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Small scale spatial and temporal variation in vegetation structure and composition of tropical forests under different management systems within Mount Kenya ecosystem

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Abstract
This study examined spatial and temporal variation in forest structure and composition of two indigenous Mount Kenya forests under state and private management by quantifying variations between seasons and in space at a small scale. To demonstrate spatial variation, slight change in altitude affected trees and shrub diversity at Mawingu. Change in slope, however affected herbaceous plants diversity in both sites during the dry season. On examining temporal variation in vegetation composition, herbs diversity was higher at Mawingu (H'=1.60) than at the conservancy ((H' =1.40) during wet season. Generally, Jaccard coefficient of community similarity depicted a low vegetation similarity between the two sites in both wet (CC=33%) and dry (CC=35%). The observed variation in vegetation composition could have been caused by changes in abiotic factors, such as elevation, slope position, water table and edaphic aspects. Additionally, biotic factors including human influence and herbivory could contributed to the variance.

Keywords: forest structure, vegetation composition, community similarity, temporal variation, spatial variation

Introduction

Tropical forests community structure and composition varies widely not only between forests in different continents (Phillips *et al*., 1994) [23], but also between forests on the same continent (ter Steege *et al*., 2000) [29] and even between different sites within the same forest (Proctor *et al*., 1983) [24]. Comparative studies of vegetation resources in tropical forests that are widely separated geographically or with marked differences in climatic patterns show obvious differences in forest structure and composition (Gentry, 1992) [12]. Within rain forests, climate and biogeography are the major determinants of species composition (Hall & Swine, 1981) [13]. At a local scale, disturbance such as fire (Webb, 1968) [31], disturbances which cause forest gaps (Whitmore, 1974) [33], physical factors within the soil (Webb, 1969) [32], soil nutrients (Tracey, 1969) [30] and topography (Lieberman *et al*., 1985) [14] may affect species composition.

Comparisons of forest composition for sites within a small geographical area of particular protected areas have received less attention. There may be significant variation at a smaller scale especially in areas with known variation in climatic patterns, altitude, and/or degree of human disturbance (Chapman *et al*., 1997) [6]. In Kibale Forest, Butynski (Butynski, 1990) [5] noted that even within the same forest type, considerable spatial heterogeneity in tree community structure and composition exist. For example, by comparing four sites in Kibale, Chapman (1997) [6] found that densities of many tree species varied widely between sites with certain species among the most abundant at some sites and absent at others. Additionally, variation in vegetation composition among and within sites in different seasons has been recorded in North-West Slopes of New South Wales (Schultz *et al*., 2014) [26]. In many instances, major differences in composition at a small scale and especially in neighboring forests exist due to changes in soil condition occurring over short distances (Marion & Cole, 1996) [15]. Such dynamism in space and time leads to shifts in plant species composition, density, and phenological phases of fruiting and flowering (Fashing & Gathua, 2004) [10]. At Mount Kenya forest, vegetation zonation occurs with change in altitude due to altitudinal variation in rainfall amounts. Vegetation zones are also modified by human interference including fire (Niemelä & Pellikka, 2004) [21]. At the species level, montane rain forests are different due to the varying altitude and soil physical structure.

Mount Kenya forest is a UNESCO world heritage site and a major water catchment area in Kenya (Enjebo & Öborn, 2012) [8]. The upper reaches of the forest is Mount Kenya National Park managed by the Kenya Wildlife Service (KWS) while the lower reaches is Mount Kenya Forest Reserve under Kenya Forest Service (KFS) management. Foothills of the forest is covered by dense evergreen vegetation forests, called montane rain forests, extending from about 2200 to 3500 meters above sea level (Niemelä & Pellikka, 2004) [21]. To regulate human-wildlife conflicts, *Cupressus lusitanica* plantations were established around the forest to buffer the adjacent agricultural lands. Salients of indigenous forests were left out at specific locations around the mountain to ease access to the national park.

The physiognomy and zonation of Mount Kenya forest vegetation been examined in details at a larger scale (Mulkey *et al*., 1992; Young & Peacock, 1992; Bussman, 1994; Estes *at al*., 2008) [17, 34, 4, 9]. To understand changes on plant communities within the forest on a small scale, this study was designed to assess variation in vegetation both in space and time on two forest sites separated by a 5Km distance. Vegetation composition and structure of two neighboring forests under different management systems was investigated. The forests included Mawingu area which is a salient inside Mount Kenya forest under KFS management and Mount Kenya Wildlife Conservancy (MKWC) forest which is privately managed.

Materials and Methods

Study Area

This study was carried out within two indigenous forest sites on the western side of Mount Kenya forest. The first site was located on the lower stretch of indigenous forest salient in an area called Mawingu which had been designated as mountain bongo (*Tragelaphus eurycerus isaaci*) sanctuary (Estes *at al*., 2008) [9] at location 0^0 3.6'S and 37^0 9.3'E. The second site was at Mount Kenya Wildlife Conservancy's forested zone. The forest is privately managed and used as the mountain bongo breeding site and located at 0^0 3.0'S and 37^0 7.3'E (Figure 1). The conservancy borders Mount Kenya forest to the east and is separated from Mawingu by a 5Km stretch of *Cupressus lusitanica* plantation. The two study sites were dominated by *Juniperus procera*, *Podocarpus falcatus* and *Olea europea* subsp. *Africana* tree species. Average rainfall on the mountain ranges from 2,300mm on the south eastern slopes to 900mm in the north (KWS, 1996) and occurs with two distinct wet and dry seasons.

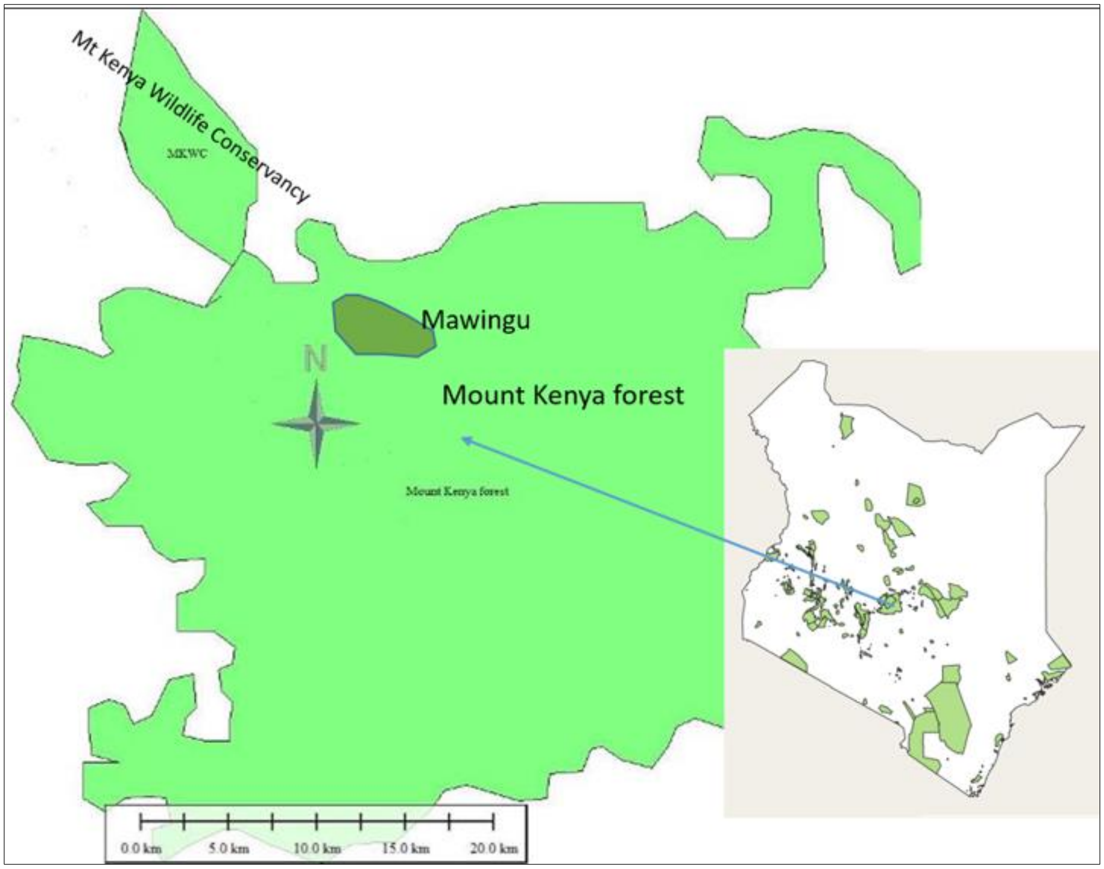

Fig 1: Map of Mount Kenya Forest showing the locations of Mount Kenya Wildlife Conservancy and Mawingu study sites

Data collection

Similar methods were used to collect data on vegetation structure and composition at the two study sites during wet season in November 2010 and dry season in February 2011. Rivers Nanyuki at the conservancy and Likii south at Mawingu were used as baselines when setting up study transects. Eleven belt transects were systematically placed at intervals of 300m perpendicular to a 3 Km baseline and 20m from the river. A sample of four transect lines were then randomly selected in both sites using random numbers and three plots of 20m by 50m demarcated systematically at intervals of 100m along the transect. These quadrats were grouped into three strata i.e. valley bottom, slope and valley top quadrats. In each plot, tree species ≥10cm diameter at breast height (DBH) taken at 1.3m trunk height from the ground and ≥10m in height (Sheil *et al*., 2000) [28] were identified by their botanical names, and standardized by following the taxonomic scheme of Beentje (1994) [1]; tree stems were counted, DBH measured and mean crown diameter taken considering the long and short crown diameters. Additionally, tree height and percentage tree canopy cover was estimated.

Shrubs were sampled within four quadrats measuring 5m by 5m placed at each corner of the plot. Shrubs were then identified, counted and percentage cover estimated. In this case, shrubs were taken to be woody multi-stemmed plants ≥1m above the ground and <10cm DBH (Nkurunungi *et al*., 2004) [22]. Herbs and grasses were identified, counted and recorded within six 1m by 1m quadrats placed at the four corners and at the east-west ends of the main plot.

Plants were identified in the field where possible or collected and pressed for identification at the National Museums of Kenya herbarium section. This data collection procedure was replicated in the two study sites during wet and dry seasons.

Data analysis

To analyze variation in vegetation structure, mean tree heights, mean percentage canopy cover and mean basal areas were used and unpaired sample t-test used to check for significant differences between the two sites. Relative densities, relative frequencies and relative dominance of all tree species encountered were calculated. Stem basal area was used to estimate relative dominance (Muller-Dombois & Ellenberg, 1974) [18]. These relative values were used to calculate tree species Importance Value Index (IVI) as per Curtis (1959) [7]. The index was a sum of relative abundance, relative frequency and relative dominance. Shannon-Wiener information Index was used to compute diversity indices of trees, shrubs and herbs (Shannon & Wienner, 1963) [27].

$$H' = \sum_{i=1}^{S} - (P_i * \log_{10} P_i)$$

Where:
H' = Shannon diversity index
P_i = fraction of the entire population made up of species i
S = number of species encountered
$\sum$ = sum from species 1 to species S
Student's t-test was used to compare vegetation structure, tree heights, canopy cover and basal areas between the two sites. Using distance from the river channel (slope) as the random factor, One Way Analysis of Variance (ANOVA) was then used to assess spatial changes in plants diversity within sites. On the other hand, Student's t-test was used to test for temporal mean difference in plant diversity between and within the two sites during wet and dry seasons.

The degree of vegetation similarity between Mawingu and MKWC was assessed using Jaccard coefficient of community similarity (Muller-Dombois & Ellenberg, 1974) [18].

$$CC_J = \frac{C}{S_1+S_2-C}$$

Where:
CC_J= Jaccard coefficient (As a percentage)
S_1 and S_2= number of species in communities 1 (conservancy) and 2 (Mawingu) respectively
C= number of species common to both communities

Results and Discussion

Overall, a total of 218 plant species were identified in both sites. Plant richness was however, high at Mawingu with a total of 175 species being recorded compared to MKWC where 106 plant species were identified. This was attributable to heavy grazing and browsing by mountain bongos at the conservancy. Sixty three plant species were however common to both sites. Species-area curves suggested that the number of new species recorded decreased after sampling approximately 8 quadrats (Figure 2). Species densities of most plants are, therefore, well represented in the areas sampled.

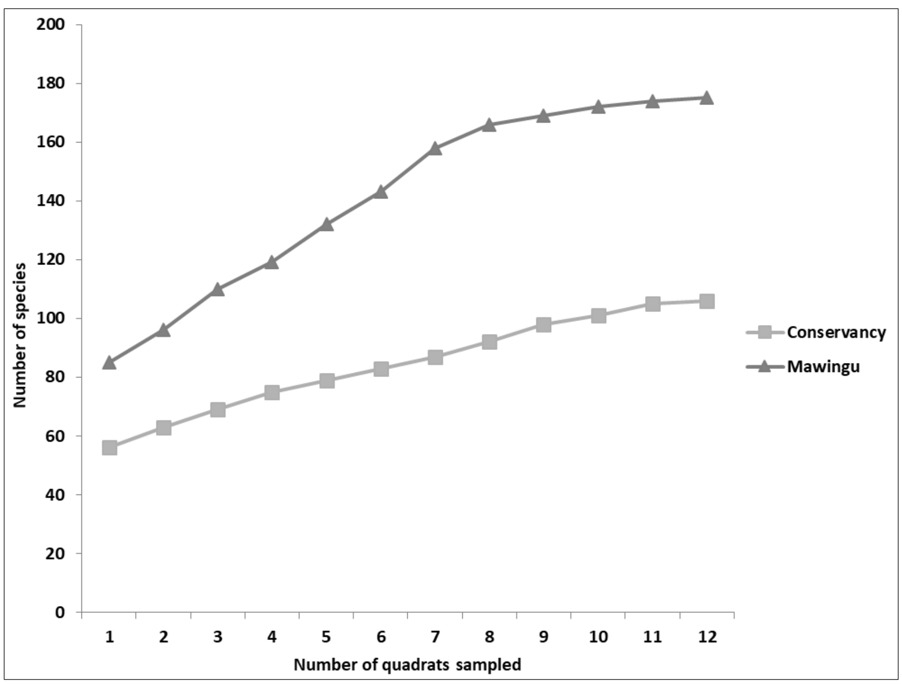

Fig 2: Cumulative species-area relationship of the two sites sampled.

Vegetation structure

Forest canopy (height ≥10m) within the conservancy was dominated by *Juniperus procera* (IV=0.25) while Mawingu was dominated by *Podocarpus latifolius* (IV=0.29). Overall, MKWC had more tree species (18) than Mawingu (13) sites with no significant difference (t=1.28, df=12, $p>0.05$) in mean tree densities between the conservancy (9.26 ± 2.86 trees/acre) and Mawingu (6.99 ±1.85 trees/acre). This was an indication of similarity in trees species composition between the two sites.

The two sites being riverine forests, their structure did not have much variation with tree heights and canopy cover showing no significant differences (Table 1). Mean tree basal area between the two sites, however had a significant variation (t=2.65, df= 107, $p<0.05$). The conservancy had lower mean basal area and mean tree height than Mawingu site. Mount Kenya Wildlife Conservancy having been in existence since 1967, the riverine forest could be at its secondary stage hence the observed low stem basal area. This could also occur due to the common perceived limitation of private conservation areas not conserving land in as pristine state as government conserved protected areas (Bleher *et al*., 2006) [2]. Other structural attributes (tree heights, canopy cover and stem density) did not have much difference between the sites, an indication of minimal forest destruction especially from logging at Mawingu which is under Kenya Forest Service management.

Table 1: Structural data collected from quadrat surveys (12 quadrats per site). The differences in mean tree heights, basal area and cover between MKWC and Mawingu were analyzed using t-test. Percentage canopy cover data was arcsine-transformed.

Parameter	MKWC	Mawingu	t Value	d.f.	*p*
Mean tree height (m)	15.0±6.5	15.8±5.9	0.87	106	>0.05
Mean canopy cover (%)	56.2±14.6	54.8±12.1	1.75	106	>0.05
Mean Basal area (m^2/acre)	0.15±0.02	0.23±0.03	2.65	107	<0.05
Tree density per acre	9.26 ±2.86	6.99 ±1.85	1.28	12	>0.05

The mean shrub cover within MKWC during the wet (65.3±2.5%) and dry season (62.2±2.4%) had no significant difference (t=1.96, df=47, $p>0.05$). This indicates that shrub cover was not affected by seasonal variation in rainfall availability within the conservancy. Shrub cover at Mawingu however, had a significant difference (t=2.11, df=47, $p<0.05$) between the wet (50.6±3.4%) and dry (46.3±3.5%) seasons. This was attributable to herbivore distribution between seasons rather than rainfall variations. Interseasonal shrub cover between the two sites was significantly different during the wet season (t=3.73, df=47, $p<0.05$) and dry season (t=3.63, df=47, $p<0.05$). Despite the short distance separating the two study sites, differences in rainfall amounts received was evident due to their differences in altitude. Additionally, differences in density and diversity of herbivores in the two sites could have contributed to the variation in shrub cover.

Shrub and herb composition

The sub-canopy layer (<10m height) at MKWC was dominated by *Rhus natalensis* (density = 92.5 plants/ acre) whereas *Ocimum lamiifolium* (density = 55.8 plants/acre) was dominant at Mawingu. The canopy and sub-canopy plant species formed a continuous dense cover in Mawingu, except for few gaps formed by natural disturbances like tree falls. At the conservancy, continuity was interrupted by fences and tree falls mostly due to anthropogenic activities. *Stipa keniensis* was the dominant grass on both sites while *Hypoestes forskaolii* and *Hypoestes aristata* were the dominant herbs at the conservancy and Mawingu respectively.

Comparing the wet and dry seasons, shrub diversity had a slight variation in both sites. Herbs diversity was, however relatively high at Mawingu during the wet (H' =1.60) and dry (H' =1.40) seasons than the conservancy (Figure 3). At Mawingu, the low herbivore density could have had minimal impact on herbaceous cover compared to the high mountain bongo density per acre at the conservancy's forest. The potential sources of these differences in species composition between sites had also been highlighted by Nchanji and Plumptre (2003) [20] to include small scale inter-site variation in rainfall, soil composition, elevation, and temperature and differences in logging history.

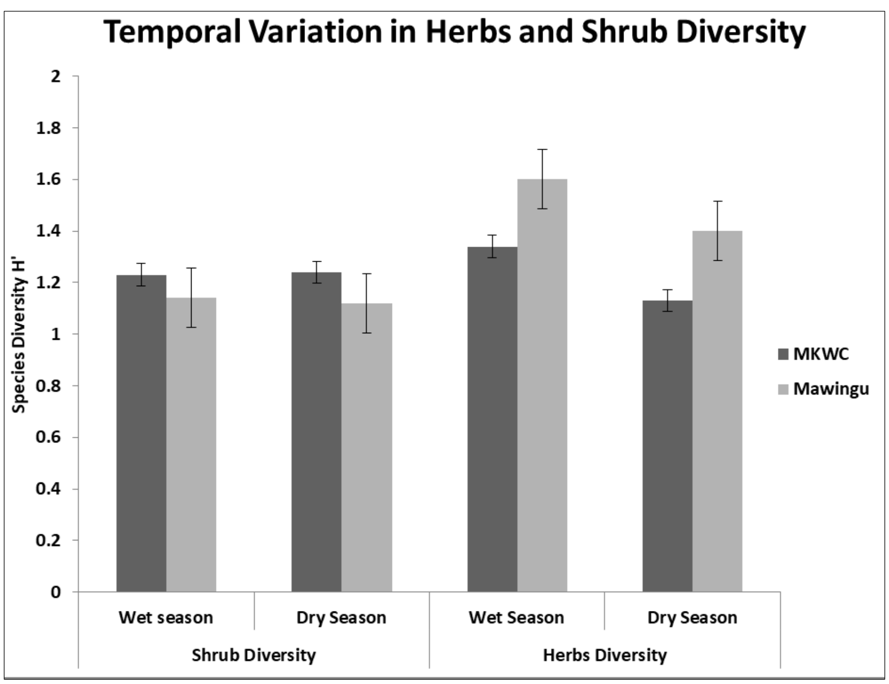

Fig 3: Variation in shrub and herb diversity during wet and dry season at Mawingu and Mount Kenya Wildlife Conservancy

Spatial and temporal variation

The variance in tree diversity with change in altitude (2137 to 2241 meters above sea level up stream) at the conservancy was not significant ($F_{3,8}$ =1.45, p>0.05). Additionally, the variance in tree diversity up the slope the conservancy had no significant difference ($F_{2,9}$ =0.93, p>0.05). Tree diversity however, had a significant difference ($F_{3,8}$=5.13, p<0.05) with change in in altitude (2240 to 2424 meters above sea level up stream) at Mawingu with Turkey post hoc analysis for multiple comparisons indicating significant difference (p<0.05) at the fourth transect which was at the transition zone of the rain forest and bamboo. Change in slope however, did not affect tree diversity at Mawingu ($F_{2,9}$=0.07, p>0.05).

Comparing the two sites between seasons, mean herb diversity at the conservancy (*H'* =1.19±0.35) and Mawingu (*H'* =1.60±0.25) had a significant difference (t=7.94, df=71, p<0.05) during wet season. Herbaceous plants density, however, had no significant difference (t=1.72, df=71 p>0.05) during the dry season. Such differences could have been caused by the differences in slope. The incline at Mawingu area was generally higher than MKWC hence experiencing heavy surface runoff during rainy season causing reduction in herbaceous cover. Still, at the conservancy, heavy grazing during dry period could have resulted in sprouting of a diverse herbaceous cover in wet season. One Way Analysis of Variance did not show significant difference (p>0.05) in shrub diversity (using Shannon Weinner diversity index) within the conservancy with increase in altitude (2137 to 2241 meters above sea level) upstream and up-slope during the wet and dry season (Table 2). At Mawingu, shrub diversity however, had a significant difference as altitude increased (2240 to 2424 meters above sea level) during both seasons (Table 2). Turkey post hoc analysis was used to test for the source of observed variation in shrub diversity and detected significant difference (p<0.05) in transect 3 (2188m above sea level) and 4 (2241m above sea level). This may be due to the natural altitudinal zonation of Mount Kenya forest and the last transect was falling within the rain forest and Bamboo zone ecotone. Biotic factors such as seed dispersal otherwise called neighborhood effects because they operate within a spatial context or neighborhood might also be contributing to this variation (Frelich *et al*., 1998) [11].

Herb diversity at the conservancy was significantly different (p<0.05) with increase in altitude (2137 to 2241 meters above sea level) during the dry season which could have been caused by uneven distribution of mountain bongo densities within the forest. There was no variation (p<0.05) in herb diversity up the slope during wet season (Table 2). At the same time, herb diversity had no significant difference (p>0.05) at Mawingu with increase in altitude and up the slope during wet season. However, herb diversity was significantly different (p<0.05) as the slope increased during the dry season at Mawingu. This variation was detected in transect 4 using Turkey Post Hoc analysis (p<0.05). The effects of elevation, slope position and topographic aspects of an area have been demonstrated to affect floristic composition, community structure and distribution of plant species (Sardinero, 2000) [12]. Additionally, distance from the river up the slope significantly affected herb diversity with quadrats located next to the river having the highest diversity. This is due to the influence of soil moisture in both seasons.

Table 2: One Way Analysis Of Variance indicating variation in shrub and herb diversity with increase in altitude and change in slope from the river at Mount Kenya Wildlife Conservancy and Mawingu during wet and dry seasons

Season	Site	Plant type	Source of Variation in diversity	Df	F	Sign diff.
Dry	MKWC	Shrub	Altitude	3,44	3.05	p>0.05
			Slope	2,45	1.99	p>0.05
		Herb	Altitude	3,68	0.08	P>0.05
			Slope	2,69	1.66	p>0.05
	Mawingu	Shrub	Altitude	3,44	11.38	P<0.05*
			Slope	2,45	2.23	p>0.05
		Herb	Altitude	3,68	1.64	p>0.05
			Slope	2,69	4.03	P<0.05*
Wet	MKWC	Shrub	Altitude	3,44	4.58	p>0.05
			Slope	2,45	1.45	p>0.05
		Herb	Altitude	3,68	17.84	P<0.05*
			Slope	2,69	0.86	p>0.05
	Mawingu	Shrub	Altitude	3,44	11.38	P<0.05*
			Slope	2,45	2.23	p>0.05
		Herb	Altitude	3,68	0.99	p>0.05
			Slope	2,69	8.35	p>0.05

* The mean difference is significant at 0.05 level. df indicate within (transects) and between groups (quadrats) degrees of freedom respectively

Jaccard coefficient of community similarity during the study period indicated an overall low level of community similarity (28%) between sites. Additionally, vegetation similarity was not affected by seasonal variation. Jaccard similarity index (CC) didn't show much seasonal variation in species composition during wet (CC=33%) and dry seasons (CC=35). Based on what is known about woodland dynamics (Naiman, 1988; McNaughton *et al*., 1988) [19, 16], it is sensible to suggest that the spatial and temporal differences in vegetation composition between the two sites at Mount Kenya forest are largely as a result of animals (particularly elephants at Mawingu and Mountain Bongos at the conservancy) impacting on the ecosystem. Abiotic factors such as rainfall, altitude, edaphic factors and slope could also be affecting species composition and distribution but, this requires further investigation.

Conclusion

In summary, this study highlights the extent in which two areas of forests in relatively close proximity and of similar structure can differ in plant species composition and abundance. It shows that variation in species composition can occur within the same forest patch at a finer spatial scale. Zonation in soil types at Mount Kenya described by Bussman (1999) [3] can largely contribute to variation in the forest vegetation on a smaller scale. This, however, requires further investigation focusing on soil variation and the associated preference of forest vegetation to specific soils on a smaller scale. Additionally, water table could have contributed to the observed forest variation, especially with change in slope. Comparative studies of vegetation structure and animal populations within the study sites and including additional sites within Mount Kenya Forest would help determine the extent to which the patterns revealed by this study hold over larger spatial scales.

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