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Determining the influence of gap size on three selected microsite conditions in Southwestern Mau Forest reserve, Kenya

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

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

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Abstract

Southwestern (SW) Mau is experiencing anthropogenic and natural disturbances; creating canopy gaps influencing microclimate in the forest. This study determined the influence of canopy gap size on three microsite conditions (soil temperature, soil moisture and light intensity) in SW. The study utilized Ecological Survey Research Design; plots of 500 m by 500 m were laid in disturbed and undisturbed sites of Itare, Maramara and Ndoinet blocks. In the sampled gaps within the plots in disturbed sites; soil moisture and temperature were measured using Kensizer soil tester (3-in-1 moisture/light/pH). Light intensity was measured using the Luxmeter (model HTC LX-104). In undisturbed sites, 500 m by 500 m plots were laid and 30 m by 20 m quadrats randomly nested 19 times within. Four measurements were taken for every Microsite condition per sub-plot. Data was analysed using R and Microsoft excel. Descriptive statistics were given and Kruskal-Wallis test employed to determine differences in microsite conditions among the gap sizes. Wilcoxon rank sum test was used to compare microsite conditions between disturbed and undisturbed sites. The study revealed that there was significant difference in soil temperature (Kruskal-Wallis chi-squared=19.00, df=3, p-value=0.0002732) in the gaps. Additionally, there was significant difference in light intensity between disturbed and undisturbed sites (W=555, p-value=0.01). Non-significant results of some microsite conditions were attributed to *Piper capensis* and *Ribes spp*. which invaded medium and large canopy openings. It was concluded that canopy cover influences microsite conditions in forests. Gaps should be allowed to occur naturally for biodiversity conservation.

Keywords: Canopy gaps; Disturbances; Disturbed sites; *Piper capensis;* Undisturbed sites

1. Introduction

Afromontane forests in Kenya are estimated to be 58 million hectares (7.4%) while montane forests are estimated to be 740,000 ha (57.0%) of the total forest cover [1]. These forests are experiencing disturbances both from natural and artificial sources. In Kenya, this forest type is found on hilly/mountainous regions, western and central regions of the country threatened by human activities such as logging [2]. This was catalysed during the colonial era when most of the indigenous forests were replaced with exotic tree plantations due to their fast growth rate [3].

Mau forest is one of the Afromontane forests in Kenya with seven blocks; Southwestern (SW) block being the largest remnant indigenous forest block [4]. However, this forest is susceptible to both natural and anthropogenic disturbances such as land uses, climate change, agriculture, senescence, fires among other disturbances [3]. Most parts of the forest have been converted into agricultural lands over the last decades leading to dwindling of the forest [4].

* Corresponding author: Jemimah Achieng Ocholla
Department of Natural Resources, Faculty of Environment and Resource Development, P.O Box 536-20115, Egerton University-Kenya.

Approximately 553 km^2 of the forest was recently excised by the government as a resettlement scheme for victim clashes [3]. Moreover, politics also led to illegal settlements furthering the forest destruction [2]. These human activities resulted into fragmentation of the forest consequently impacting forest biodiversity. Human activities together with natural disturbances have resulted into loss of woody species in SW Mau Forest [3].

Forest gaps are initiated by disturbances in the forest which can be naturally or artificially created [6, 7]. Natural disturbances in the forest are important in influencing ecosystems [8] and shaping of landscapes [9]. Natural disturbances include senescence, wind storms, fires, droughts, floods, pests, diseases [10]. Besides, artificial disturbances include anthropogenic activities such as land uses, deforestation, grazing, firewood collections, charcoal burning, agriculture, settlement among other activities [7]. These disturbances create canopy gaps of different sizes depending on the magnitude of the disturbances. Consequently, this provide microsite conditions [11] and locations that are good for fast plant reproduction and growth for species [8, 12].

Small gap sizes are filled with lateral ingrowth from the bordering trees and seedlings that emerge from underneath [12]. Small gaps can be attributed to the architecture of the tree crown such as spaces in the crowns and intra-crown porosity which may be due to 'canopy shyness' [8]. On the other hand, with large gaps, diverse species are likely to colonize the gaps usually a mixture of both non-pioneer and pioneer species. Pioneer species only regenerate in large gaps where light intensity is high. When they reach the degenerate phase, they die creating small gap sizes which are later assumed by the growth of underneath non-pioneer species that are released [12]. With time, the gap is be filled with climax/non-pioneer species which have long rotational period of up to over 100 years [6].

Therefore, in any forest, gap phase is vital in the growth cycle hence influences the floristic composition of the forest [3,8]. Forest gaps also influences microsite conditions such as; light, temperature, nutrients [9, 11], litter, depth and moisture [12]. The conditions affect species regeneration since they are necessary for growth [9]. Therefore, microsite conditions within these gaps favours species depending on the conditions [13] that are necessary for their growth [8]. Nevertheless, as the building phase approaches, microsite conditions are gradually returning to pre-disturbance levels [11]. This favours diverse species and only strong competitors persist [2]; hence niche partitioning [12]. Regardless of the gap size, canopy openings create environmental heterogeneity in the forest ecosystem in terms of regeneration microsites. These have a greater contribution in maintaining forest structure as well as composition in forest gap dynamics [11, 12].

Despite studies on forest gaps influence on microsite conditions, there is still paucity of information on how individual forest gap sizes influence soil temperature, soil moisture and light intensity in Afromontane forests such as Mau Forest. Again, studies done have been those revolving around artificially created gaps [6, 7] as opposed to those naturally created. Additionally, no study on forest gap size have been done in Mau Forest (SW reserve). Therefore, there is need to provide information on soil moisture, soil temperature and light intensity in the various gap sizes to forest managers and decision makers. The objective of this study was to determine how forest gap size influence microsite conditions (soil moisture, soil temperature and light intensity) in SW Mau Forest in order to contribute to biological diversity conservation in natural forests.

2. Material and methods

2.1. Site Description

This study was conducted in Southwestern (SW) forest reserve (0˚15'S- 0˚47'S, 35˚28'E - 35˚69'E) in Mau Forest, Bomet county-Kenya [14]. The reserve has an area of 60,000 ha of natural forest at an elevation of 2100 to 3300 m asl [15]. It consists of three forest blocks; Itare, Maramara and Ndoinet [4,16]. Since 1997, the forest has been experiencing serious excisions for tea plantations, settlement and other agricultural activities. This resulted into reduction of the forest area from the former 84, 000 ha to the current 60, 000 ha [15,16].

Despite this reserve being the largest remnant indigenous block of Mau, about 25% was excised by the government to settle the Ogiek community who were displaced by ethnic clashes [2, 15]. The government later decided to conserve the forest by undertaking various evictions also to maintain the environment in terms of rivers and climate. The most affected block by human activities was Ndoinet block. This contributed to the block consisting of young trees mixed with exotic species such as *Acacia mearnsii*, eucalyptus and cypress.

Therefore, in an attempt to conserve Ndoinet block, reclamation was done whereby enrichment planting was in-cooperated to trigger natural regeneration. Additionally, there were some parts of Ndoinet block that were reclaimed and protected by Initiative for Sustainable Landscape (ISLA) and IDH-the Sustainable Trade Initiative agencies to facilitate natural regeneration for the forest continuity [16].

2.2. Research and sampling design

The study utilized an Ecological Survey Research Design both in disturbed and undisturbed sites. In every site, a plot of 500 m by 500 m was laid. Disturbed plot was laid at 100 m from the forest edge while undisturbed plot (500 m by 500 m) was demarcated towards the interior with limited human access. In disturbed plot, forest gaps were randomly identified and area determined for gap size categorization. The longest and shortest distance from the gap centre were measured using linear tape (30 m) and area calculated using ellipse formula;

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

Where;

A represented gap area, L represented the longest distance from the gap centre while W represented the shortest distance from the centre; since most gap shapes appeared regular [17]. The forest gap sizes were categorized into three; gap area ranging from 6-100 m^2 being small gap size, 101-300 m^2 being medium gap size while >300 m^2 being large gap size.

Soil moisture, soil temperature and light intensity were determined in every gap size by inserting Kensizer 3-in-1 soil tester into the soil to a 10 cm depth for moisture and temperature measurements. Light intensity was measured using Luxmeter (model HTC LX-104) exposed at the gap centre. Every microsite condition was measured four times in every gap size to get the average.

Within another 500 m by 500 m plot in undisturbed plot, sub-plots of 30 m by 20 m were randomly placed 19 times using linear tape of 30 meters. Soil moisture, soil temperature and light intensity were taken four times in every sub-plot and average for both calculated. This procedure was done both in the disturbed and undisturbed plots.

2.3. Data analysis

Data was analysed using R version 4.1.2. And Microsoft excel. Descriptive statistics were used followed by inferential statistics for hypotheses testing. Shapiro-wilk test was used to determine normality followed by Kruskal-Wallis *H* test and Wilcoxon rank sum test.

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

Where;

H was the Kruskal-Wallis test, N was the total number of observations in all groups, n_i was the number of observations in the i^{th} group, $R^2{}_i$ was the total sum of ranks in group i [18].

Wilcoxon rank sum test with continuity correction was used to compare microsite conditions between disturbed and undisturbed sites of the forest.

$$\mu w = \frac{n_i(N+1)}{2} \quad \text{.......................................} \quad \text{(iii)}$$

while standard deviation

$$\delta w = \sqrt{\frac{n_1 \, n_2 \, (N+1)}{12}} \quad \text{.......................................} \quad \text{(iv)}$$

Where;

w was the sum rank, N was the total number of observations, n_1 *and* n_2 were the two sample sizes (disturbed and undisturbed sites) (19).

3. Results

The results of the study showed that the dominant disturbance in Ndoinet disturbed site was mainly due to anthropogenic activities such as tree felling, debarking, grazing, charcoal burning, firewood, footpaths, fire, logging. Others were natural though few and included; snagging, wind snapping and stinging nettles which killed most of *Psydrax schimperiana* at sapling stage (Figures 1 & 2).

Examples of human disturbances in SW Mau Forest reserve

a b

Figure 1 Examples of human disturbances in SW; a) firewood and b) debarking; Data source: field sampling by researchers

In Itare and Maramara, human disturbances were very few and included; footpaths, firewood collections, debarking, grazing at the border with Nyayo tea zone and debranching. However, the dominant disturbance in the two blocks was natural which included; stem breakage, senescence and wind snapping hence edge effect.

Examples of natural disturbances in SW Mau Forest reserve

a b

Figure 2 Examples of natural disturbances in SW; a) wind snapping and b) insect pests. Data source: field sampling by researchers

3.1. Gap Size Categorization

In summary, 13 gaps were recorded in Itare block, 11 in Maramara and 17 in Ndoinet (Table 1). Ndoinet block recorded the highest number of gaps even though most were small gap sizes. This was due to incessant human activities in the block such as tree felling, grazing, burning, footpaths which were rampant among other disturbances.

Table 1 Total number of gap sizes in the disturbed sites of SW Mau Forest

Sites		**Itare**	**Maramara**	**Ndoinet**
Gap sizes	Large	3	3	1
	Medium	7	2	2
	Small	3	6	14
Grand total		13	11	17

In addition, a total of 7 large gaps, 11 medium gaps and 23 small gaps were identified (**Figure 3)** and the summation of all gaps in SW Mau was 41.

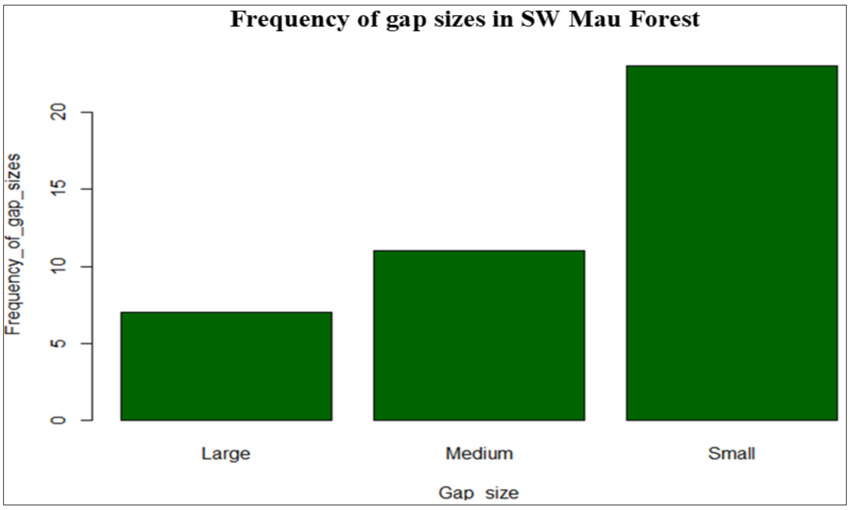


Figure 3 Frequency of gap sizes in SW Mau Forest; Data source: field sampling by researchers

Gap size distribution in terms of area was also as illustrated in **Figure 4**; where large gaps ranged between 330-518 m^2; medium gaps between 101-300 m^2 and small gaps between 6-91 m^2.

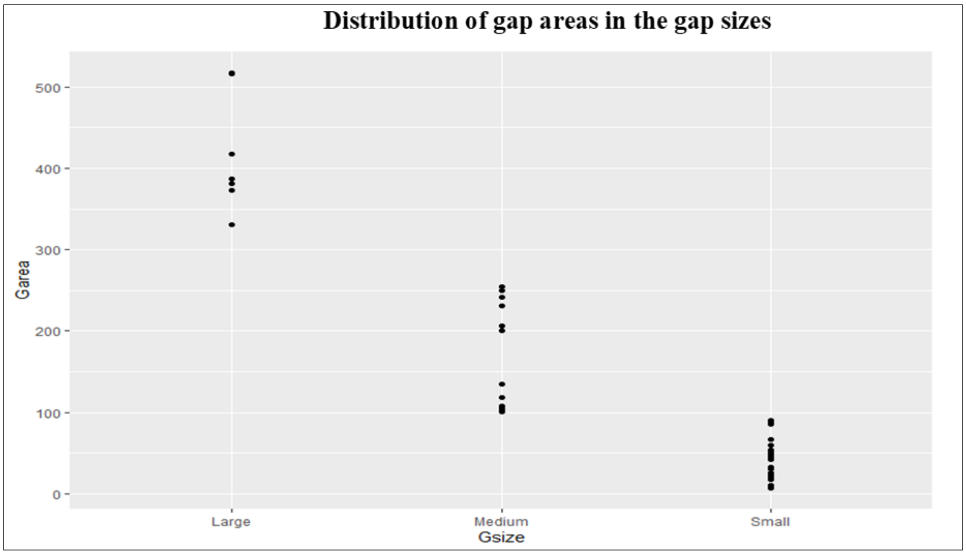


Figure 4 Gap size areas in SW disturbed sites; Data source: field sampling by researchers

Garea represent gap area while Gsize represent gap ssize.

3.2. Microsite conditions in the gap sizes

From SW Mau reserve, small gaps recorder the highest mean soil moisture (24.70%) followed by medium gaps (22.40%) then large gaps (21.10%). Moreover, mean light intensity was recorded highest in large gaps (888.00 Cd), followed by medium gaps (783.00 Cd) and lastly small gaps (707.00 Cd). This trend in mean light intensity was expected due to variations in gap sizes. Again, large gaps recorded the highest mean soil temperature (18.60^{0}C), followed by medium gaps (17.50^{0}C) and lastly small gaps (16.80^{0}C) (Table 2).

Table 2 Summary of mean microsite conditions for disturbed site in SW Mau Forest

Gap sizes	count	Mean		
		Soil moisture (%)	Light intensity (Cd)	Soil temperature (^{0}C)
Large	7	21.10	888.00	18.60
Medium	11	22.40	783.00	17.50
Small	23	24.70	707.00	0

Light intensity was measured in Candela

3.2.1. Soil moisture and forest gap sizes

From the three study sites, mean soil moisture was highest in small gap sizes (24.70%) followed by medium and large gap sizes. However, Kruskal-Wallis rank sum test gave a chi-squared = 16.72, df = 10, p-value= 0.08. The p-value revealed that there was no significant difference in soil moisture in the gap sizes since p-value was >0.05. Therefore, we failed to reject the null hypothesis that gap size had no influence on soil moisture in SW Mau Forest.

3.2.2. Soil temperature and forest gap sizes

Mean soil temperature was highest in large gap sizes (18.60^{0}C) compared to medium and small gap sizes. Kruskal-Wallis *H* test reported that chi-squared = 19.00, df = 3, p-value =0.0002732. This revealed that there was a statistically significant difference in soil temperature across the three gap sizes since p<0.001. Therefore, *posthoc* test was done using Wilcoxon rank sum test with continuity correction for pairwise comparison; with small and medium gap sizes being significantly different p=0.02 (Table 3). Therefore, null hypothesis was rejected and was concluded that gap size had influence on soil temperature.

Table 3 Pairwise comparisons using Wilcoxon rank sum test with continuity correction

Large gap size	Medium gap size	
Medium gap size	0.02	-
Small gap size	0.00	0.02

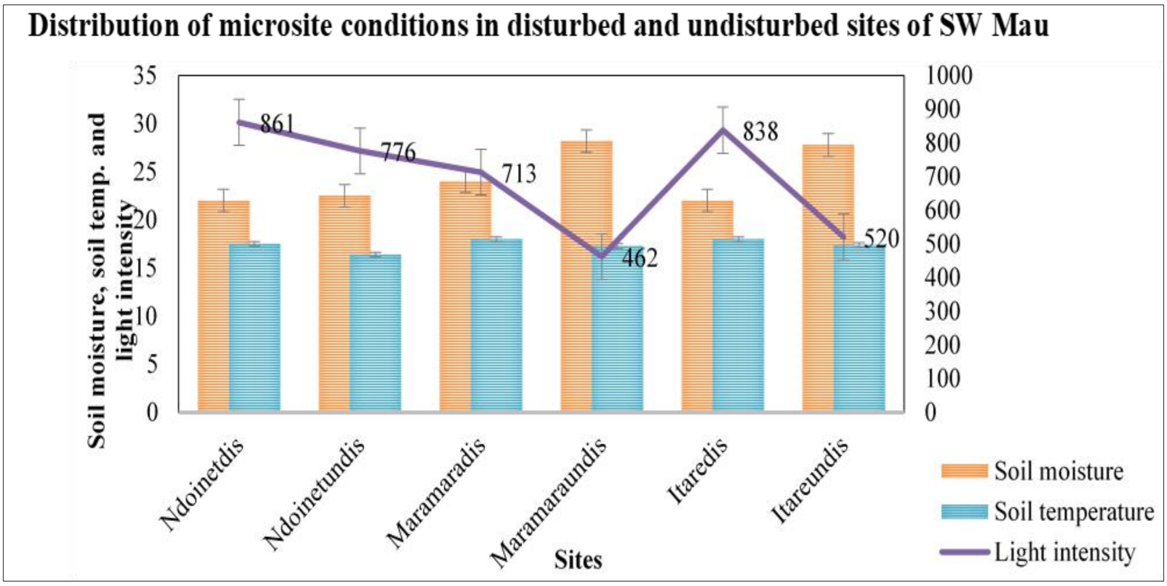
Data: SW Soil temperature and Gap size; P value adjustment method

3.2.3. Light intensity and forest gap sizes

Consequently, Kruskal-Wallis H test was used to determine light intensity in the three gap sizes which gave a result of chi-squared = 30.73, df = 27, p-value = 0.28. This revealed that there was no significant difference in light intensity in the three gap sizes hence no sufficient evidence to reject the null hypothesis that gap size had no influence on light intensity in SW Mau Forest.

3.3. Determining microsite conditions in disturbed and undisturbed sites of SW Mau

Results showed that mean soil moisture was higher in undisturbed sites than in disturbed sites (**Figure 5**). Moreover, mean light intensity also recorded higher value in disturbed sites than in undisturbed sites. In addition, soil temperature was recorded high in disturbed sites than in undisturbed sites.



Note; dis represented disturbed while undis represented undisturbed in the graph

Figure 5 Microsite conditions in SW; Disturbed and Undisturbed sites; Data source: field sampling by researchers

Wilcoxon rank sum test with continuity correction was used to compare the microsite conditions between disturbed and undisturbed sites of the forest. For soil moisture, the Wilcoxon rank sum test revealed that there was no significant difference in soil moisture between disturbed and undisturbed sites of the forest (W = 275, p-value = 0.07 and the difference between medians= -2.00) at 95% confidence level. Therefore, null hypothesis failed to be rejected that there was no significant difference in soil moisture between disturbed and undisturbed sites of SW Mau Forest reserve.

Images of *Piper capensis* roots and shoots in Itare and Maramara

a

b

Figure 6 *Piper capensis* roots and stem in Itare and Maramara; a) Piper stilt roots and b) Piper shoots: Data source: field sampling by researchers

Moreover, Wilcoxon rank sum test revealed that W = 446, p-value = 0.34 and difference between the medians= 5.38-05, p>0.05. Therefore, there was no significant difference in soil temperature between disturbed and undisturbed sites of the forest hence null hypothesis failed to be rejected. As a result, there was no significant difference in soil temperature between disturbed and undisturbed sites of SW Mau Forest.

However, at 95% confidence interval, the medians in light intensity between disturbed and undisturbed sites of the forest were significantly different. The Wilcoxon rank sum test revealed that W = 555, p-value = 0.01, and the difference between the medians= 150.00, p<0.05. Therefore, there was a significant difference in light intensity between disturbed and undisturbed sites hence null hypothesis was rejected and was concluded that there was a significant difference in light intensity between disturbed and undisturbed sites.

SW reserve was highly invaded by pioneer species (*Piper capensis, Ribes spp*. and ferns) in the gaps hence resulted into a somehow closed canopy. This could have been the cause of non-significant differences in most microsite conditions in the gap sizes and between disturbed and undisturbed sites of the forest (Figure 6).

4. Discussions

The distribution of soil moisture, soil temperature and light intensity was generally not equal in the different gap sizes as well as in disturbed and undisturbed sites hence heterogeneity [11]. The mean availability in resources differed vertically and horizontally collaborating with other earlier studies [13]. Some resources such as soil moisture were spatial variables since they differed in every site thus might not normally increase in gaps [21].

4.1. Forest gap sizes and soil moisture

Even though many studies reported that forest gap size influence microsite conditions [21], this was not the case in SW Mau forest. Being a natural forest and with less human manipulations [13], conditions were different from the expected. There was no significant difference in soil moisture in the three gap sizes. This could be attributed to *Piper capensis*; invasive plant which was common in Itare and Maramara blocks intercepting rainfall [20]. The species could be found in all medium and large gaps growing prolifically forming a dense canopy covering the forest floor. This could not allow for intense evaporation during day time as was expected hence no difference in the gap sizes [11].

Moreover, more of debris were witnessed in the gaps hence could not allow for moisture escape [11]. The debris were from twigs, leaves, chippings from tree cutting among others [22]. This result was therefore different from other studies which indicated that soil moisture differed with gap size [21]. Again, Ndoinet was invaded by *Ribes spp.* and ferns which were part of the forest succession, however, soil moisture still trailed low in Ndoinet. This could be due to increased forest floor exposure since it was under regeneration following excessive human disturbances [20]. Moreover, the disturbances could have made the block vulnerable to soil erosion due to reduced land cover hence increased moisture loss complying with other studies [11].

Unlike other studies, this study was very different on the influence of forest gap size on soil moisture. The mean soil moisture differed from every gap size with small gap size having the highest mean followed by medium gaps then lastly the large gaps. This again was contrary to the findings of other researchers that soil moisture was high in large gaps than in small gaps [23]. Soil moisture was low in large gaps due to invasion by *Piper spp.,* hence increased moisture consumption [20] by the plant roots [11].

Moreover, the invasive species could have affected soil moisture conditions via processes such as interception losses [20], percolation/infiltration [22] and evapotranspiration [11]. Accordingly, the invasive plants could have affected hydrological regulation [24] hence influenced the distribution of soil moisture [20] in the gap sizes as well as in undisturbed sites thus maintaining the soil moisture [11].

Furthermore, in the control plot (undisturbed), mean soil moisture was recorded higher in undisturbed sites than in disturbed sites [20]. However, this result was not the same when testing for hypothesis on soil moisture in disturbed and undisturbed sites of the forest. This implied that there was no significant difference in soil moisture both in disturbed and undisturbed sites. This could be because the forest floor was not fully exposed in disturbed sites but was covered by the invasive species [11] hence no much moisture loss, corroborating with earlier studies [20, 22]. Generally, soil moisture was high in Itare and Maramara Disturbed and undisturbed sites due to closed canopy hence less evaporation [20].

Nevertheless, soil moisture in forest soils should be given a lot of attention to enhance the ecosystem processes, growth and development [24]. This will help in conserving forest biodiversity through continuous cycling of the forests. This is because, soil moisture has a role both to plants and soil micro-organisms [22]. In addition, there should be recognition of the correlation between forests and soil water which plays a role in Net Primary Productivity of plants [11].

4.2. Forest gap size and Soil temperature

This study revealed that soil temperature was influenced by gap sizes. This followed the fact that the mean soil temperature was highest in large gap sizes than in small gaps thus in agreement with other previous studies [25] . Soil temperature differed in the three gap sizes hence this study was in accordance with other findings [13, 21].

Precisely, mean soil temperature in Itare and Maramara blocks was lower compared to Ndoinet. This could be due to increased forest cover from *Pipers spp*., as well as giant and tall trees that dominated the two sites concurring with other studies [20]. Moreover, there could be increased chances of solar interception or reflection (albedo) by the multistorey canopy in Itare and Maramara blocks [22]. This could have resulted into low radiation penetrating to the ground hence nearly uniform soil temperature both in disturbed and undisturbed sites of the forest [24]. However, many gaps in Ndoinet resulted into higher soil temperature as a result of more exposure by short and open vegetation cover [20]. Soil temperatures varied with the area, canopy cover, depth and time influenced by irradiation [20, 24].

There was no significant difference in soil temperature both in disturbed and undisturbed plots. This could be due to ground cover both from debris and invasive species in the three blocks (24). This reduced water loss and consequently increased water retention in disturbed sites hence low temperatures [21]. Therefore, this had other importance such as low nutrient loss, increased plant growth (*Piper capensis*) [24] as well as microbial activities [22].

4.3. Gap size and light intensity

Mean light intensity was higher in large gaps followed by medium gaps then small gaps hence corroborating with other studies [23, 25, 27]. However, this study revealed that there was no significant difference in light intensity in the three gap sizes. This was again contrary to other studies which revealed that light intensity differed with gap sizes [21]. The reason for this variation could still be attributed to the invasive species which crowned the large gaps thus barring excess light from reaching the forest floor in the gap sizes [28]. In the gaps, light intensity was reaching the ground as diffuse due to interception [22] hence no significant difference [26].

Light intensity in the forest was determined by the vertical light distribution which was again related to vegetation height in the forest. There was observed decrease in mean light intensity in undisturbed sites than the disturbed plots [28]. Therefore, there was a significant difference in light intensity between disturbed and undisturbed sites. This could be attributed to light attenuation at the top canopy by huge and tall trees in undisturbed site hence no/less light penetration into the forest floor. Additionally, the invasive species could have formed a uniformly low canopy cover allowing much sun flecks to penetrate to forest floor in disturbed sites hence higher light intensity than in undisturbed sites [29].

5. Conclusion

The study generally reported that there was no influence of gap size on soil moisture and light intensity in SW forest. However, light intensity differed between disturbed and undisturbed sites of the forest. Overall, the forest was invaded by *Piper capensis*, ferns and *Ribes spp*. in the gaps which influenced microsite conditions. Therefore, it was concluded that canopy cover influences microsite conditions in forest gaps. Forest gap sizes play an important role in forest cycles and should be left to occur naturally without human interferences. Moreover, the study recommended enrichment planting using indigenous species in the forest gaps in order to hasten forest succession for continuity and biodiversity conservation.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest declared by the authors in regard to the findings of this research.

Statement of ethical approval

The present research work does not contain studies performed on animals/humans subject by any of the authors.

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