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Is Mau Forest Changing into an Open Canopy Ecosystem? Effects of Anthropogenic Forest Disturbances on the Population Structure of *Zanthoxylum gillettii* in South West Mau Forest, Kenya

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Population
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Studies were carried out to understand the effects of anthropogenic forest disturbances on the population structure and stability of *Zanthoxylum gillettii* (De Wild) in South West Mau (SWM) natural forest in Kenya. *Z. gillettii* is an indigenous tropical tree species whose seeds have poor germination and seedlings are shade intolerant. However, its timber is valued for its structural and medicinal properties. Four study sites with varying levels of human interaction described as Relatively Undisturbed (RU), Lowly Disturbed (LD), Moderately Disturbed (MD) and Highly Disturbed (HD) areas were selected. Three line transects 100 metres apart and running parallel from the forest edge up to 1 kilometre inside the forest were established in each site. Four sample plots measuring 20 metres by 50 metres starting from the forest edge were laid at 250 metres intervals along each line transect. Each sample plot was divided into 10 subplots of 10 metres by 10 metres and 5 metres by 5 metres sub-subplots nested. After the subdivision, a 1 metre by 1 metre quadrant was laid at the centre. Trees with DBH (Diameter at Breast Height) greater than 10 centimetres were measured in subplots. Saplings and seedlings were counted in sub-subplots and quadrants respectively and the growth densities were evaluated in each site. Diameter at Breast Height (DBH) values were used to classify seedlings, saplings, poles and adult trees into diameter-size classes. Regeneration densities of all life forms (seedlings, saplings, poles and adults) of *Z. gillettii* differed across the disturbance gradient. The population structure closely followed the J-curve in both the low and relatively undisturbed sites. The relative density of *Z. gillettii* across the disturbance gradient was far much lower in comparison to those of less valuable tree species such as *S. mauritianum*. These results suggest that anthropogenic disturbances such as browsing by domestic animals, shading effect, previous overharvesting and poor recruitment from one growth stage to the next as well as the irregular flowering of *Z. gillettii* influenced its relative abundances in SWM forest. Put together, these results suggest that South West Mau Forest could be changing from closed to open canopy forest. This is supported by increasing light gaps known to promote successful regeneration and recruitment of pioneers, prolific seeders, gap colonizers and invasive species such as *S. mauritianum* which will ultimately prevent the emergence of shade-tolerant species. This study proposes interventions such as direct seeding and enrichment planting of *Z. gillettii* in South West Mau Forest to promote

regeneration trends, healthy population structures, as well as remedy disturbances and exploitation.

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INTRODUCTION

Anthropogenic disturbances in natural forest ecosystems are one of the major causes of global biodiversity loss (Nyakeru *et al.*, 2023; UNEP, 2009; Vié *et al.*, 2009). Such disturbances are associated with unsustainable harvesting of trees, tree products and overgrazing, hence contributing to the degradation and loss of forests and tree species in the wild (UNEP *et al.*, 2009; Nyakeru *et al.*, 2023). In Africa, the most species-rich Afromontane Forest ecosystems have experienced pressure from anthropogenic disturbance that resulted in significant destruction of trees (FAO, 2009; Bussman, 2001). In Kenya, the increasing demand for forest products as well as increasing human population has resulted in considerable pressure on forest resources such as witnessed in Mau Forest (Kinyanjui *et al.*, 2013). Previous studies indicated that parts of South West Mau Forest, such as Maramara and Itare forest blocks have experienced different levels of anthropogenic disturbance (Kinyanjui *et al.*, 2013; Mullah *et al.*, 2011; Obati, 2007; Ronoh *et al.*, 2018; Ouya *et al.*, 2024).

Zanthoxylum gillettii (African Satinwood, as commonly known) has durable, medium-weight, timber, whitish in colour with a strong aromatic scent often preferred for furniture making and

heavy construction work (Okeyo, 2008; Orwa *et al.*, 2009). The species is a source of alternative medicines in most African communities. The stem bark juice is used in the treatment of stomach-aches, stem decoction for back pains and urogenital complaints, root bark or fruit pulp as a liniment for rheumatism and decoctions from young leaves is used to ease coughs and is said to be effective against gonorrhoea and bilharzia (Gaya *et al.*, 2013).

Z. gillettii is a secondary tree species that regenerates well in gaps, and flowers irregularly; either once a year or once every two years (Okeyo *et al.*, 2011). Its seeds are recalcitrant with low germination rates of 20 to 50 %. This could reduce the species seed bank, regeneration and recruitment (Okeyo *et al.*, 2011). The removal of upper canopy trees by agents of forest disturbance has ecological consequences due to weeds colonization of the gaps created. Little is known about the effects of such weeds on its natural regeneration while the instability of other tree species population due to poor regeneration trend in SWN forest has been hypothesized (Ronoh *et al.*, 2018). The purpose of this study is therefore to evaluate the effects of anthropogenic forest disturbances on the population structure of *Z. gillettii* in South West Mau Forest, Kenya.

MATERIALS AND METHOD

Study area

This study was conducted in the western part of South West Mau Forest, Kenya, which lies between latitudes 00° 22' 46.77'' S - 00° 38' 51.25'' S and longitudes 035° 17' 28.22'' E - 035° 35' 06.75'' E (Google Map, 2023). SWM forest is a tropical moist montane forest that is characterised by a bimodal rainfall (2000-3000 mm per annum) with peaks in April and August (Tea Research Foundation (TRF), 2005; Kinyanjui *et al.*, 2013). The mean annual temperature ranges between 12 °C to 16 °C (Kinyanjui *et al.*, 2013; Mullah *et al.*, 2011; Obati, 2007). The forest has a relatively closed canopy, high biodiversity and hosts high value indigenous tree species such as *Z. gillettii* and *P. africana* (Mullah *et al.*, 2011; Ronoh *et al.*, 2018; Mullah *et al.*, 2013).

Study sites

This study was done in four stratified sites of SWM natural forest, each representing a different degree of anthropogenic disturbance as briefly described by Ronoh *et al.* (2018), as follows: The forest site bordered by large-scale multinational tea estates was described as lowly disturbed (LD) while the one bordered by tea belt of 100 m width that stretched between farmlands and the forest boundary represented moderately disturbed (MD) site. The forest site bordered by farmlands and homesteads was described as highly disturbed (HD) while the area next to Forest Station offices represents a relatively undisturbed site (RD). In each study site regeneration density, population

structure and stability of *Z. gillettii* was determined.

Experimental design

This study adopted experimental design described by Ronoh *et al.*, 2018. In each of the three study sites, three parallel line transects that ran from the forest edge up to 1 km into the forest were established such that the distance from one transect to the next was 100 m. Ground Positioning System (GPS) coordinates of the starting points of the established transects were recorded. Sample plots measuring 20 m x 50 m (0.1 ha) were laid at 250 m intervals along each transect and further subdivided into 10 subplots of 10 m x 10 m. A quadrat of 1 m x 1 m was laid at the centre of 5 m x 5 m plots nested in each of the 10 m x 10 m subplots.

Regeneration Density of *Z. gillettii*

The regeneration density of *Z. gillettii* in each stage of growth was evaluated as described by Ronoh *et al.*, 2018 and briefly explained as follows: In each 10 m x 10 m subplot, the number and the DBH of all *Z. gillettii* adult trees and poles were counted and measured respectively. The DBH was used to segregate *Z. gillettii* into size classes as follows: seedlings (DBH < 5 cm or 1.3 m in height), saplings (DBH 5-9.9 cm), poles (DBH 10-19.9 cm) and adult trees (DBH >20 cm). In each (5 m x 5 m) nested subplot, *Z. gillettii* saplings were counted while in each (1 m x 1 m) quadrant, seedlings were counted. The DBH of *Z. gillettii* trees with buttresses were assessed at points just above the buttresses. The regeneration density (stems ha⁻¹) of *Z. gillettii* in each study site was calculated as follows (equation 1):

$$\text{Density (Stems ha}^{-1}\text{)} = \frac{\text{Number of stems of individual species}}{\text{Area in ha}} \dots \text{(Equation 1)}$$

One-way Analysis of Variance (ANOVA) at $p = 0.05$ significance level was used to test for differences in regeneration densities of *Z. gillettii* species between the study sites. Pearson correlation analysis was used to determine the

relationships between the regeneration density of *Z. gillettii* species and disturbance indices. The obtained correlation coefficient (r) was used to determine the strength and direction of the relationship.

Population Structure of *Z. gillettii*

Data on the regeneration density of *Z. gillettii* was summarised as per its four development stages as follows: seedlings (diameter <5 cm), saplings (diameter 5-9.9 cm), poles (DBH 10-19.9 cm) and adult trees (DBH >20 cm) and the density of each development stage was calculated. Density bar graph of every development stage in each study site was produced and then compared to an inverse-J shape curve which reflects the population structure of a tree species in typical undisturbed forests. The structures were interpreted according to the system by (Tripathi *et al.* 2010; Owiny, & Malinga, 2014; Ronoh *et al.*, 2018) as good if seedlings > saplings > poles > adults; fair if seedlings > saplings > poles ≤ adults; and poor if sapling stage is present but no seedlings or any other imbalance in the structure.

Diameter Size Distribution of *Z. gillettii*

The population stability of *Z. gillettii* on each study site was described based on its ten (10) cm

diameter size-class distribution and briefly is as follows: <10, 10-19.9, 20-29.9, 30-39.9 and so on up to >110 cm. Seedlings and saplings (<10 cm) were grouped as regenerations. The relative density for each DBH size class in each site was computed in a line graph and compared to a reverse-J curve. The curve obtained was used to gauge the species stability of *Z. gillettii* in all the study sites as influenced by anthropogenic disturbances. From the graphs, it was easy to determine the recruitment of individual species from one diameter class to the next.

Relative Abundance of *Z. gillettii*

The relative abundance of *Z. gillettii* is expressed as a ratio of its density to that of all the species in the study area (equation 2) (Hitimana *et al.*, 2004). The relative abundance of *Z. gillettii* was computed for every study site and every development stage (seedlings, saplings, poles and adult trees).

$$\text{Relative density (RD)\% for species } i = \frac{\text{Density of species } i}{\sum \text{Densities of all species}} \times 100.. \text{ (Equation 2)}$$

Where $\sum$ = summation

Pearson correlation analysis was used to establish a relationship between the relative abundance of *Z. gillettii* and anthropogenic disturbance indices at each study site while ANOVA at $p = 0.05$ significance level was used to establish the difference between the relative abundance of *Z. gillettii* in all the study sites.

RESULTS AND DISCUSSION

Regeneration Density of *Z. gillettii*

Table 1 reports the mean regeneration densities of *Z. gillettii* at different stages of development and disturbances.

Table 1: Regeneration Densities of *Z. gillettii* (stems ha⁻¹) at different stages of development and disturbance indices

Disturbances		Seedlings (Stems ha ⁻¹)	Saplings (Stems ha ⁻¹)	Poles (Stems ha ⁻¹)	Adults (Stems ha ⁻¹)
Gradient	Indices (%)				
LD	10	0.8 _a	5.8 _a	12.5	2.5 _a
RU	19	5.8	9.2	26.7 _a	8.3
MD	34	14.2 _b	5.0 _a	10.8 _b	17.5
HD	37	5.0	20 _b	15.0	20 _b
(p) value	-	0.021	0.011	0.042	0.036

Key: LD = lowly disturbed site; RU = relatively undisturbed site; MD = moderately disturbed site; HD = highly disturbed site. Values followed by letters “a” and “b” in a column are statistically different at $\alpha = 0.05$.

The mean regeneration density values (stems ha^{-1}) of all the development stages of *Z. gillettii* were statistically different ($p < 0.05$) across the disturbance gradient. The gradient showed high effect sizes (> 0.14) among the development stages of the species as demonstrated by eta-squared (η^2). The post hoc test revealed that the seedlings' densities at the LD site differed significantly ($p = 0.016$) from the MD site, however, it did not differ from the densities at both HD and RU sites ($p > 0.05$). The regeneration densities of saplings showed a wider significant variation in both MD and HD sites ($p = 0.029$), likewise to those in MD and HD sites ($p = 0.012$). Regeneration densities of poles differed significantly in both LD and HD sites ($p = 0.048$) while adult trees differed significantly ($p = 0.047$) in RU and MD sites.

Low regeneration densities of adult trees (10 to 26 stems ha^{-1}) (Table 1) and the absence of some diameter classes may suggest that *Z. gillettii* could have been over-harvested in the past before the exploitation of indigenous trees in natural forests was banned in Kenya in 1986 (Mullah, *et al.*, 2013). The observed erratic recruitment of *Z. gillettii* into the four development stages could be due to stiff competition by thick undergrowth in South West Mau Forest and harvesting of the species in the past. Huang *et al.* (2003) pointed out that a disturbed forest is characterised by a large number of smaller trees and understory invasive plants whereas undisturbed forest in contrast is characterised by fewer larger-diameter native trees. The fewer larger-diameter classes of *Z. gillettii* in South West Mau Forest may be an indication of a disturbed forest. In disturbed parts of Mount Kenya forest, UNEP (2009) reported the dominance of *Cassipourea malosana* and the likelihood of loss of rare species in highly diverse ecosystems as forest ecosystems respond to disturbance. Similar observations were made in the upper Amazonian Forest by Huang *et al.*

(2003) where species appeared to have been restricted to a single forest type whereas Sapkota *et al.* (2010) concluded that disturbances favoured single species regeneration. The presence of less valuable tree species that indicate forest disturbance such as *C. malosana*, *Solanum mauritianum*, *Neoboutonia macrocalyx* (Ronoh *et al.*, 2018) points to a decline in the poor population of important tree species such as *Z. gillettii* in SWM forest.

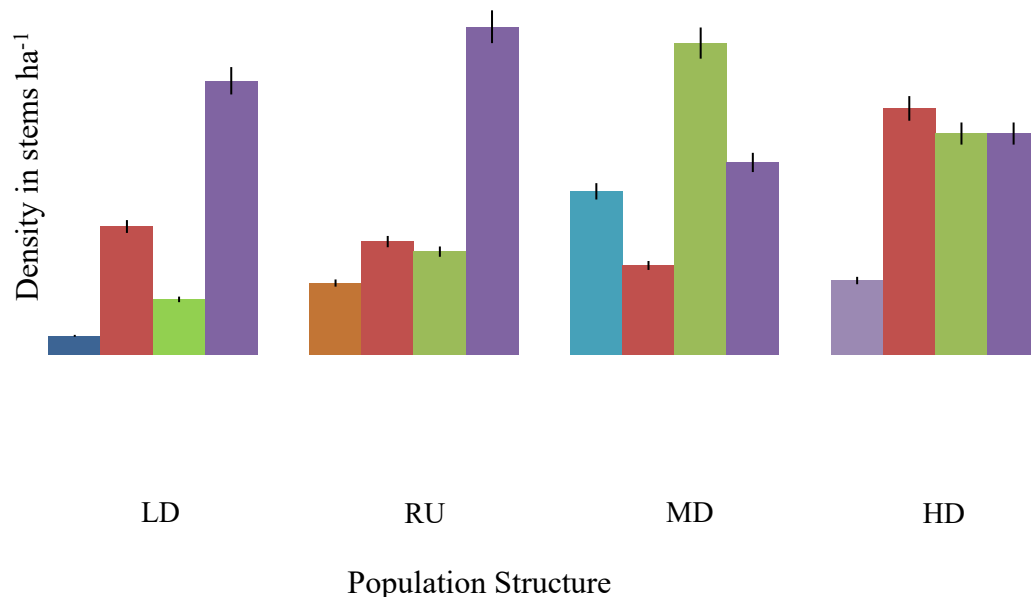
Canopy openings as measured by light screening efficiency (Ronoh *et al.*, 2018) differed significantly $F_{(3, 44)} = 3.58$, $p = 0.021$, $\eta^2 = 24.4$. The statistics revealed that the site that bordered Nyayo tea zone was different from the relatively undisturbed site ($p = 0.15$). Different canopy openings and seedlings and saplings density of *Z. gillettii* showed a weak positive and non-statistical significant correlation across the sites, $r(46) = 0.201$, $p = 0.172$. The weak positive relationship between canopy openings and regeneration density of *Z. gillettii* implies that *Z. gillettii* is not a purely primary species therefore the species is a less light demanding species. Its dispersal by birds confirms this because purely primary species is dispersed by wind. The small effect size given by coefficient of determination $r^2 = 0.04$ (Cohen, 1988) of the correlation implied that approximately 4 % of the difference in regeneration density may be attributed to canopy openings.

The availability of high amount of light at the forest floor promotes pioneer species which are light demanding. The observed significant variation of the canopy openings and its considerable ANOVA medium effect size (η^2) of approximately 24 % (Cohen, 1988) in SWM forest implied that this forest could be changing from closed canopy to open canopy forest. A study by Mutiso *et al.* (2015) in Mt. Blackett Forest of Western Mau Forest in Kenya, associated anthropogenic disturbances to light gaps which promoted successful regeneration and recruitment of pioneer species including invasive *S. mauritianum*. Tree species regeneration and recruitments prevent the emergence of shade-

tolerant species and later succession of native species.

Population Structure of *Z. gillettii* at Different Levels of Disturbances

Figure 1: Population structure of *Z. gillettii* development stages.



Key: LD (lowly disturbed site bordered by multinational tea company); RU (relatively undisturbed site near forest station office); MD (moderately disturbed site bordered by Nyayo Tea Zone); HD (highly disturbed site bordered directly by farmlands).

The population structure of *Z. gillettii* is close to J-curve in both the low and relatively undisturbed sites, even though more saplings than pole sizes were counted in both sites (*Figure 1*). Highly and moderately disturbed sites did not show any specific shapes relative to J-curve respectively. The J-shaped curve reflects the population structure of tree species in disturbed forests while the reverse-J-shaped curve reflects the population structure of tree species in typical undisturbed forests (Ronoh *et al.*, 2018). The behaviour of these structures in most instances could be

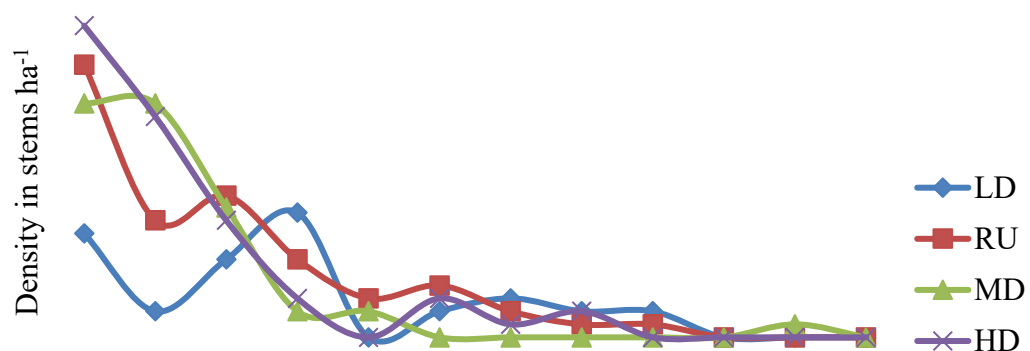
Figure 1 shows the population structure of *Z. gillettii* of all its development stages (seedlings, saplings, poles and adult trees).

attributed to high trampling and browsing by domestic animals and shading effect hence poor recruitment from one growth stage to the next (Ronoh *et al.*, 2018). *Z. gillettii* irregular flowering; once a year or once in two years may contribute to irregular growth of life forms (Orwa *et al.*, 2009; Tripathi *et al.*, 2010; Owiny, & Malinga, 2014), hence poor population structure across the disturbance gradient.

Diameter-Size Distribution and Relative Abundance of *Z. gillettii* at Different Levels of Disturbances

Figure 2 reports results on the diameter-size distribution (cm) of *Z. gillettii* development stages (seedlings, saplings, poles and adult trees) in the least, relatively undisturbed, moderately and highly disturbed sites of South West Mau Forest, Kenya.

Figure 2. Diameter-size distribution of *Z. gillettii* development stages



Diameter-size distribution

Key. LD = lowly disturbed site bordered by multinational tea company; RU = relatively undisturbed site near Forest Station office; MD = moderately disturbed site bordered by Nyayo Tea Zone; HD = highly disturbed site bordered by farmlands directly.

Figure 2 indicates an almost reverse-J curve on the diameter size distribution of *Z. gillettii* in relatively, moderately and highly disturbed forest sites except in the lowly disturbed site (bordered by a multinational tea company) where there was

a comparatively low density of stems in diameter class 10-19.9 cm and absence of trees in class 40-49.9 cm, therefore, forming an almost zigzag curve. There was a well-distributed diameter size for adult trees (>20 cm in DBH) in the relatively undisturbed site near the Forest Station Office.

Table 2, on the other hand, presents the mean relative densities of *Z. gillettii* development stages (seedlings, saplings, poles and adult trees) in the lowly, relatively, moderately and highly disturbed sites of South West Mau Forest, Kenya.

Table 2. Relative Density (%) of *Z. gillettii*

Disturbance gradient	Disturbance index (Scale: 100 %)	Relative density of <i>Z. gillettii</i> (%)
LD	10	3.78a
RU	19	4.73a
MD	34	6.01a
HD	37	5.77a
Σ	100	1.73

Key. LD = lowly disturbed site bordered by multinational tea company; RU = relatively undisturbed site near Forest Station office; MD = moderately disturbed site bordered by Nyayo Tea Zone; HD = highly disturbed site bordered by farmlands directly. Values followed by the same

letter in a column are not statistically different at $\alpha = 0.05$

These results indicate that there is no significant difference in the relative density of *Z. gillettii* across the disturbance gradient $F(3, 44) = 2.51, p = 0.071, \eta^2 = 0.146$, however, the site bordered by

Nyayo Tea Zone had the highest relative density while the site bordered by multinational tea company had the lowest. A weak negative and non-significant correlation between the disturbance indices and the relative density of *Z. gillettii* exists in these sites ($r(46) = -0.046$, $p = 0.754$). Despite the lack of statistically significant difference in the relative density of *Z. gillettii* between the sites, the moderate effect size of approximately 15 % according to Cohen (1988), implied that biologically, anthropogenic disturbance may have influenced the relative abundances of the *Z. gillettii*. This is supported by the negative correlation of the disturbance and relative density implying that disturbances had

negatively influenced the relative abundance of *Z. gillettii* in South West Mau Forest.

Because the relative abundance of future tree species depends on the availability of other species, the abundance of regenerations (seedlings and saplings) relative densities of the regenerations of *Z. gillettii* together with those of other species were computed. The position of *Z. gillettii* in terms of its relative density in relation to the relative densities of the other tree species in every study site was therefore evaluated and results are presented in Table 3.

Table 3. Relative Densities of all Tree Species in South West Mau Forest.

Species	Relative Density (%)			
	LD (10%)	RU (19%)	MD (34%)	HD (37%)
<i>Albizia gummifera</i>	6.40	5.79	5.19	5.87
<i>Allophylus abyssinicus</i>	4.07	2.45	1.06	1.47
<i>Aningeria adolfi-friedericii</i>	1.02	0.00	0.00	0.00
<i>Anthocleista keniensis</i>	0.44	0.08	0.24	0.10
<i>Casearia battiscombei</i>	5.67	2.94	3.42	4.59
<i>Cassipourea malosana</i>	0.73	0.24	0.35	0.10
<i>Celtis gomphophylla</i>	1.16	1.22	0.94	0.29
<i>Coffea eugeniodes</i>	0.15	0.65	1.77	0.10
<i>Croton macrostachyus</i>	1.45	1.55	2.95	2.05
<i>Deinbollia kilimandscharica</i>	1.31	0.00	0.00	0.00
<i>Diospyros abyssinica</i>	1.31	0.00	0.00	0.00
<i>Dombeya torrida</i>	0.00	0.82	0.00	0.00
<i>Dovyalis abyssinica</i>	0.00	0.00	0.12	0.00
<i>Ehretia cymosa</i>	0.15	1.06	0.71	0.49
<i>Ekebergia capensis</i>	0.00	0.49	0.00	0.29
<i>Heinsenia diervilloides</i>	2.91	0.33	1.53	1.96
<i>Makaranga kilimandscharica</i>	1.74	2.45	2.36	1.96
<i>Neoboutonia macrocalyx</i>	9.16	15.58	16.75	8.99
<i>Olea capensis</i>	0.00	0.08	0.00	0.00
<i>Polyscias fulva</i>	0.87	1.31	1.42	1.08
<i>Prunus africana</i>	1.45	2.85	1.06	2.44
<i>Psychotria mahonii</i>	6.54	4.24	3.18	7.43
<i>Schefflera abyssinica</i>	0.00	0.08	0.00	0.00
<i>Schefflera volkensii</i>	0.00	0.00	0.24	0.00
<i>Solanum mauritianum</i>	3.34	21.86	13.56	17.11
<i>Strombosia scheffleri</i>	15.41	4.65	9.79	4.50
<i>Suregada procera</i>	7.99	0.98	5.19	1.96
<i>Syzygium quineense</i>	1.60	2.61	1.89	4.11
<i>Tabernaemontana stapfiana</i>	17.73	18.60	17.33	22.97
<i>Techlea nobilis</i>	0.29	0.57	0.47	0.10

Species	Relative Density (%)			
	LD (10%)	RU (19%)	MD (34%)	HD (37%)
<i>Vangueria madagascariensis</i>	0.00	0.00	0.00	0.49
<i>Vernonia auriculifera</i>	0.00	0.08	0.24	0.10
<i>Xymalos monospora</i>	3.34	1.71	2.24	3.71
<i>Zanthoxylum gillettii</i>	3.78	4.73	6.01	5.77

Key. LD = lowly disturbed site bordered by multinational tea company; RU = relatively undisturbed site near Forest Station office; MD = moderately disturbed site bordered by Nyayo Tea Zone; HD = highly disturbed site bordered by farmlands directly. “Values in parentheses adjacent to disturbance gradient abbreviations are site disturbance indices”.

Table 3 indicates that the relative density of *Z. gillettii* in all study sites was far much lower than those of the best performers like *Tabernaemontana stapfiana*, *Neoboutonia macrocalyx* and *S. mauritianum* among others in the ecosystem. In previous studies on relative densities of other tree species in South West Mau Forest, Mullah *et al.*, (2011) observed that a secondary forest which had undergone selective logging in the past was dominated by pioneer species (gap species) like *T. stapfiana*, *suregada procera*, *Xymalos monospora* and *Cassipourea malosana*. In the same forest, Mathoko and Kariuki (2000), associated a secondary forest with tree species *Ehretia cymosa* and an annual weed *Achyranthes aspera*. Presence of pioneer tree species in the studied sites confirmed that indeed South West Mau forest is a secondary forest.

In earlier studies in different parts of South West Mau Forest, Mutangah and Mwaura (1993), stated that the Mau ecosystem may take many years to regain its pre-disturbance stand structure. Similar observations were shared by Mwangi and Nahama (1991), who described the Mau Forest ecosystem as a sea of *N. macrocalyx* several years after disturbances. High densities of species *T. stapfiana*, *N. macrocalyx*, *S. mauritianum*, *Albizia gummifera*, *Strombosia scheffleri* and *Psychotria mahonii* (resultants of disturbance) in the studied sites could be as a result of anthropogenic disturbances which have taken place for many years. These species together with annual

herbaceous plants could have provided potential competition for space to the *Z. gillettii*.

These results indicate that the regenerations of *Z. gillettii* performed poorly in relation to the other stiff competitors like *T. stapfiana*, *N. macrocalyx*, *S. mauritianum*, *A. gummifera*, *S. scheffleri* and *P. mahonii* among others. *Solanum mauritianum*, a prolific renowned devastating bugweed plant in forest ecosystems (Hitimana *et al.*, 2009), an early prolific seeder (Hitimana *et al.*, 2004; 2006) and an aggressive gap coloniser associated with forest disturbance (Mutiso *et al.*, 2009) could have outcompeted the regenerations of *Z. gillettii* as the two species regenerate well in the gaps. The difficulty in germination hence regeneration of *Z. gillettii* coupled with disturbances may justify its declining population. The low relative abundance of saplings and seedlings of *Z. gillettii* indicates poor performance of this species in the South West Mau Forest. A healthy tree population should have a higher seedling abundance than saplings. This was not the case with *Z. gillettii* as it had a higher abundance of saplings than seedlings in all the sites. Such a population is not stable and may explain why the population of *Z. gillettii* did not follow the required reverse-J curve. The presence of less valuable tree species indicating disturbance such as *C. malosana*, *S. mauritianum*, *N. macrocalyx* indicate that there could be a decline of important trees species such as *Z. gillettii* in SWM forest.

CONCLUSION

Regeneration densities of all the development stages of (seedlings, saplings, poles and adults) of *Z. gillettii* differed across the disturbance gradient, while its population structure closely followed J-curve in both the low and relatively undisturbed sites. Correlation between the disturbance indicators and relative density across the

disturbance gradient was weak, negative and non-significant. The relative density of *Z. gillettii* is relatively low in comparison, to those of less valuable tree species such as *C. malosana*, *S. mauritianum*, *N. Macrocalyx*. These results suggest that anthropogenic disturbances such as browsing by domestic animals, shading effect, previous overharvesting and poor recruitment from one growth stage to the next as well as the irregular flowering of *Z. gillettii* influenced its relative abundances in SWM forest. Put together these results suggest that SWM forest could be changing from closed to open canopy forest. This is supported by increasing light gaps known to promote successful regeneration and recruitment of pioneer, prolific seeder, gap colonizer and invasive species such as *S. mauritianum* which will ultimately prevent the emergence of shade-tolerant species. This study proposes direct seeding and enrichment planting of *Z. gillettii* in South West Mau Forest to promote its regeneration trends, and healthy population structure, and remedy disturbance and its exploitation.

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