timber, than households living in areas farther away from forested areas (Omotayo 2002; Mbuvi & Boon 2009; Dash et al. 2016; Robinson et al. 2008; Martínez Romero et al. 2004; Pattanayak et al. 2004), and typically poorer households tend derive a relatively large share of their income from forests and more heavily depend on forest resources for everyday use compared to better-off households (Dash et al. 2016; Angelsen et al. 2014; Yemiru et al. 2010; Cavendish 2000).

The results from this study indicate that for certain forest types, the likelihood of a household relying on the forest for both firewood and charcoal seemed to increase as distance increased, which is different than what other studies have found. However, a global comparative analysis looking at environmental income and rural livelihoods by Angelsen et al. (2014) also found that households located close to forests do not have a significantly higher absolute or relative forest income than households that live further away. They also found that households that live close to village centers tend to have higher absolute forest and environmental incomes, which they hypothesize is because of better access to markets for those products. While this study did not measure the distance of households to the town centers, their findings further highlight the importance of location in establishing the zones of influence of forest products.

In addition to access to markets, a study by Sharaunga et al. (2015) in South Africa, found that people living further away from forests tended to hold lower anthropocentric value orientations towards the forest, and perhaps this breakdown of value makes forest product use and the potential resulting degradation less of an issue for those households. Theoretically they would not be as immediately affected by degraded habitats if they were only relying on the forest for firewood and charcoal, whereas a household living immediately adjacent to the forest would be at higher risk of experiencing the effects of erosion, reduced soil fertility, etc.

From the household and ecological surveys, we know that the species that are used for charcoal and/or firewood exert different amounts of influence over a given household based on their economic and demographic characteristics, as well as the household's physical location in relation to the forest type those products are found in. One could say that the Kijabe Forest is either limiting, or in some cases, enhancing the decisions of the household and influencing them to act in a certain way. As Dwiartama and Rosin (2014) argue, by understanding these resources as agents, and understanding their agency over households, our understanding of this social-ecological system is enhanced; a crucial component of understanding the relationship between forests and the communities depending on them.

If distance is defined as a "territorial separation of actors" (Young 2006), that separation is not confined to only spatial location, but includes natural, technological, or social dimensions as well. This was demonstrated by the changes in both which variables were significant in the zone of influence models, as well as the changes in the magnitude of their significance. Without considering both social and spatial factors, we ignore the fact that these resources are agents in complex social-ecological systems that are exert different levels of influence depending on those factors. Only considering one set of factors gives us an incomplete picture of the relationships that exist between the resource and its users. Understanding those dynamics is the only way we can hope to manage these resources to meet the goals of conserving biodiversity, restoring degraded landscapes, and meeting livelihood needs.

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Appendix I - Species Lists

Primary

Species	Count	Precent of Total
Olea europaea ssp africana	35	25.5%
Vepris simplicifolia	19	13.9%
Juniperus procera	14	10.2%
Celtis africana	8	5.8%
Cussonia spicata	7	5.1%
Olinia rochetiana	7	5.1%
Euclea divinorum	5	3.6%
Vangueria volkensii	5	3.6%
Warburgia ugandensis	5	3.6%
Albizia gummifera	4	2.9%
Maytenus undata	4	2.9%
Murigithathi	3	2.2%
Cussonia holstii	2	1.5%
Ekebergia capensis	2	1.5%
Elaeodendron buchananii	2	1.5%
Maytenus senegalensis	2	1.5%
Prunus africana	2	1.5%
Vepris nobilis	2	1.5%
Dathi	1	0.7%
DSC914-17	1	0.7%
Ficus thonningii	1	0.7%
Nemudongo	1	0.7%
Otaleleni	1	0.7%
Pavetta abyssinica	1	0.7%
Rhus natalensis	1	0.7%
Trimeria grandifolia	1	0.7%
Zanthoxylum usambarensis	1	0.7%

Degraded

Species	Count	Precent of Total
Tarchonanthus camphoratus	7	24.1%
Munyama	6	20.7%
Dodonaea viscosa	3	10.3%
Crotalaria goodiiformis	2	6.9%
Cussonia holstii	2	6.9%
Juniperus procera	2	6.9%
Vepris simplicifolia	2	6.9%
Acokanthera schimperi	1	3.4%
Calodendrum capense	1	3.4%
Cussonia spicata	1	3.4%
Dovyalis abyssinica	1	3.4%
Olinia rochetiana	1	3.4%

Secondary

Species	Count	Precent of Total
Juniperus procera	26	15.9%
Acokanthera schimperi	24	14.6%
Synadenium compactum	19	11.6%
Euclea divinorum	15	9.1%
Schrebera alata	10	6.1%
Olea europaea ssp africana	7	4.3%
Olinia rochetiana	7	4.3%
Tarchonanthus camphoratus	6	3.7%
Calodendrum capense	5	3.0%
Cussonia holstii	5	3.0%
S12	5	3.0%
Vepris simplicifolia	5	3.0%
Celtis africana	3	1.8%
Warburgia ugandensis	3	1.8%
Acokanthera oppositifolia	2	1.2%
Strychnos usambarensis	2	1.2%
Zanthoxylum usambarensis	2	1.2%
Croton dichogamus	1	0.6%
Cussonia spicata	1	0.6%
Dombeya burgessiae	1	0.6%
Dracaena ellenbeckiana	1	0.6%
Elaeodendron buchananii	1	0.6%
Erythrina abyssinica	1	0.6%
Grewia spp	1	0.6%
Ochna ovata	1	0.6%
Psydrax schimperiana	1	0.6%
Rhus natalensis	1	0.6%
S11	1	0.6%
S14	1	0.6%
S15	1	0.6%
S16	1	0.6%
S29	1	0.6%
S3	1	0.6%
S39	1	0.6%
Scutia myrtina	1	0.6%

Appendix II - Management Considerations

Threats

Dependence on Firewood and Charcoal

Forest resouces play important roles in the livelihoods of many people, and this holds true for the communities living around the Kijabe Forest, as evidenced by the results of the household surveys. Forest resources play important roles in the livelihoods of people, and can be important safety-nets for households in times of economic shock or other hardships (Wunder et al 2014, Chazdon et al 2016). However, just as forest resources are important to consider in poverty reduction strategies, and forest dependence itself should NOT be viewed as an inherent threat, but the impact of degradation and disapperance of forests can have detrimental impacts on the livelihoods of the people most dependent on those resources (Dash et al. 2016).

Figure 9: Charcoal produced in the forest both for individual household use, as well as for sale. Roadside charcoal vendors are often seen along the main roads in major towns in the area.

However, evidence from the Kijabe Forest indicates that harvesting has surpassed sustainable levels. Of the 5,489 hectares in the forest, 1,828 (33%) were found to be degraded. Little to no canopy remained, severe erosion was evident, and the area was being taken over by grasses, with no evidence of forest regeneration. These charactersitics are consistent with work done by Lemenih and Bongers (2010) on degraded forest lands research from Afromontane forest in the highlands of Ethiopia. Once forests reach this state, natural regeneration becomes unlikely. While some level of sustainable harvesting is possible in healthy forests, the current levels are exceeding the natural levels of disturbance the forest is able to withstand.

Climate Change

A changing climate is likely to exacerbate different shocks that households will be subject to (the impact of increasing landslides, or drought on a household) which increases the likelihood people will depend on the forest as a safety-net (Wunder et al 2014). The area surrounding the Kijabe Forest is already experienceing increasingly unpredictable weather patterns, with both times of drought and times of intense rainfall growing more frequent, and less predictable. While the impact of climate change is inevitable, steps can be taken to try to increase community resiliency to its effects. Understanding how the communities depend on the forest is a crucial starting point to addressing this challenge.

Timber Harvesting

While timber harvesting was not reported in the household surveys, African Pencil Cedar, used exclusively for timber, was the second most harvested species (16.4% or all harvested). African Olive, used for both timber and charcoal, was the most harvested species (32.4% of all harvested). As noted, African Pencil Cedar does not coppice, and very few seedlings or saplings were found in the forest sample plots, suggesting this species is being harvested well past its natural recruitment rate.

Figure 10: African Pencil Cedar is regularly illegally harvested for building poles, as it is prized for its resistance to rot and insects. Clockwise from left: 1) Cedar posts being used as fence posts in one of the forest adjacent towns. 2)A pile of cedar posts found stashed in the forest after being harvested. 3) A load of cedar posts seized from the forest

Recommendations

Conservation challenges are notoriously complex, and require an equally multi-faceted and creative approach to adequantely address. While the following recommendations are in no way comprehensive, they offer a starting point to addressing the threats facing the Kijabe Forest strip and the communities living around it.

Recommendation: Biogas Pilot Project
Threat Addressed: Dependence on Firewood and Charcoal as Cooking Fuel and Climate Change

Summary:
85.7% of the surveyed households reported using firewood, and 95.8% reported using charcoal. These forest prodcuts are the primary source of cooking fuel used by households (Table 3), and are thus a very well-defined target for reducing forest dependence.

By targeting households that live within the zone of influence of charcoal and firewood with an intervention aimed at reducing wood-based fuel for cooking, it could be possible to efficiently reduce the number of households that are dependent on those resources. For example, the zone of influence for firewood includes households having loans, with few years of formal education, and who live around degraded or secondary forest. An intervention targeting households that fit these criteria that focuses on providing alternative sources of cooking fuel could decrease forest dependence in these households and decrease overall harvesting pressure on those sections and species of the forest.

Agricultural waste products, particularly manure, is a valuable source of energy in rural areas. Biogas digesters are an easy way to utilize this energy, which also provides local, clean energy for rural development, improves public health, and has been shown to reduce pressures on fuelwood (Hallding et al 2012). Additionally, the composted waste makes valuable compost and fertilizer for crops.

Of the households surveyed 67% reported owning livestock, and 46% of households reported owning cattle, one of the preferred sources of fuel for biofuel systems. There are multiple local comapanies that produce the digesters, and offer a range of financing solutions for households to purchase them.

The houshold data and the forest data show that the communities living around the Kijabe Forest strip are prime candidates for running a biogas pilot project as a means to reduce pressure on the forest. Households that report dependency on firewood or charcoal, and that own or have access to waste from livestock should be targeted for the intervention.

Ideally, KFT would track household fuel use as well as spending patterns for each household where a biodigester is installed, both for a period of time before installation, as well as after installation, as a way to measure the impact the biodigester has on the amount of forest products each household uses for fuel, as well as the impact on overall household economics.

Recommendation: Plantation Woodlot Establishment
Threat Addressed: Dependence on Firewood and Charcoal as Cooking Fuel, Timber, and Climate Change

Summary:

With ~2000 hectares (33%) of forest in the Kijabe Forest strip classified as degraded, significant restoration is needed to stabilize the soil, encourage indigenous tree stand replacement, and protect floral and faunal species diversity. Communities are also likely to remain dependent on the Kijabe Forest strip, either directly (through firewood, charcoal, and timber utilization) as well as indirectly (through ecosystem service provision such as restored water-tables and stabilized hillsides). KFT will need to take steps to actively restore degraded habitats if it is to fulfill its mission of protecting biodiversity and providing for community needs. Establishing tree plantations is one concrete step the trust can take to help achieve that goal.

While plantations replacing intact ecosystems would reduce overall biodiversity and impact people relying on that biodiversity (Lemenih and Bongers 2010, Scherr et al. 2004), it has also been shown that when established on degraded lands, plantation forests can jump-start natural fores succession processes, restore ecosystem functions, contribute to the restoration of soil quality, improvement of living conditions in forest-dependent communities, and the reduction of poverty by minimizing economic and environmental risks (Lemenih and Bongers 2010, UNFF 2003, Lamb et al. 2005). A plantation of fast growing, useful species established on the degraded sites within the Kijabe Forest strip could be capable of fostering the return of diverse flora and fauna, as well as continue providing for community needs.

Planting Considerations

There is debate about the effectiveness of exotic vs. indigenous trees when it comes to encouraging species diversity and reforestation success. In an extensive review titled "The Role of Plantation Forests in Fostering Ecological Diversity", Lemenih and Bongers (2010) found that plantation forests established on degraded lands are incredibly effective at contributing to biodiversity restoration, regardless of whether the stand was made up of exotic or native species. They found that even the most contentious species, *Eucalyptus*, can play a positive role. What was more important than the origin of the species were intrinsic species charactiristics and plantation management strategies such as crown structure, stand density, proximity to natural seed sources, stand or landscape level structural diversity, stand age, and plantation size.

For degraded sites where cutting is most intense (Map 4) KFT should consider establishing mixed plantations of fast-growing, high-value native and exotic species that can provide the communities adjacent to those areas with alternative sources of fuel and timber. However, the plantations should also be established adjacent to remianing indigenous forest patches to encourage natural seedling recruitment within the plantation as time goes on. The goal is NOT for the plantation to remain full of exotic trees forever, but rather to jumpstart the successional process while initially stabilizing the soil, providing habitat for animals, and reducing pressure on the remaining indigenous species.

Species with high market demand (both for timber and non-timber products) should be considered to help meet acceptable economic objectives of forest user groups. Species should be easily available and fast growing. Plantations should be established with a mix of exotic and indigenous species that have high value and are also adapted to the harsh conditions found at these sites. *Croton* and *Juniperus* would be approrpriate indigenous species, as *Juniperus* has high use value and commercial value as for timber and building poles. Both these species also produce berries that attract wildlife, encouraging not only their own seeds to be further dispersed in the area, but also increase the likelihood of seeds from native species from adjacent forest patches that are consumed will be dispersed into the plantation area. In addition to economic and forest product use considerations, species with N-fixing characteristics should also be included in the planting regime.

Recommendation: Steep Slope Reforestation and Stabilization
Threat Addressed: Site Degradation, Species Loss, and Down-slope Community Risk

Summary:
The trust should also consider prioritizing some of the steepest areas of the Kijabe Forest strip for replanting. The escarpment is already prone to landslides, and the steep, heavily degraded areas are particularly at risk. In these areas, KFT should focus on measures to stabilize the soil, as soil erosion on these slopes is the largest barrier to successfull seedling establishment.

Bioengineering principles from streambank stabilization have also been used to stabilize steep slopes. They focus on using readily available, cheap, materials, and while these methods do not require high levels of technical expertise, these techniques are often labor-intensive.

The following techniques were taken by the book Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control, written by Donald Gray and Robbin Sotir (1996).

Soil Stabilization Techniques

Pole Cuttings/Live Staking
Pole cuttings of live trees which root easily from cuttings are staked in the ground.Root establishment helps initially stabilize soil. This essentially creates a living fence to help control erosion. Stakes should be placed in a random pattern to prevent the formation of gullies, with 2-4 stakes per square meter. This is best used when combined with other soil stabilization methods.

Fascine Bundles
Bundles are made of both live and dead plant material, with live plant material being taken from species which root easily from cuttings. Bundles are placed in a shallow trench dug following the topographic contours across the slope of the hill. The steeper the slope, the closer they should be placed together. Stability can be increased by staking the bundles using the live staking technique discussed above.

Once the areas have shown signs of reduced erosion, planting a mixture of indigenous successional species, as well as species found in more mature forests, should be done in order to continue creating healthy soils and jump-starting the forest succession process. In addition to planting seedlings, seedballs (indigenous tree seeds encased in a protective biochar ball to protect it from predation and dessication) should also be spread throughout the area to encourage tree growth. While not much is known about the germination rates and seedling survival rates of seedballs, they are both an affordable and rapid way to disperse large amounts of seeds in an area.