MORE PEOPLE, MORE TREES: SOCIAL AND ECOLOGICAL FACTORS FOR TREE COVER DISTRIBUTION AND THEIR IMPLICATIONS FOR FOREST CONNECTIVITY IN SOUTHERN TANZANIA

by

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Introduction

More People, More Trees

Fragmented habitats are a core concern for biodiversity, as isolation threatens survival of vulnerable species. Conservationists recognize that the creation of protected areas is insufficient for long-term preservation of biodiversity. Whereas protected areas are designated as zones of no-use that provide a safe haven for the life within their borders, the areas outside are free to be transformed to other land uses. As a result, protected areas become islands that provide both a refuge and an entrapment for the wildlife within. Conservationists have therefore called for landscape-scale conservation approaches (Fischer & Lindenmayer, 2007; Hilty et al., 2006; Lindenmayer & Fischer, 2007). Landscape-scale conservation aims to create a network of habitats both by linking the protected areas and by softening the sharp transitions between the protected and the human use areas. Methods used for achieving landscape-scale conservation include creation of corridors, buffer zones, community wildlife management areas, agroforestry initiatives, and payments for ecosystem services. The major puzzle for these landscape-scale approaches is the degree to which conservation goals can align with other land uses, agriculture in particular.

In areas of intensive agricultural use, connectivity becomes even more important since these are regions where the transition between protected areas and human land use is often sharp. Sharp boundaries between the protected areas and agricultural landscape are a defining feature of East African Rift montane forests (Martino, 2015; Plumptre, 2002; Sassen, 2014): a region of high biodiversity and high rural population density. In creating landscape-scale conservation, connectivity efforts may come in direct confrontation with established agriculture by smallholder farmers. Connectivity in montane forests is challenging since dominant land use (i.e, agriculture) is seemingly incompatible with the type of land cover necessary to increase forest habitat connectivity (i.e, tree cover) and the demands of priority species that reside in those forest habitats (e.g, arboreal primates).

This thesis explores prospects for enhancing habitat connectivity at Bujingijila Gap in the Southern Highlands of Tanzania, an area of globally significant endemism and high human population density. Specifically, I look at trends in tree planting and natural forest regeneration in the Bujingijila Gap that separates two protected areas: Mount Rungwe Nature Reserve and Livingstone Forest (managed as part of Kitulo National Park). Connecting these forest blocks is vital to the survival of an endangered primate: *Rungwecebus kipunji*. In fact, researchers have identified this as high priority area for a corridor (Caro et al., 2009). The stakes are potentially high also for local agriculturalists, some of whom depend on access to farmland in the Gap for their livelihood.

The Bujingijila Gap covers 3 km^2 with a slight elevation incline of 320m (1686m – 2008m asl) from South to North, and receives high annual rainfall above 2000 mm (Bracebridge et al., 2012). Aerial photographs show that the Northern section of the Gap has not been cultivated for more than five decades, and local informants claim that it has never been cultivated. However, instead of becoming a forest, the North Gap has been dominated by grass for that entire period. The Southern section is subdivided into ~ 300 individually owned land parcels, some of which are planted with trees (mainly *Pinus patula* See Figure 1).

Figure 1: a) Typical view of grass-dominated the Northern Gap, versus b) Pine-planted south Gap.

Meanwhile, the Southern Gap has gone through several land use changes: some forest was cleared for crop cultivation between 1949 and 1969, then farmers left their individual plots fallow due to crop-raiding pressure or other reasons. In the past decade, individuals started planting pine, cypress and eucalyptus for cash, timber and firewood. Paradoxically, then, the presence of smallholders, and their decision to undertake tree farming in the Southern section has led to more trees than the absence of cultivation in the Northern section. Woodlots of pine and eucalyptus are a source of cash for farmers, but they are biologically impoverished compared to adjacent natural forests. However, if present tree planting trends continue, the woodlots in the Southern Gap may lead to a functional corridor for *Rungwecebus kipunji* faster than natural regeneration in the Northern Gap. With its many users and varied outcomes, the Gap offers a setting for a natural experiment for looking at land use at protected area edges, and for examining processes of forest regeneration along a gradient of land uses.

My primary research questions are:

1. *For the farmers that own plots in the Gap, how do their land use along forest edges compare to how they use plots in the rest of their land portfolio?*
2. *What natural and human-mediated factors explain the distribution of natural tree seedlings in the Gap?*

In Chapter 1, I describe my interview results, focusing primarily on the land use outcomes in the southern section of the Gap. Specifically, I inquire about the entire land use portfolios of 92 respondents who own a plot in the Gap, paying attention to tree planting outcomes and landholding sizes. To make sense of the Gap land uses, I look at the Gap from the perspective of farmers, who view the Gap landholdings as forest edge plots. I show that a given individual's total land endowment and having trees planted in plots elsewhere in the landscape are good predictors for tree-planting outcomes against forest edges. I also show that neighboring the Kitulo National Park, a recently created strict-protection protected area, has less tree planting. I conclude that connectivity in the Gap has to take into account how rural farmers make land use decisions, and proximity to forest edges and a strict-protection forest affects those decisions.

In chapter 2, I turn to tree seedlings and forest regeneration, and use field-collected vegetation sampling from both the Northern and the Southern Gap to show patterns of tree seedlings distribution. I integrate the physiographic factors (distance from forest edge, grass height and proximity to large trees) and human use factors (current land use, length of fallow, legacy of forests) to find which suite of factors best explains seedlings distribution. I show that the Southern Gap has potential for faster connectivity even when only naturally regenerating seedlings are considered. I highlight known caveats from literature on use of exotic plantations for improving forest regeneration and for connectivity, and suggest conservation actions.

My research project, then, is a case study that assesses the social and biophysical factors linked to increased tree cover in one proposed corridor in Southern Tanzania. This research is meant to contribute to literature about habitat connectivity, forest regeneration and park edge land use in tropical highlands, particularly in Africa. It furthers efforts to understand how conservation needs can be balanced with human needs (Goldman, 2009; Pozo-Montuy et al., 2011), using the specifics of the case study to compare tree cover outcomes from regeneration and from cultivation. The project is a direct response to the need to combine research and conservation practice that can be broadly applicable to the Rift Valley montane forests(Plumptre & Kabagumya, 2011). It is my hope that a detailed understanding of land use and natural seedlings patterns will help guide efforts to create a connective corridor that is both ecologically viable and socially equitable.

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The Greening Forest Edge

Characterizing smallholder tree planting outcomes at the forest edge

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1. ABSTRACT

In tropical areas where access to natural forests is limited, some poor farmers are planting trees for timber, firewood, and cash. This Type 2 of forest transition (Rudel et al., 2005) is playing out in Bujingijila Gap and in the surrounding densely settled rural landscape. Here I consider Bujingijila Gap plots as forest edge plots, and posit that their land use outcomes are best explained by considering land use dynamics in farmers' non-edge plots. This study demonstrates three things: 1) Individuals have other plots away from forest edges. 2) Contemporary land use outcomes along the park edge are shaped in part by the total amount of land the individual holds. In other words, those who grow food crops against the park have more limited land endowment, whereas those planting trees at the park edge are more likely to have more land elsewhere. 3) Though some edge plots have been fallowed for several decades because they are marginal landholdings to the farmer, proximity to a strict-protection forest increases the likelihood that they will continue to be under fallow, even as other edge plots are rapidly transforming to tree planting. Tree planting is an important land use trend along forest edges, as it softens sharp boundaries between forests and agricultural land. In Bujingijila Gap, spatially clustered plantings can offer possible biodiversity benefits. Contiguous tree cover is key for habitat connectivity for arboreal primates, particularly the critically endangered *Rungwecebus kipunji* (Bracebridge et al., 2011). The woodlots can also be used to enhance forest regeneration by helping natural tree species recovery (Chazdon et al., 2009). The identified patterns of land use indicate that individuals with greater land

endowments are voluntarily planting trees, whereas the land poor will need special assistance if they are to manage their land for enhancing connectivity.

2. INTRODUCTION

Land use adjacent to protected forests has significant implications for both biodiversity and human wellbeing. Some land uses sharpen the gradient between forest and non-forest habitat (DeFries et al., 2008), or erode the quality of the edge-habitat (Radeloff et al., 2010). East African forest edges have attracted the attention of many researchers concerned about park impacts on local people and vice versa. Their work pays close attention to the users of the land right at the forest edge: demonstrating the challenges of their location and implications for biodiversity. They show that livelihoods are at risk particularly from crop raiding (Hsiao et al., 2013; Laudati, 2010; Naughton-Treves, 1998), but also that forest edges are increasingly crowded (Plumptre, 2002; Sassen, 2014), which negatively affects wildlife (Bracebridge et al., 2011; Onderdonk & Chapman, 2000). Studies centered on people/park edge interactions rarely incorporate local's overall land use strategies (but see Naughton-Treves et al., 2011 for a broader comparison of livelihood at forest edge vs far away).

This chapter investigates smallholders' land use, paying special attention to farmers' tree planting and its relationship to access to multiple plots of land near and far from park edge. The study is conducted in the Southern Highlands of Tanzania, where natural forests and forest fragments are scarce outside protected areas (Bracebridge et al., 2011). Forest edge land use bears important concerns for conservation of arboreal primates – particularly the critically endangered *Rungwecebus kipunji*, a newly described genus of primate whose current area of occupancy is disjointed by Bujingijila Gap (Bracebridge et al., 2013; Davenport et al., 2008). Recently, Bujingijila Gap has seen a surge in tree planting among some smallholders. The smallholders are acting independently, but the aggregated outcome of their planting trees (albeit exotics) in the Gap could offer biodiversity benefits by providing an arboreal pathway for the primates to travel between blocks of natural forest. Additionally, growing tree crops has the potential to reduce the incidence of wildlife crop raiding at the forest edge.

In order to realize these biodiversity benefits from subsistence farmer's tree planting, we have to switch our perspective from the Gap as a connectivity corridor to the Gap as land under varied human uses. From the point of view of a rural subsistence farmer, the Gap is a forest edge plot with high crop raiding pressure from wildlife: a marginal landholding compared to the rest of the farmer's land portfolio. The study will demonstrate that edge plots have differing land use outcomes from non-edge lands. Tree planting outcomes in forest edge plots are dependent on the plot owner's land endowment and which protected area (Strict-protection vs Nature Reserve) the farmer neighbors.

More specifically, I ask: 1) How do smallholders allocate their land at the edge, and away from it? 2) How do the tree-planters differ from other smallholders, and do these differences hold for edge and non-edge landholdings? 3) Which one is a more significant predictor of tree planting outcomes at the forest edge: overall land holdings OR proximity to a less strict protected area?

In addition to providing specific, actionable information on how to improve connectivity in Bujingijila Gap, I contribute to literature on East Africa park-people relations by highlighting that smallholders use their plots adjacent to the forest edge differently from how they use their land elsewhere in the landscape. I hope to demonstrate that a "portfolio" approach that takes into account the farmer's broader strategy offers greater insights for understanding park edge land outcomes than a focus only on the farmer's single plot that is adjacent to the park. Though a raft of published studies have looked at livelihood and ecological implications of neighboring a protected area (Hill & Wallace, 2012; Martino, 2015; Naughton-Treves et al., 2005), they have rarely systematically assessed whether edge farmers have access to multiple plots and how this shapes their land use decisions. Ultimately, my case study offers lessons for conserving bio-diverse forests in densely settled tropical montane regions.

3. BACKGROUND

3.1. Study Site

Field research was conducted in three villages in the Southern Highlands of Tanzania. The study area's forests are home to a critically endangered primate, the *Rungwecebus kipunji* (hereafter the kipunji), whose genus was newly described to science in 2007 (Davenport et al., 2008). The region also has rare highland grassland habitat (elevation: 2600m, nearly 1km higher than Bujingijila Gap) with endemic orchids, and holds the only national park in Tanzania protected for its flora (Salter & Davenport, 2011). The focal location of this study is a strip of non-forest land between two protected forests (3.5 km long; 0.25 km at the narrowest point and ~ 0.8 km at the widest: See Figure 2). This Bujingijila Gap (hereafter the Gap), has been identified as a critical site for creating a corridor for reconnecting kipunji habitat (Caro et al., 2009). It has also been cited as an area where habitat for the kipunji could be potentially expanded, perhaps in conjunction with a carbon-stock enhancement project (Bracebridge et. al, 2011). Subsistence farmers own and utilize land in the Gap, but have their homesteads away from it, in the villages where the interviews were conducted. The southern highlands has one of the highest rural population densities in

Tanzania: the 2012 national census[1] shows the highlands' average population density at 157 people per km^2 (National Bureau of Statistics, 2013), an increase from the 2002 national census when it was 152 people per km^2 (Tilumanywa, 2013), – a value four times the national average. Individual landholdings in the area surrounding the protected forests are small (<2 ha), and planted in a wide array of crops (eg: maize, potatoes, yams) (Bracebridge et al., 2013). Some farmers also plant tea, eucalyptus or pine. Previous studies report that people inherit their land, and some supplement their inherited landholdings with purchases. Most individuals engage in subsistence agriculture, though other economic activities such as livestock keeping, timber cutting and selling, carpentry and small businesses have been reported (Bracebridge et al., 2013). Land use pressure is uniformly high owing to the dense rural population. Cultivation occurs right up to the forest edge (See illustrative photographs in (Bracebridge et al., 2013).

The study site is unusual in its placement between two protected forests: Rungwe Forest Reserve and Livingstone Forest (managed as part of Kitulo National Park) that have very different management regimes. The Rungwe Forest Reserve is a nature reserve created in 1948 to protect a water catchment forest, and managed by the regional natural resources office with limited funding. Livingstone Forest is managed as part of Kitulo plateau, highland grassland protected for its orchids. Kitulo National Park was gazetted as a national park in 2005. As per Tanzanian conservation practice, National Parks are areas of strict protection and the park management has a strong hierarchy of decision-making. A contrast between the management approaches for the two forests is revealed in the forest monitoring practices: whereas Rungwe Nature Reserve has a long-term community-based forest

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[1] Population density calculated as population per area for Rungwe District. Area: 2154 km^2 calculated from nationally released GIS layers for 2012 census enumeration sites. Population size: 339,157 reported in publically available, aspatial national census data.

guarding program, Kitulo National Park is patrolled by trained, uniformed and armed park rangers.

3.2. Broader land use context

It is uncertain when extensive forests last covered the land outside the current protected area boundaries. Researchers, however, suppose that, “forests have been extensively cleared across the ‘Mwakaleli Bay’ area (c. 1500–1700m a.s.l.) and possibly relatively recently”, based on contiguous presence of primates in isolated blocks (Bracebridge et al., 2011, pp 694). An aerial photograph of the study site from 1949 shows surprising conformity to current edges. I calculated that only ~170 ha forest has been lost outside modern-day protected forest boundaries, all of which concentrated on the south-eastern tip of the study site. Missionary and colonial government maps from c.1953, mark most of non-forested land with huts and crop cultivation, indicating extensive settlement. In short, for the past six decades, large swatches of montane forests were absent outside the protected area boundaries, even though rapid forest loss and degradation has been documented elsewhere in the Rift Valley in this same period. Several studies have indicated concern for forest loss especially at Bujingijila Gap (Caro et al., 2009; Davenport et al., 2008) with multiple calls to enhance Kipunji habitat through a “targeted and careful selection of priority sites … foremost the reforestation of the Bujingijila Corridor, an area of around 2 km^2 almost wholly cleared for agriculture” (Bracebridge et al., 2011 pp 694, citing Davenport et al., 2008). This study suggests that Bujingijila is possibly experiencing localized afforestation -- tree planting is underway, in part due to scarcity of forests outside protected areas. Studies on forest transition and afforestation for woodland African locations have two famous examples of rural locations that have achieved increased tree cover despite high population, though not always for conservation (Fairhead & Leach, 1996; Siedenburg, 2006). Their case studies may provide insights into social factors for afforestation, an aspect that may become important when providing recommendations for conservation actions in Bujingijila.

The challenges of conserving this biodiverse montane forest that is surrounded by a densely settled landscape provide lessons applicable to analogous eco-regions in the East African Rift. Understanding the patterns of land use around protected forests is necessary if conservation is to succeed in these crowded landscapes (Plumptre & Kabagumya, 2011; Sassen, 2014), where high rural population and cultivation pressure runs alongside globally significant biodiversity (Cordeiro et al., 2007). This study contributes to emergent research on perennial crops at montane park edges (L'Roe & Naughton-Treves, in prep) as well as challenges of balancing biodiversity and livelihood concerns.

4. METHODS

During June-August 2015, I conducted one focus group activity and interviewed citizens who own land in the Gap. The focus group had 7 participants, and provided general information on broad land use history and characteristics of tree planters. Two of the focus group participants led me on a guided walking tour of the Gap, other forest edge locations and key tea-planting areas. For individual interviews, the total number of respondents was 92 and they were selected from a list of all plot owners in the Gap (~300 owners) by a stratified random sample. I intended to get at least 30 responses for each land cover type in the Gap including: fallow, land planted in annual food crops, and land planted with trees. Within each land cover type a comprehensive list of owners was made with the help of village officials and local research assistants, and then a random subset selected. The interview was conducted in Kiswahili at the farmer's homestead and lasted about 1.5 hours for each respondent. In many cases, both the husband and wife were present during the interview. The interviews focused on land use in the Gap adjacent compared to land use elsewhere. I asked several open-ended questions on approximate sale price for each plot of land the farmer owns, and on reasons for fallowing some plots while planting trees or food crops on others. I also noted extenuating circumstances eg: widowhood, old age, and children living far from homestead if the respondent brought them up. See survey attached in Appendix 1. A random subset of respondents (n = 30) were asked further questions about their plot acquisition and decisions on where to plant and harvest trees. The interviews were structured with guidelines outlined under the agriculture section of the Living Standards Measurements Survey (Grosh & Glewwe, 2000). Verbal informed consent was obtained from respondents. They were assured anonymity including a detailed explanation of voluntary participation and an option to decline participation or responding to specific questions.

Using the respondent's answers on their plot locations, I categorized plots as adjacent to the forest edge (which includes all Gap plots, and plots that are outside the Gap but located along the forest edge) vs. plots that are further from forest edges (average distance > 1 km). I am confident in the assignment of edge/non-edge given the respondent's location details, my knowledge of local sub-areas built from walking surveys and focal group discussion. I use the outcome to assess three things 1) How smallholders allocate their land to different uses at the edge versus away from it. 2) How tree-planters differ from other smallholders, and whether these differences hold for edge versus non-edge landholdings. 3) Significant predictors of tree planting at the forest edge and away from the edge, comparing overall land holdings and proximity to a less strictly protected area.

4.1. Characterizing edge vs. non-edge land use

Respondents self-reported the attributes of each of their landholding; including plot area, crops planted on the plot the previous session, fallowing regime, the number of trees on the plot, and location of the plot. The respondents were selected based on their Gap-plot ownership, but since each respondent had at least one other plot outside the Gap (i.e., away from the forest edge), land use at the edge can be compared to land use further away from forest edges. For each respondent, I calculated the percentage of land area devoted to a given land use for edge vs. non-edge plots. To obtain the proportion of non-edge land devoted to food cultivation for a given respondent, the calculation would be:

$$\%FOOD = \frac{\Sigma(FOOD\ AREA)_{NONEDG}}{\Sigma Area_{NONEDG}}\%$$

I applied this formula to four land use categories: Trees, Food, Tea and Fallow. I obtained proportion land use allocation to each of these four categories, at the forest edge versus away from the forest edge, for all 92 respondents. A paired t-test was applied to the data to detect whether the proportions of land devoted to various activities are significantly different between park edge locations vs. non-edge locations.

The respondents reported short- and medium-term (next season and next three to five years) land use plans for their Gap plots. These responses are used to assess possible land use trajectories for the Gap. I also use responses from the open-ended questions on land values to compare prices and willingness to sell land for edge vs. non-edge plots.

4.2. Tree planters vs. Non-tree planters

Mixed cropping complicates the distinction between tree vs. non-tree farmers. It is common for some plots (particularly near homesteads) to contain several food crops, a section of tea, a section of avocado, and a border crop of trees. However, respondents provided an estimate of the number of planted trees and the area of the plot, from which I calculated tree density. Estimates of planted trees are fairly reliable as individuals can recall the number of tree seedlings purchased, and generally know the size of their tree holding asset. Based on focus group interviews on tree planting in the community, fulfilling one of these criteria qualifies a respondent as a tree farmer:

- at least one plot devoted entirely to trees
- at least one plot with tree planting density of at least 400 trees/acre
- an overall tree count of above 300

The data is partitioned into tree planters and non-tree planters. I use a two-sample, unequal variance t-test on the grouped data, testing for statistical significance in differences in land endowment, overall food cultivation, and tea cultivation across all landholdings between the two user categories. I also tested whether tree planter individuals preferentially place trees at the park edge.

4.3. Predicting tree planting outcomes

I constructed a General Linear Model for predicting tree planting as a land use outcome at any plot for all the plots recorded. The following equation is used:

$$\begin{aligned} Trees \sim \beta_o + \beta_1 totalLandArea_{plotOwner} + \beta_2(Neighborhood\colon NATRSV\ or\ NP\ or\ NONEDG) \\ + \beta_3 numberOfPlots_{plotOwner} + \beta_4 plotSize + \in \end{aligned}$$

Table 1 explains the variables and their expected relationship with tree planting outcome. The resulting *Trees* variable is a continuous count of trees based on the landowner's report of the number of trees in their plot. I check for correlation among variables, particularly *totalLandArea* and *numberOfPlots* before constructing linear models. A first model is constructed for all the plots recorded for all respondents, regardless of their location relative to the forest edge. A second model is constructed for only the forest edge plots, using the same predictor variables to test if the predictors, particularly for the variable "Neighborhood", would show a stronger signal.

5. RESULTS

5.1. Land use at the forest edge vs. away from the edge

All respondents have a non-edge plot. The respondents were selected based on the fact that they had a plot inside the Bujingijila Gap. I found that all respondents also had a plot somewhere else in the area. Their additional landholdings include a homestead plot because no respondents lived in the Gap. The total number of plots per respondent ranged from 2 – 11, with a mean of 4.7 (See Figure 3). Each plot averaged 0.6 Ha and the total land area owned ranged from 0.4 to 36 Ha (mean = 3.2 Ha SDEV = 4.0).

Edge plots are cheaper than non-edge plots. Respondents often refused to provide price estimates for their plot, or insisted that the plot was strictly not for sale. By adding up edge and non-edge plots, 514 (370 non-edge, 144 edge plots) unique plots were recorded, but a price estimate was recorded for only 120 plots (69 edge plots and 43 non-edge plots). In general, participants were more willing to estimate a price for their edge plots than for their non-edge plots. After converting the estimated price to USD using the July 2015 exchange rate (1 USD = 2165 TSH), and normalizing the price by area, the data shows that edge plots are cheaper than non-edge plots (Price per acre = USD 423 vs USD 580 p = 0.07 See Figure 4).

Individuals plant food crops away from the edge. On average, individuals own nearly double the amount of land holdings in plots away from the forest edge than at the forest edge (Figure 5). On average, respondents leave only 4% of their non-edge land fallow, versus

47% fallow at the forest edge. The results also suggest that individuals prefer to plant their food crops in non-edge plots (paired t-test difference = 32%, p-value = 2.5E-08) and opt to leave their park edge plots as fallow (difference = -42%, p-value = <.0001) Though individuals devote slightly more of the forest edge land to tree planting than non-forest edge land (35% vs 30% respectively), this difference is not statistically significant (See Table 2).

Fallowing: More plots were fallowed adjacent to the strict-protection area (21% of all edge plots) than adjacent to the Nature reserve (9% of all edge plots). Respondents gave multiple reasons for not cultivating their plot along the forest edge, but most often mentioned crop raiding by wildlife (32 out of 41 respondents mentioned this; but each respondent gave multiple reasons for fallowing). Respondents' sense of vulnerability to crop loss to wildlife apparently interacts with other personal circumstances such as old age (27 mentions), and the absence of children to help guard crops (2 mentions). Other respondents pointed to external factors such as the distance of the plot from their homestead (22 mentions), and the fact that other neighboring farmers stopped attending to their forest edge plots, which concentrates the risk of crop loss to whoever continues to cultivate without neighbors (11 instances). All of these factors interact to shape a sense of marginality of agricultural land. For example: old age makes what was a reasonable distance to walk to one's farm an unsurmountable one, and similarly, the task of guarding against crop raiders becomes too difficult. Interestingly, the farmers provided these complex and varied reasons when asked why they stopped cultivating the plot in the past, but when asked whether they would cultivate the plot in the near future, the farmers pointed out that the plot had been "taken"[2] from them by the national park 4). (15 instances, See Table 3)

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[2] An adult male respondent that inherited the plot from his father stated *" Upande wa Ndala TANAPA walininyang'anya ploti tangu 2012"* "*Nyang'anya*" in Kiswahili clearly means "taking."

Intention to plant more trees at the edge. Respondents were asked about their plans to use the forest edge plot, both for the upcoming rain season and in the next three to five years. Current tree planters at the forest edge intend to keep planting trees (29 responses), while some food growers intend to keep growing food (8 responses). The majority of food growers intend to convert their edge plot to a tree plot (10 responses), while those that have left their edge plot to fallow signaled they might convert it to a tree plot or sell the plot (21 responses), given certain conditions (Table 4). Taking these possible conversions in land use, the forest edge land may be apportioned different in the future, with shrinking food and fallow land uses, and expanding tree cultivation (See Figure 6).

5.2. Characterizing tree farmers

From my dataset of 92 respondents, I ended up with a post-hoc partition between tree planters (n = 59) and non-tree planters (n = 33). Among the 59 tree planters, 30 were individuals who reported owning at least one plot devoted entirely to trees. 7 were individuals that had at least one plot with tree planting density of 400 trees/acre though the plot could have other crops on it as well. 22 were individuals had an overall tree count of above 300. Overall, the tree planters own about 1.5 times more total land compared to the non-tree planters. The tree planters have about the same amount of land at the edge as the non-tree planters, but double that amount away from the edge. The non-tree planters, on the other hand, have slightly more of their landholdings at the edge than away, though this difference is not statistically significant (See Table 5).

The land use apportioning differs among the tree-planters and non-tree planters. The tree planters devote slightly more of their land at the edge to trees than the land away from the edge, although the difference is not statistically significant (Difference = -9.51%, p =

0.21). The average non-tree planter, on the other hand, has a lot of their edge land left as fallow (71% -- compare it to 34% of edge land left as fallow by the tree planter; Figure 7). Meanwhile, the non-tree planter devotes about 64% of their (already small landholding) in the area away from the edge to food cultivation. The tree planter devotes only about 43% to food cultivation away from the edge (Figure 7). It is worth noting that even though the proportion of the land devoted to food cultivation between the tree farmer and the non-tree farmer are different, the actual area devoted to growing food is about the same between the two groups. (Tree planter = 2.49 acres; Non-tree farmer = 2.93 acres. Difference = 0.44 acres; p = 0.15).

5.3. Can we predict plots that would be tree planted?

Plot area, number of plots, plot location and overall landholding size are all significant predictors of tree planting (number of respondents = 92; all plots recorded = 514). In general, the predictors used are not highly correlated (correlation between the total landholding area, and the number of plots is 0.36; Table 6). Larger land holdings slightly increases the odds of a plot having trees (odds ratio = 1.01) while a larger plot area also slightly increases the odds of the plot having trees (odds ratio = 1.10). Plot location (ie, Non-edge vs Edge) suggests that everything else being equal, proximity to forest edge slightly increases the odds of the plot having trees (odds ratio = 1.12). For plots with no trees on them, the location matters even more: proximity to the strict protected area means that the plot is 1.46 times more likely to have no trees than if located elsewhere. (See Table 7)

In the data subset that considered only edge plots, overall land area slightly increases the odds of the plot having trees on them (odds ratio = 1.06), while proximity to strict-protection park decreases the odds of having trees (odds ratio = 0.66). For plots at the edge that have no trees on them, the only significant predictors are the plot area and which protected area the plot borders. If a plot is larger, then it is less likely that it will have no trees (odds ratio = 0.61). Proximity to the strict protection park increases the odds of having no trees by 1.85 (See Table 6)

6. DISCUSSION

Key findings

Not surprisingly, farmers with less land were obliged to plant food crops against the forest edge where wildlife abounds. Those with more land could leave edge sites fallow or plant trees. Results also show that those planting trees against the forest edge were planting more trees on their plots elsewhere. What was surprising, however, is the roughly equal overall land area devoted to food cropping, both for the tree-planters and non-tree planters. This is unexpected as it suggests that households have to first devote a certain amount of land to food cultivation, with trees planted only on excess landholdings. One respondent put it simply: “you must grow enough food for feeding the family.” [an old man owner of 4 plots, July 2015]

The predictor models for tree planting outcomes at the forest edge and away from it showed that all things being equal, proximity to forest edge slightly increases chances of a plot having trees on it. This would be consistent with farmers preferring to place food crops away from the forest edge. It suggests that tree planting is filling a land use niche for marginal landholdings. If a farmer has an edge and a non-edge plot, they may prefer to cultivate crops on the non-edge plot since it is costly to service the edge plot given crop-raiding pressure. Thus planting trees at an edge plot is an attractive alternative for this marginal landholding, but the farmer must have the capacity to utilize the edge plot that would otherwise be left fallow.

The concentration of fallow plots against the forest edge is reflective of how that piece of land has marginal value to the farmer. However, this study also revealed that the type of management of a protected area affects the farmer's perception of the plot usability. Proximity to the strict-protection reserve strongly increased the odds of a plot having no trees planted on it and the chance of the plot being fallowed. When asked about future plans for plot use, half of the farmers with fallow plots mentioned that their use depends on "permission from TANAPA [the agency responsible for Kitulo, the strictly protected park]". The farmers made this statement even though those same plots have been fallowed long before 2005, when the protected area was created. Some respondents even used strong language such as "TANAPA took the plot from me since 2012" or "I may plant trees if I am allowed by TANAPA." [Young man with plot at edge, 7/28/2015, and widowed woman with plot at edge, 7/8/2015]. The persistence of fallowing amidst the new wave of tree planting is certainly related to the confusion regarding whether plot owners can still use the land adjacent to the park without repercussions. Essentially, proximity to a strict protection protected area and uncertainty about regulations has made what was already marginal land to farmers even more marginal. The marginality of these landholdings is partially reflected in the overall lower prices for forest edge plots, and by the number of farmers who stated that their future land use plan is to sell the plot.

The study also suggests that land use in the Gap is starting to change. Respondents indicated intention to convert a majority of their food plots to tree plots at the forest edge within 3-5 years. Some of the actively farmed plots already contained exotic and fruit trees in the plots, but the users continue to grow food crops while the trees are young. As one respondent explained: “for that side [ie, land next to forests] a good plan is trees.” [a man with 5 plots 7/11/2015] Other respondents indicated that they might sell their edge plot instead. Respondents’ willingness to sell edge plots versus their reluctance to sell non-edge plots was revealed in how easily they assigned a price to their edge plots but refused to do so for other locations. When I asked a local informant about whether the sale of plots would eventually deplete local land ownership, she replied “there are plots for sale, and plots for using…” [Old woman with 4 plots, 7/9/2015] This corroborates perceptions of edge lands as marginal. Land sales have been associated with a change in land use in East Africa and elsewhere (Oostendorp & Zaal, 2012). These edge lands may be at a cusp of rapid transformations in ownership and use, corroborating findings by other long-term researchers at Kibale NP in Uganda (L’Roe & Naughton-Treves, in prep)

Mixed-use lands have been shown to be useful for some primates, particularly widespread, generalist species (Blanco & Waltert, 2013; Onderdonk & Chapman, 2000; Pozo-Montuy et al., 2011). Yet there are still challenges for managing people-wildlife relations at the forest edge such as crop raiding. Even though only one snare was encountered during fieldwork, retaliatory hunting is common in the region, and permeable, connected landscape may mean more incidences of crop raiding and snaring incidents. In addition, though mixed-use landscapes would be an improvement to the kipunji connectivity by providing a traversing matrix, exotic tree plantations cannot substitute for natural habitat. Regeneration of natural forest remains a key goal.

Are observations from the study consistent with other EA findings? The link between fallowing and crop raiding pressure has been shown in several studies, where smallholders abandoned their plots after catastrophic crop losses, particularly to elephants (Naughton-Treves, 1998). Even though specific reasons for farm abandonment was not discussed, (Chapman & Chapman, 1999) conducted their study in abandoned agricultural fields, where tree seedlings establishment was slow. At a Kenyan highland park, with the construction of a wildlife proof fence, park-edge fallows were quickly replaced with intense cultivation and land prices soared (Kahumbu, P. pers. Comm.). Taken together, these studies indicate that the presence of fallow next to protected areas is not unique to the Southern Highlands.

Another East Africa study has suggested that tree planting along the protected area edges is a result of rapid changes in land markets; bringing new, wealthier actors to the forest edge (L'Roe & Naughton-Treves, in prep). Previous conservation reports have detailed the role of tree planting as a source of alternative income in communities surrounding protected forests, or as a way to ameliorate scarcity of wood products (Chhetri et al., 2004). The confluence of new land markets and targeted tree planting suggests that East African forest edges may be undergoing transformations in land use, but the broad causes and patterns are still difficult to pin-point.

East Africa's Economics and Development literature recognizes the importance of rural household's access to multiple plots, but point to the difficulty in collecting and utilizing such data (Bardhan & Udry, 2000; Grosh & Glewwe, 2000). So far, scholars tend aggregate the discrete plots into one land area (Deininger & Savastano, 2015; Fox, 2015; Kassie et al., 2012) smoothing over the land use outcome by respondent in order to make inferences about agriculture and livelihoods. Applications have been even more limited in the park/people literature. Crop raiding studies, (Hill & Wallace, 2012), would benefit from comprehensively assessing the differential impact of crop loss among farmers by incorporating the overall attributes of the farmer's land use portfolio. With the availability of the Living Standards Measures Survey (LSMS) there exist opportunities for filling this knowledge gap.

Biases/problems with the data: The respondents were selected based on owning land in Bujingijila Gap, and this focal study area is small (3 km^2). Therefore, some of the conclusions are only applicable to the farmers in this site. For example: it is tempting to look at its results and conclude: "17% of land at the forest edge is devoted to active farming" but that is not the case. Instead, the conclusion should be "On average, farmers at this site place about 17% of their edge land under active cultivation." The study only reveals how an average user within the Gap apportions their land, at the edge and away from the forest edge. The study also lacks systematic socio-economic data, which is known to be a powerful predictor of land use.

7. CONCLUSION

Scholars of livelihoods along protected areas recognize that the land use outcomes along the edge influence wildlife wellbeing (Martino, 2015), but rarely consider these outcomes as being connected to decisions that smallholders make elsewhere in the landscape. Essentially, scholars tend to focus on the one plot encountered against the edge, but from this and other regional studies, we see that individuals may be operating at multiple locations in the landscape. Land use outcomes at the edge, therefore, do not exist in isolation, but are related to decisions made elsewhere. By taking a portfolio approach, I hope to have shown that even when the land use right at the edge is of utmost importance, it is worth paying attention to the broader land use constraints and endowments, as these can explain and affect the forest edge outcomes.

If the tree-planting trends observed in this study persist, Bujingijila Gap has potential to be a functional human (i.e, tree farm) and ecological (i.e connective corridor/travel matrix) landscape. It will be necessary to consider the long-term plan for desirable landscape outcomes that benefit both the natural environment and people. Incorporating local tree planting trends in conservation planning may reduce the cost of afforestation. For instance: woodlot owners next to forests can be incentivized to plant native seedlings through programs that are well monitored. (eg: providing woodlot seedling discount with appropriate care of natural seedlings). Clarifications of regulations for plots neighboring a strict-protection area may be a necessary step for inducing desirable local land uses.

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9. TABLES AND FIGURES

Table 1: Variables used for a GLM predicting tree-planting outcome for a given plot

Variable	Explanation	Variable type	Expected relationship
plotSize	Plot size	Continuous	?
(NATRSV/NP/NONEDG)	Nature Reserve (1)	Nominal	>>
	National Park (2)	Nominal	<<
	Non-edge (0)	Nominal	?
totalLandArea	Total land area	Continuous	>>
numberOfPlots	Number of plots	Continuous	>>

Table 2: Significance test for land use portions for all users for edge plots vs non-edge plots

	Edge	Non-Edge	Difference	p-value
Total Land Area	3.1	5.4	2.3	0.05**
% Trees	34.8	29.3	-5.5	0.30
% Tea	0	15.3	15.3	0.00***
% Food	17.9	49.2	31.3	2.50E-08***
% Fallow	46.3	4.1	-42.2	0.00***

Table 3:Reasons for fallowing edge plot (users gave more than one reason)

Reasons for fallowing edge plots	# Of mentions	National Park Mentioned
Illness	12	1
Old Age	27	3
Children live far away	2	
Crop raiding	32	4
Others stopped farming	11	2
The plot is too far away	22	3
National Park	2	
The soil is not fertile enough	2	1
Owner had other plots	2	1

Table 4: Transition matrix for forest edge land use, showing intention to plant more trees in the future

		Reported land use in the near future (3-5 years)		
		Active Farm	Fallow Farm	Tree Farm
Current land use	Active Farm	8	4‡	10
	Fallowed Farm	1	21*	17
	Tree Farm	1	0	29

‡ Depends on neighboring farmers' activities: if they farm, the respondent will also farm
*If there is a suitable buyer plot will be sold (6), If TANAPA "allows" plot will be tree-planted (15).

Table 5: Land use characteristics of tree planters and non-tree planters at the forest edge and away from the forest edge.
Tree planting attribute is based on a post-hoc partition of the data with a set of criteria

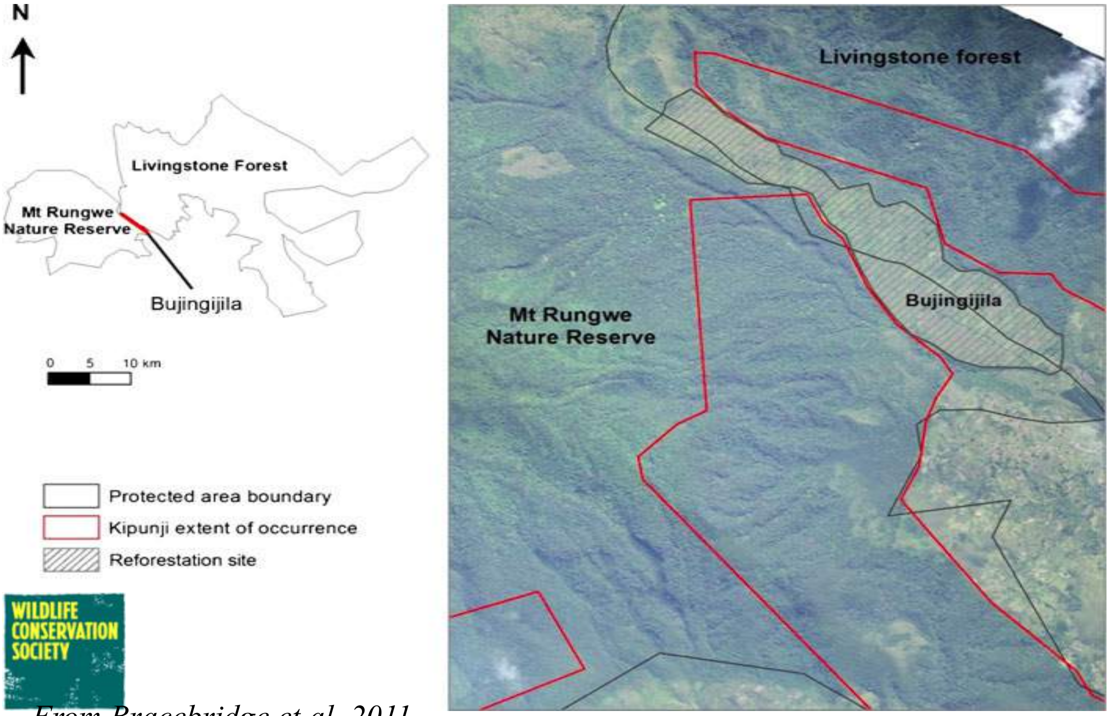
	Tree Planter (n = 59)				Non-Tree Planter (n = 33)			
	Edge	Non-Edge	Difference	p-value	Edge	Non-Edge	Difference	p-value
Total Land Area	2.9	6.7	3.7	0.02	3.3	3.1	-0.2	0.9
Trees	46.4	36.8	-9.6	0.21	12.1	13.8	1.7	0.79
Tea	0	14.8	14.8	1.60E-07***	0	16.7	16.7	4.90E-07***
Food	19.3	42.8	23.5	0.001***	15.9	62.1	46.1	1.38E-07***
Fallow	34.3	3.9	-30.4	4.05E-06***	69.0	4.4	-64.6	5.30E-10***

Table 6: Correlation matrix for all variables

	Plot Area	Area Total	Number of Plots	Number of Edge Plots
Plot Area				
Area Total	0.60***			
Number of Plots	0.08	0.36***		
Number of Edge Plots	0.05	0.16***	0.30***	
Plot Price	0.77***	0.49***	0.31***	0.29***

Table 7: Odds Ratio for predicting tree planting outcome in all plots recorded from respondents and in the edge plots

	ALL PLOTS		EDGE PLOTS	
	Trees Present (Count) (LOGLIKELIHOOD)	Trees Absent (LOGIT)	Trees Present (Count) (LOGLIKELIHOOD)	Trees Absent (LOGIT)
Area Total	1.01***	0.98	1.05***	0.98
Number of Plots	1.04***	0.86**	0.93***	0.89
Non-edge (0) Nature Reserve (1) National Park (2)	1.12***	1.46**	0.66***	1.85*
Plot Area	1.10***	0.64***	1.09***	0.64*
Log-Likelihood (DF)	-190200(10)		-26420 (10)	



From Bracebridge et al, 2011

Figure 2: Kipunji extent of occurrence, complex management, and site of gap

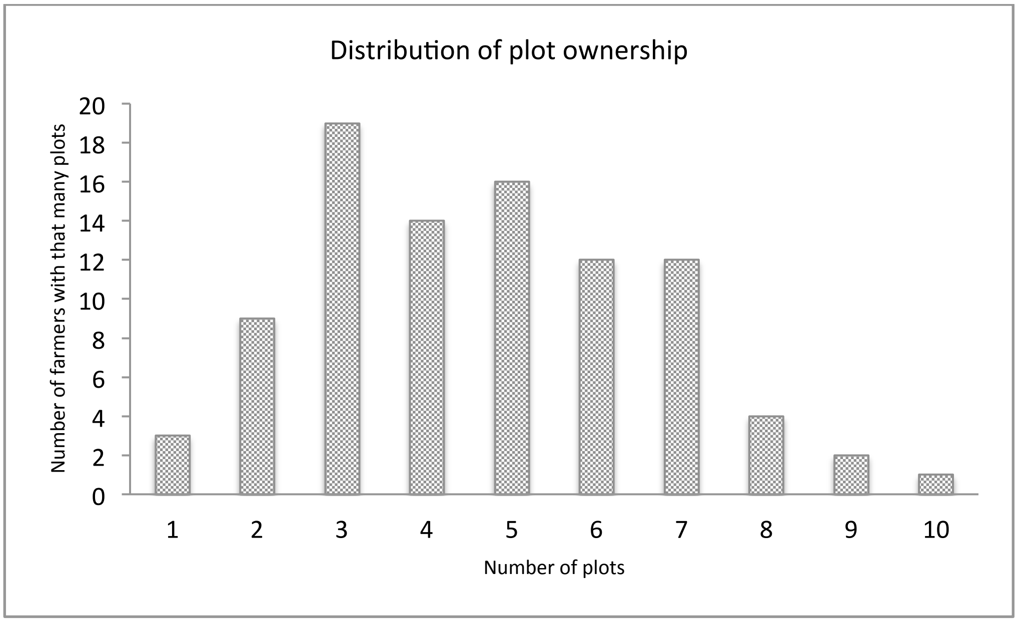


Figure 3: Distribution of plot ownership for all respondents surveyed

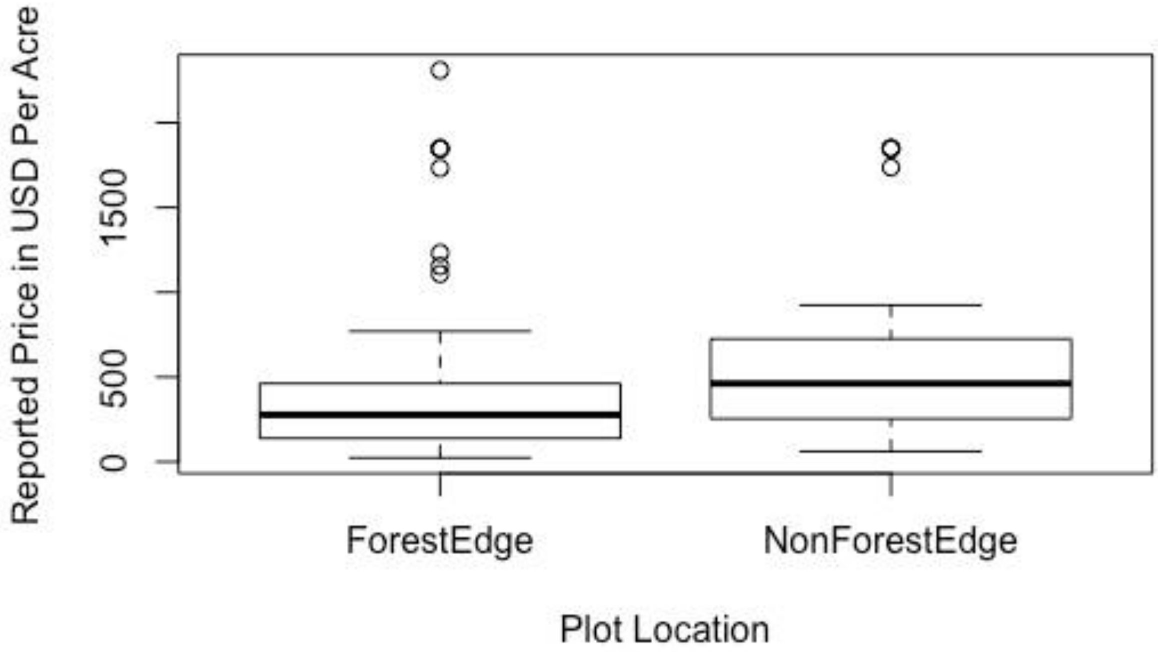
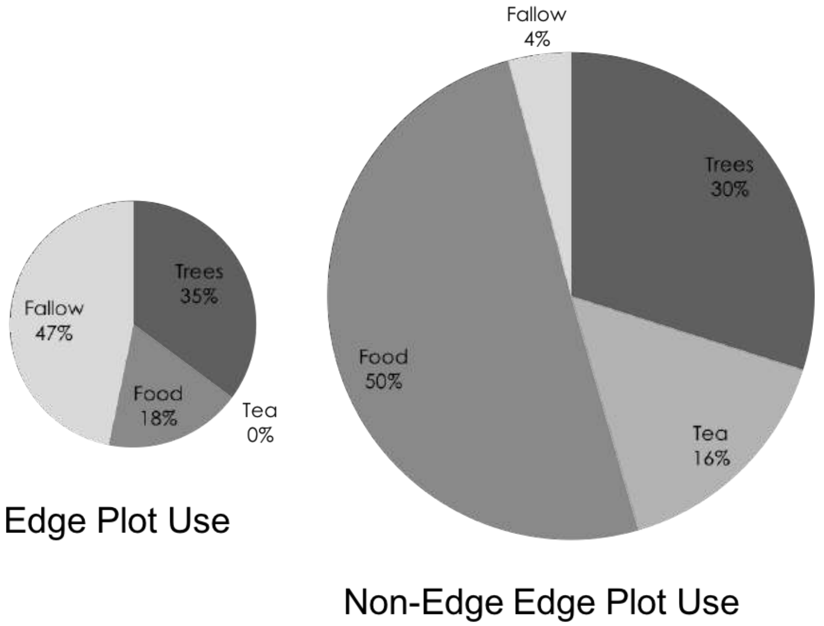


Figure 4: Range in self-reported price for Forest Edge(n =69) versus Non-Edge (n = 43) plots. Mean price per acre: Edge = 423 USD and Non-edge = 580 USD Difference = 57 p = 0.07. 1 USD = 2165 TZSH based on July 2015 exchange rate). Values 100X above mean prices were removed.



Edge Plot Use

Non-Edge Edge Plot Use

Figure 5:Percentage apportioning of land uses for edge vs non-edge plots for all respondents.

The size of the chart is proportional to mean land size for each respondent at the forest edge vs at non-forest edge locations.

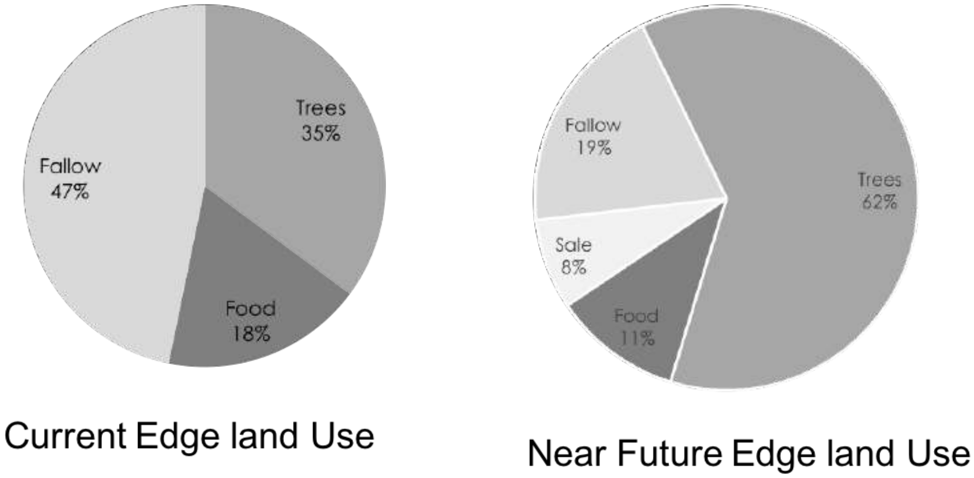


Figure 6: Edge plot use at present + edge plot use within 3-5 years

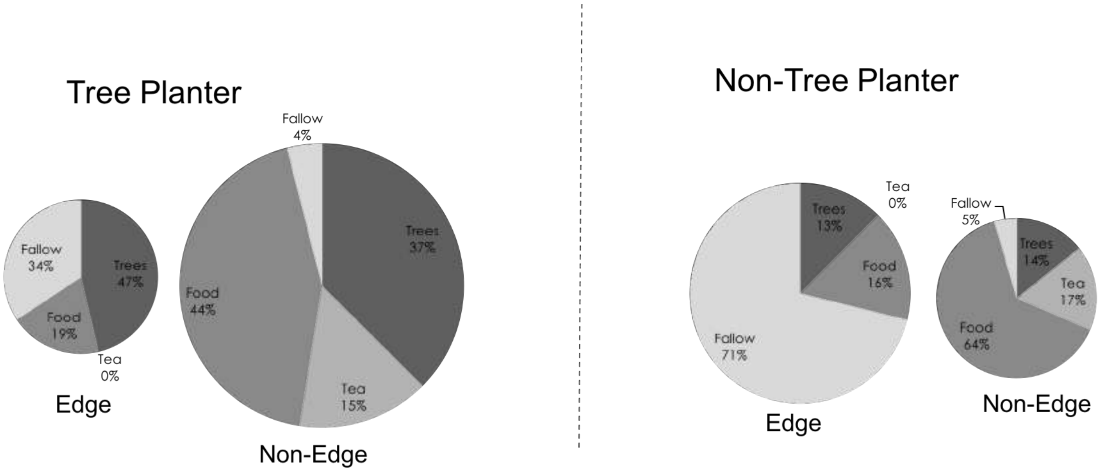


Figure 7: Land use apportioning for tree planters and non-tree planters; at the forest edge and away from the edge

Suppressed Natural Forest Regeneration

Patterns of tree seedling distribution in the Gap

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1. ABSTRACT

Natural forest regeneration in marginal agricultural lands is useful for restoring forest habitat and for providing a transitional zone between protected forests and human-dominated landscapes. Though most East African Rift forests are bordered by annual crop smallholder farms, few marginal lands exist in the form of farms in disuse, long-term fallow or lands planted with perennial crops such as tree woodlots. Forests in the Rift have a pressing conservation need to improve forest connectivity that necessitates site-specific understanding of forest regeneration in these marginal lands. This study examined patterns of tree seedling distribution at Bujingijila Gap, in the Southern Highlands of Tanzania through physiographic and human use factors known to affect forest regeneration. Using spatially explicit circular-samples located 0 to 400 m from the forest edge, I determined the seedlings incidence and species composition. Three native species dominated the area: *Morella salicifolia* subsp *kilimandscharica*, *Maesa lanceolata* and *Myrsine melanophloeos* (together 52% of total seedlings, n = 484). Tree seedlings of native species were more abundant in exotic softwood plantations within the human-managed, southern section of the Gap than in the northern section that has been in disuse for c.50 years (Northern section 0.03 seedlings/meter of survey effort, Southern section 0.07 seedlings/meter). Seedlings were more abundant closer to the forest edge and close to large trees (DBH > 20). In contrast, tall grass reduced the likelihood of encountering seedlings. These results accord with studies of 'suppressed' generation adjacent to mid-elevation forests elsewhere in E. Africa, and suggest that human

management (tree planting, herbaceous cover suppression) may be necessary for expediting forest regeneration.

2. INTRODUCTION

As the human footprint continues to expand, natural habitats are becoming increasingly fragmented and isolated (Fischer & Lindenmayer, 2007; Hilty et al., 2006; Margules & Pressey, 2000). Reconnecting or even expanding isolated habitat fragments is a conservation priority particularly in the montane forests of the East African Rift; a globally significant biodiversity hotspot with high levels of endemism for plant and animal species, including endangered primates (Burgess et al., 2007; Plumptre & Kabagumya, 2011; Plumptre et al., 2007). Reconnection and expansion of forest habitat in this region is limited by densely settled communities of agriculturalists. (Bracebridge, et al., 2013; Cordeiro et al., 2007; Sassen, 2014). Occasional opportunities do arise for improving habitat connectivity within zones of human use – in abandoned farms, plots left to long-term fallow, or through agroforestry along forest edges. Given the endangered status of primates and other wildlife, conservationists seek to reconnect forest habitats quickly. However, regeneration is a complex ecological process that depends on multiple factors such as seed availability, competition with other vegetation, historical and current land use, and sufficient time for re-growth.

Natural factors limiting forest regeneration: It is widely known that natural factors such as seed availability, dispersal and germination, (Fink et al., 2009; Holl, 1999; Wijdeven & Kuzee, 2000) and seedling out-competition by grass or shrubs (Chapman & Chapman, 1999; Holl, 1999; Zimmerman et al., 2000) can limit regeneration. Other natural factors such as proximity to forest or remnant trees (De Souza & Batista, 2004; Fink et al., 2009), microclimate control by shade trees or shrubs (Holl, 2002; Vieira et al., 2009) can assist natural regeneration (See summary in Table 8). Which factor ends up having the best explanatory power for forest regeneration pathway depends on the site. Differences in functional traits of plants or unique plant species assemblages can assist or hinder regeneration in a region. For example: only 2% of East African forest tree species are wind-dispersed (as opposed to Brazil's 15%). Mid-elevation forest trees in East Africa rely instead on frugivorous such as bats and primates for dispersal (Chapman & Chapman 1999), hence dispersal of seeds may be an important limitation to regeneration in some East African forests. The presence of aggressive grass and shrub species that tend to grow in former-forest sites in East Africa is an example of plant assemblages that make out-competition of tree seedlings a limitation to forest growth (Chapman & Chapman, 1999).

Role of historical and current land use on regeneration: Neo-tropic research has shown that land use history strongly affects forest regeneration. Seed banks were better retained logging and shifting agriculture than in monoculture or long-term grazing (Barbosa et al., 2009; Holl & Aide, 2011; Holl, 2002; Moran et al., 2000). Mechanized agriculture was also shown to significantly impact canopy increase rate compared to shifting agriculture (Moran et al., 2000). Less intensive land use practices may have minimal effect on regeneration outcomes. Agroforestry in particular, has been shown to be at least compatible with native forest regeneration. In East Africa, one study has showed that there is no significant difference in native tree species richness and diversity in logged and unlogged pine plantations (Chapman & Chapman, 1996). Agroforestry has even been proposed as a solution for forest restoration (Barbosa et al 2009; Holl et al 2011; Lamb, 1998).

Role of time in forest regeneration: Although land use history clearly can have an effect on regeneration, most studies of forest regrowth emphasize the role of time. If not terribly degraded, agricultural lands do revert to forest if given enough time (Holl & Aide, 2011), often becoming forest within four to five decades of abandonment. Given the presence of a seed bank (Wijdeven & Kuzee, 2000) and an 'amiable' environment for regeneration (Holl, 1999) forest regeneration is expected if enough time passes.

The goal of my project was to assess predictors of tree seedling distribution in Bujingijila Gap (hereafter the Gap), an area singled out as a high priority for establishing a forest corridor between two protected forests. I combined historical data from landowner interviews and aerial photographs with on-the ground vegetation transect to evaluate which factors best explain the field observations of tree seedlings. I evaluated forest regeneration factors identified as important in literature. I show that height of grass, distance to forest edge, proximity to large trees and current land use best explain the tree seedlings distribution observed.

The results of this study provide useful site-specific information to guide forest regeneration efforts that aim to reconnect protected montane forests in East Africa. More broadly, I provide a case where small-scale farmers may prove to be the more effective agents of forest recovery than costly large-scale tree planting campaigns.

3. BACKGROUND & SITE DESCRIPTION

Bujingijila Gap is a narrow area (width: 250m – 800m) of non-forest between two blocks of protected montane forests. The Gap has an elevation difference of 320m (1686m – 2008m asl) from South to North, and receives high annual rainfall above 2000 mm (Bracebridge et al., 2012). The Gap is a region where conservation needs and human land use demands are closely juxtaposed. The Gap has received attention from researchers because of its role as a link between habitats of a critically endangered primate *Rungwecebus kipunji,* latest monkey to be described to science from Africa (Davenport et al 2008), whose conservation plan includes reforestation of Bujingijila Gap (Bracebridge et al 2011; Caro et al 2009; Davenport et al 2008). Scientists have pointed out that "Bujingijila corridor … is in critical condition due to agricultural expansion and logging, and predicted to disappear entirely within 5 years" (Bracebridge et al., 2011 pp 694; Caro et al., 2009a; Davenport et al., 2008). This implies current forest loss, which is true of other analogous East African forest sites(Southworth et al., 2010), but not in the Gap. An aerial photograph from 1949 shows surprising conformity to current edges. I calculated that only ~170 ha of forest lost outside modern-day protected forest boundaries has been lost near the Gap, and this occurred between 1949 and 1969.

To improve kipunji connectivity, a corridor running west to east to connect two known home ranges is necessary. This creates the first important axis of variation for this chapter. The second analytical axis is the contrast between the uncultivated Northern section of the Gap and the cultivated Southern section. The high number of farm plots (~300) and the varied outcomes (i.e fallow, tree planting and active cultivation) provide an interesting range of conditions for studying tree regeneration. Given interest in making Bujingijila a treed corridor or an expansion of kipunji habitat, it is worth exploring the present regeneration patterns and how they vary 1) In the West-East axis and 2) across land uses, that is, in the N-S axis.

4. FIELD METHODS AND DATA ANALYSIS

In June-August 2015, I conducted vegetation surveys and land use history interviews in Bujingijila area. Within the Gap I oriented my overall sampling design along two axes: (i) an East-West axis which captures the distance from closed canopy forest, an important habitat connectivity variable, especially for arboreal primates, and (ii) a farm-based sampling that captured different management conditions: the North section has not been cultivated for at least 50 years, and the South section which has been cultivated, fallowed or planted with trees on and off over the past decades. I also obtained historical aerial photographs of the site, including one image dating from 1949.

4.1. Field Data Collection

Vegetation sampling: In the uncultivated, northern section of the Gap, I set vegetation transects 150m apart, oriented E-W, from one forest edge to another. This resulted in 22 transects with an average length of ~ 200m, for a total observation length of 4400m. I recorded tree seedlings of <1m height at points every 50m along transects. At each point, all seedlings were identified by their local name, and each species count obtained within a circle of 1m radius. Proximity to a large tree (DBH > 20cm) was recorded as "true" if there was a large tree within 5m of the sampling circle. The GPS location and the average height of grass within each sampling radius were also recorded (See Figure 8). Along the length of each transect, I recorded an overall estimate of presence and abundance of shrubs, trees and stumps using the Braun-Blanquent scale.

The same data were collected in the southern, actively managed portion of the gap. Here I sampled seedlings on smallholders' plots (average size, 0.6 Ha, range 0.1 to 2.4 Ha) to facilitate linking vegetation data to the land use history interviews. Within each smallholder plot, I placed five observation circles along the middle of the plot, with the inter-circle spacing ranging from 15m to 50m depending on the size of the plot. All seedlings within a sampling circle were counted, and their status as either “planted” or “naturally occurring” noted. At each sampling circle, I recorded the GPS location, the seedlings species, the number of seedlings per species, presence of a tree of DBH > 20cm, and the presence and height of grass. Outside the sampling circle, the surrounding land use was recorded at the scale of a typical “field”, ~0.25 acres. Further land use information including fallow age was obtained from interviewing the plot owner. The distance to the nearest forest edge for each sampling circle was calculated in a GIS during analysis.

Land user interviews: I conducted detailed interviews on land use history with 92 farmers who owned plots in the Gap. These 92 were selected from the total ~300 plots by a stratified random sample based on Gap plot land use outcomes. For each of the 92, I documented current broad categories of land use: active farms, woodlots and fallow plots. Even though farmers frequently fallowed a portion of their land, a plot was identified as fallow only if the entire area was in fallow. In the other two categories, the land use that covered > 70% of the plot was recorded; otherwise the plot was identified as mixed use. Next, I inquired about when the plot was initially cleared, and recorded the local names of species the farmer found on the plot at the time of clearing. For fallowed plots, I inquired about the year the farmer started fallowing their plot, their reason for fallowing and the types of vegetation that has grown on their fallow plots. Since plot histories reached back several decades, only approximate dates were possible. Similarly, some respondents were adult individuals whose parents had cleared the plot. The respondents were asked if they had worked the plot with their parents as children, and their estimates of clearing and fallow dates recorded if that was the case. From the 92 respondents, 60 plots were visited. Of these 60, 45 plots touched a protected forest (23 Rungwe, 22 Livingstone), the remaining 15 plots were more centrally located in the Gap, but only within 400 m of forest edges.

4.2. Data analysis

I analyzed the vegetation data in four ways: 1) I account for spatial autocorrelation by calculating semi-variance on all seedlings observations: a necessary step to ensure that data can be analyzed with an appropriate statistical approach. 2) I test the effect of natural factors (e.g distance from forest edge, height of grass and proximity to large trees) against seedling incidence. 3) I also examine patterns of seedling presence against human-mediated factors such as current land uses and length of fallow. 4) Finally, I include the natural and human land use factors in a general linear model and determine which variable best explains seedling distribution.

4.2.1. Spatial distribution of seedlings

To explore spatial structure, I generated semivariograms. A semivariogram is a plot showing the changes in the variance for every possible combination of data pairs at various distances, for up to half the maximum separation distance for the given spatial observations. The semivariograms were created at three levels: active lag distance of 200m, 720m and 1500m. The three lag distances correspond to a lag class interval of 15m, 34m and 45m respectively. The active lag distance and lag class intervals are user-defined, and correspond to field data sampling. The three lag class intervals are necessary (instead of looking at just one active lag distance and lag class interval), because the data were not collected at consistently equal intervals (See Figure 9) as the site was sampled differently in the Northern and in the southern side. The first lag distance/lag class represents the first “mean separation distance" and the shortest maximum separation distance. The second represents an overall average of separation distances, while the third represents the second peak in separation distances. The variable partitioning ensures that fine-scale variations are not missed while looking at the broader scales. A second spatial structure analysis was performed on just the seedlings in the Northern side of the Gap where sampling was every 50m, and on the Southern side where an average separation distance of 25m was used.

When there is spatial autocorrelation in the data, the ideal semivariogram will have an asymptotic curve. This means that the variance increases as separation distance increases, then stops increasing and plateaus. The point at which the variance stops increasing is the "range" of the data: it is the distance where your observations are no longer spatially autocorrelated. All the calculations for spatial autocorrelation in this analysis were performed using the software GS+.

4.2.2. Physical factors and seedling distribution

Distance from forest edge: Using GPS-recorded coordinates, distance from the nearest forest edge was calculated for each sampling circle. I segment the seedling data into four distance-from-edge bins: 0-100m, 100-200m, 200-300m and 300-400m. Using all observed seedlings, I normalize the seedling count by the sampling effort at each distance interval, and call the resulting ratio "seedling incidence." I perform a one-way ANOVA to test whether distance from forest edge has an effect on species abundance. I consider the incidence of seedlings given distance from forest edge in the human-managed Southern side vs the Northern side of the Gap; as well as the distribution of just the naturally regenerating seedlings (ie, removing human-planted species from the dataset).

Historical Land Cover: Aerial photographs detailing pre-satellite land cover were obtained from a national archive of aerial photographs in Dar-es-Salaam, Tanzania. Four timesteps (1949, 1969, 1975 and 1985) of the study site were available. All scenes were georeferenced in QGIS, with Google Earth as a reference layer, and WGS 1984 Pseudo-Mercator as the projection. At least ten ground-control points were selected for each scene. Thin Plate Spline transformation was used (Table 9). The referencing paid particular attention to alignment of forest edges and the extent of the Gap.

The sampling circles from the field data were overlaid on the earliest (1949) geo-referenced image that showed highest land cover contrast to present day forest extent. A binary category ("FOREST/NON-FOREST") was manually assigned to each sampling circle by visual interpretation of the aerial photograph. The categorical variable is also used later in an integrated general linear model that looks at which factor is the best predictor of regenerants distribution.

Herbaceous Cover: I relate the number of seedlings found at the location with the height of grass at the point of observation. The herbaceous cover is expected to be a good predictor of tree seedlings presence/absence, as it has been shown to outcompete tree seedlings in an analogous eco-region (Chapman & Chapman, 1999).

4.2.3. Human use factors vs. seedling species abundance

Length of fallow: The length of fallow for each plot was determined by subtracting the year at the time of interview from the date when the farmer reported having stopped working the land for annual cropping. If the farmer planted the plot with trees recently (ie, the past five years) even if the plot had been fallowed for decades, the fallow length is recorded as time since trees were planted. If a plot goes from fallow to tree-farmed, it gets cleared of the existing vegetation first. The time elapsed since trees were planted allows for capturing the duration that both natural and planted seedlings have had to establish in the people-use areas.

Current Land Use: Current land use for the entire study site can be divided into two broad classes: unoccupied (northern section) and managed by smallholders (southern section). The latter category, human use, is sub-divided into annual/active farm, tree farm and fallow plot. Some plots have a mix of any of the two, considered as unique categories while creating categorical variables. The land use categories were noted during landowner interviews, and confirmed at the farm during plot surveys. Interaction between land use and other non-seedlings outcomes, eg: grass cover is explored.

4.2.4. Integrating data from unoccupied and managed land within the gap

Table 8 summarizes the variables from literature and explored above, and their expected effect on tree seedling abundance (natural and exotic species) and seedling species diversity. Some of the variables co-vary over space, and thus are expected to have high correlation. Thus, first, collinearity among the predictor variables is calculated. Based on its results, the number of predictors is reduced, and a General Linear Model used to detect variable importance in explaining observed seedlings distributions, using the sampling circles as the unit of analysis.

5. RESULTS

5.1. Field Data Summary

Transect Results: A total of 401 sampling circles were recorded, representing 0.04% of the study site, along 9040 meters of transects. Of these, 111 sampling circles lay in the

Northern portion of the site, and 290 in the Southern use side. Of the 401 observations, nearly half (i.e, 190 sampling circles) had no tree seedlings. The proportion of null observations is higher in the unoccupied section of the Gap than in the managed section (63% vs 41% respectively). Overall, a total of 589 seedlings were encountered, representing 32 species, 28 native and 4 exotics. In the Northern, unoccupied section, 140 seedlings were encountered, representing 13 species, while in the Southern, managed section; the seedling count was 449 representing 28 species. *Morella salicifolia* subsp *kilimandscharica* was the most frequent species overall and in the Southern section. *Maesa lanceolata* was the most frequently encountered species in the Northern section (See Table 10).

The seedlings represent a wide range of ecological and human use characteristics. *Garcinia kingaensis, Aphloia theiformis* and *Ilex mitis* are species commonly found in Kipunji habitat. Some seedlings are of fruit-bearing trees that are found in kipunji diet (e.g *Bridelia micrantha, Parinari excelsa, Myrianthus holstii* and *Ficus sur*). *Maesa lanceolata* and *Agarista salicifolia* are fast-growing species found in both forest and woodlands, while *Hagenia abyssinica* and *Podocarpus latifolius* are slow-growing species, protected by Tanzanian forestry code due to their importance and scarcity. About 18% of all seedlings tallied were planted exotic species that are important for firewood, timber and fruit production needs. See summary in Appendix 2 for ecological and human use of each encountered seedling species.

Interview results: Of the 92 respondents, 50% are children of those who first cleared plots in the Gap. Many remember working the land with their parents and have since inherited the plot. 37% of the respondents were elderly individuals who performed the initial plot clearing. A minority (14% of the farmers) purchased the plot in the past 10 years. Most of the initial farm clearings were reported to have taken place before 1980 (59 responses) with a peak in clearing in the late 1960s (35 respondents.) (n=92). Part of the farm clearing in the Gap is attributed to creation of collective farms: a historically famous Tanzanian government villagization initiative. One respondent, who was among the collective farmers of the era, even had a roster of individuals who worked the plots in 1973. (See picture in Figure 10)

5.2. Data Analysis Results

5.2.1. Is there any spatial autocorrelation in the data?

Semivariogram analysis over the entire sample (401 observation locations) showed minimal spatial correlation for the seedlings count across the entire Gap ($R^2 = 0.21$). The low correlation held even when the lag intervals were varied (see Table 11). The correlations remained low when the data were partitioned by Southern, managed land samples ($R^2 = 0.215$) and Northern, unoccupied samples ($R^2 = 0.44$). The spatial correlation was slightly higher for species count (Overall: $R^2 = 0.46$, Unoccupied: $R^2 = 0.56$ and Managed $R^2 = 0.25$). High spatial autocorrelation would mean that closer observation was similar enough to be non-independent, but these low correlation values between observations suggest that our sampling circles are sufficiently independent to proceed with standard statistical analyses.

It is possible that the spatial correlation is low since the dataset has a high proportion of "NULL" observations (NULL = 190 of 401). This potentially weakens the correlation between samples, as one is likely to encounter no seedlings about half of the time. Given the low correlation between the observations, it suggests that near observations are not so unlike each other that they are independent, thus it is appropriate to conduct traditional statistical analysis.

5.2.2. Physical factors and regeneration

Distance from forest edge & seedling distribution The gap is narrower at the Northern end (width range 250m to 550m) than at the Southern end (width range 430m to 800m), which means the furthest any sampling circle location can be from the forest edge is at most half the width of the gap (ie, no more than 400m). To account for the variation in width when looking at seedlings encounter by distance from forest edge, I normalize the number of seedlings observed by the sampling effort at various distance intervals from the forest edge. Overall, the highest encounter of seedlings is within 50m of the forest edge in managed (Southern) section of the gap (2.4 seedlings per observation), followed closely by the 50m – 100m interval in the unoccupied side of the Gap (2.3 seedlings per observation, see Table 12). This difference is confirmed by a significance test, where seedling abundance in at 100-200m from the forest edge is from 0-100m, ($p = 0.08$) but the seedling abundance values at 200-300m and at 300-400m are significantly different from 0-100m. ($p = 0.001$ and $p = 2.14E-07$ respectively.) Once human-planted seedlings (pine, eucalyptus, cypress and avocado) are removed from the sample, the unoccupied side had the leading regenerants incidence, at the 50m-100m distance interval, but the human use side still has greater overall seedlings encounter.

Naturally occurring seedlings are more abundant closer to the forest edge for both sections (Figure 11). In the unoccupied section, seedling encounters decay to 0 beyond 200m from the forest edge, even though sampling circles were recorded up to 350m away from the edge. For the human use side, conversely, natural seedlings are encountered at all distance intervals, even though there is a strong decay in the encounter rate after 100m from the forest edge (see Figure 11). The decay of seedling incidence with distance from the edge is weaker if planted seedlings are included (Figure 12). See Appendix 3 for a detailed distribution of species and distance from forest edge.

Historical Land Cover: A section of forest measuring 170 Ha was lost in the southern, human use side of the Gap between 1949 and 1969. After that initial loss, the extent of forest has surprisingly confirmed to present-day edges (See Appendix 4 for extent of forest edge compared to present-day at the four time-steps.)

From the historical aerial photograph from 1949, 169 sampling circles were assigned to "No Forest" category, while 232 were assigned to "Forest" category. The outcomes are spatially clustered: 89% of the "Forest" category from 1949 is categorized as human land use (South Gap) while 62% of the "No Forest" category are located in the Northern portion of the gap.

Herbaceous Cover: Both sides of the gap contained tall grass locally called *lusanje* and identified by on-site researchers as *Hyparrhenia rufa*. The Northern portion and fallow plots with the managed section had the tallest grass (mean height: 1.8m, max 6.5m, min .5m), while active farms and active farms with nascent planted trees had the shortest grass (mean height: 0.3 m, max .5 m, min 0 m), (Figure 13). In general, shorter grass favors seedling presence and abundance, though tree seedlings are occasionally found even in above-average height grass. Appendix 5 shows scatter-plot distributions of grass height and natural seedlings abundance.

5.2.3. Human land use and seedling distribution

Length of fallow: The fallow dates in the Southern, managed section of the Gap are self-reported estimates, therefore prone to recall biases (eg, the values tend to favor mid-decade or end of decade dates, or include an approximation qualifier). In general, plots have been fallowed for an average of 15 years (maximum = 42 yrs, min = 0). The fallow years and durations for 8 plots were unknown, while 13 plots were reported as never fallowed. The rest of the dataset – about half, (202 sampling circles) had no fallow length information.

Current Land Use: Mixed land uses at plots such as active farm and tree farm or active farm and fallow were common. Areas with mixed annual crop farming and tree crop farming logically have the shortest grass, since mixed crop and tree farming only occurs when the trees are of a very young age before they can shade crops. There the farmer works to clear grass around the small trees. Fallow areas have the widest range of grass heights, potentially related to the length of time the plot had been under fallow.

5.2.4. Predicting seedling distribution in the study site

The cross-correlation matrix among the variables (Table 13) shows some collinearity especially for broad-scale factors that vary along the north vs south axis. For example, the North vs South predictor and presence of forest in 1949 have a significant negative correlation (-0.45). This makes some intuitive sense since the current "south" region of the study site where human land use takes place is where most of the 1949 forests existed. The next strong and significant correlation, which is expected, is between the grass height and length of fallow (0.37).

Based on the correlation matrix, a General Linear Model of the physical factors (distance from forest edge, grass height and proximity to forest) was constructed. All three factors are significant predictors of seedling counts. However, the residual variance in the model is much larger than the degrees of freedom, suggesting an overly dispersed model. Given that the seedlings data is based on "counts" and that about half of the observations were zeroes, I fit a zero-inflated Poisson model to account for the overdispersion in the data.

The zero-inflated model does not have the overdispersion problem observed in the GLM. It also provides different significance results: Proximity to large trees and distance to forest edge are significant predictors of non-zero seedlings counts, while grass height is a significant predictor for zero seedlings counts. Holding other variables constant, proximity to a large tree increases the odds of encountering seedlings (Odds ratio = 1.42), while increasing the distance from forest edge reduces chances of encountering a seedling (Odds ratio = 0.21). A unit increase in grass height has a slightly stronger prediction of seedlings absence, where it increases the chances of a null observation by 1.6 times (See Table 14).

When only natural seedlings are considered, presence of grass reduces the odds of encountering seedlings (odds ratio = 1.55). Though the distance from forest edge is still a significant predictor for both the positive and the zero encounters, it doesn't seem to affect the odds of finding natural seedlings (odd ratio = 1, See Table 15).

The human use factors are considered one variable at a time for North vs South, length of fallow, and land use category. If a sampling circle is located in the North (ie uncultivated) portion of the gap, its odds of having *no* tree seedlings increase significantly. (Odds ratio = 2.89, see Table 15) The length of fallow seems to have no statistically significant effect on seedlings distribution. Categories of land use have a significant effect on tree seedlings presence, with a mix of tree farming and fallowed land strongly increasing the odds of encountering natural tree seedlings (Odds ratio = 4.4).

6. DISCUSSION

Limitations: The site layout, with the Gap's narrow East-West bounds and the stark contrast between the North and the South section management regimes limits sampling design and data analysis. For example: the E-W forest edge bounds means that the sampled circles simply run out of space after 250m in the Northern edge of the gap, making it seem like the sampling effort sharply decayed with distance from forest edge. Given that vegetation in the southern end of the gap was sampled at a plot-level in order to facilitate linking with interview data, it produced results that were not as evenly spaced as the Northern Gap. It also clustered the surveyed plots, even though a robust representation of the study site was obtained. Mixed land uses are a strong feature of the southern Gap, while the Northern Gap is fairly homogeneous. It is common for individuals to devote one part of the plot to tree planting, and another to food cultivation, or to mix food cultivation in with tree planting. This presented a challenge for categorizing land use: If a plot has nascent pine trees, but also has potatoes in between the pine rows, is it a food crop plot or a tree-planting plot? An intermediate solution was to introduce mixed categories; though this greatly reduced the predictive power of land use on seedling observations.

Sporadic fires, set by farmers in their own plot in the southern Gap, occasionally make it to the northern Gap. The study did not manage to collect systematic fire record. This is a significant limitation, as fire regimes are important factors in grass ecology and can play a role in limiting regeneration.

Findings

Proximity to a tree predicts seedling presence: My findings accord with literature on tropical regeneration which reveal the role of trees for attracting dispersers, and latering the micro-climate around the tree to favor seedling growth (Holl, 2002). In Bujingijila, this may potentially function as shading out of *Hyparrhenia rufa,* allowing the seedlings to grow better. It is also possible that the adult trees may be just propagating their own seeds nearby, a correlation test between seedling and mature tree will be necessary for determining this relationship. This insight provides actionable guideline for reforestation activities, where planting seedlings close to existing trees may increase their survival chance.

Lots of seedlings in human use section of the Gap, including natural seedlings: Even though the human land uses are varied, more seedlings were encountered in the managed, southern section than in the unoccupied section. This is also true for naturally regenerating seedlings. Naturally regenerating seedlings were found in most land uses, even existing pine woodlots and mixed-use active farms. Pine plantations have been shown to support natural vegetation in tropical sites (Chapman & Chapman, 1996; Chazdon et al., 2009) the only problem being the damage to seedlings during tree harvesting. This finding suggests a possibility for integrating indigenous tree planting into an already ongoing wave of tree woodlot development. Such suggestions for reforestation have been made at other tropical sites (Barbosa et al., 2009; Rodrigues et al., 2011). There may be limited support for integrating softwood woodlots and forest regeneration, given ongoing efforts to remove pine trees from areas inside adjourning forests.

More active management of the Northern area could potentially hasten regeneration. Use of agro-successional restoration has been proposed for the early phase of forest succession (Vieira et al., 2009). By combining human use and restoration, the researchers foresee a reduced cost to both people and conservation, and increased engagement of communities near conservation areas in conservation activities (Aronson et al., 2010)

7. CONCLUSION

Edge dynamics are important for forest connectivity, but at East African forest edges, human land uses and natural regeneration processes interact. Even though these forest edges tend to have a sharp transition between forest and non-forest habitat, and are driven by complex human management, they still present opportunities for conservation. A few studies have identified cases where these farms get abandoned (Chapman & Chapman, 1999; Naughton-Treves, 1998). Knowing how they would reforest is important, as some regions can be passively afforested, while others require intensive intervention and management. Understanding the interactions between human land use outcomes and patterns of forest regeneration enhances conservation management.

This chapter provided site-specific information that would guide intervention at Bujingijila Gap. It showed that distance from the forest edge and grass height significantly reduced natural seedling presence. To improve lateral connectivity for the kipunji, effort needs to be focused on distances further from the forest edge. If appropriate, suppression of *Hyparrhenia rufa* may be necessary. Proximity to large trees (DBH > 20 cm), on the other hand, improves natural seedlings survival. These results accord with studies of ‘suppressed’ generation adjacent to mid-elevation forest elsewhere in E. Africa, and suggest that human management (tree planting, herbaceous cover suppression) will be necessary to create arboreal corridors. The presence of seedlings in human-utilized land provides opportunities for a community-based afforestation program that incorporates ongoing tree-planting trends (Ch 1) with assisted natural forest regeneration.

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9. TABLES AND FIGURES

Table 8: Factors limiting forest regeneration across regions and hypothesized relationship for seedling abundance at study site.

Factor	Citation; Location	Variable in this study (Expected relationship to seedling distribution)
Seed dispersal		
Wind	Chapman & Chapman, 1999; Uganda	
Frugivores	Fink et al 2009; Costa Rica	Distance from forest edge (↓)
Proximity to source	Holl, 2002; Costa Rica	
Seed germination		
Soil, water, micronutrients	Holl, 1999; Costa Rica	
Predation		
Seed	Chapman & Chapman, 1999; Uganda	
Seedling		
Competition		
Shrubs	Chapman & Chapman, 1999; Uganda	Height of grass (↓)
Grass	De Souza & Batista, 2004; Brazil	Proximity to large trees (--)
	Zimmerman et al 2000; Puerto Rico	
Current Land use		
Agroforestry	Chapman & Chapman, 1996;Uganda	Active farms (↓)
	Holl et. al, 2011;Costa Rica	Woodlots (--)
	Lamb, 1998; NA	Fallow (↑)
	Rodrigues et al 2011; Brazil	
Land use history		
Mechanized	Chapman & Chapman, 1999;Uganda	Length of fallow (↑)
Agriculture	Moran et al 2000; Brazil	Legacy forest cover (↑)
Shifting Cultivation	Rodrigues et al 2011;Brazil	

↑ or↓should be interpreted as directly proportional or inversely proportional respectively. For the categorical variables, ↑ or↓ means that the values are expected to be higher or lower for the category, respectively. Variables whose relationships are uncertain in the literature are indicated as (--).

Table 9: Georeferenced historical aerial photographs of the study site

Aerial Photo	Scale	Ground-Control Points	Transformation	Mean RMSE
SHEET 259 YR.1949 FILM 82A-294 EXP.5017	1:44,000	10	Thin Plate Spline	3.139 E-08
SHEET 259 YR.1949 FILM 82A-294 EXP.5018	1:44,000	11	Thin Plate Spline	1.284 E-07
SHEET 259 YR.1949 FILM 82A-294 EXP.5019	1:44,000	10	Thin Plate Spline	3.216 E-08
SHEET 259 YR.1949 FILM 82D-612 EXP.5004	1:22,000	10	Thin Plate Spline	1.102 E-07
SHEET 259 YR.1949 FILM 82D-612 EXP.5005	1:22,000	10	Thin Plate Spline	1.130 E -04
SHEET 259 YR.1949 FILM 82D-612 EXP.5006	1:22,000	7	Thin Plate Spline	2.066 E-07
SHEET 259 YR.1969 ROLL 13 LINE 2 EXP. 48	1:68,000	10	Thin Plate Spline	4.431 E-08
SHEET 259 YR.1969 ROLL 13 LINE 2 EXP. 49	1:68,000	10	Thin Plate Spline	2.588 E -09
SHEET 259 YR.1969 ROLL 13 LINE 3 EXP. 84	1:68,000	10	Thin Plate Spline	1.311 E -07
SHEET 259 YR.1976 FILM 1829 LINE 73 EXP.24	1:50,000	12	Thin Plate Spline	4.242 E -08
SHEET 259 YR.1976 FILM 1829 LINE 73 EXP.25	1:50,000	11	Thin Plate Spline	1.819 E -06
SHEET 259 YR.1976 FILM 1829 LINE 73 EXP.35	1:50,000	15	Thin Plate Spline	1.660 E -07
SHEET 259 YR.1976 FILM 1829 LINE 73 EXP.36	1:50,000	11	Thin Plate Spline	7.282 E -08
SHEET 259 YR.1985 FILM 3 LINE 4 EXP.6631	1:25,000	10	Thin Plate Spline	1.840 E -07
SHEET 259 YR.1985 FILM 3 LINE 4 EXP.6632	1:25,000	11	Thin Plate Spline	9.097 E -08
SHEET 259 YR.1985 FILM 3 LINE 4 EXP.6633	1:25,000	11	Thin Plate Spline	1.377 E -07
SHEET 259 YR.1985 FILM 3 LINE 5 EXP.6628	1:25,000	11	Thin Plate Spline	3.115 E -07
SHEET 259 YR.1985 FILM 3 LINE 5 EXP.6629	1:25,000	20	Thin Plate Spline	2.688 E -08

Table 10: Sampling effort and general data collected

	Number of Sampling Circles	Number of Empty Sampling Circles	Total Number of Seedlings	Number of Species	Total Number of Natural Seedlings	Top Three Seedling Species
Overall	401	190	589	32	484	1.*Morella salicifolia* subsp *kilimandscharica;* *2.Maesa lanceolata;* *3.Pinus patula*
North Gap (Uncultivated)	111	70	140	13	140	*1.Maesa lanceolata;* *2.Myrsine melanophloeos;* 3.*Morella salicifolia* subsp *kilimandscharica;*
South Gap (Human Use)	290	120	449	28	344	1.*Morella salicifolia* subsp *kilimandscharica;* *2.Pinus patula;* *3. Maesa lanceolata*

Table 11: Variation in spatial structure for seedlings count and species data

Sample	Active lag distance (m)	Lag Class interval (m)	Model	Nugget	Sill	Range (m)	R^2	Proportion Structural Variance (C/C_0+C)
Overall seedling count (n = 401)	200	15	Spherical	0.09	2.12	42	0.58	0.96
	720	34	Exponential	0.46	2.39	102	0.37	0.81
	1000	50	Spherical	0.11	5.57	73	0.21	0.98
	1500	45	Exponential	0.18	2.16	48	0.03	0.92
Overall species count (n = 401)	1000	50	Exponential	0.65	1.29	651	0.46	0.50
Uncultivated seedling count (n = 111)	600	40	Spherical	3.6	12.6	196	0.44	0.70
Uncultivated Species (n = 111)	756.45	50.43	Exponential	0.53	1.33	372	0.56	0.60
Human use seedling count (n = 290)	400	25	Spherical	0.01	3.87	35	0.22	0.99
Human use species count (n = 290)	1800	75	Exponential	0.61	1.22	525	0.25	0.5

Table 12: Distance-based seedlings distribution (Southern, Human use Gap vs. Northern, uncultivated Gap)

Distance Bin	Southern: Human Use					Northern: Uncultivated				
	No. Obs	NULL Count	Total No Seedlings	Species Count	Avg Sdln/Obs	No. Obs	NULL Count	Total No Seedlings	Species Count	Avg Sdln/ Obs
0-50	56	12	133	23	2.4	28	19	26	7	0.9
50-100	53	20	109	15	2.1	27	17	63	8	2.3
100-150	46	12	86	15	1.9	25	13	32	5	1.3
150-200	40	23	39	9	1.0	21	11	19	9	0.9
200-250	28	13	35	5	1.3	7	7	0	0	0.0
250-300	22	11	20	2	0.9	3	3	0	0	0.0
300-350	31	19	17	4	0.5	NA	0	NA	0	NA
350-400	15	10	10	7	0.7	NA	0	NA	0	NA
Sum	290	120			111	111	70			
Proport.		0.41					0.63			

Table 13: Correlation matrix for the seedlings count predictors

	Distance to Edge	Grass Height	Near Tree (Less 5M)	Forest Cover in 1949	Seedling Count
Grass Height	0.01				
Near Tree (Less 5M)	-0.25***	-0.05			
Forest Cover in 1949	-0.27***	-0.29***	0.1		
Seedling Count	-0.22***	-0.10*	0.16**	0.18***	
North/South	-0.23***	0.24***	-0.03	-0.45***	-0.05
Fallow Length	-0.02	0.37***	-0.06	-0.28***	-0.11

Table 14: Odds ratios for the occurrence of tree seedlings for physiographic factors

	ALL SEEDLINGS		NATURALLY OCCURING SEEDLINGS	
	Count Model	Zero Model	Count Model	Zero Model
Grass Height	0.97	1.6***	0.99	1.44***
Near Tree <5M	1.42***	1.06	1.55***	1
Distance to Forest Edge	0.21***	1	1***	1**
Log-Likelihood (DF)		-663(8)		-571(8)

Table 15: Odds ratios for the occurrence of tree seedlings given human land use predictors

	ALL SEEDLINGS		NATURALLY OCCURING SEEDLINGS	
	COUNT MODEL	ZERO MODEL	COUNT MODEL	ZERO MODEL
Land Use Category				
Active Farm / Tree Farm	2.6*	0.20*	2.25.	0.19*
Fallow Area	2.7*	0.64	2.05	0.33•
Fallow Area/Tree Farm	6.1***	0.53	4.4**	0.27
Uncultivated	3.8**	1.04	2.9*	0.54
Tree Farm	2.8*	0.12**	2.03	0.08***
Log Likelihood (DF)	-717(12)		-629.9(12)	
Length of Fallow	0.99•	1.01	0.99	1
Log Likelihood (DF)		-387(4)		-326.7(4)
Uncultivated VS Human Use	1.36**	2.89***	1.38**	2.19**
Log Likelihood (DF)	-750(4)		-655(4)	

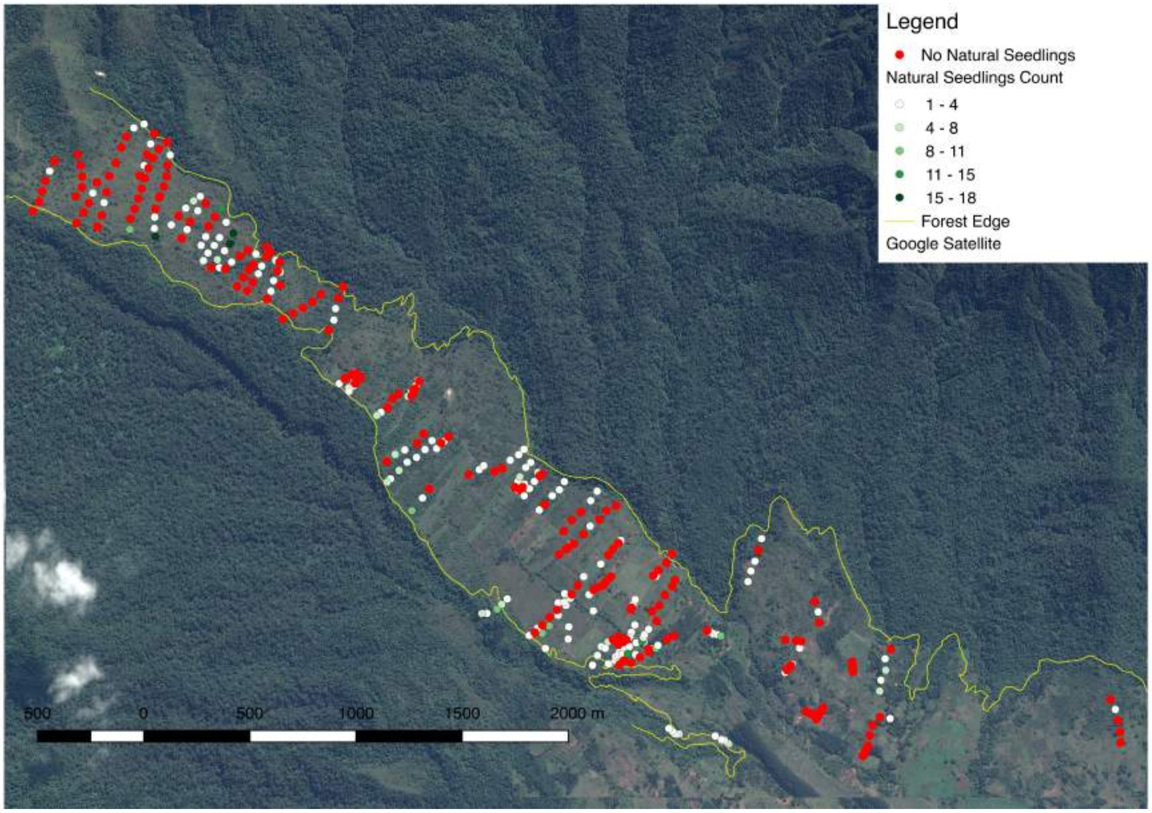


Figure 8: Map of sampling effort and natural seedling encounter distribution

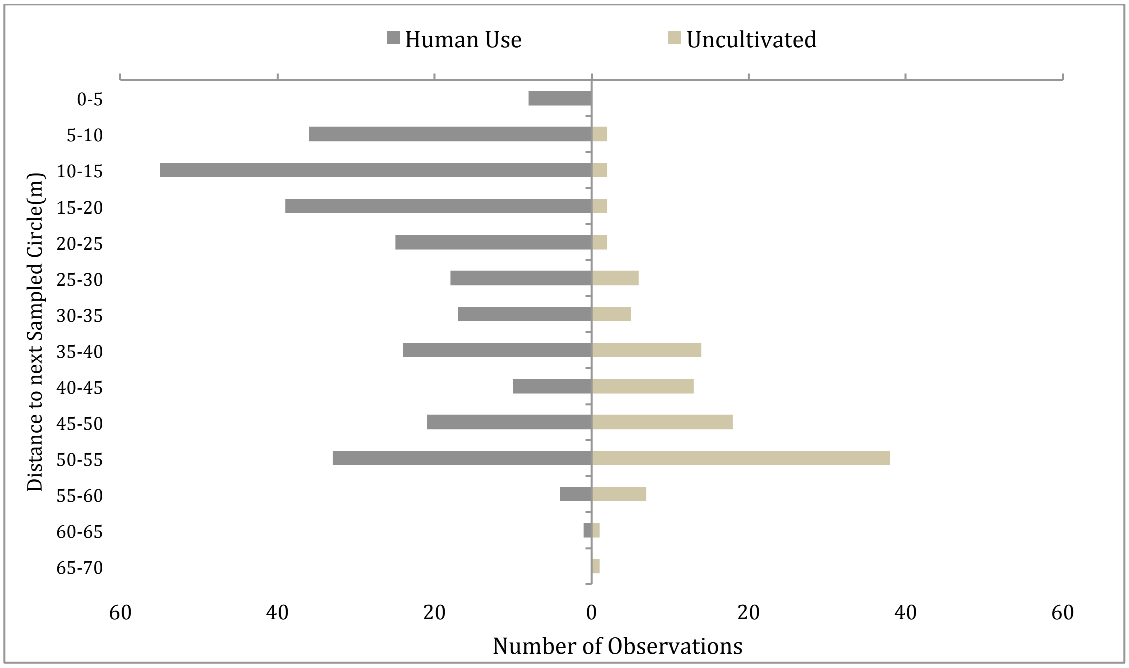
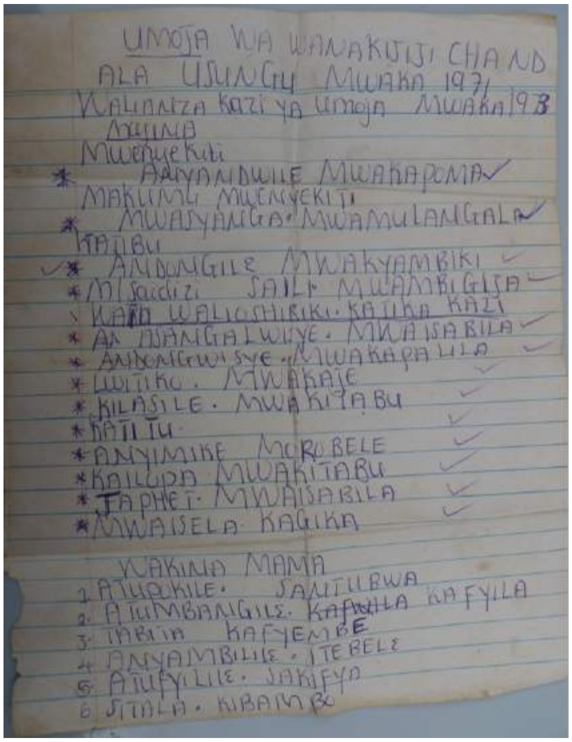


Figure 9: Variation in spacing between sampled circles



UMOJA WA WANAKIJIJI CHANDALA USUNGU MWAKA 1971
WALIANZA KAZI YA UMOJA MWAKA 1973
MAJINA
Mwenyekiti
* AANYANDWILE MWAKAPOMA ✓
MAKAMU MWENYEKITI
* MWASYANGA. MWAMULANGALA ✓
KATIBU
✓* ANDUNGILE MWAKYAMBIKI ✓
* M/Saidizi SAILI MWAMBIGIJA ✓
KAYA WALIOSHIRIKI. KATIKA KAZI
* ANANGALWIYE. MWAISABILA ✓
* ANDONGWISYE. MWAKAPALILA ✓
* LWITIKO. MWAKAJE ✓
* KILASILE. MWAKITABU ✓
* KATITU ✓
* ANYIMIKE MORUBELE ✓
* KAILOPA MWAKITABU ✓
* JAPHET. MWAISABILA ✓
* MWAISELA KAGIKA

WAKINA MAMA
1 ATUPAKILE. SANTULBWA
2. ATUMBANGILE. KAPWILA KAFYILA
3. TABITA KAFYEMBE
4 ANYAMBILILE. ITEBELE
5 ATUFYILILE. SAKIFYA
6 SITALA. KIBAMBO

Figure 10: Picture of collective farmers roster from 1973

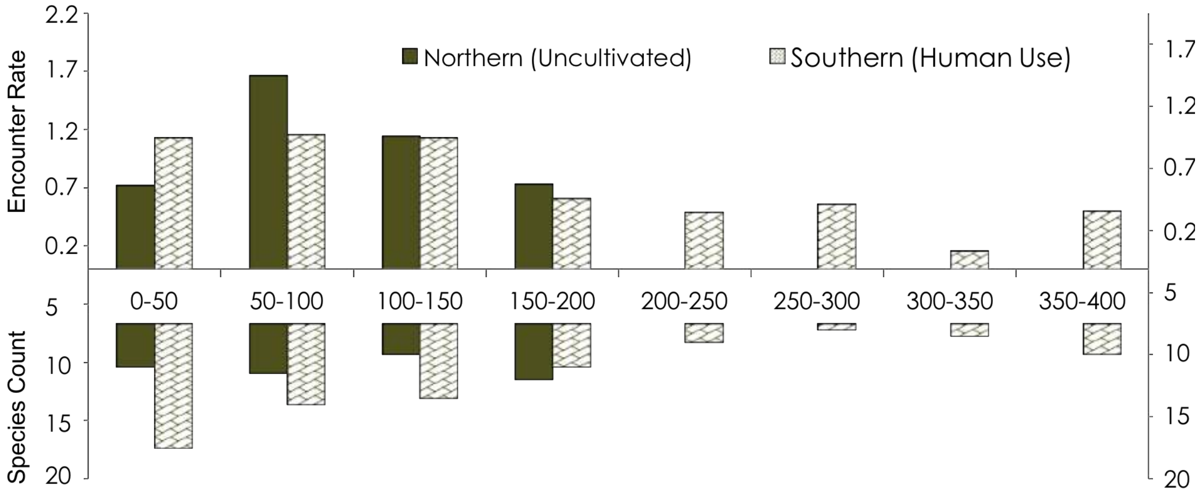


Figure 11: Chart of seedlings encountered/sampling circle and count of species encountered

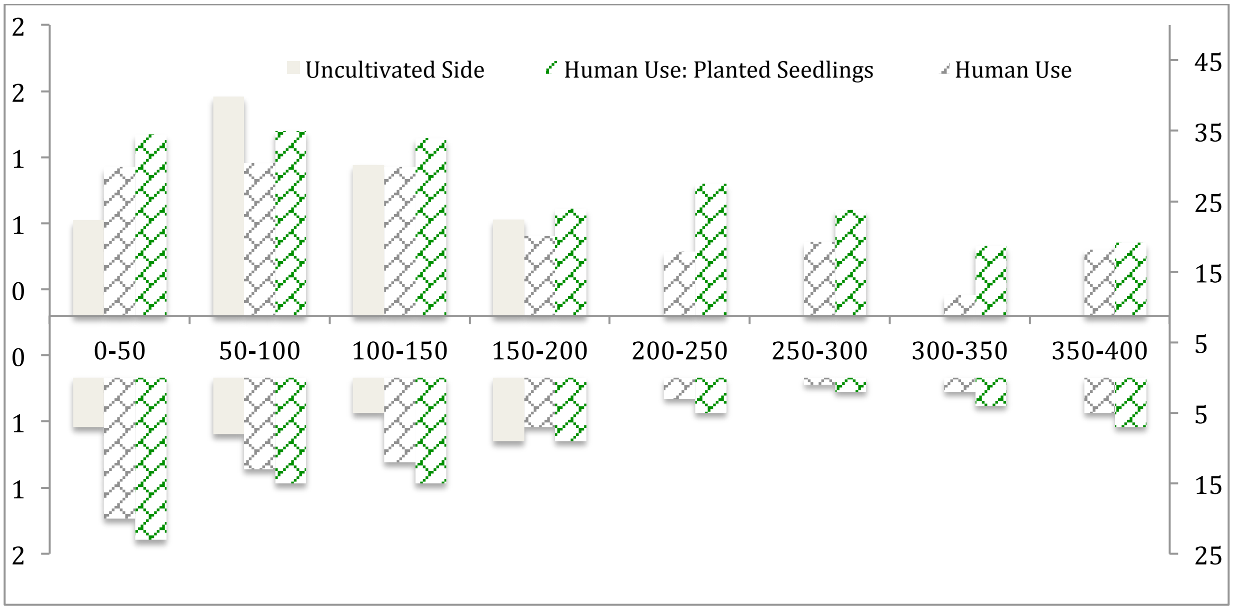


Figure 12: Patterns of seedlings distribution when human-planted trees are included

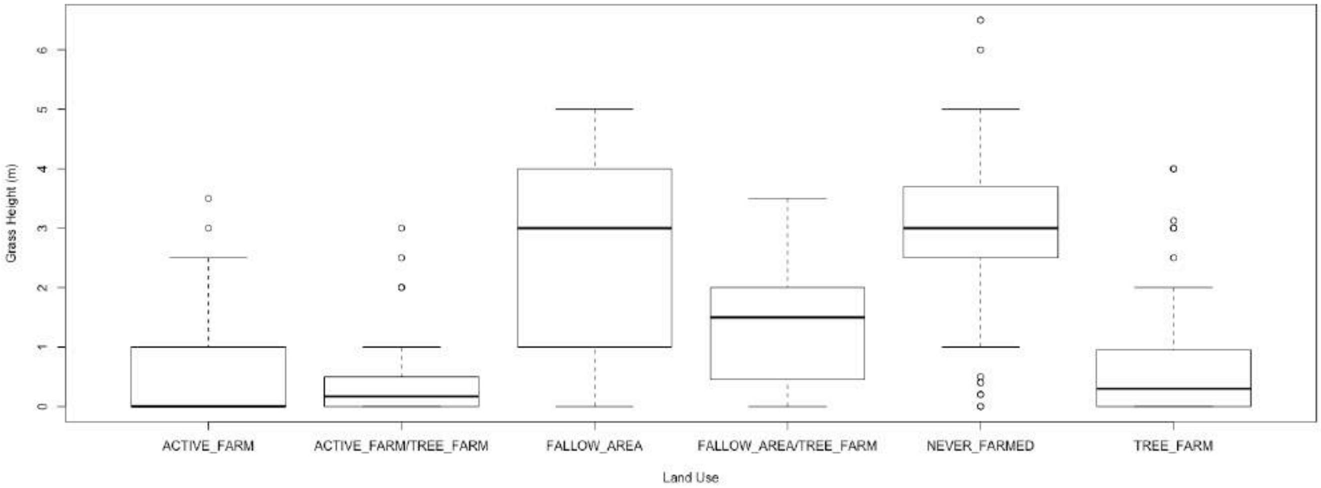


Figure 13: Variation in grass height by land use

APPENDIX 1: INTERVIEW INSTRUMENT

1: DETAILED INTERVIEW ON BUJINGIJILA PLOT

1. Geometry outline code	
2. Waypoint at mid-point	

1B: PLOT OWNERSHIP

3. Is the interviewee the plot owner: YES NO

4. Current owner code	
5. Home village of owner	

6. Do you have any document indicating your ownership?	
1	Village office statement
2	Sales transaction note
3	Note of inheritance
4	No document: common knowledge in the village
5	Other:_______________

7. Size of plot	
7a. Heka	
7b. Paces width	
7c. Paces length	
7d. GPS-Measured Area	

1C: PLANS ON PLOT USE

8. What are you going to do on the plot this rainy season?

9. How about next year, or the year after that?

1A:GEO-REF INFORMATION

11. Was the plot cultivated in that rain season? YES NO

12. Is the interviewee the one who cultivated the plot? YES NO

13. Current user code	
14. Home village of user	

15. What was cultivated on the plot? ________, ________, ________

16. Is that what is normally cultivated on that plot? YES NO

17. What is the relationship between the person who cultivated the plot (plot user) and the plot owner?	
1	No one cultivated the plot
2	The plot owner is the one cultivating the plot
3	The plot user is a member of the family (son/daughter/extended)
4	The plot user is squatting the plot
5	The plot user has been given the farm for free
6	The plot user is renting the plot Cost of renting________________

18. How much (Name crop) was harvested? ____________

19. How much did you sell vs consume ____________

1E: QUESTIONS ON BUJNG PLOT ACQUISITION AND TRANSACTIONS

20. How plot was acquired	
20a. Purchase price	

the past? YES NO	

21. What was the vegetation on the plot like when first acquired?

22. When did you clear the farm for the first time ____________

23. What was the vegetation like when you cleared it?

24. Number of years owning ______ 25. Cultivating _________

1F: QUESTIONS ON FALLOWING IN BUJINGIJILA PLOT

26. When is the last time you cultivated the Bujingijila plot?

27. What are some of the reasons you have left it uncultivated?
____
____
____

28. If you leave your farm uncultivated for several years, might any of the following things happen? (circle all that apply)	
1	The village office will give it or sell it to someone else
2	Someone else will start to farm on it, without asking you or the village office
3	Someone would want to buy it
4	Own child will start to farm it
5	Someone else will ask if they can farm on it
6	It will be considered part of TANAPA

1G: REMITTANCE, WEALTH, SOME HOUSEHOLD STATUS

29. Do you conduct any activity such as timber cutting, selling local brew, working on other people's farms, etc? YES NO

30. List some activities __________, _____________, __________

31a. Does anyone in your family conduct such activities? YES NO
31b.Since when? ___________

32. What do they normally spend the cash on?

33a. Do you have a tea plot? YES NO
33b.What do you normally spend the income from tea on?

34. Do you sometimes pay someone else to prepare your farm, or assist with weeding and harvesting? YES NO

35. Do any of your neighbors have plots in several different locations, apart from their homestead? YES NO DON'T KNOW

36. Describe the location of some of the plots for two neighbors

36a.Neighbor 1	36b.Neighbor 2

37. Does your plot have pine, eucalyptus, cypress or avocado?

38a. Planting date(s) ____________ 38b. No of trees(each) __,__,__,__

39. Do you use or own any other plots? YES NO

2: QUESTIONS ON OVERALL FARM OWNERSHIP & USE FOR EACH INTERVIEWEE

Exclude Bujingijila plot

1.Name of the farm **(list out all the farms first before asking about details)**	2.Description of its location relative to TANAPA, RNR **(Star Homestead plot.)**	3.Estimate size of farm (heka: 70X70 paces)	4.GPS track code (from ecol transect)	5a.How was the farm used in the previous session Farmed---1 Rented out----2 Rented in----3 Given to someone for free----4 Fallowed-- 5 Forest --- 6 Sold ---- 7 Other --- 8 5b.(if 'Other' describe)	6.What was the main crop planted in the farm the past rain season?	7.Has the plot been fallowed recently? Y --- 1 N---- 2	8.How many years was the farm fallowed? 8a.Start yr 8b.End yr)	9.Does this plot have Pine-1 Avocado-2 Eucalyptus-3 Cypress-4 Tea--5	10.How many of each do you have **(indicate species + number of plants)**	11a.Do the trees cover the whole plot? Y/N 11b.What fraction? 11c.Are they intercropped? Y/N	12a.Do you apply manure on this plot? YES NO 12b.Fertilizer? YES NO	13.What is the landscape position of this farm? Low-lying& flat --- 1 Flat, on high ground---- 2 Somewhat steep ----3 Very steep --- 4	14a.Sales Rank 14b.Possible sale price

15. Further Notes & comments on interview ____

____

____

____

____

3: OPEN-ENDED QUESTIONS ON WILDLIFE, CROP RAIDING AND TREE PLANTING DECISIONS

1.When did you last DIRECTLY see a:

Y/N	1a.SPECIES	1b.APPROX DATE (MM/YYYY)	1c.APPROX LOCATION
	1a1. Moloney's Monkey		
	1a2.Colobus Monkey		
	1a3.Kipunji		
	1a4.Wild pig		
	1a5.Blue duiker		
	1a6.Hyena		
	1a7.Mongoose		
	1a8.Abbott's Duiker		
	1a9.Serval cat		
	1a10.Genet		

2. Have you recently seen a SIGN of a:

Y/N	2a.SPECIES	2b.APPROX DATE (MM/YYYY)	2c.APPROX LOCATION	2d.SIGN
	2a1. Moloney's Monkey			
	2a2.Colobus Monkey			
	2a3.Kipunji			
	2a4.Wild pig			
	2a5.Blue duiker			
	2a6.Hyena			
	2a7.Mongoose			
	2a8.Abbott's Duiker			
	2a9.Serval cat			
	2a10.Genet			

3. Why did you plant `(name tree)` on `(name plot)`

4. Why did you not plant those trees on `(name other plots)`

5. Under what circumstances would you plant trees in those plots?

6. Has your Bujingijila plot experienced crop raiding? YES NO

7a. On what crop(s) ______________

7b. By what species ______________

8. What did you do about it?

9. If you stop cultivation in Bujingijila, what kinds of plant grow?

10a. Ecological Transect Filled for Bujingijila plot? YES NO

10b.Shrubs: PRESENT ABSENT

10c. Tree Stumps: PRESENT ABSENT

10d. Large Trees dbh > 5 PRESENT ABSENT

10e. Regenerants dbh < 5 : PRESENT ABSENT

11. Interviewed by ________________________ 12. Date __________________________ 13. Start time _____________ 14. End time _________________

4A: OTHER PLOTS IN BUJINGIJILA GAP AND HOW TREE FARMS WERE ACQUIRED

1. Name of the respondent	
2. Village of the respondent	
3. The respondent is: (e.g: the one who cleared the plot, the widow of the one who cleared, the child of the one who cleared, inherited from the one who cleared, the wife/brother/uncle of the plot buyer etc)	

5.Name of the owner/user	
6.Village of the owner/user	

7. Do you have any other plot in Bujingijila gap? YES NO

7b.Plot count: NDALA _____ MWATISYE____

8. Other Plots count: W/Trees ____ W/Crops______ W/Tea ______

9. Notes ____

____

3. The plot detailed is in the side of river: NDALA MWATISYE

4. The plot detailed: NOW HAS A DIFFERENT OWNER IS BEING USED BY SOMEONE ELSE IT IS USED BY MYSELF

4B: ADDITIONAL QUESTIONS ON TREE PLOTS

1.Name of the tree plot (**List all the plots before asking about each individual plot)**	2.Side of NDALA or MWATISYE **(If outside the gap write the name of the area)**	3.How was plot acquired? Bought--1 Inherited--2 Given by a relative/someone--3 Clan Farm--4 Family farm--5 Has been borrowed--6 Distributed from village land--7 **(Record the code and brief explanation)**	3b. Brief explanations	5.Year plot was acquired	4.Price if it was purchased	6. When were the trees that are currently on the plot planted?	7.Who decided to plant them? Myself--1 My child--2 My husband--3 My parents--4 My brothers/sisters--5 Other--6 (**Record the code and brief explanation)**	8.While you were planting trees, what vegetation was on the plot? Tall grass/natural trees/shrubs--1 Pine/eucalyptus/cypress--2 Re-sprouts of no.2&shrubs--3 Crops eg maize, yams, or crop remains--4 (**Record the code and brief explanation)**	9.Before planting trees, was the plot fallowed? 9a.Year fallowing started 9b.Year fallowing ended (**Record the year and brief explanation)**	10.Who has authority to harvest trees in this plot? Only myself--1 Wife/Husband--2 The brothers of husband/brother-in-laws--3 My children--4 Parents/In-laws--5 Other --6 (**Record the code and brief explanation)**	11.Why was this plot planted with trees?

APPENDIX 2: LIST OF TREE SEEDLINGS ENCOUNTERED AT STUDY SITE

Local name	Scientific Name	Encounters	Seedling Tally	% Total Tally	Kipunji food	Kipunji habitat	early colonizer	Woodland Species	Slow-growing native	Fast-growing native	Planted / exotic	Comments
msibisibi	Morella salicifolia subsp kilimandscharica	103	169	28.7	no	yes	no	yes	yes	no	no	Trees found in both woodland and forest
mkuti	Maesa lanceolata	51	120	20.4	yes	yes	yes	yes	yes	no	no	Trees found in both woodland and forest
paina	Pinus patula	67	93	15.8	NA	NA	NA	NA	NA	NA	yes	exotic trees that disperse seeds very fast
msese	Myrsine melanophloeos	8	32	5.4	no	yes	no	no	yes	no	no	
msenye	Agarista salicifolia	21	28	4.8	no	yes	yes	yes	yes	no	no	trees found both in the forest and woodland and are used mostly for firewood
msya	Bridelia micrantha	12	20	3.4	yes	yes	no	no	yes	no	no	kipunji eat fruit of this tree
mporopotwa	Vernonia myriantha	6	17	2.9	yes	yes	yes	yes	no	yes	no	not a large tree,its a wooded shrub that grows in the forest and woodland
msangabale	Aphloia theiformis	9	13	2.2	yes	yes	no	no	yes	no	no	
mkolya	Dodonaea viscosa var angustofolia	6	10	1.7	no	no	yes	yes	no	yes	no	not a large tree, wooded shrub that can tolerate grass
Local name	Scientific Name	Encounters	Seedling Tally	% Total Tally	Kipunji food	Kipunji habitat	early colonizer	Woodland Species	Slow-growing native	Fast-growing native	Planted / exotic	Comments

msyunguti	Bersama abyssinica	7	9	1.5	yes	yes	no	no	yes	no	no	
mtangasale	Albizia gummifera	4	7	1.2	yes	yes	no	yes	yes	no	no	
mkandana	Parinari excelsa	1	7	1.2	yes	yes	no	no	yes	no	no	Fruits eaten by Kipunji as well as people
mpodo	Podocarpus latifolius	4	6	1	no	no	no	no	yes	no	no	Tree used for hardwood timber. Harvest controlled under Tanzanian forest laws
mfwandilo	Ilex mitis	6	6	1	yes	yes	no	no	yes	no	no	Kipunji eats leaves of the tree
msongwa dume	Garcinia kingaensis	5	5	0.8	yes	yes	no	no	yes	no	no	
mkambokambo	Cupressus lusitanica	4	5	0.8	no	NA	NA	NA	NA	no	yes	
kipwa	Galiniera saxifraga	2	5	0.8	yes	yes	no	no	yes	no	no	
mlimbo	Maytenus acuminata	3	4	0.7	yes	yes	no	no	yes	no	no	
msiiti	Ficalhoa laurifolia	2	3	0.5	yes	yes	no	no	yes	no	no	
mparachichi	Persea americana	2	4	0.7	yes	yes	NA	NA	NA	NA	yes	Seeds dispersed into forests by loggers

Local name	Scientific Name	Encounters	Seedling Tally	% Total Tally	Kipunji food	Kipunji habitat	early colonizer	Woodl and Species	Slow-growing native	Fast-growing native	Planted / exotic	Comments
mlingoti	Eucalyptus maidenii	3	3	0.5	no	NA	NA	NA	NA	NA	yes	
Mturuhunga	Hagenia	1	2	0.3	yes	yes	no	yes	yes	no	no	Pioneer species.

	abyssinica											Harvest controlled under Tanzanian forest laws
mswisa	Myrianthus holstii	2	2	0.3	yes	yes	no	no	yes	no	no	Fruits eaten by Kipunji as well as people
msuluti	Catha edulis	2	2	0.3	yes	yes	no	no	yes	no	no	
msengela	Macaranga capensis var kilimandscharica	2	2	0.3	yes	yes	no	no	yes	no	no	
mpembati	Polyscias fulva	2	2	0.3	yes	yes	no	no	yes	no	no	
mkuyu	Ficus sur	2	2	0.3	yes	yes	no	no	yes	no	no	kipunji eats the fruits of this tree
mtitisieli	Peperomia tetraphylla	1	1	0.2	yes	yes	yes	yes	no	yes	no	not a large tree,its a wooded shrub that grows in the forest and woodland
mbojo	Tecomaria capensis	1	1	0.2	yes	yes	yes	yes	no	yes	no	not a large tree, wooded shrub that can tolerate grass
mberigati	Cornus volkensii	1	1	0.2	yes	yes	no	no	yes	no	no	

APPENDIX 3: SEEDLING DISTRIBUTION BY SPECIES, USING LOCAL NAMES

	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
NOETHERN, UNCULTIVATED	138	140

	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT		NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
0-50	36	26	100-150	28	32
mberigati	1	1	mkuti	3	12
mkolya	1	1	mpodo	1	1
mkuti	5	11	msenye	4	6
msenye	1	1	msese	2	4
msese	2	3	msibisibi	5	9
msibisibi	6	8	NONE	13	0
Msyunguti	1	1			
NONE	19	0			
50-100	38	63	150-200	26	19
mbojo	1	1	mkolya	2	4
mkuti	3	17	mkuti	3	3
mpodo	3	5	mlimbo	1	2
msangabale	1	1	msenye	1	2
msenye	4	5	msese	1	1
msese	3	24	msibisibi	4	4
msibisibi	5	9	msongwa	1	1
msongwa	1	1	msuluti	1	1
NONE	17	0	Msyunguti	1	1
			NONE	11	0
200-250	7	0	250-300	2	0
NONE	7	0	NONE	2	0
300-350	1	0			
NONE	1	0			

	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
SOUTHERN, HUMAN USE	398	449

	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
0-50	97	133
kipwa	2	5
mfwandilo	2	2
mkandana	1	7
mkenenge	1	1
mkuti	11	18
mkuyu	2	2
mlimbo	1	1
mlingoti	1	1
mpembati	1	1
mporopotwa	1	5
msangabale	3	3
msengela	2	2
msenye	3	3
msibisibi	21	37
msiiti	2	3
msongwa	1	1
msuluti	1	1
mswisa	1	1
msya	6	11
Msyunguti	3	4
mtangasale	1	1
NONE	13	0
paina	16	22
parachichi	1	1

	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
50-100	78	109
mfwandilo	1	1
mkuti	9	25
mlingoti	1	1
mpembati	1	1
mporopotwa	1	1
msangabale	2	6
msenye	2	3
msibisibi	19	34
msongwa	1	1
msya	3	3
Msyunguti	2	3
mtangasale	2	5
Mturuhunga	1	2
NONE	20	0
paina	12	18
unknown	1	5

	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
100-150	64	86
mfwandilo	2	2
mkambokambo	1	2
mkenenge	1	1
mkolya	1	1
mkuti	10	24
mlimbo	1	1
mporopotwa	3	9
msangabale	2	2
msenye	2	2
msibisibi	15	22
mswisa	1	1
msya	3	6
mtangasale	1	1
NONE	12	0
paina	8	9
parachichi	1	3

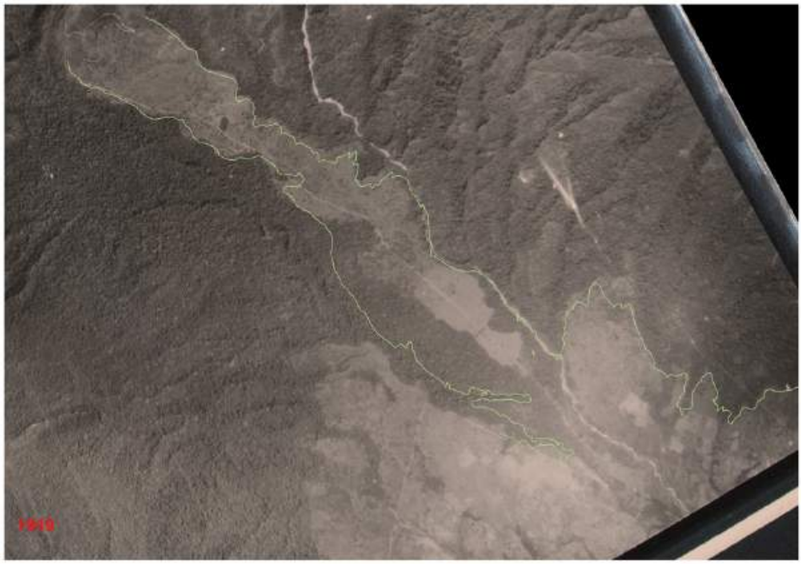
	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
150-200	48	39
mfwandilo	1	1
mkambokambo	1	1
mkuti	5	8
mporopotwa	1	2
msangabale	1	1
msenye	2	2
msibisibi	7	14
msongwa	1	1
NONE	23	0
paina	6	9

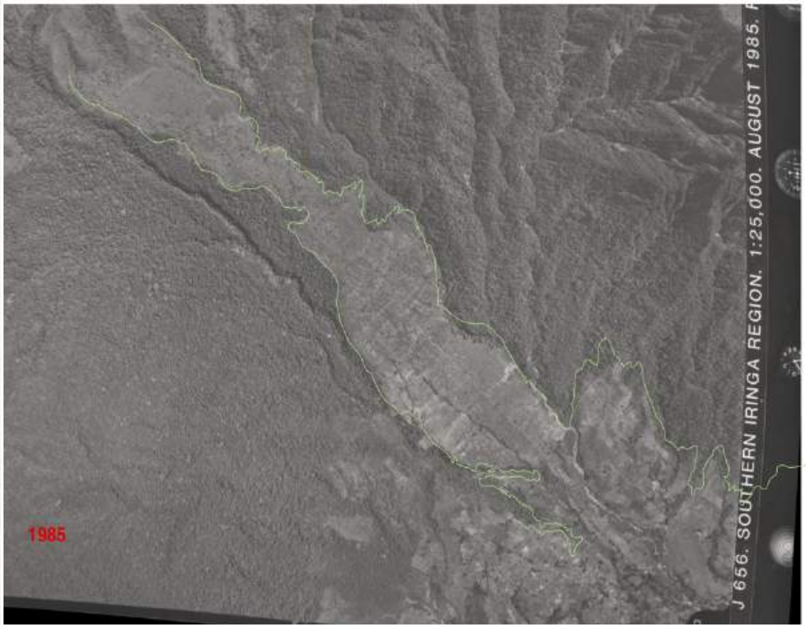
200-250	35	35
mkambokambo	1	1
mkuti	1	1
msenye	1	1
msibisibi	10	15
NONE	13	0
paina	9	17

250-300	25	20
msibisibi	9	14
NONE	11	0
paina	5	6

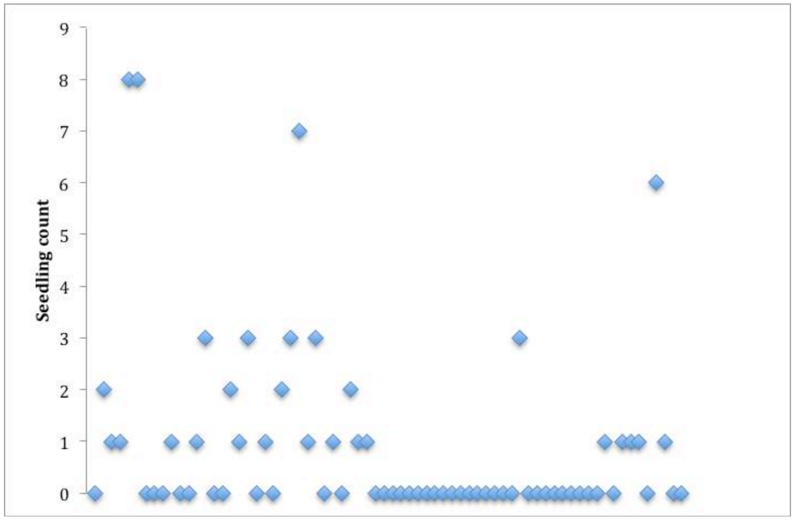
	NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT		NUMBER OF NON-INDEPENDENT OBSERVATIONS	SEEDLING COUNT
300-350	32	17	350-400	19	10
mkambokambo	1	1	mkolya	1	2
mkolya	1	2	mkuti	1	1
msibisibi	2	3	mlingoti	1	1
NONE	18	0	msenye	1	3
paina	10	11	mtitisieli	1	1
			NONE	12	0
			paina	1	1
			unknown	1	1

APPENDIX 4: AERIAL PHOTOS FROM FOUR TIME-STEPS

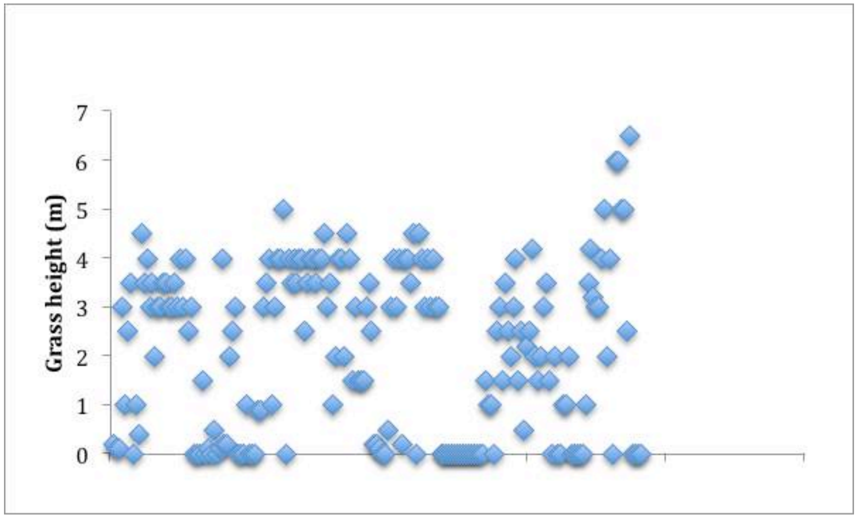




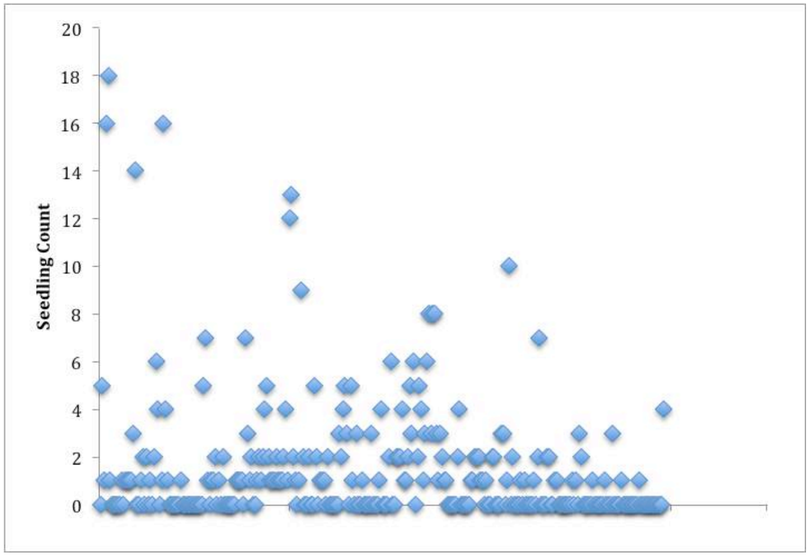
APPENDIX 5: GRASS HEIGHT AND SEEDLINGS DISTRIBUTION



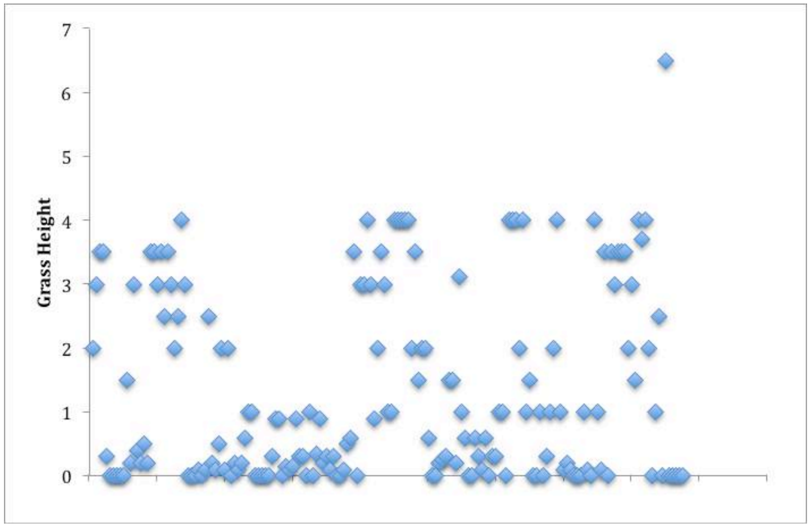
Seedling Count, Grass Ht = 0: Average seedling count 0.95



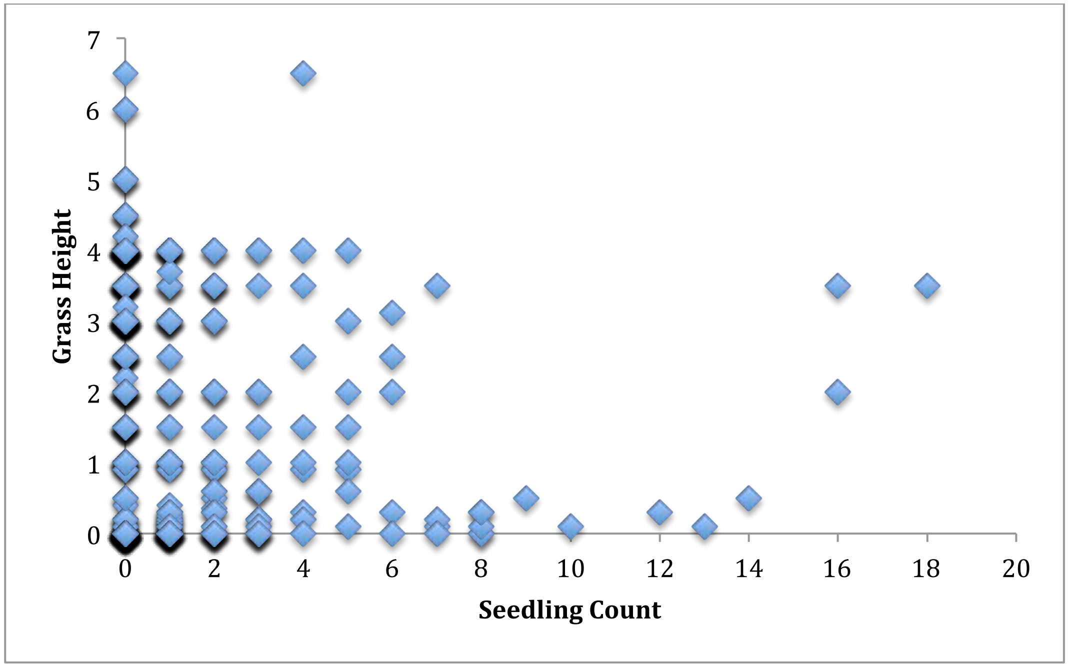
Grass Height, seedling count = 0, Average grass height 2.15



Seedling count for grass height > 0 Average seedling count = 1.46



Grass height for seedling count > 0. Mean grass height = 1.43



OVERALL: Grass Height vs seedlings count for all seedlings