ABSTRACT

A BIOPHYSICAL ANALYSIS OF FOREST DIVERSITY PATTERNS AT MT. KASIGAU, KENYA

by Michael A. Henkin

This study examines how biophysical site conditions across a mountain landscape influence geospatial patterns of diversity and response in woody vegetation community types at Mt. Kasigau, Kenya. Statistical analyses tested relationships between temperature and moisture conditions, and eight ecologically classified vegetation types that might explain distribution patterns as gradients or patches. IDRISI Earth Trends Modeler determined relationships between seasonality from 2001-2012 in biophysical conditions and vegetation phenological response. Biophysical conditions show a steep altitudinal gradient that correlates with continuous change among six montane forest types, bordered by discrete occurrences of bushland and cloud forest. Vegetation phenology is distinctive along the gradient in the timing of maximum and minimum amounts of green vegetation. The study provides a fine scale analysis of biophysical conditions on the mountain as they relate to patterns of diversity in the vegetation types and correlate to seasonal changes in this tropical wet-dry climate.
A BIOPHYSICAL ANALYSIS OF FOREST DIVERSITY PATTERNS AT MT. KASIGAU, KENYA

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by
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# Table of Contents

List of Tables ................................................................................................................ iv
List of Figures .................................................................................................................. v
Dedication ........................................................................................................................ vi
Acknowledgement ......................................................................................................... vii

CHAPTER ONE .............................................................................................................. 1
  1.1 Introduction .......................................................................................................... 1

CHAPTER TWO ........................................................................................................... 5
  2.1 Research Context ................................................................................................ 5
    2.1.1 Biophysical conditions and landscape structure in montane environments ... 5
    2.1.2 Phenology and plant diversity ..................................................................... 6

CHAPTER THREE ......................................................................................................... 7
  3.1 Data and Methods ............................................................................................... 7
    3.1.1 Study Area .................................................................................................... 7
    3.1.2 Relationships between biophysical site conditions and patterns of diversity ........................................................................................................ 11
    3.1.3 Relationships between seasonality in biophysical conditions and vegetation response .................................................................................................. 13

CHAPTER FOUR ........................................................................................................ 16
  4.1 Results .................................................................................................................. 16
    4.1.1 Relationships between biophysical site conditions and patterns of diversity ........................................................................................................ 16
    4.1.2 Relationships between seasonality in biophysical conditions and vegetation response .................................................................................................. 24

CHAPTER FIVE .......................................................................................................... 33
  5.1 Discussion ............................................................................................................ 33
    5.1.1 Relationships between biophysical site conditions and patterns of diversity... 33
5.1.2 Relationships between seasonality in biophysical conditions and vegetation response
5.1.3 Limitations of the study
5.1.4 Conservation implications and future applications
REFERENCES
List of Tables

Table 1: Descriptions of the eight woody vegetation community types at Mt. Kasigau 10
Table 2: Monthly mean temperature in the bushland from June 2011 – May 2012 12
Table 3: Elevation pairwise comparisons 18
Table 4: MANOVA Results 23
Table 5: Annual total precipitation at Voi, Kenya (2001-2011) 25
List of Figures

Figure 1: Location of the study area at Mt. Kasigau, Kenya __________________________ 7
Figure 2: Location of 55 vegetation sample plots designated by their woody vegetation community type _________________________________________________ 9
Figure 3: Location of the 19 climate data loggers designated by their woody vegetation community type and one Hobo Pro v2 Temperature-Humidity data logger in Semi-evergreen woodland ___________________________________________ 11
Figure 4: Landcover map of Mt. Kasigau and surrounding lowlands _____________ 15
Figure 5: Elevational gradients in climate parameters at Mt. Kasigau for June 2011 – June 2012 (annual), and in February 2012 (warm season) and July 2011 (cool season) 16
Figure 6: Elevation Boxplots ________________________________________________ 18
Figure 7: Slope and Curvature Boxplots ______________________________________ 19
Figure 8: Slope in relation to the vegetation types along an altitudinal gradient ___________________________________________________________ 20
Figure 9: Annual temperature in relation to the vegetation types along an altitudinal gradient _________________________________________________ 21
Figure 10: Temperature, Dew Point and Relative Humidity Boxplots______________ 22
Figure 11: Mean monthly precipitation at Voi, Kenya (2001-2011) _______________ 24
Figure 12: Mean monthly EVI values (2001 to 2011) ____________________________ 26
Figure 13: Regional annual trend in the amount of greeness from 2001-2012 _____ 26
Figure 14: Spatial patterns of change in EVI per 16-days for the Kasigau area_______ 27
Figure 15: Change in mean annual green vegetation for each vegetation type _____ 28
Figure 16: Fitted seasonal curves for vegetation types in 2012 _______________ 29
Figure 17: Fitted seasonal curves for vegetation types (2001-2012 _____________ 32
Dedication

To Howard, Susan, Melissa, Samuel and Rosie whose unconditional love and support is beyond what any words can describe. Thank You.

I Love You All.
Acknowledgement

Thank you Dr. Kim Medley and Dr. John Maingi for providing invaluable guidance, support and encouragement. Thank you Kim for all of your patience and yes even for the nudging. Thank you Robbyn Abbitt for also providing excellent advice. I am very fortunate to have met and developed relationships with each of you over the past 4-5 years.

Thanks to Moses Mwamodo, Juma Zungi, Danson Mwatate, Nicholus Kangai and Nashon Njege for their invaluable guidance and sharing of knowledge at Mt. Kasigau. Special thanks to the entire Kasigau community who opened their arms and instantly made me feel at home. Thank you Ken Maingi, your friendship and assistance are much appreciated and kept me sane in the field.

Thanks to my fellow Miami University graduate students who helped me but more than often provided distractions, especially the research triangle. I am grateful for the strong bonds that we formed. Thanks to the Miami University Department of Geography who made this all happen.

Thank you National Science Foundation for supporting my assistantship and research.

Chavucha sana
CHAPTER ONE

1.1 Introduction

Mountains comprise 24% of Earth’s land surface, contain one third of its terrestrial plant diversity, and supply water to one half of the world’s population (Price 2003; Körner 2007). Classic biogeographic studies by von Humboldt in the nineteenth century certainly provide an important foundation for mountain research that maps landscape patterns of diversity, relates physical-environmental conditions to vegetation types, and considers the value of and modification of mountain resources for human livelihoods (Funnel and Price 2003). The applied conservation significance of mountain research, however, gained prominence in 1993 when Chapter 13, “Managing Fragile Ecosystems: Sustainable Mountain Development” was included in Agenda 21 for sustainable development (Funnel and Price 2003; Debarbieux and Price 2008). The United Nations established 2002 as International Year of Mountains, recognizing the importance of mountains to biodiversity conservation and human livelihoods, and the susceptibility of montane systems to profound environmental change (Funnel and Price 2003; Debarbieux and Price 2008).

Montane forests are typically more diverse compared to nearby lowland vegetation types (Price 2003) in part due to the spatially heterogeneous and temporally unique conditions that characterize mountains (Lomolino 2001; Körner et al. 2011). Many montane regions are considered Biodiversity Hotspots (17 of 34 Biodiversity Hotspots sensu Conservation International; Meyers et al. 2000) and Global 200 Ecoregions (sensu World Wildlife Fund; Olson et al. 2001) because of their high species density, number of endemic plants and animals, and recognized threat from human population pressures. For example, the Tropical Andes contains the largest number of endemic plants of all hot spot regions (Myers et al. 2000) and the Eastern Arc Forest ecoregion, part of the Eastern Afromontane hotspot, has the highest concentration of endemic species (number per unit area), of all conservation priority areas (Olson et al. 2001; Newmark 2002).

Diversity patterns for and among mountains occur as environmental gradients of elevation and climate, geographic gradients of size, and historical gradients of relative biogeographic isolation and connection (Gentry 1988; Lomolino 2001; Körner et al. 2011). Diversity studies on mountains in the tropics often focus on evergreen montane and cloud forest systems because they show highest species richness at locations (alpha diversity) or among
locations for the community type (beta diversity; sensu MacArthur 1965). Tropical montane cloud forests were historically given *de facto* protection for their unique diversity conditions (Scatena et al. 2010), and accordingly comprise many of the montane biodiversity hotspots and ecoregions (Bruijnzeel et al. 2010). However, diversity for the mountain system should also consider gamma diversity, or the cumulative sum of diversity among all community types on the mountain (Whittaker 1960) as they might occur across multiple gradients in a heterogeneous montane system.

Two dominant perspectives guide studies of landscape heterogeneity, as discrete or continuous, and debate continues on which view most accurately describes landscape structure and its influence on ecological function and diversity patterns (Moss 2005; Kent 2007). The discrete perspective views landscape heterogeneity as a ‘mosaic of patches’ (sensu Forman 1995) determined by discontinuity in environmental conditions and congruence among species adaptations to environmental conditions as community types (Forman 1995; McGarigal and Cushman 2002). Discrete hypotheses best explain the zonation of vegetation bounded by “critical altitudes” (Hemp 2006, 28) such as those defined by Kitayama (1992) for Mt. Kinabalu, Malaysia, Boughey (1955) for Mt. Cameroon, Cameroon and Hemp (2006) for Mt. Kilimanjaro, Tanzania. McGarigal and Cushman (2002), however, argue that landscape diversity patterns are better described as continua in response to environmental gradients and ecological processes. Research documenting montane patterns of vegetation diversity as continua of change includes Hamilton (1975) for forests in Uganda, Lovett (1996) for the West Usambara, Nguru and Udzungwa in Tanzania, and Vázquez and Givnish (1998) for the Sierra de Manantlán, Mexico.

Spatial patterns, as gradients or patches, certainly relate to environmental conditions but are also modified by complex histories of human influences (Olsson et al. 2000; Tilman and Lehman 2001) and for mountains, their reliance on montane resources (Smiet 1992; Olsson et al. 2000). Human influences drive changes in montane land cover (Olsson et al. 2000) and vegetation structure and composition (Smiet 1992; Ramírez-Marcial et al. 2001; Armenteras and Villareal 2003) that may modify species relationships with physical-environmental conditions and accordingly patterns of diversity as mosaics or gradients across a landscape.

Many montane forests of biodiversity significance occur in tropical regions where most forest types experience seasonality in rainfall (Walter and Leith 1976). Total precipitation,
amount of rainfall received during the wet season, and timing and duration of dry periods influence change in growth form (from deciduous to semi-evergreen to evergreen, Walter 1971). The occurrence and duration of dry periods generally correlate with latitude across the tropics (Holdridge 1967) but they also exist along altitudinal gradients (Körner 2007). According to Leith (1974), vegetation adapts to seasonality through phenological changes such as color change, leaf fall, and new leaf emergence that can provide their own measure of vegetation diversity across heterogeneous montane landscapes. Phenological change, therefore documented through the use of time-series analyses of remotely-sensed vegetation indices, provides an important measure of spatial patterns of diversity, as gradients or patches among vegetation types in tropical seasonal environments, and may provide an important indicator of short-term climate change (Hüttich et al. 2009; van Leeuwen et al. 2010).

The purpose of this study is to examine how biophysical site conditions across a mountain landscape influence landscape patterns of diversity in montane forest community types at Mt. Kasigau, Kenya, the most northeastern mountain in the Eastern Arc. The Eastern Arc mountain forests are important for biodiversity conservation because of their high species density, high degree of endemism, and a very high degree of forest fragmentation (Lovett 1993; Schipper and Burgess 2004; Burgess et al. 2007). The forests are hypothesized to be among the oldest in Africa, providing an important refuge during the Pleistocene and site for the persistence and diversification of species (Fjeldså and Lovett 1997; Burgess et al. 2007). The Eastern Arc Mountains occur in a tropical seasonal environment, where seasonality in precipitation forms a dominant climatic factor that determines forest limits, distribution patterns, and phenological response (Lovett 1993).

Two questions guided the research in this setting:

1. What relationships exist between biophysical site conditions and patterns of diversity, as gradients or patches, in woody vegetation community types at Mt. Kasigau in Kenya?

2. What relationships exist between seasonality in biophysical conditions and vegetation response that might explain spatial patterns of diversity as gradients or patches across the mountain landscape?

The study uniquely focuses on diversity patterns at Mt. Kasigau, as gradients or patches among forest types and their cumulative contribution to landscape heterogeneity for the
mountain. Most profound are the vegetation changes from tropical dry bushland to wet cloud forests that occur with an increase in elevation of approximately 1000 m in only two kilometers of distance on the mountain. Biophysical site conditions are hypothesized to vary over short distances across this landscape (Körner 2007), contributing to changes up and potentially across the complex mountain landscape in a short elevational range. Phenological change also provides a potentially sensitive indicator of diversity patterns among vegetation types that is particularly important in tropical seasonal environments.

Under a changing climate, applied biogeographic research on how diversity patterns relate to biophysical site conditions and their change over the short-term are critical to projections of how forests may change in the future. For example, Walther et al. (2002) document a variability of about 10% from average annual precipitation rates and about 0.7 °C from average annual temperatures over each decade for the past 30 years in southeastern Kenya, and the International Panel on Climate Change (IPCC) predicts that seasonal climate conditions are only expected to become more unpredictable in the future (IPCC 2007). Shifts in species occurrences and their phenological change may also be a sensitive indicator of how biophysical site conditions are changing in fragile environments.
CHAPTER TWO

2.1 Research Context

2.1.1 Biophysical conditions and landscape structure in montane environments

The analysis of relationships between community diversity and environmental heterogeneity is a key issue in ecological research (Zhang and Zhang 2011). Topographic and climatic variables are commonly explained as primary determinants of landscape patterns, especially in montane environments where they change over short distances (Hadley 1994; Rey Benayas 1995; Svenning 2007), because of their spatial dependence and consequent influences on the spatial patterns of species distributions and diversity in vegetation types (Franklin 1995; Cayuela et al. 2006). Topographic parameters, including elevation and slope serve as “surrogate measures” (Cayuela et al. 2006, 604) of processes that directly affect vegetation growth (Cayuela et al. 2006; Gallardo-Cruz et al. 2009), including insolation (Lomolino 2001; Cayuela et al. 2006; Zhang and Zhang 2011), soil water conditions (Cayuela et al. 2006; Zhang and Zhang 2011), nutrient availability (Cayuela et al. 2006) and temperature (Lookingbill and Urban 2003) because field data of these parameters in tropical montane landscapes are infrequent (Cayuela et al. 2006). Topographic parameters are easily compiled from Digital Elevation Models (DEM) that provide a regional view of changing conditions across a landscape (Lookingbill and Urban 2003; Cayuela et al. 2006; Gallardo-Cruz 2009).

Climatic measures of temperature and moisture, when available, add resolution to these analyses because of their direct physiological effects on vegetation (Cayuela et al. 2006). Temperature and moisture conditions exhibit distinct patterns of change along altitudinal gradients (Körner 2007) and show strong relationships with geospatial patterns of community diversity (Cayuela et al. 2006; Gallardo-Cruz et al. 2009). Methods of obtaining climate data include the interpolation of nearby weather stations (Cayuela et al. 2006), global climate image data (Gallardo Cruz et al. 2009), and from established loggers at physical sites (Lookingbill and Urban 2003). For montane settings, analyses of topographic and climatic variables show distribution patterns that correlate with continuous (e.g., Lovett 1996 for the Eastern Arc) and discrete changes in forest types (e.g., Hemp 2006 for Mt. Kilimanjaro).

Quantitative analyses of vegetation and biophysical relationships are important for testing hypotheses on patterns of vegetation diversity (Zhang and Zhang 2011). Statistical techniques include Pearson correlations to test the significance of relationships between biophysical
parameters (Chain-Guardarrama et al. 2012), analyses of variance to test relationships between biophysical parameters and vegetation types, and pairwise comparisons for determining the significance of differences between vegetation community types (Gallardo-Cruz et al. 2009).

2.1.2 Phenology and plant diversity

Phenological metrics (phenometrics) are measures of vegetation response to biophysical conditions (Hermance et al. 2007; van Leeuwen 2008; van Leeuwen et al. 2010), providing a unique measure of structural or physiognomic changes across a montane landscape. Phenometrics look for changes in leaf conditions over the growing season, mostly measured by the amount of greenness in the canopy (van Leeuwen et al. 2010). Climatic and topographic variables directly influence plant physiological process (Franklin 1995), affecting the timing, length and spatial patterns of growth seasons (van Leeuwen et al. 2010). Therefore, phenometrics provide unique spectral signatures of plant diversity that may be easily captured and compared through the use of remote sensing (van Leeuwen et al. 2010; Hermance et al. 2007). Many phenology studies use remotely sensed vegetation index (VI) time series data to derive phenometrics (van Leeuwen et al. 2010).

The advanced Very High Resolution Radiometer (AVHRR) was at first the only sensor to obtain global Normalized Difference Vegetation Index (NDVI) data until the Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor was launched aboard the Terra satellite in 1999. The MODIS sensor provides an improvement for studying ecological processes due to its increased spectral, spatial and temporal resolution (Clark et al. 2010). The MODIS sensor compiles data for two vegetation indices, NDVI and Enhanced Vegetation Index (EVI), which were “designed for precise, seasonal and inter-annual monitoring of the earth’s vegetation,” (Justice et al. 1998, 1234). EVI measures the amount of green vegetation per pixel derived from an algorithm based on the red, near infrared and blue bands, and environmental coefficients. Unlike NDVI, EVI reduces soil and atmospheric noise and does not saturate in high biomass areas (Li et al. 2010). Seasonal Trend Analysis (STA) created at Clark Labs provides an effective analysis of VI time series data for ecological monitoring of vegetation plant response (Eastman et al. 2009). STA produces outputs that show seasonality (i.e. amount of green vegetation, change in amount of green vegetation, and timing of green vegetation) for areas of interest (Eastman et al 2009; Neeti et al. 2012).
CHAPTER THREE

3.1 Data and methods

3.1.1 Study Area

Mount Kasigau (3° 49’ 25” S, 38° 39’ 40” E), rises steeply from arid plains to a moist summit, Nyangala, at 1641 m in southeastern Kenya (Figure 1). The study area (~115 km²) includes the mountain and surrounding Acacia-Commiphora bushland. The geology of the mountain consists of granitoid gneiss, resulting in steep slopes and high topographic heterogeneity (Saggerson 1962). A digital elevation model (DEM) for the study area at a 30 m resolution shows a range in slope from 0 to 70.7 degrees with an average slope of 5.87 degrees and a high range in curvature between convex and concave slopes. The summit faces northeast toward Makwasinyi village.

Figure 1: Location of the study area at Mt. Kasigau, Kenya.
Mt. Kasigau (black star) located in southeastern Kenya is the most northeastern mountain in the Eastern Arc Mountain Forest ecoregion (distribution represented in green). The Worldview-2 satellite true color image to the right (1.8 m resolution) shows the mountain, the surrounding lowland bushland, the cultivated lands and the village settlements.
The region is semiarid and experiences two rainfall seasons that are designated locally as the long rains from March to May that capture moisture from southeast monsoon winds and the short rains from October to December that capture moisture from northeast monsoon winds. Annual rainfall for the surrounding plains, measured at Voi, Kenya for the years 2001 to 2011 shows great inter-annual variability in the timing and amount of rainfall received during the two rain seasons with measurements as low as 210 mm (2003) and as high as 800 mm (2004). The mountain captures sufficient moisture from the Indian Ocean to support evergreen cloud forests at its summit and a sustainable water source for the Kasigau Taita, who live at the mountain’s base in five main villages: Rukanga, Jora, Bungule, Makwasinyi, and Kiteghe (Figure 1).

Different vegetation types occur along an altitudinal gradient from deciduous bushland (<650 m) at its base, through deciduous and semi-evergreen montane woodland (650 to 1000 m) and to evergreen forest (>1000 m). A biogeographical survey conducted by Medley and Maingi (in press) describes eight woody vegetation community types at Mt. Kasigau that provide a basis for the biophysical analyses of diversity patterns (Figure 2, Table 1): *Acacia-Commiphora* bushland; *Euphorbia quinquecostata* woodland; Lower montane woodland I; Lower montane woodland II; Semi-evergreen woodland; Evergreen forest; Riverine forest; and Cloud forest. From 2002-2006, Medley established 55 50 x 20 m (0.1 ha) plots along altitudinal transects from each of the five villages, measuring large trees with a diameter at breast height >10 cm. The eight vegetation community types were derived from Cluster Analysis and Indicator Species Analysis (sensu McCune and Grace 2002) based on the relative importances of the trees, providing a classification of the woody vegetation types.
Figure 2: Location of 55 vegetation sample plots designated by their woody vegetation community type.
<table>
<thead>
<tr>
<th>Forest Community Type</th>
<th>Elevation range (m)</th>
<th>Tree density (#/ha)</th>
<th>Stem basal area (m²/ha)</th>
<th>Most important trees (RI%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acacia-Commiphora bushland</strong></td>
<td>520-930</td>
<td>150</td>
<td>5.05</td>
<td><em>Mantikaramochistia</em> (10.0), <em>Acacia mellifera</em> (7.5), <em>Commiphora holziara</em> (6.7), <em>Boswellia neglecta</em> (5.6), <em>Acacia senegal</em> (5.5)</td>
</tr>
<tr>
<td><strong>Riverine forest</strong></td>
<td>610-800</td>
<td>337</td>
<td>32.15</td>
<td><em>Tabernaemontana stapfiana</em> (29.0), <em>Rauvolfia caffra</em> (17.6), <em>Sorindeia madagascariensis</em> (14.2), <em>Trichilia emetica</em> (12.8), <em>Ludia martiana</em> (12.7)</td>
</tr>
<tr>
<td><strong>Lower montane woodland II</strong></td>
<td>650-915</td>
<td>197</td>
<td>16.86</td>
<td><em>Acacia robusta subsp. usambarensis</em> (12.1), <em>Ficus ingens</em> (12.1), <em>Leucauliodiscus fraxinifolius sups. vaughanii</em> (7.0), <em>Albizzia zimmermanii</em> (6.1), <em>Dombeya kirkii</em> (4.0)</td>
</tr>
<tr>
<td><strong>Lower montane woodland I</strong></td>
<td>600-988</td>
<td>313</td>
<td>11.47</td>
<td><em>Commiphora baulensis</em> (17.0), <em>Cassipourea celestroides</em> (6.9), <em>Manilkara sulcata</em> (6.3), <em>Ziziphus mucronata</em> (5.4), <em>Acacia ethiaca</em> (5.3)</td>
</tr>
<tr>
<td><strong>Euphorbia quinquecostata woodland</strong></td>
<td>755-955</td>
<td>725</td>
<td>28.99</td>
<td><em>Euphorbia quinquecostata</em> (59.9), <em>Manilkara sulcata</em> (5.5), <em>Commiphora baulensis</em> (4.9), <em>Obetia radula</em> (2.9), <em>Cussonia hoistei</em> (2.7)</td>
</tr>
<tr>
<td><strong>Semi-evergreen woodland</strong></td>
<td>890-1250</td>
<td>429</td>
<td>16.39</td>
<td><em>Commiphora eminii subsp Trifoliatata</em> (15.1), <em>Trichlocladus ellipiticus</em> (13.0), <em>Cussonia spicata</em> (8.0), <em>Manilkara discolor</em> (6.2), <em>Apodytes dimidiata</em> (5.3)</td>
</tr>
<tr>
<td><strong>Evergreen forest</strong></td>
<td>1086-1380</td>
<td>353</td>
<td>50.68</td>
<td><em>Newtonia buchananii</em> (49.5), <em>Strombosia scheffleri</em> (7.9), <em>Syzygium guineense</em> (5.9), <em>Xylocas monospora</em> (3.2), <em>Cassipourea gummiiflua</em> (2.7)</td>
</tr>
<tr>
<td><strong>Cloud forest</strong></td>
<td>1470-1640</td>
<td>674</td>
<td>57.47</td>
<td><em>Syzygium mickletiwaetii</em> (49.5), <em>Panecia golungensis</em> (20.0), <em>Newtonia buchananii</em> (6.8), <em>Apodytes dimidiata</em> (6.6), <em>Tabernaemontana stapiflana</em> (3.8)</td>
</tr>
</tbody>
</table>
3.1.2 Relationships between biophysical site conditions and patterns of diversity

Topographic and climatic parameters were measured at the formerly established ecological plot locations to indicate the biophysical heterogeneity of Mt. Kasigau in relation to vegetation diversity. From June 13-17, 2011, Hobo Pro v2 Temperature-Humidity data loggers were placed in 20 plots stratified by their community type: *Acacia-Commiphora* bushland (4), Riverine evergreen forest (1), Lower montane woodland II (1), Lower montane woodland I (2), *Euphorbia quinquecostata* woodland (2), Semi-evergreen woodland (6), Evergreen forest (3), and Cloud forest (1) (Figure 3). The loggers recorded temperature, dew point, and relative humidity at hourly intervals each day. These data were extracted from the data loggers June 15-
26, 2012. One data logger placed in evergreen forest collected data incorrectly, reducing the number of data collection sites to 19 (n=19) for the climate variables. Topographic variables, included elevation, slope, and slope curvature. These topographic variables were obtained from an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM, 30 m) at each of the 55 vegetation sample plot locations using ArcGIS’s Spatial Analyst extension. Aspect is important on the mountain because it influences climate conditions other than insolation but was omitted from the study because the resolution at which the data was compiled (at each plot) is not suitable for analysis. The aspect of the watershed that each plot belongs is important but was only considered qualitatively in the interpretation of the other topographic parameters because of the low number of sample plots for a vegetation type in each village watershed.

I first examined how temperature and moisture conditions varied on Mt. Kasigau in relation to elevation, slope, and curvature. The tested climate parameters included annual (June 13-17, 2011 to June 15-26, 2012), cool season (July 2011), and warm season (February 2012) average temperatures, dew point, and relative humidity. Linear regressions were performed to examine gradients of temperatures (e.g. Table 2), dew point and consequent relative humidity with elevation, and the corresponding lapse rates for the three representative time periods. I was interested in the steepness of the temperature-moisture gradient and how it varied seasonally for the mountain.

Second, I explored how the biophysical parameters varied by woody vegetation community type on the mountain. Box plots compiled from the data first showed how the 55 ecological plots, classified by their woody vegetation community type, compared in relation to the topographic attributes that included elevation, slope, and slope curvature. Pairwise analysis of variance calculated for elevation tested whether particular vegetation types were distinctive for this biophysical attribute, suggesting a more discrete

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2011</td>
<td>23.01</td>
</tr>
<tr>
<td>July 2011</td>
<td>22.49</td>
</tr>
<tr>
<td>August 2011</td>
<td>22.50</td>
</tr>
<tr>
<td>September 2011</td>
<td>22.93</td>
</tr>
<tr>
<td>October 2011</td>
<td>23.48</td>
</tr>
<tr>
<td>November 2011</td>
<td>24.83</td>
</tr>
<tr>
<td>December 2011</td>
<td>25.49</td>
</tr>
<tr>
<td>January 2012</td>
<td>26.20</td>
</tr>
<tr>
<td>February 2012</td>
<td>26.54</td>
</tr>
<tr>
<td>March 2012</td>
<td>26.10</td>
</tr>
<tr>
<td>April 2012</td>
<td>25.32</td>
</tr>
<tr>
<td>May 2012</td>
<td>24.48</td>
</tr>
<tr>
<td><strong>Annual Average:</strong></td>
<td><strong>24.37</strong></td>
</tr>
</tbody>
</table>

Table 2: Monthly mean temperature in the Bushland from June 2011 – May 2012
These data are from Mwandoe’s Boma located in Jora.
distribution, whereas no significant differences and overlap among the boxplots suggested
continuous distribution. Box plots also showed how the 19 ecological plots classified by their
community type compared in relation to climatic attributes, including temperature, dew point and
relative humidity.

Third, I used Multivariate Analysis of Variance (MANOVA) to determine statistical
differences among community types based on the topographic and climatic biophysical
parameters. Separate MANOVA tests were performed for all the community types and
topographic parameters (n = 55), the lower-montane communities (Riverine evergreen forest,
Lower montane woodland II, Lower montane woodland I and Euphorbia quinquecostata
woodland, n =24) and topographic parameters, and for the woody vegetation community types
with topographic and annual climate parameters (n = 19). Climate variables on their own were
not included because the data did not follow a normal distribution, which is necessary for
MANOVA. ANOVA, a simple Analysis of Variance, was then conducted to test for differences
among the individual biophysical parameters as an influence on the constructed multivariate
model.

3.1.3 Relationships between seasonality in biophysical conditions and vegetation response

I first focused on regional analyses of relationships between intra- and inter-annual
moisture conditions and vegetation phenological response. Mean monthly rainfall data for 2001-
2011 were collected from the Voi weather station located in the surrounding plains about 60 km
northwest of Mt. Kasigau (Fig 1). These data supported a measure of short-term inter-annual and
seasonal intra-annual variability in rainfall that could be related to vegetation response for the
region and among the vegetation types.

Remotely sensed time series data were obtained to examine the amount of green
vegetation and change in the amount of green vegetation over a twelve-year period from 2001
(the earliest dataset for the region) to 2012. 16-day EVI composite data at a spatial resolution of
250 m were obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) data
(MOD13Q1). The images were re-projected to WGS84 UTM Zone 37S and subset to a study
region surrounding the mountain (1042.93 km²). EVI values were extracted from each MODIS
pixel and mean monthly averages were computed to represent a measure of the amount of green
vegetation.
To examine relationships between this important biophysical parameter and vegetation response (amount of green vegetation), Pearson’s correlations between rainfall and EVI values for 2001-2011 were calculated for the eleven years and for each respective year. The time series data were then converted to a format supported by IDRISI Selva and imported into the IDRISI Selva Earth Trends Modeler (ETM) (Eastman 2012). Seasonal trend analysis (STA) was used in IDRISI ETM to calculate and map the twelve-year (2001-2012) trend in greenness for the Kasigau region based on a Thiel-Sen estimator (Eastman 2012). Ordinary Least Squares (OLS) series trend analysis visualizes the spatial patterns of change per 16 days in green vegetation at two different temporal scales: twelve years (2005-2012) and four years (2001-2004, 2005-2008 and 2009-2012).

The second part of the analysis compared how phenology varied among each woody vegetation type. The woody vegetation community data used in the analysis were derived from a land cover map that Maingi (2012) generated from 12 reflective bands and two thermal bands from two Landsat images (acquired 10/07/10 and 03/16/11), six Tasseled Cap Transformation bands and five DEM-derived topographic measures bands. The land-cover classification corresponded for the most part with the woody vegetation community types derived from the ecological plot samples (cf. Figure 4 and Figure 1). Lower Montane Woodland I and Lower Montane Woodland II (Table 1) were difficult to delineate so they were combined into a single Lower montane woodland class. Maingi created multiple land classes for the bushland, but the largest class (Commphiora bushland) was selected for the analysis. The land cover map was then resampled to 250 m. Vector shapefiles were created to represent contiguous pixels that contain greater than 80% of each respective vegetation type.
First, Seasonal Trend Analysis (STA) was used to describe the overall trend in the growth of vegetation from 2001 to 2012 for each community type based on a Thiel-Sen estimator (Eastman 2012). Second, STA was used to create fitted seasonal curves for each vegetation community type for a twelve-year comparison and also for a detailed intra-annual comparison of seasonality in 2012 among the woody vegetation community types (Eastman 2012). Comparative analyses over the 12 years focused on changes over time in the amount of green vegetation and inter-annual timing of maximum and minimum green vegetation. For 2012, I especially considered differences among the community types in their intra-annual seasonality and phenometric measures (i.e. amount of maximum and minimum greenness and timing of maximum and minimum greenness).
4.1 Results

4.1.1 Relationships between biophysical site conditions and patterns of diversity

The steep rise in elevation at Mt. Kasigau corresponds most directly with a decline in temperature and an increase in moisture availability (relative humidity), but actual moisture in the atmosphere (dew point) declines (Figure 5). The study made a comparison of the annual
trend with trends for the warmest and coolest months during the study period. Linear regressions for temperature versus elevation show significant declines in July \((R^2 = 0.9661)\) with a lapse rate equal to 9.2° C per 1000 m, February \((R^2 = 0.9416, 8.4° C \text{ per } 1000 \text{ m})\) and the year \((R^2 = 0.984, 8.1 °C \text{ per } 1000 \text{ m})\). Dewpoints are highest during the warm season (February), similar to annual mean conditions, and decline with elevation by approximately 3° C for the three time periods (Figure 5).

The significant rise in relative humidity, or the availability of moisture, is therefore explained by the steep lapse rates in temperature, with higher measures for July and the year. Moisture availability at the upper elevations is greatest during the cool season (>95%) but even annual mean conditions for the mountain show the persistence of high moisture (≥90%) at the upper elevations (>1200 m).

Vegetation community types are distributed along the altitudinal gradient as environmentally discrete and overlapping in their biophysical conditions (Figure 6). The *Acacia-Commiphora* bushland occupies the lowest elevations (range: 526 – 1138 m, mean= 666.7 m) but shows exception for two plots at 895 m and 1138 m designated as bushland, that have characteristic bushland species. The Cloud forest occupies the highest elevations (range: 1479 – 1642 m, mean = 1537 m). The lower montane vegetation types overlap altitudinally, including Riverine evergreen (range 640 – 806 m, mean = 729 m), Lower montane woodland II (range: 663 – 931 m, mean = 794), Lower montane woodland I (range: 604 – 1008 m, mean = 827 m) and *Euphorbia quinquecostata* woodland (range: 722 – 918 m, mean= 836 m). The Semi-evergreen woodland (range 894 – 1250 m, mean=1085 m) and the Evergreen forest (range 949 – 1444 m, mean= 1230 m) occur mostly above these lower-montane types and distinctly below the Cloud forest. Among the communities, a pairwise analysis of variance that tests differences in relation to elevation is only statistically significant for the Cloud forest (prob. < 0.05) in relation to all other vegetation types (Table 3). The *Acacia-Commiphora* bushland and the lower montane vegetation types are statistically different from the upper montane semi-evergreen woodland, evergreen and cloud forest types but the lower elevated communities are not significantly different from each other, respectively.
Figure 6: Elevation Boxplots

Table 3: Elevation pairwise comparisons
Results in bold identify significant (< 0.05) differences in elevation between the two compared vegetation types.

<table>
<thead>
<tr>
<th></th>
<th>Acacia-Commiphora Bushland</th>
<th>Riverine Evergreen Forest</th>
<th>Lower Montane Woodland II</th>
<th>Lower Montane Woodland I</th>
<th>Euphorbia quinquecostata Woodland</th>
<th>Semi-evergreen Woodland</th>
<th>Evergreen Forest</th>
<th>Cloud Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia-Commiphora Bushland</td>
<td>1</td>
<td>0.997</td>
<td>0.696</td>
<td>0.174</td>
<td>0.271</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Riverine Evergreen Forest</td>
<td></td>
<td>1</td>
<td>0.998</td>
<td>0.962</td>
<td>0.958</td>
<td>0.01</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lower Montane Woodland II</td>
<td></td>
<td></td>
<td>1</td>
<td>0.999</td>
<td>0.999</td>
<td>0.014</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lower Montane Woodland I</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>0.007</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Euphorbia quinquecostata Woodland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>0.037</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Semi-evergreen Woodland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>0.404</td>
<td>0</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>0.037</td>
</tr>
<tr>
<td>Cloud Forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Differences among the vegetation types by slope and curvature show greater overlap and are not different among the different vegetation types (P > 0.05) (Figure 7). The lowest slopes (mean slope of 6.17°) occur in the *Acacia-Commiphora* bushland and highest slopes were recorded for the plots in Semi-evergreen woodland (mean = 20.72°) and the Evergreen forest (mean = 25.48°). Overall, the slope measures show impressively steep slopes and broad ranges for the vegetation types (Figure 8). All community types occur on flat, convex (positive curvature values) and concave (negative curvature values) sites, demonstrating high variance in slope curvature. The range in values (-5.22 – 5.11) suggest a complex heterogeneous topography.

![Figure 7: Slope (a) and Curvature (b) Boxplots](image-url)
Vegetation types also show discrete and overlapping characteristics in their temperature and moisture biophysical conditions (Figures 9 and 10). Temperature, which correlates with elevation (Figure 9) shows a gradient of change that supports differences among lowland bushland, lower montane communities (Riverine evergreen forest, Lower montane woodland II, Lower montane woodland I and *Euphorbia quinquecostata* woodland) and upper montane communities (Semi-evergreen woodland, Evergreen forest) and the Cloud forest. Dew points decrease with increasing elevation and have high degrees of overlap among the woody vegetation community types. These changes in the amount of moisture held in the atmosphere appear to support zones in contrast to the more linear gradient of change in temperature. Relative humidity increases with elevation, with overlap among the lower montane communities and no overlap with the upper montane communities. Distinct communities include the *Acacia-Commiphora* bushland that experiences the highest temperatures, highest dewpoints and lowest relative humidity, and the Cloud forest that experiences the lowest temperatures, lowest dew points and highest relative humidity.
Figure 9: Annual temperature in relation to the vegetation types along an altitudinal gradient
Multivariate comparisons among the vegetation community types further support these descriptive interpretations. First, a MANOVA for the mean topographic parameters are statistically different among communities, but the univariate analysis of each parameter shows statistical differences for only elevation and slope (Table 4). Second, a MANOVA comparing the topographic conditions among the lower-montane communities is not significant. Third, a
MANOVA test of differences among the communities based on their mean topographic and climate attributes is significant, and the univariate analysis shows that elevation, temperature, dew point, and relative humidity make uniquely significant contributions to the multivariate model.

Table 4: MANOVA Results
Results for the MANOVA tests and univariate tests, (P < 0.05)

<table>
<thead>
<tr>
<th>Topographic Parameters for all forest community types (N=55)</th>
<th>F</th>
<th>df</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANOVA</td>
<td>4.141</td>
<td>8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Elevation</td>
<td>20.575</td>
<td>8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Slope</td>
<td>4.832</td>
<td>8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Slope Curvature</td>
<td>1.243</td>
<td>8</td>
<td>0.296</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topographic Parameters for Mid-montane forest community types (N=23)</th>
<th>F</th>
<th>df</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANOVA</td>
<td>0.307</td>
<td>3</td>
<td>0.996</td>
</tr>
<tr>
<td>Elevation</td>
<td>0.717</td>
<td>3</td>
<td>0.553</td>
</tr>
<tr>
<td>Slope</td>
<td>0.334</td>
<td>3</td>
<td>0.801</td>
</tr>
<tr>
<td>Slope Curvature</td>
<td>0.427</td>
<td>3</td>
<td>0.735</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topographic and Climatic Parameters (Annual, N=19)</th>
<th>F</th>
<th>df</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANOVA</td>
<td>3.686</td>
<td>7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Elevation</td>
<td>12.128</td>
<td>7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Slope</td>
<td>1.66</td>
<td>7</td>
<td>0.217</td>
</tr>
<tr>
<td>Slope Curvature</td>
<td>2.954</td>
<td>7</td>
<td>0.052</td>
</tr>
<tr>
<td>Temperature</td>
<td>3.522</td>
<td>7</td>
<td>0.031</td>
</tr>
<tr>
<td>Dew Point</td>
<td>9.222</td>
<td>7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>12.558</td>
<td>7</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
4.1.2 Relationships between seasonality in biophysical conditions and vegetation response

Total monthly rainfall between 2001-2011 at Voi, Kenya (representative of the lowlands surrounding Mt. Kasigau) shows distinct seasonality and varied inter-annually (Figure 11, Table 5). Annual rainfall averaged 603 mm and ranged from a high of 800 mm in 2004 to a low of 255 mm in 2007 (Table 5). The dry season for all years, occurred in February after the short rains, and in June, July and August after the long rains. Monthly rainfall was typically highest during the short rains (October to December) rather than during the long rains (March to May). This observation is clearly illustrated for the years 2001, 2002, 2006, 2009, and 2011 (Figure 11). In contrast, during drier years such as 2003, 2004, 2005, 2007, 2008, and 2010 rainfall amounts were similarly lower during both rainy seasons. The timing of when the rains begin and when they are at maximum also varied for the years examined. For the long rains, rainfall usually begins in February, but maximum rain occurred in March 63.63% of the time (2001, 2003, 2005, 2007, 2008, 2010, and 2011), April 27.27% of the time (2004, 2006, and 2009), and in May 9.1% of the time (2002). The short rains can begin as early as July 9.1% of the time (2002), but reach maximum amounts in October 9.1% of the time (2007), November 45.45% of the time (2004, 2005, 2008, 2010, and 2011) or December 36.36% of the time (2001, 2003, 2006, and 2009). Based on this rainfall data, rainfall in the surrounding lowlands at Kasigau is highly variable in its timing and magnitude.

![Figure 11: Mean monthly precipitation at Voi, Kenya (2001-2011)](image-url)
Mean monthly EVI values, providing a measure of green vegetation, show a significant correlation with rainfall for the 11-year time period (P < 0.001). Similar to rainfall, EVI shows a bimodal peak corresponding to the short and long rains, and is at its lowest during the dry seasons (Figure 12). When EVI values for individual years are compared with rainfall, however, only 2001, 2002, 2005, 2007, 2008 and 2009 show a significant correlation (P < 0.05). The year 2007 shows an anomalous pattern, with the lowest documented rainfall amount (255.1 mm) but among the highest EVI values.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>579.5</td>
</tr>
<tr>
<td>2002</td>
<td>798.5</td>
</tr>
<tr>
<td>2003</td>
<td>210.4</td>
</tr>
<tr>
<td>2004</td>
<td>799.9</td>
</tr>
<tr>
<td>2005</td>
<td>281.2</td>
</tr>
<tr>
<td>2006</td>
<td>778</td>
</tr>
<tr>
<td>2007</td>
<td>255.1</td>
</tr>
<tr>
<td>2008</td>
<td>479.3</td>
</tr>
<tr>
<td>2009</td>
<td>679</td>
</tr>
<tr>
<td>2010</td>
<td>438.5</td>
</tr>
<tr>
<td>2011</td>
<td>795</td>
</tr>
</tbody>
</table>
Over the 12-year period, the regional trend in green vegetation for the Kasigau area was a small increase (slope = 0.0011; Figure 13). The mountain region shows greater increases during 2001-2012 in greenness across the eastern lowlands with the highest increases observed for the 2005-2008 period. In contrast, the western bushland and montane vegetation showed either a decrease or no change in greenness (Figure 14). These localized patterns of change were especially prominent in the 2001-2004 and 2009-2012 observed periods, when the mountain showed a distinct loss in green vegetation in contrast to an increase across the plains below the east-facing slopes. Although these changes in greenness can be attributed to phenologic change, they may represent a change in land cover.
Figure 14: Spatial patterns of change in EVI per 16-days for the Kasigau area
The black square shows the location of the mountain relative to the larger study area. Green tones represent increases in greenness (as indicated by MODIS EVI values) while red tones represent decreases in greenness over the indicated period.
Figure 15: Change in mean annual green vegetation for each vegetation type
The green line represents mean annual measures of green vegetation. The red line represents the trend after using the Thiel-Sen estimator.
Comparison in the amount of green vegetation from 2001 to 2012 among the different vegetation types documents change over the 12-year time period. With the exception of the *Euphorbia quinquecostata* woodland, all other vegetation types show an increase in greenness (between 2001 and 2012) over the study period (Figure 15). Steepest overall increases in greenness are observed in the Riverine evergreen forests and in the Semi-evergreen woodlands. Lowest amounts of green vegetation occur in the bushland.

Fitted monthly EVI curves for the different vegetation types illustrate differences in the timing and magnitude of peak and minimum greenness in 2012 (Figure 16). The Riverine evergreen forest and the Semi-evergreen woodland have the highest amounts of green vegetation and the highest variability in greenness based on highest EVI values and range from maximum to minimum values. The *Acacia-Commiphora* bushland has the lowest amounts of green vegetation and the Cloud forest has the least amount of change in the amount of green vegetation. Highest amounts of green vegetation occur following the short rains for every community except the Lower montane woodland and the Semi-evergreen woodland. Lowest amounts of green vegetation occur in the dry season following the long rains for every vegetation type except the Evergreen forest and the Cloud forest.

![Figure 16: Fitted seasonal curves for vegetation types in 2012](image)
There is an increased lag time with increasing elevation between the timing of maximum greenness and the end of the short rains. Timing of maximum greenness following the short rains begins in early January for the Acacia-Commiphora bushland and lower montane communities, to mid-January for the Semi-evergreen woodland, to February for the Evergreen forest and March for the Cloud forest. The timing of maximum greenness following the long rains also shows a similar altitudinal gradient with indistinct trends in the timing of maximum greenness among the lower montane communities. Maximum greenness first occurs at the beginning of June in the Acacia-Commiphora bushland and the Riverine evergreen forest, followed by in mid-June in the Euphorbia quinquecostata woodland and the Semi-evergreen woodland, and then in the Evergreen forest in September followed by the Cloud forest in October. The lower montane woodland shows an anomalous pattern, reaching a maximum greenness the earliest in mid-May.

The timing of minimum greenness in the dry season following the short rains shows greater variability among forest community types and within lower and upper montane zones (Figure 16). Minimum greenness occur in March for the Lower montane woodland, late March for the Semi-evergreen woodland, April for the Acacia-Commiphora bushland and the Riverine evergreen forest, May for the Euphorbia quinquecostata woodland, and June for the Evergreen forest and the Cloud forest. Minimum greenness following the long rains occurs earlier at lower elevations and later at high elevations. The Acacia-Commiphora bushland, the Lower montane woodland, the Riverine evergreen forest, the Euphorbia quinquecostata woodland, and the Semi-Evergreen woodland all experience minimum greenness during September separated by days. The communities at the highest elevations experience minimum greenness following the long rains later than the lower communities; in October for the Evergreen forest and then in December for the Cloud forest.

All forest community types show distinct intra-annual seasonality but the patterns of change vary a lot among the years between 2001 and 2012 and also among the vegetation types. For example for 2001 and 2012, maximum amounts of green vegetation occur during or following both rain seasons for every community type (Figure 17); showing a phenological response to rainfall in the region.
Difference in the timing of maximum and minimum greenness also varied among vegetation types between 2001 and 2012 (Figure 17). Peak greenness, followed the short rains, for all vegetation type except the Evergreen forest. There was a lag between peak greenness and end of the short rains with the lag increasing with elevation. For example, maximum greenness occurs at the beginning of January for bushland and lower montane communities, mid-January for Semi-evergreen woodland, early February (2012) and March (2001) for Evergreen forest, and the end of February for Cloud forest. The timing of maximum green vegetation following the long rains shows more variability between 2001 and 2012 as some communities reached maximum greenness earlier in 2001 and some earlier in 2012. Similar to the short rains, there is a lag between the end of the long rains and maximum greenness with the lag increasing with elevation. Minimum greenness also varied in its timing when comparing 2001 and 2012 with some vegetation types reaching minimum greenness earlier in 2001, in 2012 or during the same time for both years, however the upper montane evergreen communities reach minimum greenness later than the community types at lower elevations in both 2001 and 2012.
Figure 17: Fitted seasonal curves for vegetation types (in 2001- and 2012).
CHAPTER FIVE

5.1 Discussion

5.1.1 Relationships between biophysical site conditions and patterns of diversity

This research investigated how physical-environmental conditions influence spatial patterns among different woody vegetation community types at Mt. Kasigau, an isolated mountain in the exceptionally biologically diverse Eastern Arc Mountains. The results document gradients of change in biophysical conditions that contribute to the characterization of lower-montane and upper montane zones with different forest community types that are bordered by *Acacia-Commiphora* bushland and Cloud forest at the lowest and highest elevations, respectively.

The steep altitudinal gradient corresponds with a high temperature lapse rate for Mt. Kasigau and corresponding changes in moisture availability. The lapse rate for this isolated tropical mountain is higher than the observed lapse rates for temperate mountains (Parker 1991; Lookingbill and Urban 2003) and tropical mountains (Kitayama 1992; Hemp 2006). Elevation, therefore, emerges as a primary determinant of landscape diversity similar to other studies in tropical montane ecosystems: Hamilton and Perrott (1989) for Mt. Elgon, Kenya; Vázquez and Givnish (1998) for the Sierra de Manantlán, Mexico; and Hemp (2006) for Mt. Kilimanjaro, Tanzania. Additionally, the altitudinal gradient may influence patterns of diversity through the Massenerhebung effect where forest types occur at lower elevations on smaller isolated mountains compared to larger less isolated mountains due to differences in localized climate (Lomolino 2001). It was first hypothesized that moisture was highest at the upper elevations, where moisture is captured from clouds. However, changes in moisture occur along the steep altitudinal gradient with an increase in moisture availability but decrease in actual moisture. This study is less clear on the influences of slope and slope form on vegetation change. Patterns of landscape heterogeneity within elevation zones show no correlations with these parameters.

The unique spatial patterns of community diversity at Mt. Kasigau show both discrete distributions and continuous distributions from lowland *Acacia-Commiphora* bushland through seasonal woodlands and to evergreen forests. Discrete distributions result in the zonation of vegetation types within four distinct zones; lowland bushland, lower montane, upper montane and cloud forest. Kitayama (1992) and Hemp (2006) also show zonation of discrete vegetation types for Mt. Kinabalu, Malaysia and Mt. Kilimanjaro, Tanzania respectively. Continuous
distributions occur within the lower and upper montane zones, with overlap between biophysical conditions similar to other mountains in the Eastern Arc (Lovett 1996).

Vegetation diversity patterns within the lower and upper montane zones vary and add to landscape heterogeneity in important ways that are not directly related to the biophysical parameters examined in the study and may relate to complex human histories. Complex human histories contribute to heterogeneity in landscape diversity (Foster et al. 1992) where change in species composition and degree of change is dependent on the intensity and complexity of historical land use by the locals (Tasser and Tappeiner 2002). Evidence suggests that people have altered the Eastern Arc forests for 2,000 years (Schmidt 1989), contributing to high degrees of fragmentation and change in forest area (Newmark 1998). Historical and local accounts document that the Kasigau Taita lived and farmed on the mountain until they were relocated to the coast during WWI. Resettlement on the mountain occurred during the 1930’s where the Kasigau Taita had homes, farms and grazing lands until they ultimately moved down the mountain and settled in the lowlands (Kalibo and Medley 2007). Additionally, the Kasigau Taita still extract woody resources from the mountain for many uses that include construction and fuel wood (Kalibo and Medley 2007).

5.1.2 Relationships between seasonality in biophysical conditions and vegetation response

The tropical wet-dry region of East Africa represents an “impressive climatic anomaly” (Trewartha 1981, 134). Inter-annual variability can be 20-30% or more of the average annual precipitation (Rasmusson 1987). The use of remotely sensed time series data provides an effective means of studying phenologic response to seasonal moisture conditions of this region. In particular, the use of MODIS time series is beneficial given the increased spatial, spectral and temporal resolution compared to other time series data, which allows for the detection of both intra-annual and inter-annual changes in plant response. MODIS data analyses over a 12-year time period are now available, enabling the study of diversity in plant response at a landscape scale along a steep environmental gradient (cf. van Leeuwen et al. 2012).

The documented seasonality at Mt. Kasigau and the surrounding lowlands provide evidence of a variable and unpredictable climate. The amounts and timing of annual rainfall, however, show predictable correlations with the phenology of vegetation. Despite an overall trend toward an increase in the amount of green vegetation for the mountain region, substantial
decreases occur at smaller temporal scales and at specific geographic locations. Differences in phenologic response serve as another measure of diversity patterns (Wright 1996). Year to year comparisons of the amount of green vegetation and timing of maximum and minimum amounts of green vegetation for the Kasigau area provide further evidence of an increasingly unpredictable and variable climate.

There is strong seasonal variability in vegetation response among the vegetation types adding to the spatial patterns of diversity documented for the mountain. Timing of responses occurs along an altitudinal gradient, with seasonal delays in the timing of maximum and minimum greenness as elevation increases at certain points contributing to the zonation of the vegetation types. Moser et al. (2010) show a continuous decline in vegetation growing seasons along an altitudinal gradient and Vitasse et al. (2009) show seasonal delay in vegetation response at high elevations for temperate montane vegetation.

5.1.3 Limitations of the study

Rainfall data at a smaller scale for the mountain is not yet available. Availability of finer spatial scale rainfall data would allow for the testing of relationships between rainfall and seasonal vegetation response among the forest types. Rainfall loggers were established on the mountain by Medley and Maingi, however the data contains errors including gaps in the recordings and malfunctioning equipment. An alternative is Tropical Rainfall Measuring Mission (TRMM) data which is remotely sensed rainfall data for the tropics, first launched in 1997 (Kummerow et al. 1998). TRMM data could potentially improve these analyses but they are still not readily available. More time and effort are required to obtain these data for this study. Relationships between vegetation type and climate data are based on a sample of 19. Interpolation of the climate results for the mountain might provide a better description of the relationships because there would be a larger sample ensuring that all topographic settings are accounted for, with more measurements for each forest type. Seasonal Trend Analysis only allows one contiguous vector as an area of interest (Clark Labs), so if differences in phenometrics for each vegetation type occur at different locations on the mountain, these differences are not captured.
5.1.4 Conservation and future applications

An understanding of the patterns of diversity in relation to biophysical conditions can help provide insight into forest management and sensitivity to climate change. Diversity on the mountain is greatest at mid-elevation sites within the lower montane zone. Given that protection of the evergreen forests has been the high priority, it is recommended that an equal focus be placed on the lower montane communities. Although rates of forest loss have not been researched at Mt. Kasigau, a 93% loss in forest area occurs between 800-1200 m for other mountains in the Eastern Arc (Hall et al. 2009).

This study provides further insight into the relationships between biophysical site conditions and diversity of forest community types along environmental gradients. These relationships document diversity at all elevations. Knowledge of these relationships is essential to sustainable resource extraction practices and conservation strategies that incorporate the entire mountain.

Mt. Kasigau is located in a problem climate (Trewartha 1981) with projected increases in the unpredictability of temperature and moisture conditions (IPCC 2007). The examination of short term dynamics in vegetation response can help to better project long term climate change effects, since phenologic change can be a short term response to climate change when observed in “long-lived plants” (Corlett and Lafrankie Jr. 1998, 439). Additionally, one can monitor the different forest community types to understand the effects of climate change at a finer scale and within different local site conditions.

This examination of cumulative patterns of diversity at Mt. Kasigau as they relate to biophysical conditions illustrates the importance of studying all patterns of diversity and can contribute to the successful conservation and monitoring for future change.
REFERENCES


Holdridge, L. R. 1967. *Life zone ecology*. San Jose, Costa Rica: Tropical Science Center


