Asian Journal of Research in Agriculture and Forestry

Volume 9, Issue 1, Page 38-48, 2023; Article no.AJRAF.95923
ISSN: 2581-7418

Comparative Assessment of Regeneration, Structure and Species Diversity of Woody Vegetation in Disturbed and Undisturbed Sites of a Secondary Montane Forest, Kenya

Jemimah Achieng Ocholla [a*], Shadrack Kinyua Inoti [a] and Gilbert Obati Obwoyere [a]

[a] Department of Natural Resources, Faculty of Environment and Resources Development, Egerton University, P. O. Box 536-20115, Kenya.

Authors' contributions

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

Article Information

DOI: 10.9734/AJRAF/2023/v9i1195

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/95923

Original Research Article

Received: 25/11/2022
Accepted: 30/01/2023
Published: 07/02/2023

ABSTRACT

Secondary montane forest is created by either natural or artificial disturbances resulting in open canopies. It is an important resource in relation to economic and ecological values, however, it faces over-exploitation. The objective of this study was to compare regeneration, forest structure and species diversity of woody vegetation between disturbed and undisturbed sites of the South-Western (SW) Mau forest reserve in Kenya. A nested research sampling design was used, whereby, plots of 500 by 500 m were demarcated in Itare, Maramara and Ndoinet blocks. In disturbed sites, canopy openings were randomly selected to constitute the sample units. In

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**Corresponding author: E-mail: jemmy.achieng@gmail.com;*

undisturbed sites, sample plots of 30 by 20 m were randomly nested. Regeneration, forest structure and species diversity were then determined per sample unit. Wilcoxon rank sum test with continuity correction was then used to compare the three parameters in disturbed and undisturbed sites of the forest. A total of 41 gaps were selected (7 large, 11 medium and 23 small gap sizes) in disturbed sites while a total of 19 sub-plots (Itare 5, Maramara 6 and Ndoinet 8 times) were laid in undisturbed sites. There was a significant difference in forest structure between disturbed and undisturbed sites of the forest (P = 0.01, *P value adjustment method*: *BH*). The forest was invaded by *Piper capensis, Ribes spp.* and ferns in disturbed sites which affected the three woody vegetation population parameters. Therefore, enrichment planting was recommended in disturbed sites to conserve biodiversity within the forest.

Keywords: Canopy openings; disturbances; gaps; Piper capensis; Ribes spp.; vegetation population.

1. INTRODUCTION

Tropical montane forest is an important resource due to ecosystem goods and services that accrues from it [1,2]. Examples of the importance include; hydrological, biodiversity conservation, endemicity protection and carbon sequestration [3]. It is heterogeneous in forest structure and floristic composition of plant communities [2]. However, these forest type experience disturbances especially from the anthropogenic origin [1,2] creating another type of forest called secondary montane forest. Secondary montane forest is rapidly spreading around the globe [4] which is important as it helps to alleviate the impacts of deforestation and contributes to forest conservation [5]. It is an important resource in relation to the economic and ecological values that it provides [6].

Secondary montane forest is characterized by discontinuous canopy layers with short trees (<15 m in height) and dense understory. Other characteristics include; numerous lianas and bent trunks [7], and increased species diversity triggered by the coexistence of shade-tolerant and shade-intolerant species [4,5,8]. Such discontinued canopy favours invasion by alien species and herbs which may affect regeneration and succession by indigenous tree species [6]. Secondary montane forest regenerate mostly through natural processes (secondary succession) following disturbances of original forests [3]. However, successional development results in the recovery of plant species that are affected by disturbances (artificial/human sources), consequently influencing biodiversity [6].

Therefore, secondary montane forest is driven by disturbances; natural or artificial. Natural disturbances are, however, characteristics of all natural forest ecosystems. They can be defined as discrete events that alter forest structure and composition [8,9]. Examples entail; tree falls, landslides [4], wildfires from lightening, senescence, pests, snagging, diseases, and droughts all resulting in tree mortality [10]. Artificial disturbances on the other hand are from human activities which do not retain forest structural complexity, connectivity and landscape heterogeneity [9]. Examples include; logging, debranching, barking, deforestation [11]. Artificial disturbances have resulted in the loss of species diversity in natural forest ecosystems. This has often been linked to human population growth, agriculture [4], industries and construction resulting in over-exploitation of the forests [1, 12,13]. Even though human disturbances, such as deforestation is the major one, there are other sporadic disturbances, such as pollution [7,2].

Disturbances are the determinants of forest dynamics and biodiversity both at the local and regional scale, therefore, crucial in creating natural communities in forest ecosystems [9]. Moderate disturbances are known to increase species diversity. This hypothesis is, however, debated by other researchers who still doubt it [9]. Secondary montane forest species tend to resemble the initial species diversity before disturbances after 45 years of natural recovery, hence, stability in the forests. Secondary montane forest is, therefore, highly resilient and recover fast after disturbances, such as commercial logging. Such forest is, however, known to take a longer duration for trees to have a large diameter (dbh) as well as for saplings of shade-tolerant species to fully develop into full-grown trees [8].

A previous study was done on a secondary montane forest and how canopy openings in disturbed sites influence regeneration, forest structure and species diversity in South-Western (SW) Mau forest [9]. Other studies have also affirmed that understanding processes, such as regeneration can be vital since disturbed forests are quickly spreading [4]. Therefore, comparison can help in deriving a conclusion on which site; disturbed or undisturbed conserve biodiversity as well as increases species diversity and improve forest structural development. The study, therefore, focused on bridging the lacuna by comparing regeneration, forest structure and species diversity between disturbed and undisturbed sites of South-Western (SW) Mau forest reserve which is a secondary montane forest. This will not only contribute to ecological restoration of the forest but also to biological diversity conservation.

2. MATERIALS AND METHODS

2.1 Site Description

The study was conducted in the South-Western (SW) Mau forest (0˚15'S- 0˚47'S, 35˚28'E - 35˚69'E), one of the reserves of Mau forest in Kenya [14]. It is the largest remnant of the indigenous forest reserve of Mau and the home of the Ogiek community. It occupies an area of 60,000 ha and has an elevation of 2100-3300 m above sea level [15]. South-Western (SW) Mau forest reserve has three blocks; Ndoinet, Maramara and Itare. Since 1997, the forest has been experiencing adverse human disturbances, such as; deforestation, grazing, burning [12], consequently, resulting in its reduction from 84,000 ha to 60,000 ha in the area [16,17].

2.2 Research and Sampling Design

A nested research sampling design was used, whereby, a plot of 500 by 500 m was demarcated in disturbed parts of Ndoinet, Itare and Maramara blocks at 100 m from the forest edge. Likewise, another plot of 500 by 500 m was laid towards the interior (undisturbed). In undisturbed sites, sub-sample plots of 30 by 20 m were randomly nested while canopy gaps randomly selected in disturbed sites to constitute the sample units.

Regeneration was determined by tossing two quadrats; 1 by 1 m twice per quarter the sample unit (8 times in total) and 5 by 5 m (4 times in total) for seedlings and saplings respectively, and population size was taken per sample unit. Trees with dbh >3 cm were considered for forest structure. The diameter (dbh) was measured using a diameter calliper (for small trees with dbh <65 cm) and diameter tape (for large trees, dbh>65 cm) while height was taken using a Suunto clinometer. To determine the structural complexity of the forest, Holdridge's Complexity Index [18] was used;

$$HC = (Axdxnxh)/1500\ m^2 \quad \text{……………………. (1)}$$

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, species from the two sites (disturbed and undisturbed) were identified and names inventoried. Two indices were used;

a) Simpson's Diversity Index (1-*D*) for species dominance [19];

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

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

$$H' = \sum_{i=1}^{s}(P_i)ln(P_i) \quad \text{……..……………………. (3)}$$

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 from this study was analyzed using RStudio and Microsoft Office Excel. Results were displayed using descriptive statistics and inferential statistics to test hypotheses. Wilcoxon rank sum test with continuity correction was used to compare woody vegetation population parameters in disturbed and undisturbed sites of SW Mau forest.

$$W_c = \sum_{i=1}^{N} \delta_i R_{i+,} \quad \text{……..………………………… (4)}$$

Where;

$W_{c=}$ Wilcoxon Rank Sum, *N*=*m*+*n* clusters in group 1 and 2, R_{i+}= total sum of rank in group i; $\sum_{j=1}^{z} R_{ij,}\ \ \delta i = 1$ [21].

3. RESULTS AND DISCUSSION

A total of 41 canopy gaps (Itare 13, Maramara 11 and Ndoinet 17) were randomly selected as sample units in disturbed sites while 19 sub-plots of 30 by 20 m were laid in undisturbed sites (Itare 5, Maramara 6 and Ndoinet 8) as sample units.

3.1 Comparing Regeneration between Disturbed and Undisturbed Sites of SW Mau Forest reserve

The table below (Table 1) show two growth levels (seedlings and saplings) which were used to determine regeneration in the two study sites. Disturbed sites recorded the highest frequency of regeneration (2035) while undisturbed sites recorded the least (1163). Among the regenerating species, *Psydrax schimperiana* was the common species both in disturbed (428) and undisturbed (233) sites, *Tabernaemontana stapfiana* and *Macaranga kilimandscharica* then followed.

However, there was no significant difference in regeneration between disturbed and undisturbed sites of SW Mau forest reserve. Pairwise comparisons using the Wilcoxon rank sum test with continuity correction reported *P*=0.58 *P value adjustment method*: *BH*. The null hypothesis, therefore, failed to be rejected and

Table 1. Frequency percentage of species regeneration in disturbed and undisturbed sites of SW Mau forest reserve

Species	Disturbed sites	Undisturbed sites
Acacia lahai	2(0.10)	--------
Acacia mearnsii	24(1.18)	24(2.06)
Albizia gummifera	89(4.37)	36(3.10)
Allophylus abyssinicus	46(2.26)	151(12.98)
Dombeya torrida	--------	1(0.09)
Dovyalis abyssinica	3(0.15)	1(0.09)
Dracaena steudneri	13(0.64)	1(0.09)
Ehretia cymosa	13(0.64)	21(1.81)
Ekebergia capensis	1(0.05)	-------
Macaranga kilimandscharica	322(15.82)	171(14.70)
Maytenus ovatus	--------	2(0.17)
Maytenus rotudos	29(1.43)	-------
Maytenus undata	--------	5(0.43)
Millettia dura	20(0.98)	3(0.26)
Morella salicifora	15(0.73)	9(0.77)
Neoboutonia macrocalyx	128(6.29)	17(1.46)
Others	11(0.54)	20(1.72)
Pittosporum viridiflorum	4(0.20)	--------
Podocarpus latifolius	65(3.19)	12(1.03)
Polycias fulva	--------	4(0.34)
Polyscias capensis	2(0.10)	-------
Prunus africana	18(0.88)	-------
Psydrax schimperiana	428(21.03)	233(20.03)
Rapanea melanophloes	34(1.67)	45(3.90)
Schefflera abyssinica	3(0.15)	-------
Schefflera volkensii	3(0.15)	-------
Syzygium guineense	261(12.83)	64(5.50)
Tabernaemontana stapfiana	339(16.66)	165(14.19)
Teclea nobilis	1(0.05)	7(0.60)
Trichilia emitica	99(4.86)	149(12.81)
Trichocladus elipticus	4(0.20)	--------
Vangueria madagascariensis	--------	5(0.43)
Xymalos monospora	13(0.64)	10(0.86)
Zanthoxyllum gilletii	45(2.21)	7(0.60)
Disturbed 29 **Undisturbed 25**	**2035(100.00)**	**1163(100.00)**

Values indicated in brackets represent the count %

was concluded that regeneration was the same in the two sites. The results were attributed to canopy cover both in disturbed (by *Piper capensis*) and crown cover in undisturbed sites of SW Mau forest reserve which could have leveled microsite conditions in disturbed and undisturbed sites.

Disturbed sites recorded a higher number of seedlings and saplings compared with undisturbed sites. The study, therefore, corroborated with other findings [6,22] that disturbed sites avail resources, consequently, favouring species regeneration. Disturbed sites are characterized by open canopies, hence, crucial for regeneration and this implies that open canopies promote population growth [23,24]. The study was again similar to other studies that open canopies found in disturbed sites are dominated by shade intolerant species [3] which in this case were *Piper capensis*, *Ribes spp.* and ferns which influenced colonization by climax species.

The increased rate of regeneration in disturbed sites was attributed to the availability of microsite conditions, such as light [13] which could be used by the seedlings for photosynthesis, thus, increasing seed germination, growth and establishment [25]. Similar results were demonstrated by other findings [26] that grazing in SW Mau forest reserve resulted in increased regeneration due to nutrients availed in form of manure [7]. However, this study was contrary to that reported by other previous studies [27] that disturbed sites are represented by scanty regeneration due to harsh environmental conditions, such as extreme temperatures.

However, there was no significant difference in regeneration between disturbed and undisturbed sites of SW Mau forest reserve. This could be because sprouting seedlings in disturbed sites could have been affected by incessant disturbances, such as animal trampling [26,22]. In addition, disturbed sites were invaded by *Piper capensis,* a light demanding species [19] utilizing resources which could have otherwise been used by woody species to regenerate. Disturbed sites usually report low regeneration due to unfavourable environmental conditions, such as low moisture availability and increased temperatures [27]. Also, undisturbed sites are known to have low microsite conditions, example being shading, hence, reduced regeneration [23].

3.2 Comparing Forest Structure between Disturbed and Undisturbed Sites of SW Mau Forest reserve

Height and dbh were used as a measure of forest structure. The seedling stage was the highest growth level in disturbed sites (1511 in total count) compared with undisturbed sites (849 total count) as presented in Table 2. However, the emergent layer was recorded least concerning frequency in the two sites. High seedling population in disturbed sites could be attributed to increased light penetration to the forest floor which could be used by seeds to germinate and for photosynthesis by seedlings.

Undisturbed sites, however, recorded higher mean tree diameter (24.9 cm) and height (26.3 m) compared with disturbed sites (24.1 cm and 23.9 m for diameter and height respectively) as can be observed in Fig. 1.

Disturbed sites also recorded a more complex structure than undisturbed sites as demonstrated in Fig. 2.

Table 2. Growth levels of woody vegetation in SW Mau Forest

Level	**Diameter (%)**	**Height (%)**
Seedlings	63.49(**58.03**)	63.49(**58.03**)
Sapling	20.80(**21.60**)	20.80(**21.60**)
U. canopy	2.73(**2.94**)	2.73(**2.94**)
M. canopy	10.92(**13.47**)	10.92(**13.47**)
E. layer	2.06(**3.96**)	2.06(**3.96**)
Total	100	100
	100	**100**

Bolded values represent undisturbed while unbolded represent disturbed sites. U. represent Under canopy; M. represent Main Canopy While E. represent Emergent layer

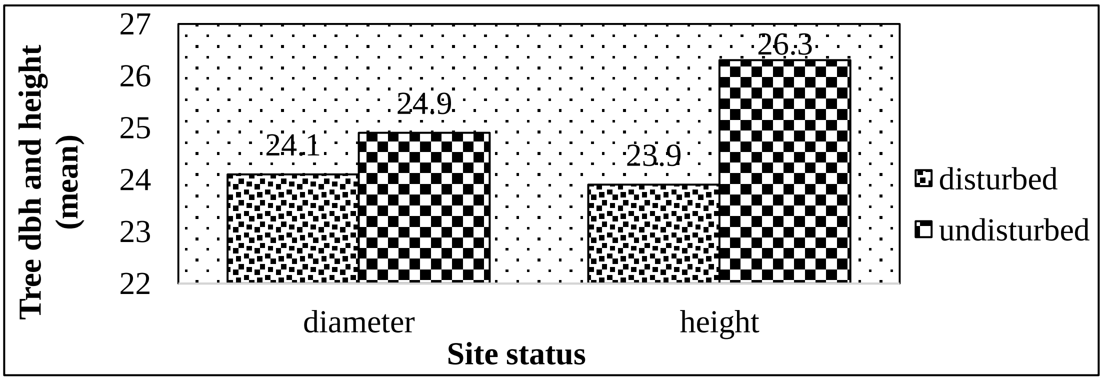

Fig. 1. Physiognomic appearance of the forest (dbh and height) (%) in SW Mau Forest. Dbh was measured in centimetres (cm) while height was measured in metres (m)

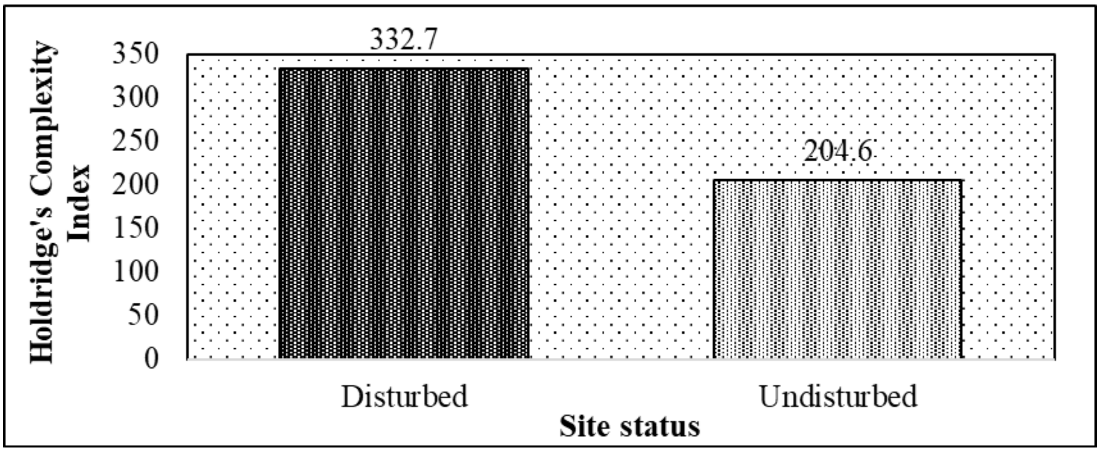

Fig. 2. Holdridge's Complexity Index

Pairwise, comparisons using the Wilcoxon rank sum test with continuity correction was used to test for the significant difference in the forest structure between disturbed and undisturbed sites of SW Mau forest reserve: *P* = 0.01, *P value adjustment method*: *BH*. The null hypothesis was, thus, rejected and was concluded that forest structure between disturbed and undisturbed sites of SW Mau forest reserve was not the same.

Seedlings and saplings' growth levels were higher in disturbed sites than in undisturbed sites and this was congruent with other studies [28]. However, undisturbed sites exhibited increased mean in tree height and dbh. Similar results were earlier reported [29] and demonstrated that this can be related to variation in resources between the two sites, thus, difference in tree growth and development [13]. Structurally, disturbed sites were again dominated by *Piper capensis* which formed a generally uniform canopy layer, hence, congruent with previous studies [3]. Variations in tree growth result in vegetation layering due to differences in tree heights and species diversity [30].

The main canopy and emergent layers were also high in undisturbed sites, leading to closed canopy but few seedlings [28]. This could be related to competition for light among other resources, therefore, trees concentrate more in height rather than crown development [31]. Disturbed sites on the other hand recorded low stem and height mean. This could be related to less light competition due to open canopies, hence, more concentration in lateral branch development [6, 31]. The study was, however, contrary to other previous studies which reported increased dbh and height in disturbed sites [28]. Canopy openings in disturbed sites influence microsite conditions which affect forest structure [32].

The study reported a significant difference in forest structure between disturbed and undisturbed sites of SW Mau forest reserve. This could be related to the invasion of the forest

Table 3. Species diversity in SW Mau Forest

Family	Genus	Species	Disturbed	Undisturbed
Alariaceae	*Polyscias*	*P. capensis*	+	-
Alariaceae	*Polyscias*	*P. fulva*	+	+
Apocynaceae	*Tabernaemontana*	*T. stapfiana*	+	+
Araliaceae	*Schefflera*	*S. volkensii*	+	-
Asparagaceae	*Dracaena*	*D. steudneri*	+	+
Boraginaceae	*Ehretia*	*E. cymosa*	+	+
Celastraceae	*Maytenus*	*M. rotudos*	+	-
Celastraceae	*Maytenus*	*M. ovatus*	+	+
Celastraceae	*Maytenus*	*M. undata*	-	+
Ebenaceae	*Diospyros*	*D. abyssinica*	+	-
Euphorbiaceae	*Macaranga*	*M. kilimandscharica*	+	**+**
Euphorbiaceae	*Neoboutonia*	*N. macrocalyx*	+	+
Fabaceae	*Millettia*	*M. dura*	+	+
Fabaceae	*Acacia*	*A. lahai*	+	-
Fabaceae	*Acacia*	*A. mearnsii*	+	+
Flacourtiaceae	*Dovyalis*	*D. abyssinica*	+	+
Flacourtiaceae	*Dovyalis*	*D. macrocalyx*	+	-
Hamamelidaceae	*Trichocladus*	*T. ellipticus*	+	-
Meliaceae	*Trichilia*	*T. emitica*	+	+
Meliaceae	*Ekebergia*	*E. capensis*	+	-
Mimosaceae	*Albizia*	*A. gummifera*	+	+
Monimiaceae	*Xymalos*	*X. monospora*	+	+
Myricaceae	*Morella*	*M. salicifora*	+	+
Myrtaceae	*Syzygium*	*S. guineense*	+	+
Oleaceae	*Olea*	*O. capensis*	-	+
Others	*Others*	*Others*	+	+
Pittosporaceae	*Pittosporum*	*P. viridiflorum*	+	-
Podocarpaceae	*Podocarpus*	*P. latifolius*	+	+
Primulaceae	*Rapanea*	*R. melanophloes*	+	+
Rhamnaceae	*Rhamnus*	*R. prinoides*	+	-
Rhizophoraceae	*Cassipourea*	*C. malosana*	-	+
Rosaceae	*Prunus*	*P. africana*	+	-
Rubiaceae	*Psydrax*	*P. schimperianas*	+	+
Rubiaceae	*Vangueria*	*V. madagascariensis*	-	+
Rutaceae	*Zanthoxyllum*	*Z. gilletii*	+	+
Rutaceae	*Teclea*	*T. nobilis*	+	+
Sapindaceae	*Allophylus*	*A. abyssinicus*	+	+
Sterculiaceae	*Dombeya*	*D. torrida*	+	+
29	31	34		
24	**26**	**27**		

Key: + represent present while - represent absent. Others represent tree species whose identity are not known

by *Piper capensis:* an invasive species suppressing seedlings of woody species in disturbed sites, therefore, similar to other findings [29]. However, the results were contrary to other studies which reported an insignificant difference in forest structure between clear-cut and closed canopies [28].

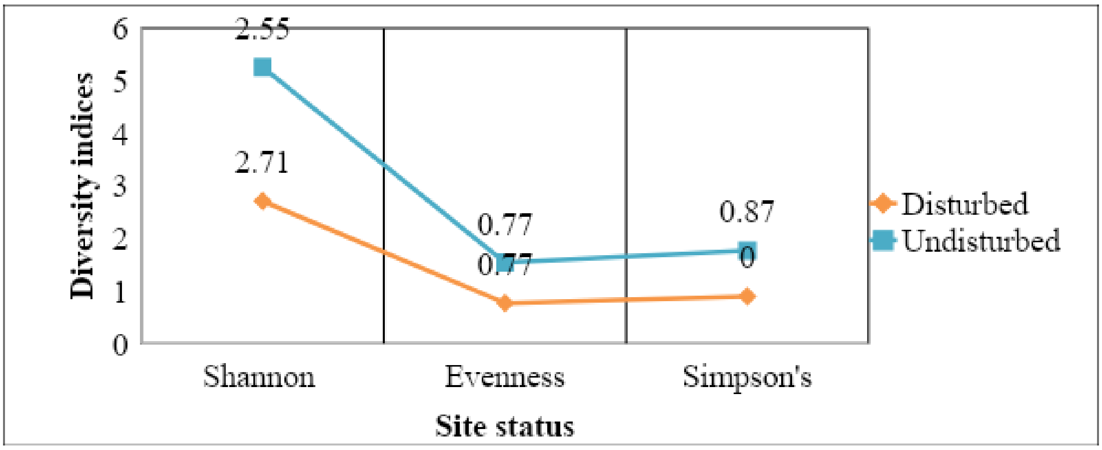

Fig. 3. Species diversity, evenness and dominance in SW Mau forest

3.3 Floristic Composition and Diversity in Disturbed and Undisturbed Sites of SW Mau Forest

A total of 29 families, 31 genera and 34 species were recorded in disturbed sites while 24 families, 26 genera and 27 species were reported in undisturbed sites. However,11 species were reported in disturbed sites but absent in undisturbed sites as shown in Table 3.

Also, 4 species were present in undisturbed sites but not in disturbed sites. The species included; *Vangueria madagascariensis, Maytenus undata, Cassipourea malosana* and *Olea capensis.* The distribution of species in the sites could be related to variation in light intensity.

Disturbed sites recorded a high species diversity using Shannon-Weiner's Diversity Index (*H*`=2.71) followed by undisturbed sites (*H*`=2.55) as observed in Fig. 2. However, Shannon Equitability Index was equal in the two sites (*HE*=0.77). Simpson's species dominance was also high in disturbed sites (*D*=0.90) followed by undisturbed sites (*D*=0.87).

Pairwise, comparisons using the Wilcoxon rank sum test with continuity correction P = 0.62 using the *P value adjustment method*: *BH*. This was above 0.05, hence, the null hypothesis failed to be rejected. It was concluded that species diversity between disturbed and undisturbed sites of the SW Mau forest reserve was the same.

Higher species diversity was reported in disturbed sites. This was similar to other findings that disturbed sites are in most cases characterized by canopy gaps which avail resources, such as sunlight to tree species, consequently, promoting species diversity [33]. Species diversity in disturbed sites could also be high due to seed dispersal without obstruction. Additionally, species whose mother plants were not spotted could also be found in disturbed sites [34]. This was also related to light seed dispersion, such as by wind [28]. Undisturbed sites on the other hand reported low species diversity which could be related to low regeneration. This could be linked to shading by the closed canopy which could have affected light penetration [29]. Furthermore, closed canopy results in debris accumulation on the forest floor hindering seed settlement, hence, low seed germination [35].

There was a non-significant difference in species diversity between disturbed and undisturbed sites of the SW Mau forest reserve. This was attributed to *Piper capensis* which utilized canopy gaps adversely affecting species colonization, hence, similar to other studies [3,36,29]. These results were also similar to the findings from SW Mau forest reserve, whereby, herbaceous plants resulted in a low number of regeneration due to closed canopy [5,9]. This, therefore, made no difference since both disturbed and undisturbed sites had closed canopies [29]. The invasive species created a canopy cover in disturbed sites, consequently reducing species colonization just as in undisturbed sites [22].

4. CONCLUSION

Forest structure differed significantly between disturbed and undisturbed sites of the forest. This can be attributed to high canopy ruggedness in undisturbed sites but an almost low uniform canopy in disturbed sites caused by *Piper capensis*. The species also results in low regeneration and species diversity in disturbed sites due to over-shading and high volume of debris that accumulate on the forest floor affecting seed germination and colonization.

5. CHALLENGES AND PROPOSED SOLUTIONS

The main challenge witnessed in the forest was *Piper capensis* which invaded disturbed sites. This could have utilized resources, such as soil moisture and light in the forest which could have hindered regeneration in the forest. Enrichment planting is then recommended, whereby, the invasive species can be cleared first before planting. This will contribute to the overall biodiversity conservation in the forest.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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