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Glade and Forest-Edge Plant Community Attributes for Three Glade Types in Arusha National Park, Tanzania

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Abstract

The aim of the study was to compare glade and forest-glade edge plant community attributes for man-made, upper and lower natural glades. Two plots were set up in twelve glades at 2.5, 12.5 m and three plots in thirteen glades at 2.5, 12.5 and 22.5 m depending on the size of the glade. The results showed that plants total abundance, percentage basal cover, species richness and species diversity for upper and lower natural glades differed significantly $p < 0.05$ and $p < 0.01$ respectively and species diversity for man-made glades $p < 0.001$. Plant species abundance, richness and diversity were highest at the forest-glade edge and decreased towards the glade interior. Plant species composition of the three glades types differed significantly (MRPP: $T = -4.51$, $p < 0.001$ and $A = 0.17$). Grasses' total abundance and species richness and forbs species diversity differed significantly for man-made glades $p < 0.01$. For upper natural glades, grasses species richness was highly significant $p < 0.001$ while for forbs species richness and diversity were significant $P < 0.01$. Lower natural glades grasses and forbs' total abundance, species richness and species diversity differed significantly $p < 0.01$ and $p < 0.001$ respectively. Growth forms in the lower natural glades were associated with the forest-glade edge or glade interior $\chi^2 = 15.95$, df = 4, $p < 0.01$. Five species (*Eleusine jaegeri*, *Heterogon contortus*, *Senna mimisoides*, *Digitaria scalarum*, *Clutia abyssinica*) were habitat indicators for disturbed areas, wet humid grey/black clay soils for upper natural glades and three (*Solanum incanum*, *Senna didymobotrya*, and *Pennistem mezianum*, were indicators of overgrazed areas and black clay soils for man-made glades. In conclusion, plant species abundance, richness and diversity were highest at the forest-glade edge and decreased towards the glade interior, while plant species composition differed significantly between the three-glade types. The plant growth form for lower natural glades was associated with forest-glade edge and glade interior.

Keywords

Forest Glade-Edge, Glade Interior, Plant Indicator Species, Plant Species Diversity, Plant Species Richness

1. Introduction

Edges are places or zones of transition (abrupt or gradual) between different ecosystems, where they interact and influence each other [1]. The forest-glade edge where the forest and opening interconnect provides specialised niches for plants and forest-glade edge animal species [2] [3]. Edge habitats benefit plant and animal species that require specialised habitat niche [4]-[9]. Because of the exclusive physical environment at the edge of a glade, the plant community will show considerable variation from surrounding forest edge and glade interior (grasslands) [9] [10] [11] [12]. The edges of glades also reflect numerical incursions of individual plant species, each with characteristic physical requirements, which results in distinctive edge plant communities and are associated with higher species richness and abundances, including edge specialist and invasive species [3] [11] [12] [13].

Furthermore, edge effects influence the microenvironment of the forest-glade interface or edge. Glade edges are typically less hot, dry and windy [6]. Higher stem densities and basal areas are found at the glade edge, reflecting the dense growth of shrubs and saplings due to an increased light response at the forest edge [14]. Herbaceous plants have a similar light response, with light-demanding species typically found near the edge [6] [15] [16] [17]. As the configuration and structure at the glade edges change, so will affect the densities and distributions of plants, ungulates, and birds [5] [6] [8] [15] [18]. More specifically, edge effects influence the microenvironment of the forest-glade interface or edge. Edge effects are a result of interaction between two adjacent ecosystems separated by an abrupt transition (edge) [6].

The forest edge habitat is made up of a distinct vegetation structure and configuration that reflects the abiotic and biotic influences on the edge habitat [11] [19] [20]. Changes in the forest edge physical environment have a pronounced impact on the edge habitat's plant growth and their distribution [10] [12]. These micro-environmental changes at the forest edges have a significant impact on the composition of plant species; with an increase in plant diversity at the edge that attracts diverse animals to use these areas [3] [6] [15] [21] [22]. The forest edge is associated with higher plant species richness, higher stem densities and basal areas, dense growth of shrubs and saplings due to an increased light penetration at the forest edge [3] [6] [12] [13] [14] [15] [17] [19].

Thus, in contrast, glade interiors are open grassland patches that can be found within a forest matrix and these grassland patches play a unique ecological role and harbour associated species [23]. The glade openings are dominated by grass, forbs and shrubs and are typically hot, dry, windy and sunny [6] [11]. Glade interior, is exposed to more sunlight and heated air in the grassland clearing [11] [23].

At Arusha National Park (formerly published as Mount Meru Game Reserve), there are three glade types: man-made, lower natural and upper natural. Upper natural glades arise on steep slopes of 2000 m.a.s.l. and above and lower natural and man-made glades occur between 1400 and 1800 m.a.s.l. These glades also vary in size and different proximities to one another. The upper natural glades are characterised by shallow soils, muddy and rocky surface that supports dense growth of grass within the proximity of wet forest with edge plants leaning into the glades and maintained by grazing animals [23]. The lower natural glades were shaped through mass movement of mud, rock, lava and water downwards on the eastern side of Mount Meru [24], maintained by grazing animal and floods during the rainy seasons. The man-made glades were created by clearing the forest trees and shrubs to form a grassland habitat and are maintained by flooding during the rainy seasons and grazing animals, such as buffalo, besides the intermittent removal of encroaching trees and shrubs at the forest glade edge and interior [23].

Thus, the reserve provides an ideal environment to conduct comparative studies on the edge effects between man-made and natural glades (Upper and Lower) and if plants of glade interiors are associated with the muddy wet soils of upper and lower natural glades.

2. Materials and Methods

2.1. Vegetation Surveys

The research design compared plants of glade edge and glade interior between man-made and natural glades of randomly selected twenty-five glades (25), out of which five (5) were man-made, five (5) upper natural and fifteen (15) lower natural glades. Within each glade, a plot of (10×5 m = 50 m^2), 10 m apart from the forest-edge into the glade interior were randomly established. Two plots were set up in twelve glades at 2.5, 12.5 m and three plots in thirteen glades at 2.5, 12.5 and 22.5 m. Plants were classified into three growth forms: (grasses, forbs and shrubs) as per [25] and [26] for plant identification to species level. For each plot, plant total abundance, percent basal cover and species richness were determined by estimating the area covered proportional percentage cover and a total number of different species found in each plot, respectively.

2.2. Glade Size and Neighbourhood Distance Measurement

Neighbourhood distance was measured by obtaining coordinates from the edge of the glades to the edge of the next nearest glade and determining the distance in meters between the coordinates using the Garmin® 12-channel GPS. Glade sizes were determined similarly, and glade altitudes were recorded.

2.3. Statistical Analysis

Data on glade size, altitude and distance to nearest neighbour between the three glades types were compared using a non-parametric Kruskal-Wallis ANOVA test. The Shannon-Wiener (SW) diversity index (H') was used to calculate species diversity and heterogeneity (1-J') [27]. Plant total abundance, species richness and species diversity along the glade edge and interior were compared within and between glade types using one-way ANOVA. Total abundance, species richness, percent basal cover and proportional plant cover for each of the five growth forms (grass, forbs and shrub) were compared between the three glade types using one-way ANOVA.

Multiple Response Permutation Procedure, a non-parametric test that evaluates the uniqueness of a group relative to all other permutations, was used to test for group differences in plant species composition between man-made, lower natural and upper natural glades. The procedure generates the test statistic, T, with a more negative value indicating a greater separation between the groups; a *P*-value describing the likelihood that the observed difference is due to chance; and effect size, *A*, which describes within-group homogeneity [28]. Indicator species analysis combines information on relative abundance and frequency of each species in a particular habitat and was used to detect and describe the value of each plant species as a habitat indicator for the three glade types. Indicator values may range from zero to 100, with a score of 100 being a perfect indication.

3. Results

3.1. Glade Type, Size, Neighbourhood Distance and Location

Glade type, size, elevation and nearest neighbourhood distances between glades, as shown in **Table 1(a)** and **Table 1(b)**, the altitude of the glade types differed significantly, with upper natural glades being significantly ($p < 0.05$) higher above sea level than man-made and lower natural glades. Glades were located at latitude 03˚14'57'' to 03˚17'44" and longitude 36˚40'47" to 36˚51'59" respectively.

3.2. Glade Vegetation

A total of 106 plant species and three growth forms were recorded in the plots surveyed in the glade edge and interior of the three glade types (see **Table 2**). Out of these, 20 plant species were common to all glade types; 16 plant species were found in both lower natural and man-made glades, 13 were found in both lower and upper natural glades and none in both man-made and upper natural glades. Some plant species were found only in one glade type, with 36 being found only in lower natural glades, 11only in the upper natural glades and ten only in the man-made glades.

Table 1. (a) Glade type, size, altitude, location and nearest neighbourhood distances between glade types; (b) Comparison of means and standard deviations (SD) for glade size, altitude and distance to nearest neighbouring glade for five man-made, fifteen lower natural and five upper natural glades using Kruskal-Wallis ANOVA.

(a)

Glade type and number	Size (m^2)	Altitude (m)	Distance (m) and nearest neighbour hood glade number in brackets	Location	
				Longitude	Latitude
Man-made					
2a	11,677	1473	2090 (9)	36˚51'49"	03˚17'43"
2b	1102	1479	190 (2a)	36˚51'59"	03˚17'44"
3d	21,406	1617	349 (3b)	36˚51'11"	03˚17'30"
13a	9876	1678	880 (26)	36˚50'45"	03˚14'50"
15	32,344	1618	170 (1)	36˚50'50"	03˚16'16"
Lower natural					
1	7679	1617	2820 (2b)	36˚51'34"	03˚16'03"
3a	6092	1626	1560 (15)	36˚51'34"	03˚15'19"
3b	33,309	1615	440 (3a)	36˚51'57"	03˚16'09"
3c	5667	1613	30 (3b)	36˚51'56"	03˚16'10"
7	6403	1617	120 (3c)	36˚51'41"	03˚16'09"
9	8240	1666	10 (10)	36˚51'52"	03˚15'12"
10	3568	1658	1260 (19)	36˚50'57"	03˚17'52"
11	9463	1639	820 (9)	36˚50'58"	03˚16'21"
12	17,795	1614	960 (3d)	36˚51'33"	03˚15'44"
13b	32,836	1706	350 (13a)	36˚50'50'	03˚14'57"
14a	26,524	1675	820 (16)	36˚50'28"	3˚15'55"
14b	2282	1683	450 (15)	36˚50'56"	03˚15'59"
26	3345	1714	1600 (14a)	36˚50'43"	03˚15'06"
19a	7733	1687	70 (19b)	36˚50'23"	03˚16'43"
19b	3453	1684	2270 (9)	36˚50'14"	36˚15'35"
Upper natural					
22	2975	2003	220 (25)	36˚49'51"	03˚15'40"
25	3239	2045	350 (27)	36˚49'41"	03˚15'34"
27	13,108	2076	400 (29)	36˚49'22"	03˚15'32"
28	2068	2070	300 (29)	36˚49'33"	03˚15'47"
29	3037	2103	300 (28)	36˚49'18"	03˚15'53"

(b)

Glade type	Lower natural (mean ± SD)	Upper natural (mean ± SD)	Man-made (mean ± SD)
Size (m^2)	11,627 ± 979	4885 ± 4619	15,281 ± 11,957
Altitude (m)	1654 ± 36	2059 ± 38	1573 ± 92
Nearest neighbor distance (m)	905 ±357	314 ± 67	734 ± 332

*$p < 0.05$.

Table 2. List of 106 plant species and their growth forms found in the glade edge and interior of man-made (MM), lower upper (LN) and upper natural (UN) glades.

Species	Growth form	MM	UN	LN
Andropogon gayana	Grass	*v*		v
Brachiaria brizantha	Grass			v
Chloris pycnothrix	Grass			v
Cynodon dactylon	Grass	*v*	v	v
Cynodon plectostachyus	Grass			v
Cyperus laevigatus	Grass-sedge	*v*	v	v
Cyperus rotundus	Grass-sedge	*v*		v
Cyperus spp.	Grass-sedge	*v*	v	v
Digitaria milanjiana	Grass	*v*		
Digitaria scalarum	Grass	*v*	v	v
Digitaria velutina	Grass			v
Ehrharta arrecta	Grass		v	v
Eleusine jaegeri	Grass		v	
Eragrostis caespitosa	Grass			v
Eragrostis tennifolia	Grass			v
Heteropogon contortus	Grass		v	v
Kyllinga alba	Grass-sedge			v
Kyllinga arrecta	Grass-sedge	*v*	v	v
Oplismenus hirtellus	Grass			v
Panicum coloratum	Grass	*v*		
Paspalum commersonii	Grass		v	v
Paspalum notatum	Grass		v	v
Paspalum spp.	Grass		v	v
Pennisetum clandestinum	Grass	*v*		v
Pennisetum mezianum	Grass	*v*		
Setaria chivalieri	Grass	*v*		v
Setaria homonyma	Grass		v	
Setaria sphacelata	Grass	*v*	v	v
Setaria megaphylla	Grass			v
Setaria plicatilis	Grass			v
Setaria phragmitoides	Grass		v	
Sporobolus africanus	Grass	*v*	v	v
Themeda triandra	Grass			v
Achyranthes aspera	Forbs	*v*		v
Ageratum conyzoides	Forbs	*v*	v	v
Anthericum cooperi	Forbs			v
Asplenium bugoiense	Forbs	*v*	v	v

Continued

Asystacia gangetica	Forbs		v	v
Beciumo bovatum	Forbs		v	
Carduus keniensis	Forbs		v	
Caucalis incognita	Forbs	*v*	v	v
Coccinia trilobata	Forbs	*v*	v	v
Commelina benghalensis	Forbs		v	v
Commelina petersii	Forbs	*v*		
Conyza floribunda	Forbs	*v*	v	v
Crateostigma plantagineum	Forbs			v
Cucumis aculeatus	Forbs		v	v
Cycnium tennisectum	Forbs			v
Cycnium tubulosum	Forbs			v
Cynoglossum coeruleum	Forbs			v
Dichondra repens	Forbs		v	v
Dolichos axillaris	Forbs		v	v
Dolichos oliveri	Forbs	*v*		
Gomphrena celosioides	Forbs			v
Hypoestes verticillaris	Forbs		v	
Justicia betanica	Forbs	*v*		v
Justicia flava	Forbs	*v*	v	v
Kalanchoe densiflora	Forbs	*v*	v	v
Oxalis cardifolia	Forbs	*v*	v	v
Oxalis corniculata	Forbs		v	v
Oxalis latifolia	Forbs	*v*	v	v
Plectranthus caninus	Forbs			v
Plectranthus elegans	Forbs			v
Polygonum salicifolium	Forbs	*v*		v
Polygonum senegalense	Forbs			v
Rhynchonsia elegans	Forbs			v
Rhynchosia densiflora	Forbs	*v*		
Rhynchosia minima	Forbs	*v*	v	v
Rhynchosia spp.	Forbs			v
Senecio spp.	Forbs	*v*		v
Senecio telekii	Forbs			v
Satureja biflora	Forbs		v	v
Sphaeranthus bullatus	Forbs			v
Taraxacum officinale	Forbs		v	
Trichodesma zeylanicum	Forbs	*v*		v
Trifolium spp.	Forbs		v	

Continued

Urtica massaica	Forbs			v
Abutilon mauritianum	Shrub	*v*		
Bersama abyssinica	Shrub		v	
Carrisa edulis	Shrub		v	
Clutia abyssinica	Shrub		v	v
Crotolaria agatiflora	Shrub			v
Crotolaria sp	Shrub			v
Croton macrostachyus	Shrub	*v*		v
Diospyros abyssinia	Shrub			v
Hibiscus vitifolius	Shrub	*v*		
Indigofera arrecta	Shrub			v
Leonotis mollisma	Shrub			v
Leonotis nepetifolia	Shrub	*v*		v
Lippia javanica	Shrub	*v*	v	v
Mimosa pigra	Shrub		v	
Ocimum suave	Shrub	*v*		v
Pentaslan ceolata	Shrub			v
Psiadia Arabica	Shrub			v
Rauvolfia caffra	Shrub			v
Senna didymobotrya	Shrub	*v*	v	v
Senna mimosoides	Shrub	*v*	v	v
Senna spectabilis	Shrub	*v*		v
Sesbania sesban	Shrub			v
Sida alba	Shrub			v
Sida ovale	Shrub	*v*		v
Solanum incanum	Shrub	*v*		v
Tephrosia holstii	Shrub	*v*		
Vernonia brachycalyx	Shrub	*v*		
Vernonia pauciflora	Shrub	*v*		v
Vernonia subuligesa	Shrub			v

Plant species composition of the three glades types differed significantly (MRPP: T = −4.51, $p < 0.001$ and A = 0.17). Growth forms in the lower natural glades were associated with the forest-glade edge or glade interior $\chi^2 = 15.95$, df = 4, $p < 0.01$. Lower natural glades had the highest plant total density, followed by upper natural glades and the least was man-made glades (see **Table 3**). Species richness was highest in lower natural glades, and lower and the same for man-made and upper natural glades. Lower natural glades had the highest species diversity, followed by man-made and upper natural glades. Upper natural glades were the most heterogeneous habitats, followed by lower natural glades, with man-made glades being the least heterogeneous (see Table 3).

In upper and lower natural glades, overall plant total abundance, percent basal cover, species richness and species diversity decreased significantly with increasing plot distance from the glade edge to the glade interior (see Table 4). Whereas, in man-made glades, only overall plant species diversity decreased significantly with increasing plot distance from the glade edge. About growth forms, in man-made glades, grass species total abundance and species richness, as well as forbs species diversity decreased significantly with increasing distance towards the glade interior (see Table 5). In lower natural glades, decreases were also observed with increasing plot distance into the glade interior for grass and forbs species richness and forbs species diversity in upper natural glades and for grass, forbs and shrub total abundance and species richness and grass and forbs species diversity.

Table 3. Comparison of overall total plant density (stems/ha), species richness and species diversity and heterogeneity by glade type.

Glade types	Total density (stems/ha)	Species richness	Shannon-Weiner Diversity Index (H')	Heterogeneity
Man-made	5018	5045	2.87	0.73
Upper natural	6691	5044	2.56	0.65
Lower natural	17,722	9285	3.07	0.68

Table 4. Comparison between glade plant parameters and plot distances from the forest-edge into the glade interior for the three glade types.

Glade type and plant parameters	Distances (m)			ANOV A =
	2.5	12.5	22.5	
Man-made				F(2, 12)
Total abundance	249.8 ± 129.1	223.8 ± 153.1	113.8 ± 128.9	1.40
% Basal cover	98.0 ± 1.9	78.2 ± 3.8	59.6 ± 54.4	1.13
Species richness	12.4 ± 3.2	9.4 ± 5.8	6.4 ± 6.1	1.67
Species diversity	0.7 ± 0.2	0.6 ± 0.3	0.5 ± 0.4	0.73[a]
Upper natural				F(2, 12)
Total abundance	357.2 ± 127.8	372.8 ± 139.3	72.2 ± 61.4	6.95[b]
% Basal cover	99 ± 0.7	98 ± 1.4	19 ± 2.5	17.49[c]
Species richness	9 ± 3.3	11 ± 4.9	1.6 ± 3.6	7.95[c]
Species diversity	0.6 ± 0.2	0.5 ± 0.2	0.1 ± 0.3	5.91[c]
Lower natural				F(2, 42)
Total abundance	386.2 ± 195.4	288.1 ± 230.4	67.3 ± 102.9	11.79[c]
% Basal cover	94.9 ± 11.5	82.2 ± 34.4	32.1 ± 47.2	13.98[c]
Species richness	11.3 ± 2.3	8.3 ± 5.0	2.6 ± 3.9	19.07[c]
Species diversity	0.7 ± 0.2	0.6 ± 0.3	0.2 ± 0.5	10.36[c]

[a]$p < 0.01$, [b]$p < 0.01$, [c]$p < 0.001$.

Table 5. Relationship between plant growth forms and plot distance from the forest-edge to the interior of the three glade types.

Glade type & Growth form parameters	Edge distances (m)			AN OV A =
	2.5	12.5	22.5	
Man-made				F(2, 12)
Grasses				
Total abundance	57.2 ± 20.8	25.6 ± 23.4	21.0 ± 22.3	3.95[b]
Species richness	4.2 ± 1.1	2.4 ± 1.7	1.4 ± 1.3	5.21[b]
Species diversity	0.3 ± 0.2	0.3 ± 0.2	0.3 ± 0.3	0.02
Forbs				
Total abundance	171.4 ± 143.3	112.0 ± 80.8	90.0 ± 102.2	0.71
Species richness	5.2 ± 1.9	3.8 ± 2.5	3.9 ± 2.6	1.3
Species diversity	0.6 ± 0.3	0.3 ± 0.2	0.2 ± 0.2	3.12[b]
Shrubs				
Total abundance	21.2 ± 39.7	39.2 ± 38.1	42.8 ± 2.1	0.41
Species richness	2.6 ± 1.9	2.0 ± 1.6	2.2 ± 2 .3	0.12
Species diversity	0.3 ± 0.3	0.6 ± 0.4	0.5 ± 0.4	0.48
Upper natural				F(2, 12)
Grasses				
Total abundance	205.8 ± 151.5	192 ± 184.8	32.0 ± 71.6	2.25
Species richness	4.2 ± 1.6	4.6 ± 3.0	0.0 ± 0.0	8.47[c]
Species diversity	0.5 ± 0.3	0.6 ± 0.4	0.2 ± 0.5	1.90
Forbs				
Total abundance	139.4 ± 106.5	174.0 ± 99.2	38.0 ± 84.9	2.64
Species richness	3.8 ± 2.6	5.0 ± 2.1	0.4 ± 0.9	7.12[c]
Species diversity	0.8 ± 0.2	0.7 ± 0.1	0.2 ± 0.5	5.49[b]
Shrubs				
Total abundance	12.0 ± 19.9	6.8 ± 7.4	11.2 ± 25.0	0.11
Species richness	1.2 ± 1.3	1.4 ± 1.1	1.8 ± 4.0	0.07
Species diversity	0.5 ± 0.4	0.6 ± 0.4	0.2 ± 0.5	1.30
Lower natural				F(2, 42)
Grasses				
Total abundance	69.8 ± 52.1	103.4 ± 117.6	27.3 ± 46.8	3.50[b]
Species richness	3.1 ± 1.6	2.9 ± 2.0	1.2 ± 1.9	4.95[b]
Species diversity	0.6 ± 0.3	0.5 ± 0.3	0.2 ± 0.2	12.58[c]
Forbs				
Total abundance	281.2 ± 210.9	181.8 ± 152.4	37.1 ± 60.3	9.50[c]
Species richness	5.8 ± 2.3	4.4 ± 2.9	0.8 ± 1.3	19.37[c]
Species diversity	0.5 ± 0.2	0.5 ± 0.3	0.2 ± 0.4	3.69[b]
Shrubs				
Total abundance	8.3 ± 9.1	2.7 ± 4.1	2.9 ± 8.8	2.51[b]
Species richness	2.3 ± 1.8	0.9 ± 1.0	0.4 ± 1.1	7.80[c]
Species diversity	2.3 ± 1.8	0.6 ± 0.4	0.2 ± 0.5	1.30

[a]$p < 0.05$, [b]$p < 0.01$, [c]$p < 0.001$.

3.3. Glade Indicator Species

As shown in "**Table 6**", eight species of plants were identified as indicator plants for the glades. Five of them, three grass and two shrub species, were indicators for upper natural glades and the other three, one grass and two shrub species, were indicators for man-made glades.

4. Discussion

The size of a given glade influences conditions within the glade and determines its physical, ecological and sociological phenomena [19]. In the three glade types, the lack of significant differences in glade sizes and nearest neighbourhood distances (**Table 1(b)**) indicates that these attributes did not influence the physical, ecological and sociological phenomena. Altitude accounted for the variations found in plant distribution, composition and abundance in the three glade types.

4.1. Upper Natural Glades

Upper natural glades had an average of 6691 stems per hectare, nearly one-third of that observed for lower natural glades of 17,722 per hectare and higher than that observed in man-made with the total stem density, at an average of 5018 per hectare. The variation in stems may be due to colder climate, higher altitude, topography and soils that affect plant growth in general. These factors may have benefited the total abundance of grasses in upper natural glades, compared to lower natural and man-made glades [29]. Reduced grazing pressures may also contribute to the relatively higher total abundance of grasses observed in the upper natural glades. The soil characteristics supported the presence of five indicator species, three grasses and two shrubs. *Heteropogon contortus* and *Digtaria scalarum* are grasses that both grow in well-drained soils with surface textures ranging from loamy sand to clay loam [30]. *Eleusine jaegeri* grows in disturbed open grassland areas. *Senna mimosoidea* and *Clutia abyssinica* are shrubs that grow in moist, disturbed sites and that are not grazed by ungulates [31] [32].

In the interior of upper natural glades, grasses and forbs species richness was lower at the forest-glade edge (2.5 m) and intermediate (12.5 m) into the glade interior and lowest closer to the glade interior (22.5 m). The decrease might be associated with increased grazing and browsing pressure at the forest-glade edge and less towards the glade interior, as grazing alter the structure and composition of the vegetation [28] [33] [34] [35] [36]. For the forbs, species diversity was highest at the forest-glade edge and decreased towards the glade interior. These phenomena are likely the result of food type's selection by animals in the course of their movements towards the glade interior and as well an anti-predatory strategy [35]. These changes along the forest-glade edge towards the glade interior could be associated with edge effects [1] as edge effects have an influence on the distribution of vegetation along the landscape [36].

Table 6. Indicator plant species, indicator value and growth form by glade type and habitat condition.

Plant Species	Growth form	Glade type	Indicator value	Habitat condition
Eleusine jaegeri	Grass	Upper natural	80.0[d]	Encroach grazing land
Heteropogon contortus (Spear grass)	Grass	Upper natural	78.5[d]	Grey/black clay soils
Senna mimosoidea	Shrub	Upper natural	71.6[b]	Disturbed areas
Digitaria scalarum (African coach grass)	Grass	Upper natural	60.6[c]	Humid soil, flood plains
Clutia abyssinica	Shrub	Upper natural	59.9[c]	Disturbed areas, on rocky hillsides
Solanum incanum (Sodom apple)	Shrub	Man-made	59.6[c]	Disturbed and overgrazed areas
Pennistem mezianum (Bamboo grass)	Grass	Man-made	58.8[c]	Black clay soil
Senna didymobotrya	Shrub	Man-made	49.1[b]	Disturbed areas

[a]Values may range from zero (none) to 100 (perfect). [b]$p < 0.05$, [c]$p < 0.01$, [d]$p < 0.001$.

4.2. Lower Natural Glades

Lower natural glades had the highest mean total stem density (17,722 per hectare), with more than three and a half times the density, observed in man-made glades (6691 per hectare) and more than two and a half times that of upper natural glades. This difference between lower and upper natural glades is probably associated with the warmer temperature and more favourable soil found at lower altitudes. As pointed out by [29], plant growth generally increases with increases in soil ambient temperature.

In the lower natural glades, grass and forbs species richness and diversity and total shrub abundance and species richness decreased with the distance from the forest-glade edge to the glade interior (**Table 5**). This difference may be due to higher grazing pressure on grasses and forbs that reduces growth in plant height, as compared to shrubs that are not grazed [28] [33] [34]. The lower natural glades were the only glade type with no indicator plant species, as compared to upper natural and man-made glades (**Table 6**). The reason for lower natural glades of having no indicator plant species may be due to increased ungulate grazing pressure in the glade interior of lower natural glades compared to upper and man-made glades, leading to changes in plant species composition with some individual species becoming more dominant in the glade interior [23].

4.3. Man-Made Glades

Total stem density for man-made glades was the lowest with an average of 5018 per hectare, three and a half times fewer than found in lower natural glades

17,722 per hectare. The total abundance and species richness of grasses and species diversity of forbs decreased from the glade edge towards the glade interior. However, for man-made glades, total shrub abundance was lowest at the forest-glade edge and highest at the glade interior (see **Table 5**). These trends could be due to disturbance caused by clearing the trees and shrubs at the forest-glade edge. The disturbance caused by clearing vegetation on the forest-glade edge of man-made glades transforms vegetation structure and could account for the observation of enhanced forbs diversity at the edge [29]. The disturbance favoured the growth of indicator shrubs, *Solanum incanum and Senna didymobotrya*, which were found at the disturbed forest edges, particularly edges that are grazed and browsed by ungulates [30] [37].

Man-made glades are located at lower forest elevations below the escarpment of upper natural glades where soils are often deeper, contain more organic matter and have high water holding capacity similar to lower natural glades [30] [37]. The man-made glades were cleared forest interiors that are seasonally flooded by water due to the removal of trees, where less transpiration takes place and the soil becomes waterlogged during the rainy season [23] Vegetation clearing, grazing and flooding are all disturbances that favour the growth of vegetation, such as the indicator grass species, *Pennistem mezianum* that grows in damp black clay soil [30] and the indicator shrub *Senna didymobotrya* an invasive plant that grows in disturbed, open, damp hollow and well-watered areas. Repeated disturbance due to vegetation clearing at the forest-glade edges maintains an open canopy condition that is favoured by most invasive plant species [38]. Overall, although man-made glades were found to be the least heterogeneous of the three glade types, they were found to have more species diversity than upper natural glades and the same for species richness in upper natural glades (see **Table 3**).

5. Conclusion

In general, plant species abundance, richness and diversity were highest at the forest-glade edge and decreased towards the glade interior, while plant species composition differed significantly between the three-glade types. The plant growth form for lower natural glades was associated with forest edge and glade interior. However, altitude accounted for the variations in plants distribution, composition and abundance in the three glades types. These results highlight the potential of forest-glade edges for species biodiversity due to changes that occur due to disturbance and edge effect influence that attract forest-glade edge animals to use it for grazing and browsing.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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