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Influence of Gap Size on Regeneration, Structure and Species Diversity of Woody Vegetation in a Secondary Montane Forest Reserve, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

South-Western (SW) Mau forest reserve has been experiencing anthropogenic and natural disturbances creating canopy openings in the forest. The objective of this study was to determine how these canopy openings influence regeneration, forest structure and species diversity. The study employed nested sampling design in disturbed sites of the forest reserve. Plots of 500 by 500 m were laid once at 100 m inwards from the forest edge in the three blocks of SW Mau; Ndoinet, Maramara and Itare. Gaps were randomly identified in the plots and gap area calculated using Ellipse Method (EM). Gap sizes were categorized based on area (m^2). Woody species surrounding the gaps were identified and names inventoried. To determine regeneration, two quadrats of 5 by 5 m and 1 by 1 m were randomly delineated in every gap size four times and eight times for saplings (1-3 m high) and seedlings (<1 m high), respectively. Tree heights surrounding the gaps were measured using suunto clinometer. Diameter at breast height (dbh) was measured using diameter caliper (65 cm for small trees) and diameter tape for large trees (dbh> 65 cm). A total of 41 gaps were identified with small gap sizes dominating (23). Kruskal-Wallis rank sum test indicated non-significant differences in regeneration, forest structure and species diversity in the three gap sizes.

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This was attributed to *Piper capensis* which invaded medium and large gap sizes creating a closed canopy. It was, therefore, concluded that canopy cover from the invasive species influenced woody vegetation parameters in the gap sizes. It is, therefore, recommended to clear the dense ground cover to allow better natural regeneration and also enrichment planting in the gaps.

Keywords: Canopy cover; canopy openings; disturbed sites; ellipse method; piper capensis; vegetation parameters.

1. INTRODUCTION

Natural forests are critical ecosystems because of the eco goods and services that accrues from them; timber, medicine, climate regulation, watershed protection, air quality improvement, habitat, biodiversity conservation, carbon sequestration among other importance [1,2]. However, these forests have been experiencing both anthropogenic and natural disturbances causing canopy gaps [3]. These disturbances influence tree mortality, injury or removal; which affects the crown layer of forests by creating gaps of various sizes [4]. Human disturbances, such as, deforestation are known to be the most common in natural forests, hence, influence resources such as light radiation, thus, influencing plant species recruitment [5].

There has been rising demand on forest products to meet the needs of people in Kenya which results into increased pressure on Kenyan forests. This has resulted in increased harvesting of high valuable species; affecting the abundance and availability of such species, hence, biodiversity loss [6]. In South-Western (SW) Mau, for example, selective extraction of high value tree species and non-wood forest products have resulted into creation of canopy openings in the once closed canopy vegetation. This results into changes in ecological functions as well as habitats necessitating species loss [3]. Therefore, disturbances lead to overall impairment of species regeneration, diversity and forest structure due to canopy gaps [7].

Apart from human disturbances, forests are also experiencing natural disturbances, examples include; hurricanes, wind, pests, climate change, diseases, wildfires [8], senescence, floods which may lead to mortality of single/many trees creating canopy gap(s) [9]. The frequency and size of a forest gap is, thus, dictated by site preconditions such as soil moisture, topography, soil type, disturbance type, magnitude and frequency of the disturbances [10].

Forest gaps are, therefore, known to influence tree species since they determine microsite conditions within such micro-environments [4]. This implies that every gap size provides resources that are vital to a particular tree species. The most influenced microsite conditions are sun light, soil moisture, pH, soil temperature, litter quality, nutrients among other conditions. In addition, forest gaps are critical in defining the composition and structure of any forest type [5]. As a result, forest gaps leads to species richness through availing of the right resources with niche diversification [11]. Canopy openness are, thus, important in community dynamics of forests since they play an integral role in species coexistence as well as regeneration [4]. Both shade tolerant and shade intolerant species need canopy gaps for growth [12]. Forest gaps, therefore, provide variations in resources within the gaps, hence, availing resources for species established underneath to grow. Species also vary in resource requirements, hence, differences in responses in gap sizes resulting into structural complexity in forests [4].

Forest understory, therefore, depends on gap sizes to thrive well when the environmental conditions are availed. As a result, the impact of forest canopy openings interacts with woody vegetation parameters, such as; forest structure, regeneration and species diversity [4]. This can be explained by partitioning of abiotic requirements for seed germination, survival and growth. This is because, diverse tree species have particular light requirement which can only be dictated by gap size and landscape topography [11,13]. Due to gap size influence on woody vegetation parameters, habitats (forests) have been affected. Also, variations in resource availability in such disturbed forests results into environmental heterogeneity given its role in establishment and recruitment of tree species in forests [5]. The composition of species within natural forests relies more on canopy gaps rather than regeneration niches. Therefore, vegetation architecture, microsite conditions, tree traits, forest types and gap characteristics all merge to influence regeneration, structure and species diversity in natural forests [11].

Disturbances precisely of human origin continue to intensify in most natural forests leading to over-exploitation of forest resources. Mau forest is an example of an indigenous forest threatened by human encroachment, logging and deforestation which creates many canopy openings [11,12]. Considering the benefits that accrues from natural forests both at the local, regional and global scale, it is, therefore, crucial to direct attention to how gap sizes resulting from disturbances influence woody vegetation population parameters. This can contribute to forest restoration and biodiversity conservation of indigenous forests.

In Kenya, studies have been done on forest disturbances [14,7], however, fewer studies exist on gap sizes that accrues from the disturbances. The objective of this study was, therefore, to determine gap size influence on three woody vegetation population parameters; regeneration, forest structure and species diversity for biodiversity conservation.

2. MATERIALS AND METHODS

2.1 Site Description

The study was carried out in SW Mau (0˚15'S-0˚47'S, 35˚28'E - 35˚69'E); one of the reserves in Mau forest located in Bomet County, Kenya [14]. Currently, the reserve has an area of 60,000 ha of natural forest after a reduction from 84,000 ha associated with human disturbances [15,16]. It has an elevation of 2100 to 3300 m above sea level and receives annual rainfall amount of 2000-3000 mm [15]. The reserve is made up of three blocks; Itare, Maramara and Ndoinet [17] (Fig. 1).

2.2 Research and Sampling Design

The study was experimental whereby, nested sampling design was employed. A sample plot of 500 by 500 m was laid in the disturbed parts of each block at 100 m from the forest edge (cutline) and gaps randomly identified within. Digital Nikon camera was used to locate gap centres [12]. A linear tape (30 m long) was used to measure longest and shortest distance (m) from the gap centre to the edge. To calculate the individual gap area, Ellipse Method (EM) was utilized given that most gaps were regular in shape [18].

$$A = \pi \frac{LW}{4} \quad \text{(i)}$$

π = (3.14159); L= longest distance from gap centre to edge; W=longest distance perpendicular to L.; 4= alternative method of dividing gap area into triangles then side measuring (‘triangles’ method).

To determine regeneration, 2 quadrats; 5 by 5 m and 1 by 1 m were randomly laid four times and eight times for saplings and seedlings, respectively in every gap size and population recorded.

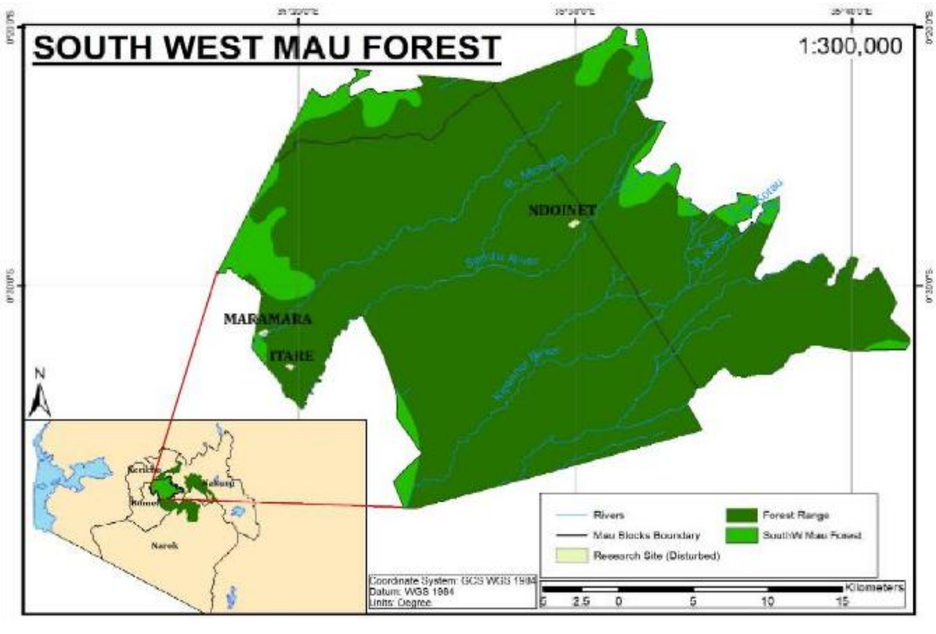

Fig. 1. Map of SW Mau forest reserve

For forest structure, tree species were grouped into; seedlings (< 1 m in height), saplings (1-3 m in height), understory (4-15 cm dbh), main canopy canopy layer (16-35 cm dbh) and emergent layer (> 35 cm dbh). Tree heights (dbh>3 cm) were taken using Suunto clinometer while saplings and seedlings were measured using a 3 m graduated rod. Tree diameter was measured using diameter calliper (65 cm for small trees) and diameter tape for huge trees (dbh > 65 cm) at 1.3 m from the ground. To determine the forest structural complexity, trees with dbh >3 cm were included and Holdridge's Complexity Index used [19]:

$$HC = (A \times d \times n \times h) \ / \ 1500 \ m^2 \qquad \text{(ii)}$$

Where;

HC = Holdridge's Complexity Index, *A* = basal area (m^2), d = tree density/1500 m^2, *n* = number of species/1500 m^2, *h* = mean tree height in meters.

To determine species diversity, all species within and surrounding the gaps were identified and names inventoried. Two indices were utilized;

a) Shannon-Weiner's Diversity Index (*H'*) for species diversity [20];

$$H' = -\sum_{i=1}^{s} (P_i) \ln(P_i) \qquad (iii)$$

b) Simpson's Diversity Index (1-*D*) for species dominance [12];

$$D = \sum \left(\frac{n_i}{n}\right)^2 \qquad \text{(iv)}$$

Where;

H`= Shannon-Wiener's Diversity Index, S= number of genera, Pi= ni/n; ni= total number of individuals of species i, n= total number of all the individuals, ln= natural $\log_{10}$ of Pi, D =Simpson's Diversity Index.

2.3 Data Analysis

Data was analysed in R software and Microsoft excel. Descriptive statistics were determined and inferential statistics for hypotheses testing. Kruskal-Wallis rank sum *H* test [21] was used to determine significant differences in the vegetation population parameters in the three gap sizes as follows;

$$H = \frac{12}{N(N+1)} \sum \frac{R^2 i}{n_i} - 3(N+1) \qquad \text{(v)}$$

where;

H = Kruskal-Wallis test, *N* = total number of observations in all groups, ni = number of observations in the i^{th} group, $R^2{}_i$ = total sum of ranks in group i.

3. RESULTS AND DISCUSSION

3.1 Forest Gap Size Grouping based on Area in SW Mau Forest Reserve

Gap sizes were grouped into three categories; small gap sizes ranging from 6-100 m^2 in area, medium gap sizes ranging from 101-300 m^2 while large gap sizes > 300 m^2. Giving the synopsis of Table 1, a total of 41 gaps were encountered of which 7 were large gap sizes, 11 were medium gap sizes while small gap sizes dominated with 23. Additionally, Ndoinet recorded the highest number of gaps (17) with the common being small gap sizes (14).

South-Western Mau Forest reserve recorded higher number of small gap sizes followed by medium and lastly large gap sizes. The findings were congruent to those reported by Hammond et al. [12] that small gap sizes in Masaryk Training Forest Enterprise Křtiny were higher than the remaining two gap

Table 1. Distribution of forest gap sizes in the disturbed sites of SW Mau blocks

Sites		Itare	Maramara	Ndoinet	Total gap sizes
Gap sizes	Large	3	3	1	7
	Medium	7	2	2	11
	small	3	6	14	23
Grand total		**13**	**11**	**17**	**41**

Table 2. Abundance of seedlings (regeneration) in different gap sizes

Family	Genus	Species	SGS (%)	MGS (%)	LGS (%)
Rubiaceae	*Psydrax*	*Psydrax schimperiana*	218(22.73)	155(23.34)	55(13.35)
Euphorbiaceae	*Macaranga*	*Macaranga kilimandscharica*	199(20.75)	42(6.33)	81(19.66)
Myrtaceae	*Syzygium*	*Syzygium guieensii*	195(20.33)	25(3.77)	41(9.95)
Apocynaceae	*Tabernaemontana*	*Tabernaemontana stapfiana*	79(8.24)	149(22.44)	111(26.94)
Podocarpaceae	*Podocarpus*	*Podocarpus latiflius*	41(4.28)	21(3.16)	3(0.73)
Mimosaceae	*Albizia*	*Albizia gummifera*	33(3.44)	45(6.78)	11(2.67)
Primulaceae	*Rapanea*	*Rapanea melanophloes*	30(3.13)	3(0.45)	1(0.24)
Meliaceae	*Trichilia*	*Trichilia emitica*	27(2.82)	67(10.09)	5(1.21)
Euphorbiaceae	*Neoboutonia*	*Neoboutonia macrcalyx*	26(2.71)	70(10.54)	32(7.77)
Fabaceae	*Acacia*	*Acacia mearnsii*	24(2.50)	----------	---------
Celastraceae	*Maytenus*	*Maytenus rotudos*	15(1.56)	----------	14(3.40)
Myricaceae	*Morella*	*Morella salicifora*	15(1.56)	----------	---------
Rosaceae	*Prunus*	*Prunus africana*	13(1.36)	3(0.45)	2(0.49)
Sapindaceae	*Allophylus*	*Allophylus abyssinicus*	9(0.9)	29(4.37)	8(1.94)
Rutaceae	*Zanthoxyllum*	*Zanthoxyllum gilletii*	9(0.94)	28(4.22)	8(1.94)
Fabaceae	*Millettia*	*Millettia dura*	7(0.73)	1(0.15)	12(2.91)
Araliaceae	*Schefflera*	*Schefflera volkensii*	3(0.31)	--------	3(0.73)
Monimiaceae	*Xymalos*	*Xymalos monospora*	3(0.31)	2(0.30)	8(1.94)
Flacourtiaceae	*Dovyalis*	*Dovyalis abyssininica*	2(0.21)	1(0.15)	---------
Fabaceae	*Acacia*	*Acacia lahai*	1(0.10)	----------	1(0.24)
Alariaceae	*Polyscias*	*Polyscias capensis*	1(0.10)	----------	1(0.24)
Others	*Others*	*Others*	9(0.94)	----------	2(0.49)
Pittosporaceae	*Pittosporum*	*Pittosporum viridiflorum*	-------	4(0.60)	---------
Asparagaceae	*Dracaena*	*Dracaena steudneri*	-------	11(1.66)	2(0.49)
Boraginaceae	*Ehretia*	*Ehretia cymosa*	-------	4(0.60)	9(2.18)
Hamamelidaceae	*Trichocladus*	*Trichocladus ellipticus*	--------	4(0.60)	---------
Meliaceae	*Ekebergia*	*Ekebergia capensis*	--------	--------	1(0.49)
	Teclea	*Teclea nobilis*	-------	--------	1(0.49)
S20,M18,L21	**S21,M19,L23**	**S22,M19,L23**	**959(100**	**664(100)**	**412(100)**

GS in the table represent gap size, S, M and L also represent small, medium and large gaps respectively

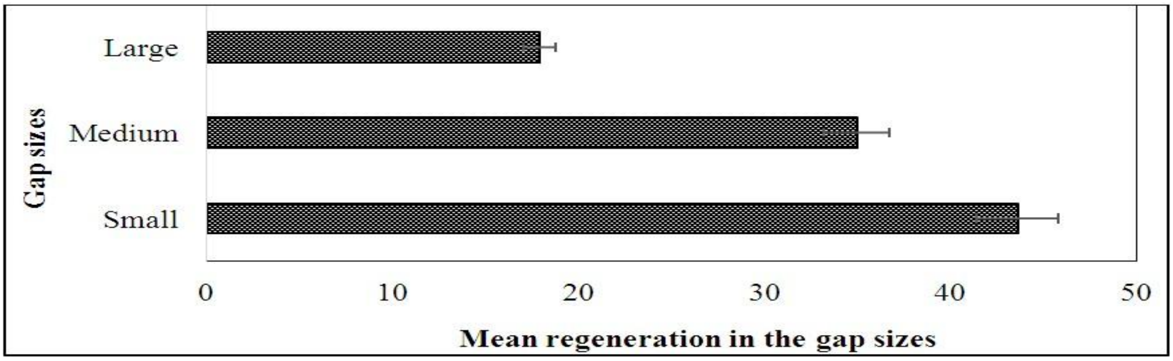

Fig. 2. Mean regeneration in the different gap sizes

sizes. Constant anthropogenic disturbances in SW Mau could be the cause of higher number of small gap sizes, thus, similar to other earlier studies [3,8,22].

Likewise, a study demonstrates same results that small gap sizes were many compared with the other gap sizes in temperate forest of Qinling Mountains, China [23]. On the other hand, categorization of small gap sizes was also similar to the current study [22]. This study was also congruent with previous findings that small gap sizes are the most common in natural forests triggered by tree death/removal [12]. Therefore, in SW Mau Forest reserve, small gap sizes are attributed to human disturbances [7] while large and medium gap sizes are occasionally caused by natural disturbances [23].

3.2 Influence of Gap Size on Regeneration of Woody Vegetation Species in SW Mau Forest

Small gap sizes recorded the highest number of seedlings (959) compared with medium and large gap sizes (Table 2). On the other hand, *Psydrax schimperiana* was the dominant species (218) followed by *Macaranga kilimandscharica* (199) then *Syzygium guineense* (195) in the small gap sizes.

The total count of seedlings in medium gap sizes was 664 with *Psydrax schimperiana* taking the lead (155) followed by *Tabernaemontana stapfiana* (149). Large gap sizes, however, recorded the least count of seedlings (412) with *Tabernaemontana stapfiana* taking the lead (111) followed by *Macaranga kilimandscharica* (81).

Mean population of seedlings in the three gap sizes exhibited an increased regeneration in the small gap sizes (43.59) compared with medium (35.95) and large gap sizes (17.91) (Fig. 2). However, Kruskal-Wallis rank sum *H* test recorded, chi-squared = 36.77, df=36, *P*=0.43), which showed no significant difference in regeneration in the three gap sizes. The null hypothesis failed to be rejected and was concluded that gap size had no influence on regeneration in SW Mau forest.

Small gap sizes recorded the highest number of seedling population regenerating compared with the other two gap sizes. This was contrary to previous findings by Hammond et al. [12] who reported a significant difference among the gap sizes; large gap sizes having the highest count of species regenerating while small gap sizes recorded the least. Regeneration of species in any forest is, thus, determined by canopy gap size which influence environmental conditions such as; light, pH, litter, moisture availability and nutrient availability [13]. Forest gap sizes, thus, positively affects species composition and abundance of seedlings [24].

Most regenerating species were reported beneath the mother plants in small gap sizes. This result was, thus, similar to other findings that there is high regeneration of species under mother plants [25]. Regeneration can, therefore, be related to gap characteristics; shape, size and position which again influence seed dispersal, root density and microsite conditions [11]. A research on spruce and beech report that regeneration of the two species is determined by diffuse light which corroborates with this study on high seedling population in small gap sizes. In addition, other previous studies also report that disturbances causing canopy gaps influences regeneration as well as species composition [10].

The low number of seedlings in medium and large gap sizes in the current study was, thus, attributed to *Piper capensis* bush among other invasive species which invaded the gaps. The results corroborated with other studies that large scale disturbances encourage the growth of shade intolerant species [24]. Additionally, small gap sizes failed to avail enough light for light demanding species, hence, lack of engulfment by invasive species, thus, regeneration of climax species was favoured [12]. The invasive species, therefore, created a canopy cover which influenced species-specific pattern caused by gradient in resources [26]. However, the results were contrary to the findings by Guo et al. [23] who showed increased regeneration in medium gap sizes. The current study, however, showed that small gap sizes are crucial for regeneration of species in SW Mau contrary also to the findings by Zhang and Yi [27] who reported increase in regeneration with increase in gap size.

Variations in species regeneration in the gap sizes can be attributed to gradients in microsite conditions; light, soil moisture, soil temperature and nutrients [28]. Therefore, invasion of medium and large gap sizes by *Piper capensis* resulted into resource deficit in the forest negatively affecting the establishment of shade bearing species [12]. This could explain the reason why medium and large gap sizes recorded low seedling population, hence, similar to previous studies [28]. Forest gap sizes influence species regeneration since environmental conditions are compromised [28,29]. This could explain the presence of some seedling species in specific gap sizes [12].

3.3 Influence of Gap Size on Forest Structure

Forest structure was determined based on tree dbh and height which showed that seedling level was the highest life form (over 60%) followed by sapling level (over 20%) in the three gap sizes (Fig. 3). Understorey population was low with small and medium gap sizes recording the least (2.46% each) compared with large gap sizes (3.70 %). Similarly, main canopy recorded a relatively high tree height in small, medium and large gap sizes; 11.39%, 8.80% and 12.40% respectively. However, emergent layer was recorded low in small gap sizes (1.91%) than in medium (2.46%) and large gap sizes (3.30%).

To determine structural complexity of the forest, trees with dbh >3 cm were used, employing Holdridge's Complexity Index (HCI). Small gap sizes recorded the highest Complexity Index (HCI 40) based on tree density, basal area, mean tree height and number of species. Medium and large gap sizes recorded HCI <10 (Fig. 4). However, there was no significant difference in forest structure recorded in the three gap sizes; Kruskal-Wallis (chi-squared =138.04, df=126, P=0.22). Since P>0.05, null hypothesis failed to be rejected. It was concluded that gap size had no influence on forest structure in the current study.

There was high number of undergrowth (seedlings) population in small gap sizes followed by saplings. However, mean tree diameter and height was higher in large gap sizes compared with medium and small gap sizes. High seedling population in small gap sizes exhibited that the gap size fostered a positive response to already established tree species. In addition, diversity in species showed variations in physiognomic appearance of the forest brought about by different techniques of species to acquire resources [30]. High seedling population in the small gap sizes was related to resource availability due to lack of interceptions from invasive species [27,28,31]. Moreover, small gap sizes recorded the lowest mean in tree diameter and height. This could be due to low light exposure which could have reduced tree development [26].

Higher structural complexity in small gap sizes could be related to optimum resources availability; soil moisture, light radiation and soil temperature. This could explain the reason for high undergrowth in small gap sizes [28]. Resource gradient in the gap sizes result into increased seedling establishment and development in small gap sizes leading to competition for the available resources, hence, complex structure [32]. Small gap sizes are easily filled by lateral branches, thus, allows for usurping by the already established seedlings [12], hence, resulting into canopy ruggedness [33].

In addition, large gap sizes recorded the highest mean in tree dbh and height compared with the other two gap sizes. This result was similar to the report by Fotis et al. [30] who demonstrated that large gap sizes increases tree development due to reduced resource competition. Furthermore, species composition in the gaps which is dictated by tree heights, leaf arrangement and crown space also lead to variations in structural complexity in the gap sizes. Low HCI in medium and large gap sizes was attributed to *Piper capensis* invasion which created a low uniform canopy layer [12]. This allowed for more sun flecks to penetrate to the ground, hence, increased tree development [29].

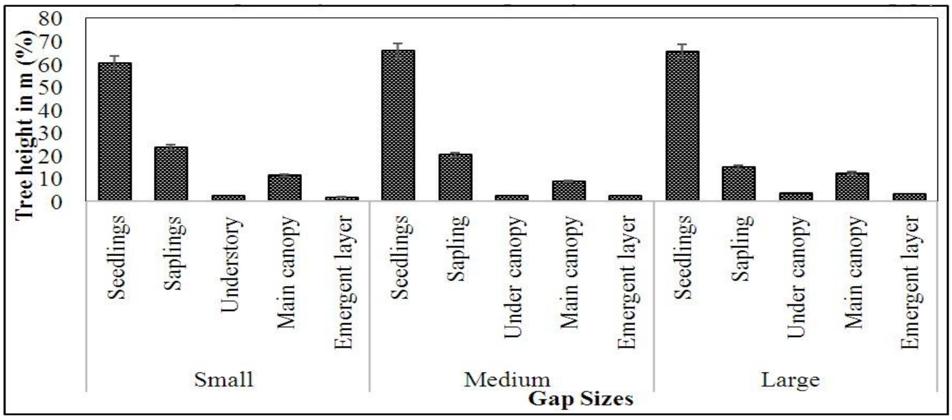

Fig. 3. Vertical forest stratification based on growth levels

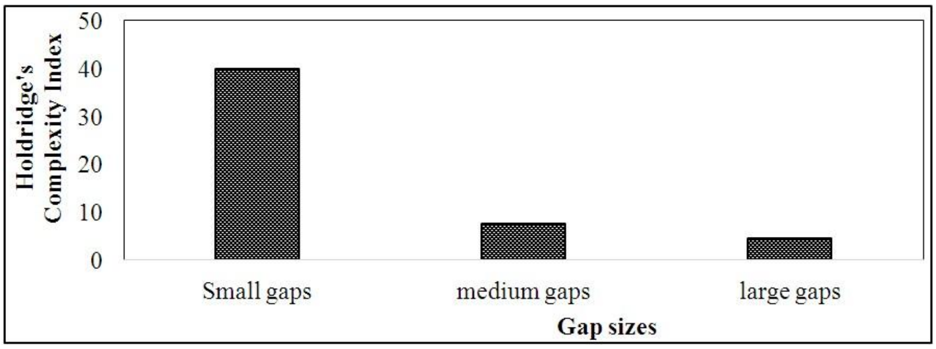

Fig. 4. Holdridge's complexity Index in the three different gap sizes

3.4 Influence of Gap Size on Species Diversity

Descriptive statistics showed that small gap sizes recorded 28 species (Table 3). Medium gap sizes followed with 25 species and lastly large gap sizes with 24 species. In overall, *Macaranga kilimandscharica* was the dominant species in the three gap sizes. Generally, small gap sizes had the highest number of species (28) compared with medium and large gap sizes.

Table 3. Species diversity status in the three gap sizes

Family	Genus	Species	SG	MG	LG
Euphorbiaceae	*Macaranga*	*Macaranga kilimandscharica*	+	+	+
Myrtaceae	*Syzygium*	*Syzygium guineensii*	+	+	+
Rubiaceae	*Psydrax*	*Psydrax schimperiana*	+	+	+
Apocynaceae	*Tabernaemontana*	*Tabernaemontana stapfiana*	+	+	+
Meliaceae	*Trichilia*	*Trichilia emitica*	+	+	+
Euphorbiaceae	*Neoboutonia*	*Neoboutonia macrocalyx*	+	+	+
Myricaceae	*Morella*	*Morella salicifora*	+	+	+
Celastraceae	*Maytenus*	*Maytenus rotudos*	+	-	+
Podocarpaceae	*Podocarpus*	*Podocarpus latifolius*	+	+	+

Family	Genus	Species	SG	MG	LG
Primulaceae	*Rapanea*	*Rapanea melanophloes*	+	+	+
Rutaceae	*Zanthoxyllum*	*Zanthoxyllum gilletii*	+	+	+
Mimosaceae	*Albizia*	*Albizia gummifera*	+	+	+
Alariaceae	*Polyscias*	*Polyscias capensis*	+	+	+
Sapindaceae	*Allophylus*	*Allophylus abyssinicus*	+	+	+
Fabaceae	*Millettia*	*Millettia dura*	+	+	+
Fabaceae	*Acacia*	*Acacia lahai*	+	-	+
Meliaceae	*Ekebergia*	*Ekebergia capensis*	+	-	+
Monimiaceae	*Xymalos*	*Xymalos monospora*	+	-	+
Fabaceae	*Acacia*	*Acacia mearnsii*	+	-	-
Ebenaceae	*Diospyros*	*Diospyros abyssinica*	+	-	-
Sterculiaceae	*Dombeya*	*Dombeya torrida*	+	+	-
Flacourtiaceae	*Dovyalis*	*Dovyalis abyssinica*	+	-	-
Boraginaceae	*Ehretia*	*Ehretia cymosa*	+	+	+
Celastraceae	*Maytenus*	*Maytenus ovatus*	+	-	-
Rosaceae	*Prunus*	*Prunus africana*	+	+	+
Araliaceae	*Schefflera*	*Schefflera volkensii*	+	-	+
Rutaceae	*Teclea*	*Teclea nobilis*	+	-	+
Others	*Others*	*Others*	+	-	+
Rhamnaceae	*Rhamnus*	*Rhamnus prinoides*	-	+	-
Hamamelidaceae	*Trichocladus*	*Trichocladus ellipticus*	-	+	-
Asparagaceae	*Dracaena*	*Dracaena steudneri*	-	+	+
Pittosporaceae	*Pittosporum*	*Pittosporum viridiflorum*	-	+	-
Flacourtiaceae	*Dovyalis*	*Dovyalis macrocalyx*	-	+	-
SG24	SG26	SG28			
MG23	MG25	MG25			
LG22	LG24	LG24			

SG represent small gap; MG represent medium gap while LG represent large gap, + represent species presence while - represent species absence

Table 4. Species diversity, evenness and dominance in different gap sizes

Diversity indices	Small gap	Medium gap	Large gap
H'	2.58	2.60	2.63
HE	0.77	0.81	0.83
D	0.88	0.91	0.90

H` represent Shannon Weiner Diversity Index, HE represents evenness and D represent Simpson's Diversity Index

Shannon-Weiner's Diversity Index was higher in the three gap sizes (= >2) with large gap sizes recording the highest (2.63) followed by medium (2.60) and small gap sizes (2.58) (Table 4)

However, Kruskal-Wallis rank sum test reported; chi-squared=24.80, df=19, P=0.17. Since P>0.05, null hypothesis failed to be rejected and was concluded that gap size had no influence on species diversity in SW Mau forest.

Small gap sizes exhibited the highest species diversity compared with medium and large gap sizes. The results were similar to the study by Hammond et al. [12] who reported increased species diversity in gaps. However, the results were contrary to other studies that species diversity increases with increase in gap size [22]. Various species are established in different gap sizes based on their techniques of acquiring resources [12]. Gap sizes are, thus, known to influence resources such as light radiation, hence, diversity in species [29].

The differences in species diversity in the gap sizes can be attributed to heterogeneity in microsite conditions [12,29]. The difference in light intensity in the gap sizes leads to species diversity given their variations in resource requirements. For example, light intensity is expected to be low in small gap sizes followed by medium then large gap sizes [12]. Large gap sizes recorded many shade-intolerant species ranging from *Piper capensis* to *Dombeya torrida,* *Macaranga kilimandscharica* among other species. This could be related to high light availability in such gap sizes [32]. The availability of rare species (shade intolerant) in medium and large gap sizes was also similar to the results by Velázquez and Wiegand [26].

The presence of many species in small gap sizes compared with the other gap sizes could also be related to 'sky view' which could not hinder seed dispersal, thus, driving species colonization [33]. Therefore, small gap sizes could have received direct sun light reaching the ground due to less interception [23]. However, less species was recorded under invasive species closed canopy due to reduced germination of shade tolerant species caused by resources deficit [25]. This could explain low woody seedling population in large and medium gap sizes under *Piper capensis* bushes.

4. CONCLUSION

South-Western Mau forest exhibits three main gap sizes; small, medium and large gap sizes created by both human and natural disturbances. Being a natural forest, it has been invaded by invasive species (*Piper capensis*) in medium and large gap sizes. This species forms a dense canopy cover which influences microsite conditions. The species form shade which cannot allow for shade tolerant species to emerge from beneath, hence, influencing woody vegetation population parameters.

5. RECOMMENDATIONS

Strategies to clear the dense ground cover caused by *Piper capensis* should be developed to allow better natural regeneration. Also, there should be enrichment planting in the gaps for biodiversity conservation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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