Miti Iko Wapi II ?

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Abstract:

Vegetative communities within the savannah ecosystem oscillate between grassland and woodland states. Research has found that ecological perturbations resulting from elephants, fire, other herbivores and humans have a significant influence on the oscillation of vegetative communities. Understanding these forces and how they interplay to influence vegetative dynamics states is essential to a developing any effective conservation management program. A previous study, in 2003, was conducted to establish baseline data on vegetative community structure, elephant damage and fire damage within Ndarakwai Ranch. (Hamilton and Downing 2003). However, the study drew few definitive conclusions and suggested further research. This study was a repeat study and examined the vegetative community dynamics within Ndarakwai Ranch and the role of elephants, fire and other herbivores. Six permanent (40m x 40m) plots in three distinct sites, within the Ranch, were examined. Data was collected to ascertain the current state of vegetation in Ndarakwai and compared to data from the previous study done in 2003. Variables that were recorded include: plant height, circumference, location, percent elephant damage, level of fire damage, seedling counts, grass abundance/cover, and soil type/pH. The study found that plant community structure within each Site changed dramatically from 2003. Evidence suggests that elephants greatly influenced the observed shift in community structure over the past six years. Fire was found to have played a minor role. Findings also indicate that herbivores, other than elephants, might influence woodland regeneration through seedling browsing. This study concluded that the vegetative communities within Ndarakwai Ranch are shifting towards a grassland state. Ecological insularization within the West Kilimanjaro region was discussed as the ultimate cause of the proximate findings and suggested certain management policies that could alleviate its effects.

Introduction:

The savannahs of Africa are a complex and dynamic ecosystem which host a wide range of vegetative communities. Within the savannah landscape, these communities have been found to shift between grassland and woodland states over time (Sinclair 1995). Initially, this change of vegetative states was viewed as a process of succession, in which habitats move toward a "climax" community due to conditions of long-term stability. Grasslands eventually succeed to woodlands. However in recent decades, researchers have noted the view of succession and a climax community is not an accurate description of the dynamics of the savanna woodland ecosystem. Instead, scientists have postulated that ecological perturbations, disturbances resulting from elephants, fire, other herbivores and humans have a significant influence on the oscillation of vegetative communities (Dublin 1995). Understanding these forces and how they interplay to influence the transition between grassland and woodland states is essential to a developing any effective conservation management program. Such is the case for a privately-owned conservation area, called Ndarakwai, which has experienced an increase in elephant and herbivore populations, an increase of human encroachment on the boundaries (Jones pers.com. 2009) and has possibly been undergoing a shift in vegetative communities in recent years.

Throughout Africa elephants, *Loxodonta africana*, are considered a keystone species and the primary agents of habitat change. The elephant is a general grazer and browser, which mostly feeds on grasses but also browses on woody species of all types. To meet its metabolic requirements, this animal must spend 16 hours per day foraging and eats up to 300lbs. of foliage (Estes 1993). Due to its large size and appetite, the elephant is an agent of damage and habitat modification within the savannah ecosystem. One elephant may knock down as many as 3 or more trees during one day (Hamilton and Downing 2003) A herd of six elephant bulls once visited a 2 km^2 mature *Acacia gerrardii* stand and within 24 hours, 34% of the trees were fatally damaged and 22% were left with multiple broken branches(Dublin

1995). The amount and severity of damage, ecological disturbances, inflicted by elephants can have a significant impact on the structure and the dynamics of tree communities. Particularly elephants have been found to influence tree mortality rates and seedling recovery.

The effect of elephants on tree communities is most notable in the Serengeti-Mara ecosystem. Here researchers have conducted extensive amount of research on elephant-tree dynamics over the past decades. Since the 1960s, scientists have observed a dramatic decrease in woodland habitats within the Serengeti-Mara ecosystem. This decline has been largely attributed to elephant populations (Dublin 1995). During this period, increasing human populations forced higher concentrations of elephants into the Serengeti and Maasai Mara national parks. Consequently the woodland habitats within these parks experienced increased pressure from elephant browsing. Facing reduced availability of browse forage, elephants concentrated their time within Croton thickets and Acacia woodlands (Dublin 1995). These habitats were the last wooded refuge for elephants and were heavily utilized for food and shade. As a result, these woodlands were severely damaged and the number of mature trees in the Maasai Mara has been greatly reduced over the past 50 years. Now the remaining mature trees are being lost at a rate of over 8% per year (Dublin 1995).

Elephants also influence woodland dynamics by browsing on seedlings. Scientist once assumed that elephants did not browse on trees under 1m and that seedlings were in "height refuge". However further investigation has revealed that elephants spend a significant proportion of time feeding on seedlings and saplings under 1m in height. In fact, it has been found that elephant browsing is a primary factor in seedling mortality within the Mara, 4% of all seedlings are killed by elephants annually (Dublin 1995). This has significant implications for woodland dynamics and recovery. Elephants are removing a large proportion of seedlings and as a result, the stock for woodland regeneration is decreased. Thus, overall potential for woodland recovery is greatly diminished and trees that are being killed by elephants are not being replaced. Therefore, elephants play a critical role in vegetative community structure by destroying trees, shrubs and seedlings. However, the affects of elephants are compounded by fire in the savannah ecosystem.

Fire is also a major component of ecological disturbances within the savannah ecosystem and it serves many roles. Primarily, fire decreases the build up of dead, decaying organic matter and releases nutrients back into the soil (Gicholi 1996). Most importantly, fire greatly influences plant community structure. It is essential to maintaining grassland habitats since it limits bush encroachment by destroying seedlings, trees under 1m (Gicholi 1996). The interplay of elephant and fire and the effects on vegetative dynamics is evident in the Serengeti-Mara ecosystem. As mentioned, elephants heavily utilized Croton thickets within the Mara ecosystem and severely damaged their internal structure, creating large clearings. These patches facilitated the growth of dense grass vegetation. The vegetation remained un-grazed, because most herbivores avoid the risk of hidden predators in dense thickets, which led to a build-up of dry, dead litter (Dublin 1995). When fire burned through these areas, the fire was very intense and severe, killing many trees and bushes. Over time the thickets became fragmented and the habitat transitioned to a grassland state. Thus, the interplay of elephant and fire creates a positive feedback loop that intensifies the process of turning forest and bushland into grassland and contributes to the oscillation between these two “stable” states.

The interaction of elephants and fire to influence vegetative dynamics has led scientist to develop a “multiple stable state” (MSS) hypothesis. This hypothesis describes that the oscillation between woodland and grassland states is an expression of equilibrium between elephant and tree population interactions. It proposes that there are two equilibria, one with many trees (woodland) and few elephants, the other with few trees (grassland) and many elephants (Sinclair 1995). Included in this hypothesis is the critical role of fire. Elephants, along with fire, limit tree populations and it is the interplay of these two factors which determines community structure. Thus, for woodlands to regenerate both fire and elephant numbers must be reduced. Yet, it is also hypothesized that many elephants with little fire can still prevent the regeneration of woodlands.

Herbivores, other than elephants, have also been shown to ploy a role in vegetative dynamics. Primarily, other herbivores, such as wildebeest, can influence the severity and fire.   Wildebeest reduce fuel loads by grazing grasses that would otherwise build up. Migratory wildebeest can remove over 90% of standing crop in their path (Dublin 1995). Decreased fuel loads results in decreased fire severity. Thus, wildebeest can influence woodland recovery. As an addition to MSS, it is hypothesized that the regeneration of trees should occur when wildebeest numbers are high, fire incidence is low and elephant numbers are decreasing (Sinclair 1995). However, herbivores, such as wildebeest, can also exacerbate the effects of elephants. During the dry season, elephants rely more on browse species. Wildebeest compete with elephants for resources and their presence increases elephant browsing. Thus, elephants put greater pressure on seedlings and adult trees during the dry season. Furthermore, it is reported that wildebeest kill 1% of all seedlings annually through trampling and inadvertent browsing (Dublin 1995).

Increasing human populations in Northern Tanzania are also having a significant impact on animal and plant community dynamics. Humans are compressing wildlife into smaller areas and increasing fire frequency. Many inhabitants of the Northern Tanzania region are Maasai. These people primarily practice pastoralism, and their cattle can come into conflict with wildlife over resources. As a result of this competition, wildlife populations are taking refuge into smaller areas, such as Ndarakwai Ranch. The Maasai also have a long history of setting fires to create grazing lawns and control bushlands which harbor the deadly tsetse fly. These fires sometimes spread quickly and can devastate large areas of land.

Similar processes seen in the Serengeti-Mara ecosystem during the 20th Century are possibly occurring in the West Kilimanjaro region of northern Tanzania, specifically in Ndarakwai Ranch. In 2003, Hamilton and Downing, conducted a study at Ndarakwai Ranch examining these processes. The study set out to establish baseline data on vegetative community structure, elephant damage and fire damage. The researchers drew few conclusions but suggested that a future study be done to further examine shifts in vegetative trends over time and the role of elephants and fire.

Thus, this study set out to perform a repeat study, examining vegetative community structure in relation to elephant and fire damage. Due to the unforeseen circumstances, this study did not develop any predictions or hypotheses. However, based on personal experience and knowledge learned during the past semester, it does appear that elephants have dramatic role in vegetative community dynamics. Thus this study believes that the vegetative community within Ndarakwai has shifted, over times, mainly due to elephant forces.

Site Description:

Ndarakwai is a 42.25 square kilometer ranch located in northern Tanzania (See Appendix 1). It is nestled in the West Kilimanjaro region, a valley between Mount Meru and Kilimanjaro and is bordered by five Maasai villages on the southern boundary. These villages engage in traditional cattle herding and agriculture practices. However, the ranch maintains a 'no-grazing' and 'no-poaching' policy for these communities.

The area was formerly a cattle ranch until Tanzanian independence in 1961. Following independence, Ndarakwai was nationalized, but between1975 and 1994 the area was left unregulated (Ndarakwai 2009). In 1995 Peter Jones signed a 33-year lease on the land from the government and began to restore the natural habitat. Currently, the ranch is a privately owned and managed conservation area, promoting tourism. The ranch contains a man-made, permanent water hole that attracts wildlife through out the year.

Ndarakwai is part of the Amboseli / Ngasurai Basin ecosystem and hosts over 65 mammal species, and 350 bird species (Ndarakwai 2009). The area serves as part of a migratory corridor used by elephants and other migrant animals, yet many species use the ranch as a permanent residence, including a resident elephant population (Ndarakwai 2009). The ranch also preserves a variety of habitats ranging from woodlands to grasslands and riverine habitats.

Ndarakwai lies at an average altitude of 1200 meters above sea level and the topography includes several small hills (Hamilton and Downing 2003). The climate of the area is semi-arid, receiving less than 700mm annually (Jones, per. com. 2009). But, it receives most of its rainfall during two rainy seasons, the long season (March-May) and the short season (November-December).

Three study sites, representing three areas of concern to the management of the Ranch, are included in the study (See Appendix 1). These sites had been established in a previous study and where placed in the southwest region of the ranch. This location was chosen because the vegetation of the area was predicted to change due to natural and/or human-induced ecological impacts. The first site is located to the West of the waterhole, an area characterized as an acacia woodland through which elephant pass on their way to utilize water. The second site is located within a zone that had been burned by fire four years prior to the previous study and has since grown back. The third site is positioned at the edge of the bushland and grassland vegetation zones. This site had also been burned before 2003. It is important to note that none of the sites were burned in the six year period between the studies (Jones per. com. 2009). Also, the ranch has no fire regime and represses all fires, whether started by humans or nature.

Methods and Materials:

This study was conducted at Ndarakwai Ranch, in the West Kilimanjaro Region of Northern Tanzania, on the 15 days between April 14th and April 29th, during the long rainy season of 2009. This was a repeat study, examining elephant damage which was first done in 2003. Many of the methods from the previous study were duplicated (for original methods see Appendix 2). Changes and improvements upon the previous methods are discussed below.

Data Collection

This study focused on the most prominent species within the plots due to the large diversity of plant species and individuals. In determining which data to collect this study followed specific guidelines. An individual plant was counted if it met the following criteria:

1. Was identifiable
2. Had a woody or tree-like appearance
3. Had at least 50% of the stem inside the plot.

Variables

Trees, Shrubs, and Seedling

- Species
- Age
- Height

Trees and Shrubs

- Location
- Percent Damage (0%, 1-25%, 26-50%, 51-75%, 76-99%, 100%)
- Type of Damage

Grass

- Species
- Cover
- Abundance

Soil

- Type

Other

- Dung

Age

As in the previous study, age of a plant was determined using trunk circumference at ground level (See Appendix 2). However, this study differed from the previous in that if a plant had multiple trunks at ground level the most prominent, widest, trunk was measured. This was thought to be a more accurate measurement of age (Severre per. com. 2009)

Age was divided into six classes, based on circumference. However, both height and circumference were used in differentiating the seedling age group. The definition of a seedling differed from the previous study in that an individual was counted as a seedling if it stood less than 0.75 meters and had a circumference less than 5 cm. Age classes were created as follows (Age classes 2-5, See Appendix 2):

0. <.05m = <1 years
1. .05-0.70 = 1-5 years

Grass Species/Abundance

Grass species were identified primarily by their inflorescence. However, only the short grasses, which had visible inflorescence were identified. Abundance of a grass species was measured by the number of visible inflorescence within each plot, rated as high or low.

Soil Types

Twelve soil samples were brought to Josiah Severre in order to identify soil type

Analysis

The collected data was analyzed using descriptive statistics. Means with standard error were calculated for variables such as height, circumference and damage rating. Age classes were created and a survivorship curve was generated based on the age classes of 2003 and 2009. While data on grasses and soil were collected, they were not included in analysis (See appendix 3 for analyzed data set).

Results:

During the month of April 2009, six, 40m x 40m, non-randomly selected plots located in three different vegetative sites were examined for evidence of herbivore and fire damage. This study identified and counted 240 adult trees, belonging to 19 different species (See Appendix 3). These findings from the individual plots and sites were compared to data from the previous study done by Downing and Hamilton in 2003. Table 1 depicts overall number of adult trees in all Plots and Sites. In addition, the table includes that two most abundant tree species of 2003.

Table 1. Comparison of the Overall Number of Individual Plants Species in all Plots and Sites Between 2003 and 2009.

	2009			2003		
Species	Site 1	Plot 1	Plot 2	Site 1	Plot 1	Plot 2
OVERALL	111	40	71	107	65	42
tortillis	32	23	9	66	44	22
mellifera	21	15	6	27	19	8
	Site 2	Plot 3	Plot 4	Site 2	Plot 3	Plot 4
OVERALL	59	36	23	132	39	93
Commiphora trothea	4	0	4	73	4	69
mellifera	15	11	4	39	24	15
	Site 3	Plot 5	Plot 6	Site 3	Plot 5	Plot 6
OVERALL	70	23	47	170	40	130
Cordia ovalis	13	1	12	68	3	65
Commiphora africana.	7	0	7	51	22	29

Note: This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. This study identified two Commiphora species, *Commiphora africana* and *Commiphora trothea* in separate plots. However, the 2003 study only identified *Commiphora sp*. These species were combined for ease of comparison

The overall number of seedlings in all Plots and Sites is shown in Table 2. Seedling abundance for the two most abundant trees in 2003, and the most abundant seedling of 2009 is shown.

Table 2. Comparison of the Overall Number of Individual Seedling Species in all Plots and Sites Between 2003 and 2009.

Seedling Species	2009			2003		
	Site 1	Plot 1	Plot 2	Site 1	Plot 1	Plot 2
OVERALL	597	44	553	56	19	37
tortillis	9	3	6	13	6	7
mellifera	8	7	1	1	1	0
Solanum incarnum	525	5	520	0	0	0

	Site 2	Plot 3	Plot 4	Site 2	Plot 3	Plot 4
OVERALL	353	69	284	169	21	148
Commiphora torthea (55) Commiphora africana (10)	65	6	59	147	15	132
mellifera	28	17	11	8	2	6
Sericocomopsis h.	83	0	83	0	0	0
	Site 3	Plot 5	Plot 6	Site 3	Plot 5	Plot 6
OVERALL	146	38	108	170	40	130
Cordia ovalis	84	12	72	68	3	65
Commiphora trothea (15) Commiphora africana (10)	25	5	20	51	22	29

Note: This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. This study identified two seedling commiphora species, *Commiphora africana* and *Commiphora trothea*. However, the 2003 study only identified *Commiphora sp*. For ease of comparison, the two species have been combined. Parentheses denote overall number of individuals for both species.

Table 3 depicts the overall mean elephant damage, along with the means of the two most damaged tree species in each site.

Table 3. Comparison of Mean Elephant Damage Rating in all Plots and Sites Between 2003 and 2009.

	2009			2003		
Species	Site 1	Plot 1	Plot 2	Site 1	Plot 1	Plot 2
OVERALL	2.74± 0.17	3.49± 0.23	2.35± 0.21	2.42± 0.27	2.72± 0.35	1.95± 0.40
mellifera	3.50± 0.27	4.00± 0.17	2.5± 0.67	2.74± 0.45	3.33± 0.47	2.13± 0.94
tortilis	3.03± 0.32	3.09± 0.35	2.67± 0.75	2.45± 0.37	2.66± 0.46	2.05± 0.62
	Site 2	Plot 3	Plot 4	Site 2	Plot 3	Plot 4
OVERALL	2.8± 0.21	2.39± 0.74	3.47± 0.5	0.84± 0.18	1.41± 0.39	0.6± 0.17
Commiphora africana	3.75± 0.95	-	3.75± 0.95	0.49± 0.18	0.75± 0.49	0.48± 0.18
mellifera	3.67± 0.42	3.36± 0.54	4.5± 0.71	1.46± 0.42	1.71± 0.56	1.07± 0.59
	Site 3	Plot 5	Plot 6	Site 3	Plot 5	Plot 6
OVERALL	3.37± 0.22	4.29± 0.22	2.82± 0.31	0.72± 0.15	0.23± 0.70	0.87± 0.17
tortillis	4.17± 0.54	-	4.17± 0.54	1.57± 0.84	-	1.57± 0.84
mellifera	3.5± 1.03	-	3.5± 1.03	1.82± 0.60	1± 0	2.2± 0.67

Note: This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. Data is represented with standard error values. The 2003 study only identified *Commiphora sp*. However this study identified *Commiphora africana* For ease of comparison, the species have been combined.

Table 4 compares the mean overall fire damage between the 2003 and 2009 study.

Table 4. Comparison of Mean Fire Damage Rating in all Plots and Sites Between 2003 and 2009.

	2009			2003		
Species	Site 1	Plot 1	Plot 2	Site 1	Plot 1	Plot 2
OVERALL	0± 0	0± 0	0± 0	0± 0	0± 0	0± 0
	Site 2	Plot 3	Plot 4	Site 2	Plot 3	Plot 4
OVERALL	3± 0	0± 0	3± 0	1.48± 0.17	1.41± 0.31	1.51± 0.20
	Site 3	Plot 5	Plot 6	Site 3	Plot 5	Plot 6
OVERALL	1.71± 0.41	2.75± 0.25	1.71± 0.54	1.68± 0.18	2.65± 0.74	1.38± 0.20

Note: This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. Data is represented with standard error values.

Table 5 compares the 2009 overall mean of elephant damage to the overall total mean of damage in all Plots and Sites.

Table 5. Comparison of 2009 Overall Mean Elephant Damage and Overall Mean Total Damage.

	Site 1	Plot 1	Plot 2
Elephant	2.74± 0.17	3.49± 0.23	2.35± 0.21
Overall	2.64± 0.16	3.4± 0.24	2.18± 0.18
	Site 2	Plot 3	Plot 4
Elephant	2.8± 0.21	2.39± 0.74	3.47± 0.5
Overall	2.77± 0.21	2.31± 0.74	3.23± 0.31
	Site 3	Plot 5	Plot 6
Elephant	3.37± 0.22	4.29± 0.22	2.82± 0.31
Overall	3.11± 0.2	4.11± 0.22	2.6± 0.25

Note: This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. Data is represented with standard error values.

Table 6 compares the 2009 seedling overall mean of elephant damage to the overall total mean of damage in all Plots and Sites.

Table 6. Comparison of 2009 Seedling Average Elephant Damage and Average Total Overall Damage.

	Site 1	Plot 1	Plot 2
Elephant	0.43± 0.13	0± 0	0.67± 0.17
Overall	0.64± 0.17	0.25± 0.09	0.76± 0.16
	Site 2	Plot 3	Plot 4
Elephant	0.13± 0.08	0.14± 0.06	0.13± 0.03
Overall	0.30± 0.06	0.26± 0.06	0.33± 0.03
	Site 3	Plot 5	Plot 6
Elephant	0.21± 0.07	0.18± 0.02	0.21± 0.08
Overall	0.59± 0.08	0.52± 0.1	0.81± 0.15

Note: This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. Represented with standard error values

Table 7 shows the overall dung counts for each species within each Plot.

Table 7: Number of Dung Piles Identified within all Plots

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Total
zebra	24	40	80	65	81	75	365
elephant	13	27	10	17	0	5	72
eland	2	1	9	25	14	19	70
wildebeest	12	14	6	0	10	21	63
impala	10	0	1	0	6	9	26
giraffe	2	6	1	1	2	0	12
baboon	1	0	0	0	0	1	2
rabbit	1	0	1	0	0	0	2
dik-dik	0	0	0	1	0	0	1
hyena	0	0	0	0	0	1	1
mongoose	0	1	0	0	0	0	1
waterbuck	1	0	0	0	0	0	1

Note: This data was collected at Ndarakwai Ranch during April 20th, 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch

Figure 1a. and 1b. depicts the age class distribution for all Sites in 2003 and 2009, respectively.

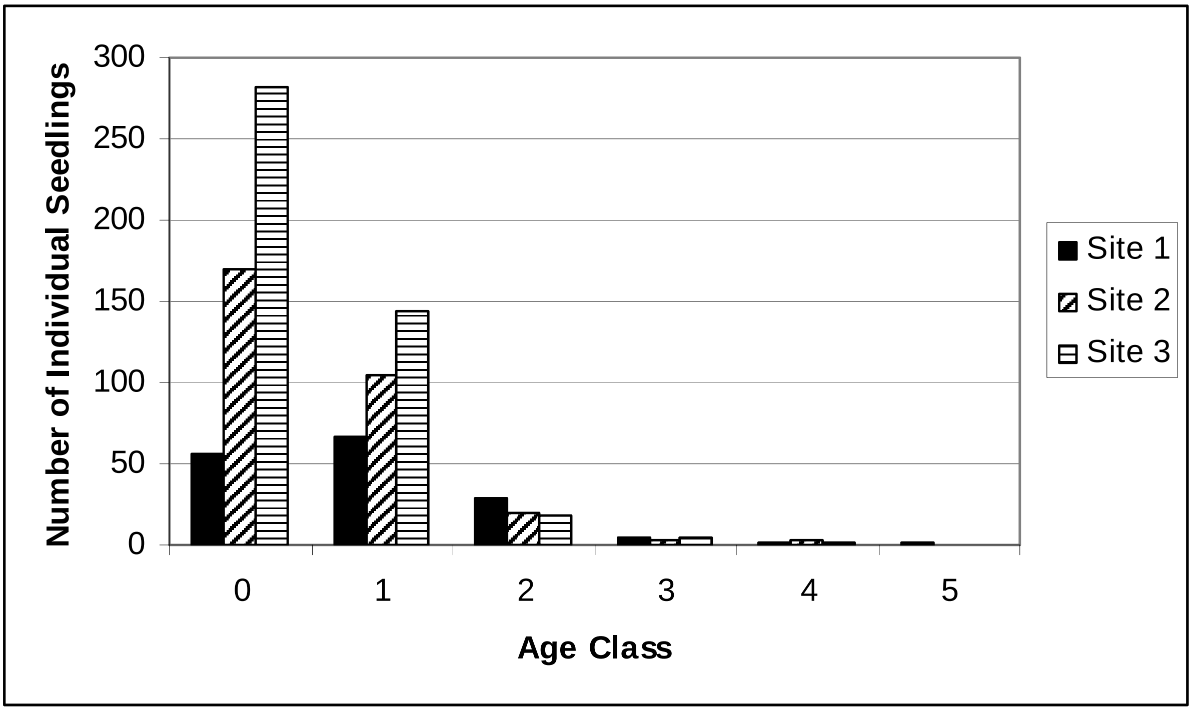

Figure 1a: 2003 Age Class Distribution. This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. Only includes species that were identified in both studies.

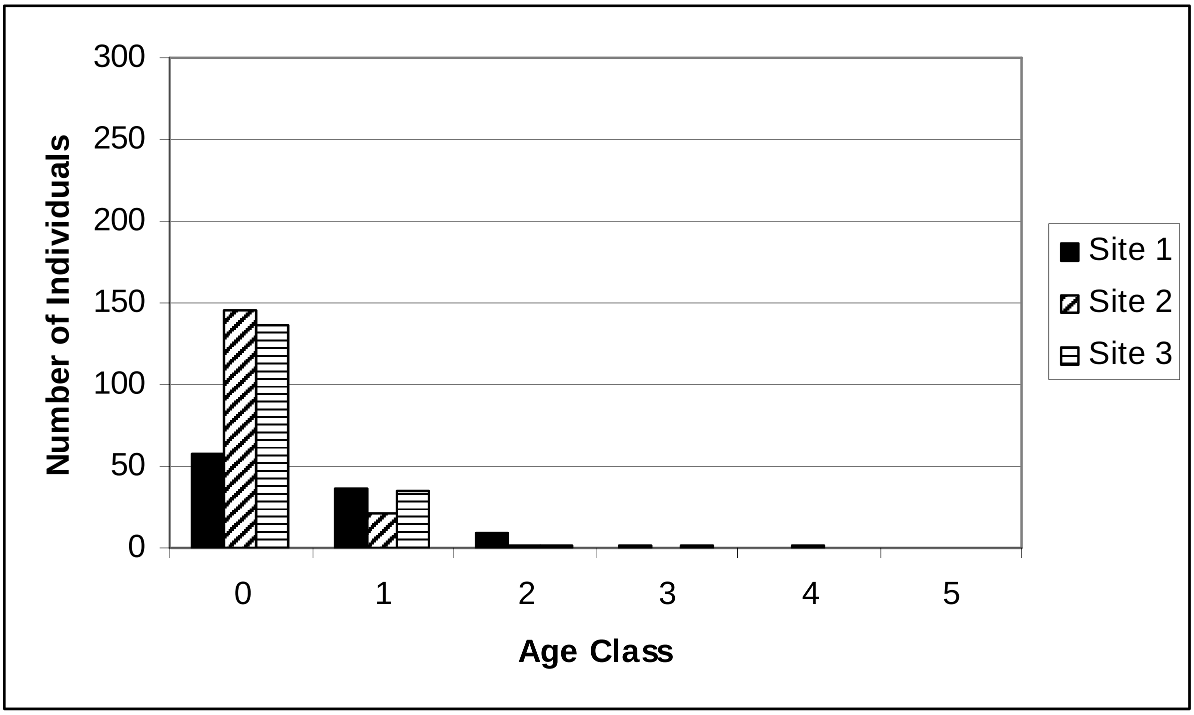

Figure 1b: 2009 Age Class Distribution. This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch. Only includes species that were identified in both studies.

Figure 2 depicts the overall survival of each age class between 2003 and 2009.

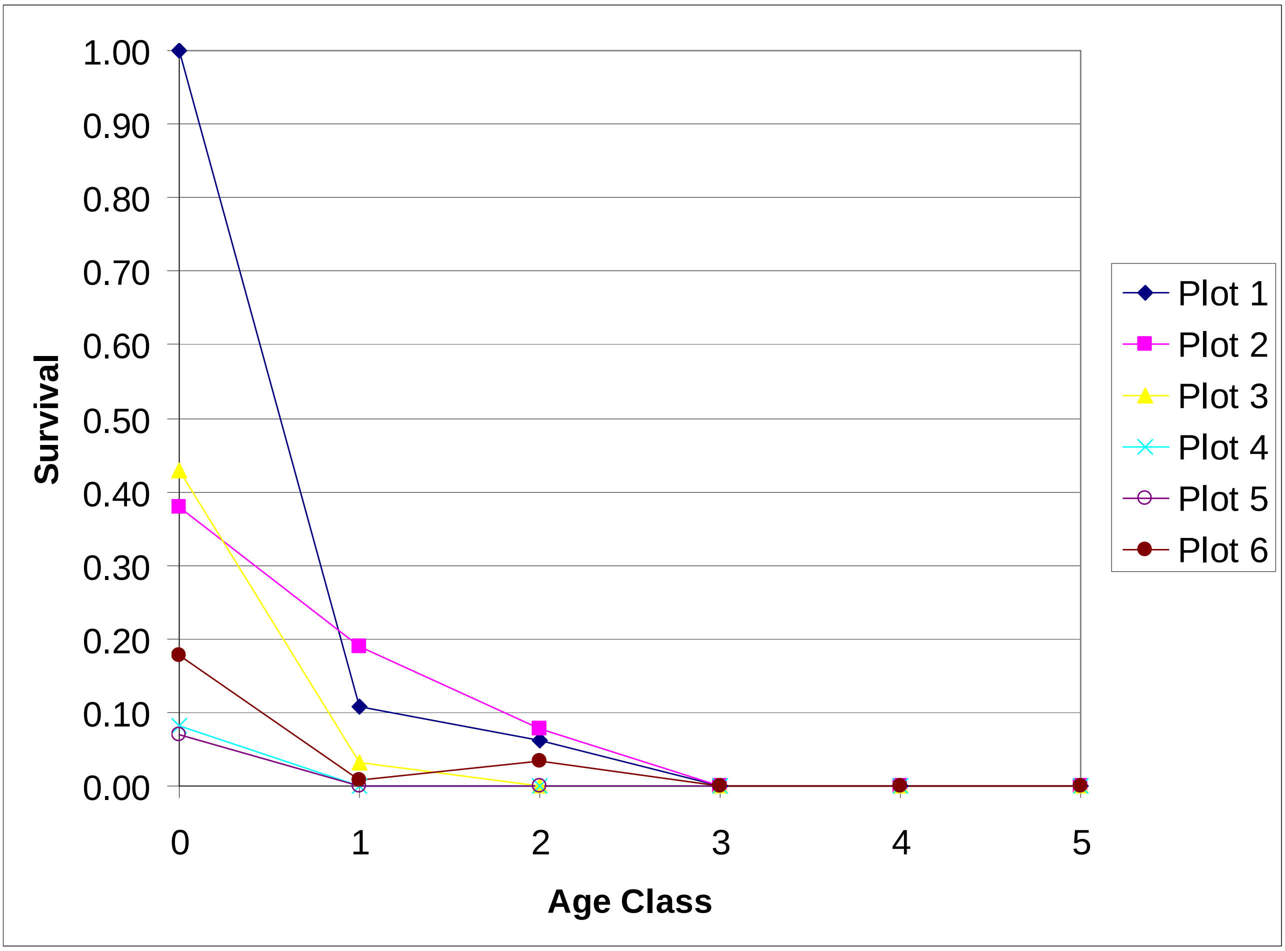

Figure 2: **Age Class Survivorship**. This data was collected at Ndarakwai Ranch during the month of April 2009 from six, 40m x 40m, non-randomly selected plots in the vegetative community within the ranch

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Discussion:

It is hypothesized that the savannah ecosystem oscillates, over time, between grassland and woodland states. As seen in the Serengeti-Mara ecosystem over the 20th century, elephants along with fire, other herbivores and humans have a significant influence on this pattern of oscillation. This study investigated whether the vegetative communities of Ndarakwai Ranch are oscillating between a grassland and woodland state and examined the factors, predominantly elephants and fire, which could influence this process. The analysis of the results will discuss overall trends in vegetative community structure within Ndarakwai Ranch over the past six years and the processes shaping them. First, this study will compare 2003 and 2009 plant community structure and discuss the role of elephants, fire and other herbivores. Second, the analysis will review current vegetative trends and possible factors influencing them. Last, this study will extrapolate these observations and information from the semester focusing on ecological insularization as the possible ultimate cause for the proximate findings and implications for the future vegetative community structure of Ndarakwai Ranch.

Overall, the plant community structure within each Site has been altered dramatically since 2003. Specifically, age class structure and relative species abundance have changed in all the Sites. As seen in Table 1, all the Plots, except Plot 2, have seen an overall decrease in the number of adult trees since 2003. As a result, the number of adults overall in Site 2 and Site 3 decreased from 132 and 170 in 2003 to 59 and 70, respectively. Site 1 has more adult trees but this is due to an increased presence of *Solunam incarnum* (Appendix 3). Conversely, the overall number of seedlings has increased. Site 1 and Site 2 have shown a large increase in the number of seedlings (Table 2). In Site 1, seedlings numbered around 65 in 2003 but increased to 597 in 2009. Likewise, the number of seedlings in Site 2 went from 169, in 2003, to 353, in 2009. This increase in seedling abundance and decrease in mature trees has created a shift in the age class distribution within the Sites, as depicted in Figures

1a.and 1b. The age distribution is now heavily weighted towards seedlings, with mature trees, those in age classes 1-5, making up a smaller proportion, from 44%(402/909) to 24% (107/447), of the population and seedlings contributing a much larger proportion, from 56% (507/909) to 76% (340/447).

Species abundance has also shifted over the six year period. In all of the Plots, the two most abundant tree species of 2003 have decreased in number (Table 1). Most notably, the number of *Commiphora sp*. in Site 2 and Site 3 has decreased from 73 and 51 individuals in 2003 to only 4 and 7 in 2009. Likewise, the seedlings of the most abundant trees have also decreased in most plots. The number of *Commiphora sp*. seedlings in Site 2 has decreased since 2003, from 147 seedlings to 65. *Tortillis* seedlings in Site 1 have decreased from 13 in 2003 to 9 in 2009. However species such as *Cordia ovalis* and *mellifera* have seen an increase in seedling abundance since 2003. In Site 2, *mellifera* seedlings increased to 28 individuals in 2009 from 8 in 2003. (For pictorial depiction of above analysis see Appendix 4)

Elephants appear to have an ecologically significant influence on this shift in community structure over the past six years. The overall mean elephant damage rating increased in all Plots and Sites between 2003 and 2009 (Table 3). Site 3 underwent the greatest increase in elephant damage (X_{2009}=3.37± 0.22, X_{2003}=0.72± 0.15). Site 2 also experienced an increase in elephant damage (X_{2009}=2.8± 0.21, X_{2003}=0.84± 0.18). However, Site 1 saw the smallest increase in elephant damage (X_{2009}=2.74± 0.17, X_{2003}=2.42± 0.27). Among the tree species, *tortillis* exhibited the highest mean elephant damage in Site 3 (X_{2009}=4.17± 0.54). The *mellifera* was one of the most damaged trees in all three Sites. Interestingly, many of the two most damaged trees in each Site, such as *mellifera* and *Commiphora sp*., were also the most abundant trees in 2003. The increase in overall elephant damage between 2003 and 2009 corresponds with the overall decrease of adult trees. These findings suggest that elephant damage could have been a large contributing factor to the decrease in adult trees. This is further supported by analysis of data from 2009 study.

In 2009, all the sites exhibited greater average elephant damage than total overall average damage for adult trees (Table 5). Site 3 exhibits the largest difference between elephant and total damage (X_{el}=3.37± 0.22, X_{ov}=3.11± 0.2). In Site 1, (X_{el}=2.74± 0.17, X_{ov}=2.64± 0.16), and Site 2,(X_{el}=2.8± 0.21, X_{ov}=2.77± 0.21, elephant damage is greater than overall total damage. Overall total damage encompasses all damaged inflicted on trees, including elephants and other herbivores. What this aspect of the analysis demonstrates is that on average, if a tree is damaged, it is damaged more by elephants than by other herbivores. While this is an indirect comparison, the methods of this study were not designed to collect data on other herbivores. However, this suggests that elephants inflict a greater proportion of damage than other herbivores, further emphasizing the role of elephants in damaging and killing adult trees.

Conversely, in 2009, total overall seedling damage is greater than elephant damage in all sites (Table 6). Site 3 exhibits the largest difference between seedling elephant and total damage (X_{el}=0.21± 0.07, X_{ov}=0.59± 0.08). In Site 1, (X_{el}=0.43± 0.13, X_{ov}=0.64± 0.17), and Site 2,(X_{el}=0.13± 0.08, X_{ov}=0.30± 0.06, elephant damage is greater than overall total damage. These finding indicate that other herbivores inflict a greater proportion of damage than elephants and suggests that other herbivores have an influence on seedling survival (See Table 7 for list of herbivore species visiting the Plots).

In general, the Sites exhibited little evidence of fire (Table 4). The level of fire damage has remained the same in Site 1 (X_{2009}=0± 0, X_{2003}=0± 0). However, the level of fire damage increased in Site 2 (X_{2009}=3± 0, X_{2003}=1.48± 0.17). Yet, this increase in fire damage could be due to the inclusion of stumps in the study and analysis (Appendix 1). In Site 3, the level of fire damage remained relatively the same (X_{2009}=1.71± 0.41, X_{2003}=1.68± 0.18). Overall, fire appears to have had a minor role within the Sites recently. These findings are consistent with the absence of reported fires within the Sites over the past six years (Jones per. com. 2009)

These findings could have important implications for Ndarakwai Ranch. Currently, trends indicate that each Site is shifting towards a grassland state. While this study was not designed to be representative of Ndarakwai as a whole and the studied habitats, the following section will increase the scale of the analysis to include Ndarakwai and the Western Kilimanjaro Basin and utilize the concept of ecological insularization to emphasize the overall negative survivorship curves seen in all Plots.

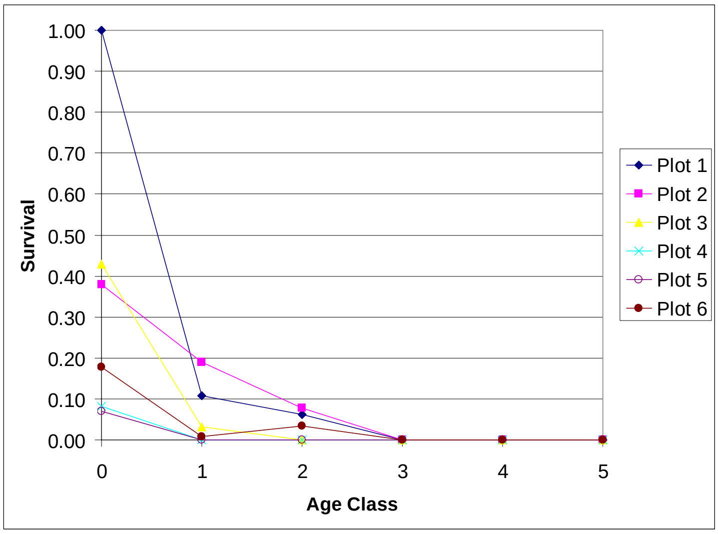

Figure 2 reprinted from Results Section.

The analysis below will discuss scenarios that could possibly maintain or increase the negative aspect of the survivorship curves shown above and conclude with scenarios that could possible ameliorate the effects.

Ecological insurlization poses a serious threat to savannah ecosystem integrity and ecological function (Gicholi 1996). It occurs when ecosystems are fragmented into smaller isolated habitats that are virtually ecological islands. This process of insurlization has been occurring in the West Kilimanjaro region and around Ndarakwai over the past decades with the population growth in Tanzanian being @2.8% per annum (Matthews per. com. 2009) propelling human encroachment and changes in land use practices. Primarily, agriculture and livestock within the region have fragmented the ecosystem. Several Maasai villages are located to the south and west of Ndarakwai ranch. These villagers are primarily pastoralists and often come in conflict with wildlife over resources. Pastoralism, altered by land use strategies including “protection”, can often lead to overgrazing, overstocking and environmental degradation. Ndarakwai also has large-scale farms to the north-east of Ndarakwai primarily for potatoes and wheat. In addition, given the land use pressures on Mt. Kilimanjaro, many small scale farmers inhabit the boundaries of the Ranch. These large & small-scale transformations of land use to agriculture and “overgrazing” dramatically alter the local habitat and drive out wildlife population thus decreasing the effective area for wildlife and ecosystem function. In addition, population growth has led to increased natural resource extraction, poaching and fire frequency. This is a concern within the area because it leads to trophic level cascades and further environmental degradation via primarily fuel wood collection, and charcoal making

Due to the decrease in suitable habitat, elephants and other wildlife populations are seeking refuge in protected areas such as Amboslei National Park (Kenya) and Mt. Meru & Kilimanjaro National Parks (Tanzania) and the only other “protected” area in the West Kilimanjaro basin - Ndarakwai. As a result, animal populations are being concentrated in smaller areas, well above ecologically sustainable density levels. Furthermore, these populations remain within these refuges and do not disperse due to the loss of corridors from human encroachment and land use changes. The large populations of permanent residents have placed immense pressure on the Ranch’s ecosystem and limited resources. Protected areas such as Ndarakwai are simply too small to encompass full ecosystems and can not support these population levels. Ndarakwai has seen an increase in wildlife concentrations and hosts a resident elephant population as well as migrant populations (Jones per comm. 2009). As discussed, elephants and herbivores have contributed to the decrease in adult trees within the Ranch. Thus, if the current trend of habitat fragmentation and compression of wildlife population continues, tree and seedling populations will further decrease and the negative slope of the survivorship curves will increase. Though my study was inclusive on the effects of fire, it would appear that increased fire frequency due to humans would only augment this decrease in survivorship.

Although ecological insularization poses a severe threat to the ecological function and biodiversity of Ndarakwai, there are some management strategies that could lessen the affects. Many of the issues afflicting Ndarakwai originate from outside of its' borders, making management of them difficult, especially human population increase and immigration with subsequent increase in poaching, illegal resource extraction, conversion of land for agriculture and "overgrazing". Ndarakwai attempts to prevent local communities from grazing and poaching within its' borders through the use of quasi-military forces. However, Ndarakwai currently participates in a community-outreach program that hopes to decrease poaching and foster "environmental sustainability". This program uses revenue from tourism to pay for tuition and lunches of school children. The goal of this program is to create amiable relationship between the local villages and ranch and encourage cooperation. Alleviation of poaching and unsustainable natural resource extraction could reduce the stress within the adjacent area and promote tree survival and woodland regeneration within the Ranch. However, this strategy relies on capital income, which is becoming scarcer during the global economic crisis, and might not be sustainable.

Fire suppression could also help to promote tree re-growth. As mentioned fire plays a critical role in it limiting bush encroachment by destroying seedlings. The suppression of fire could allow seedling growth and woodland replacement. However, this strategy requires capital and human investment which are costly.

Culling of wildlife population is an alternative strategy. Culling is the systematic removal of individual animals from populations within the area. This strategy has been effective in national parks of South Africa, Botswana and even the United States. However, permits can be expensive, particularly elephant permits. In addition, there are ethical considerations to this strategy.

An important aspect of this analysis, as with all ecological studies, is the significance of scale. We have discussed the issues within the local and regional level however these levels are affected by national and international policies and practices. Most notably, at the national and international level: poverty alleviation, education and population control and sustainable natural resource use. Before significant progress on the local level is made these issues must me dealt with on the national level.

Limitations & Biases

- The age classes are inaccurate. These classes were based on the previous study which noted that this method assumed that trees grew at the same rate and acknowledged and was imprecise. This study slightly modified the age classes, but this method remained inaccurate.
- The circumference of some trees, such as *mellifera*, had to be estimated due to the tangles/thorny nature of the plant.
- The researcher had limit knowledge on plant identification. Thus, some individuals might have been incorrectly identified. Particularly, seedlings which exhibit different morphologies during various stages of growth.
- The number of seedlings could be an underestimate. The grass in some of the plots was thick and high, above 1m., covering the seedlings
- Observer bias; this observers interpretation of the elephant and fire damage rating scale could have differed from previous study.
- Sample size is small

Recommendations

- A more extensive knowledge of plant identification would be invaluable. Lack of experience in this regard made collecting data difficult. Bring a good identification book for trees and shrubs.
- A more in-depth analysis of individual tree species ecology and life history would contribute significantly to the understanding of vegetative community dynamics. In addition, a further look into the role of other herbivores, such as wildebeest and zebra, in influencing plant community structure would also help shed more light on this complex system
- Bring lots of rope. This study used around 250 meters of rope.
- Remember to keep a keen eye, alert mind and enduring spirit.

Conclusion:

The main purpose of this study was to examine the effects of elephant and fire damage on vegetative community structure within Ndarakwai Ranch. The findings of this study indicate that the overall plant community structure within each Site has changed dramatically since 2003. Specifically, relative species abundance and age class structure have been altered. Overall number of adult trees decreased while the number of seedling increased. Elephants appear to have influenced the observed shift in community structure over the past six years. However, it was found that fire has played a minor role over the past six years. The study also indicates that herbivores, other than elephants might influence woodland regeneration through seedling browsing. While this study isn't representative of Ndarakwai as a whole, these findings along with the negative survivorship curves suggest that Ndarakwai will shift towards a grassland state in the future. This trend will be exacerbated by the processes of ecological insularization, currently occurring with in the region.

This study suggests that the management of Ndarakwai could take steps to counteract the effects of insularization and reverse the transition towards a grassland state. Some strategies, such as community-based outreach program, are already underway. However, additional strategies, such as culling of wildlife, could be implemented that would further alleviate the effects of insularization. Yet, the feasibility and sustainability of such programs is questionable. Further research is needed to better inform management over the decision-making process.

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