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

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ABSTRACT

This study examined spatial and temporal variation in forest structure and composition of indigenous Mount Kenya forests on a small-scale. This was achieved by comparing trees, shrubs and herbs density and composition among two forested sites under different management regimes and separated by 5Km stretch of exotic *Cupressus lusitanica plantation*. The sites were under state and private management. The study aimed at quantifying changes in vegetation composition between seasons and in space at a small scale. Despite the slight difference in mean trees density between the two sites, there was a significant variation in mean tree basal area as the conservancy forest wasn't pristine. 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. To demonstrate spatial variation, slight change in altitude affected shrub diversity at Mawingu during both seasons. Change in slope, however affected herb diversity in both sites during the dry season. Generally, Jaccard coefficient of community similarity depicted a low vegetation similarity between the two sites in both seasons which could be associated with variation in soil physical structure. The observed spatial and temporal variation in vegetation composition could have been caused by changes in abiotic factors, such as elevation, slope position, water table and edaphic aspects. Biotic factors such as human influence and herbivory could also lead to the observed variation in floristic composition and community structure.

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[1], but also between forests on the same continent[2] and even between different sites within the same forest[3]. 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[4]. Within rain forests, climate and biogeography are the major determinants of species composition[5]. At a local scale, disturbance such as fire[6], disturbances which cause forest gaps[7], physical factors within the soil[8], soil nutrients[9] and topography[10] 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[11]. In Kibale Forest, Butynski[12] suggested that even within the same forest type, considerable spatial heterogeneity in tree community structure and composition can exist. For example, by comparing four sites in Kibale, Chapman[11] 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[13]. 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[14]. Such dynamism in space and time leads to shifts in plant species composition, density, and phenological phases of fruiting and flowering[15].

Understanding variations in habitat characteristics on a small scale is useful when considering resource availability and utilization, spatial requirements, population dynamics, and adaptations of animals to their environment[12]. 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[16]. The forest is a UNESCO world heritage site and a major water catchment area in Kenya[17]. Upper reaches of the forest is Mount Kenya National Park under Kenya Wildlife Service (KWS) management while the lower reaches is Mount Kenya Forest Reserve managed by Kenya Forest Service (KFS). The foothill of Mt. Kenya, managed by KFS, is covered by dense evergreen vegetation forests, called montane rain forests, extending from about 2200 to 3500 meters above sea level[16]. At the species level, the montane rain forests are different due to the varying altitude and soil physical structure. As a buffer to the agricultural lands, and to regulate human-wildlife conflicts, *Cupressus lusitanica* plantations were established around the forest. To ease access to the national park, salients of indigenous forests were left out around the forest.

On a larger scale, Mount Kenya forest vegetation zonation and physiognomy has been examined in details[16,18-20]. 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. To do this vegetation composition and structure of two neighboring forests under different management systems was investigated. The forests included Mawingu area inside Mount Kenya forest under KFS management and Mount Kenya Wildlife Conservancy (MKWC) forest which is privately managed. Potential ecological and human induced differences were discussed.

RESEARCH METHODS AND MATERIALS

Study area

This study was carried out within two indigenous forest sites on the western side of Mount Kenya forest. The first site was within Mount Kenya Forest on a salient of natural forest which stretches from the high altitude bamboo and moorlands zone. Specifically, the site was located on the lower stretch of the indigenous forest salient in an area called Mawingu which had been designated as mountain bongo sanctuary[21] at location 0° 3.6'S and 37° 9.3'E. The second site was at Mount Kenya Wildlife Conservancy's forested zone. The conservancy is privately managed and used as the mountain bongo breeding site and located at 0° 3.0'S and 37° 7.3'E (Figure 1). The conservancy borders Mount Kenya forest to the east and is separated from Mawingu by a 5Km stretch of *Cuppressus lucitanica* plantation. The two study sites were riverine forests dominated by *Juniperus procera*, *Podocarpus falcatus* and *Olea europea* tree species. The region experiences two distinct wet seasons and two distinct dry seasons which mirrors wet and dry seasons in Kenyan lowlands. Additionally, the area receives an average annual rainfall of 800mm and a minimum temperature range of about 2°C to 6°C, creating hot diurnal conditions and cold nights.

Methods

Similar methods were used to collect data on vegetation structure and composition at the two study sites during wet season in November2010 and dry season in February 2011. Rivers Nanyuki at the conservancy and Likii south at Mawingu were used as the baselines in setting up study transects. Eleven line

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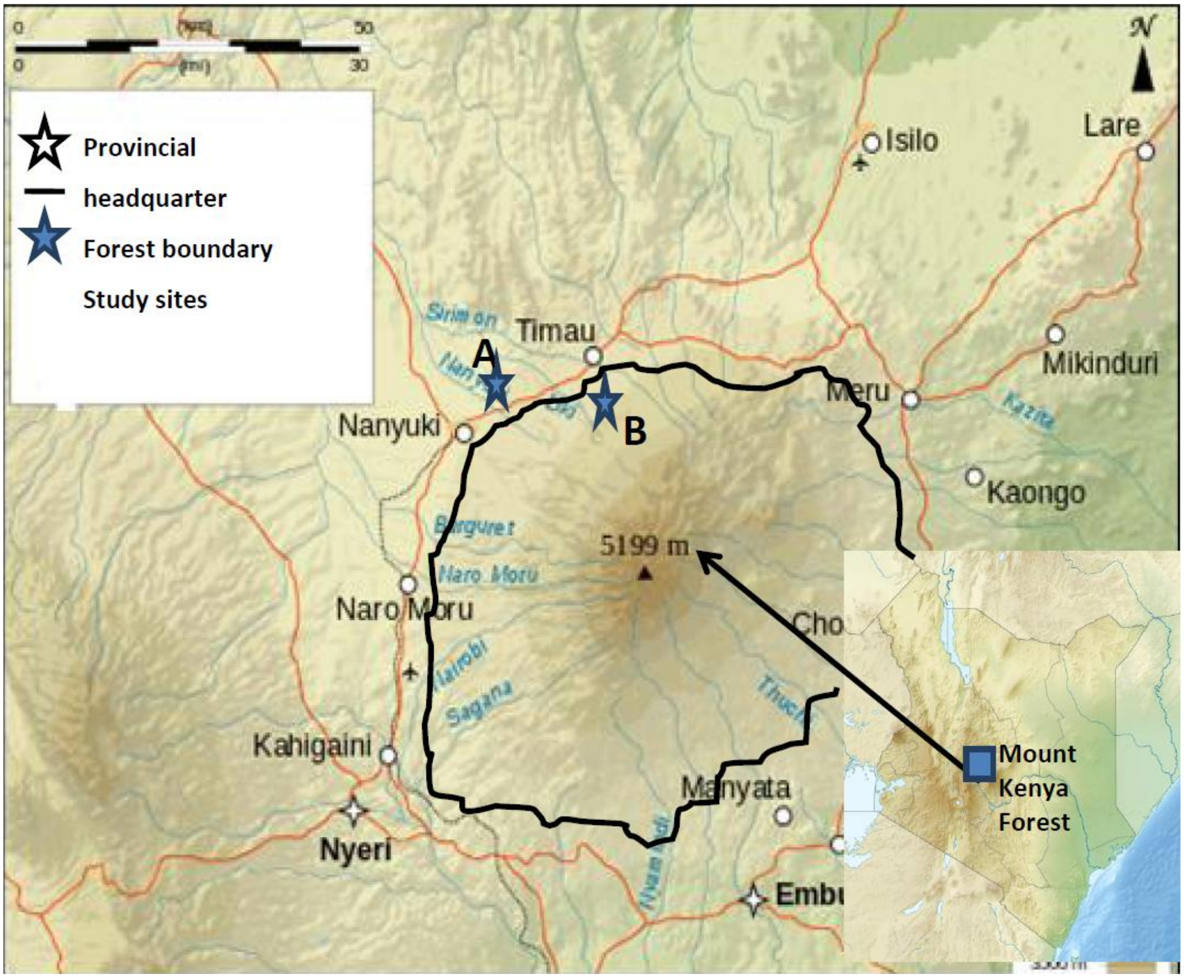

Figure 1: Map of Mount Kenya forest showing the locations of Mount Kenya Wildlife Conservancy (A) and Mawingu (B) study sites

transects with a maximum length of 400m were systematically laid up the slope perpendicular to the baseline and 20m from the river at 300m equidistant from each other. To adequately collect vegetation data, a sample of four transect lines were randomly selected at each site and along each transect quadrats measuring 20m by 50m were demarcated systematically at intervals of 100m to have three quadrats per transect. These quadrats were grouped into three strata i.e. valley bottom, slope and valley top quadrats. A 50m tape measure was used to demarcate quadrats and all sampling locations were georeferenced using a GPS (GPSmap 60CS model). At each quadrat, tree species ≥10cm diameter at breast height (DBH) taken at 1.3m trunk height from the ground and ≥10m in height[22] were identified by their botanical names, and standardized by following the taxonomic scheme of Beentje[23]. For every species, 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.

To sample shrubs, a grid of 5m by 5m quadrats was generated within the 20m by 50m quadrats and four of these quadrats were randomly selected from the grid. 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[24]. Herbs and grasses were identified, counted, percentage cover estimated and recorded within six 1m by 1m quadrats taken randomly within main quadrat.

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.

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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[25]. These relative values were used to calculate tree species Importance Value Index (IVI) as per Curtis[26]. The index was a sum of relative abundance, relative frequency and relative dominance. Shannon-Wiener information Index[27] was used to compute diversity indices of trees, shrubs and herbs.

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

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[25].

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

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.

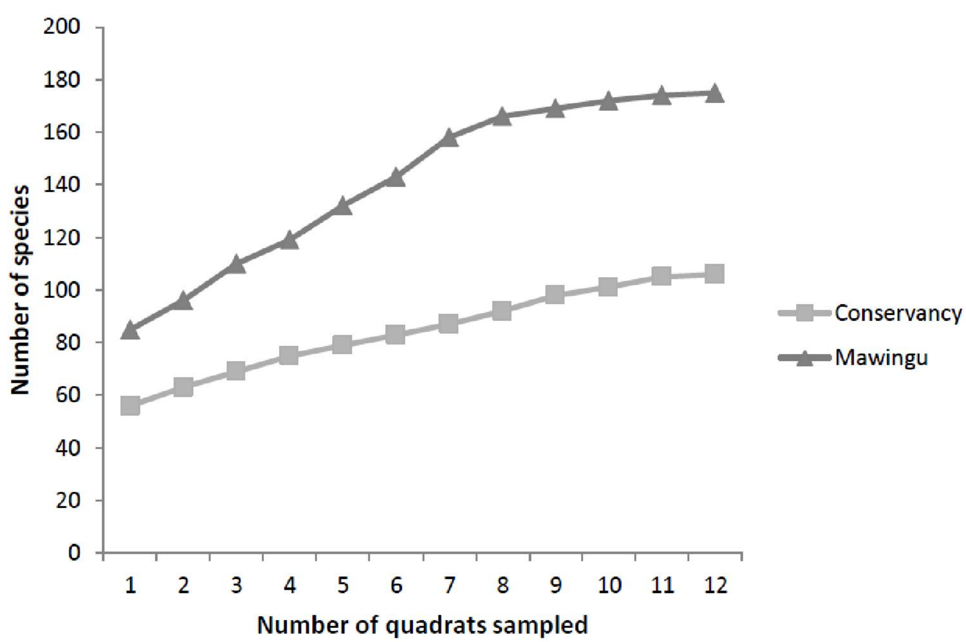

Figure 2: Cumulative species-area relationship of the two sites sampled.

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, mean tree height and percentage canopy cover 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[28]. 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
Stem density per acre	9.26 ±2.86	6.99 ±1.85	1.28	12	>0.05

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 = 55.8plants/acre) was dominant at Mawingu. More similarity in species composition was recorded at undergrowth where *Stipa keniensis* (grass species) and *Hypoestes aristata* (herbaceous species) dominated both conservancy and Mawingu sites. Comparing 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[29] to include small scale inter-site variation in rainfall, soil composition, elevation, and temperature and differences in logging history.

Spatial and temporal variation

Comparing the two sites between seasons, mean herb diversity at the conservancy ($H'=1.19 \pm 0.35$) and Mawingu ($H'=1.60 \pm 0.25$) 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,

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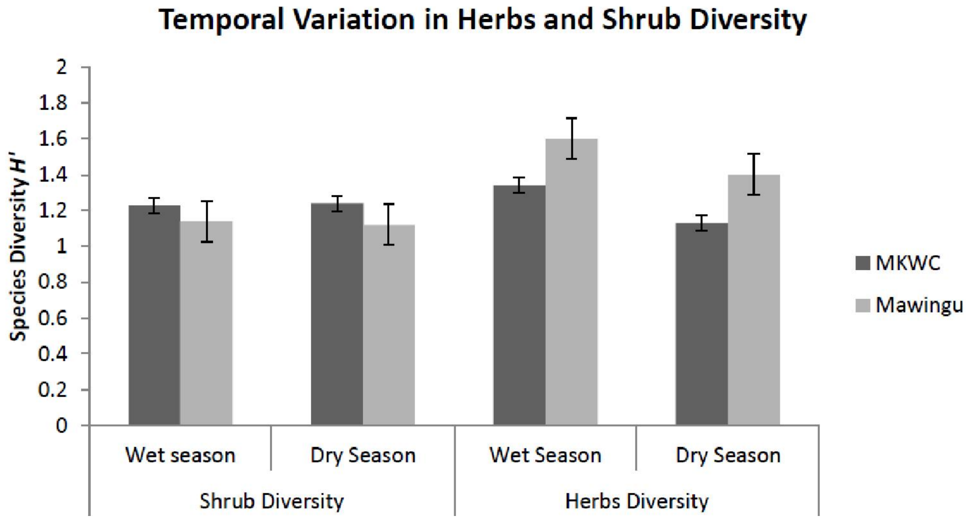

Figure 3: Variation in shrub and herb diversity during wet and dry season at Mawingu and Mount Kenya Wildlife Conservancy

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[30] might also be contributing to this variation.

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 dry the 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 vegetation species[31]. 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 high 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**

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Jaccard coefficient of community similarity during the study period indicated an overall low level of community similarity (28%) between sites. The two sites having a small geographic variation, vegetation similarity was not affected by seasonality. 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[32,33], it is sensible to suggest that the spatial and temporal differences in vegetation composition between the two sites at Mount Kenya forest are 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 also affected species composition and distribution.

CONCLUSION

In summary, this study highlights the striking extent to 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[34] 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.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding publication of this work.

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