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Influence of Forest Canopy Gaps on Soil Properties and Richness of Understory Vascular Plants in 2-hectare Long-Term Ecological Research (LTER) Site in Mt. Musuan in Bukidnon, Southern Philippines

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***Abstract*:** Several studies have reported on the influence of forest canopy gaps on understory plant growth and species richness. In this study, soil properties and the richness of understory vascular plants under forest canopy gaps of varying sizes in a permanent Long-Term Ecological Research (LTER) plot in Mt. Musuan were determined. Based on the results, the light and photosynthetically active radiation varied among canopy gaps. There was an observed variation in the mean pH, percent organic matter content, extractable P and exchangeable K among forest canopy gap classes but the variations were not statistically significant. Large gaps had higher species richness of trees, shrubs and vines. Mean species abundance was also higher in large gaps (81) in comparison with small (60) and medium gaps (76). Although there are many species of trees present, there are only very few numbers of individuals. *Donax canniformis* (G.frost) K.Schum., *Orania palindan* (Blanco) Merr. and *Calamus sp.* were the most abundant species. The abundance of *D. canniformis* increased with canopy gap size which may indicate that it can easily spread in open sites. This could be indicative of the potential harm that the species can pose to tree regenerates if its spread is not controlled.

Keywords: Canopy gaps, Understory, Vascular plants, Soil properties, Mt. Musuan

The gap dynamics theory postulates that at any given time within any closed forest stands, disturbances may spontaneously happen to cause the death or injury of one or more canopy trees leading to gaps creation. Disturbance is a phenomenal forest activity which paves the way for the creation of canopy openings called canopy gaps (Hammond and Pokorny 2020). Disturbances that open gaps provide specific microenvironmental conditions in light, soil moisture, and temperature regimes, which often initiate regeneration processes and development (Muscolo et al 2014). Forest canopy gaps have an important forest ecological role (Schliemann and Bockheim 2011). Gaps in the canopy bring about significant effects on the structure and dynamics of most temperate and tropical forests. Death and fall of trees due to wind, disease or over-maturity can lead to the creation of forest gaps (Amolikondori et al 2021). Environmental changes particularly light intensity that reaches the understory can accompany gap creation. The formation of canopy gaps decreases canopy interception of precipitation and increases rain flushing and solar radiation in the understory. These impact the temperature, humidity, physical-chemical properties, and microbial community structure and function of soils, in addition to altering the forest environment (Xu et al 2016). This in turn can have an influence on plant diversity (Richards and Hart 2011) and soil nutrient cycling (Schliemann and Bockheim 2014).

Several studies indicated the effect of forest canopy gaps on understory plant growth and diversity. Tree growth is largely dependent on light capture (Fichtner et al 2013). Pedersen and Howard (2004) reported higher stem radial growth rates for overstory trees at gap edges compared to trees which were not positioned at canopy gap edges in a mature mixed forest. Seedling establishment, survival, and growth exclusively depend on light (Diaci et al 2008). Gap size is a strong predictor of species composition in forest gaps (Čater et al 2014). The importance of the effect of gap size on plant species diversity and composition in different forest types in tropical (regions has been validated (Schnitzer et al 2008, Marra et al 2014). The size of canopy gaps also relates to the amount of different light conditions that reach the forest floor and the type of light condition species exploit in gaps (Nagel et al 2010). Shade-tolerant tree species grow well in small gaps, while shade-intolerant species survive better in large gaps (Nagel et al 2010). Small gaps with low direct light levels supported shade- tolerant fir regeneration in mixed Dinaric forests (Čater et al 2014). For instance, large gaps are generally beneficial to the regeneration of light-adapted species (Čater 2017, Hammond and Pokorný 2020).

Previous studies on forest canopy gaps were mostly done on forest plantations and in temperate setting. Although several studies have been conducted in natural forests, only few were done in the Philippines. To gain an understanding on the dynamics of understory species richness and soil properties under natural forest canopy gaps, a study was conducted in a 2-hectare permanent plot inside a tropical forest. This study hypothesizes that plant diversity and the abundance of some plants increase with gap size. Soil physicochemical property values decline with increasing gap size. This study aimed to generate meaningful insights on the dynamics of soil and richness and abundance of understory vascular plants under various canopy gaps, with emphasis on forest regeneration and management.

MATERIAL AND METHODS

Study area: The study was conducted within the 2 ha. LTER permanent plots established in the natural forest of Mt. Musuan from March-May 2023. The LTER plot is approximately located at geographic coordinates 7.882361 North & 125.065694 East. In general, Mt. Musuan is 2005, the mean annual rainfall was about 1935 mm. June to October are also the wettest months on record, while the driest months were January to April with less than 100mm. The ecosystems in Mt. Musuan fall onto 4 general types; natural forest, plantation forest, grass-shrubland, and agro-ecosystem (Paquit et al 2023).

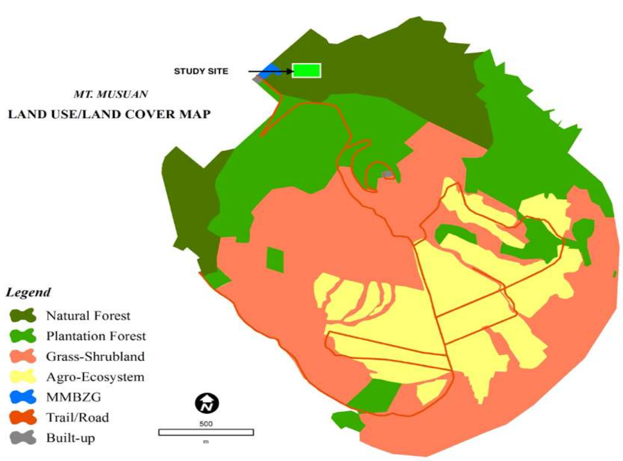

Fig. 1. Location of the study (Map from Paquit et al 2023)

Characterization of canopy gaps: A reconnaissance survey was conducted to assess the presence of forest canopy gaps. Data on the location and estimated size (m^2) of the gaps were also collected. Three classes of gaps, namely small gaps (SG) (no central opening), medium gaps (MG) (100-200 m^2) and large gaps (LG) (>200 m^2) (modified from Hammond et al 2020) were characterized. Three replicates of NG, SG, and LG for a total nine forest canopy gaps were sampled. The geographic coordinates, elevation and the number of downed trees were also recorded.

Establishment of transect and sampling plots: Four transect lines oriented on a north-south and east-west directions were established (Fig. 2). The length of each

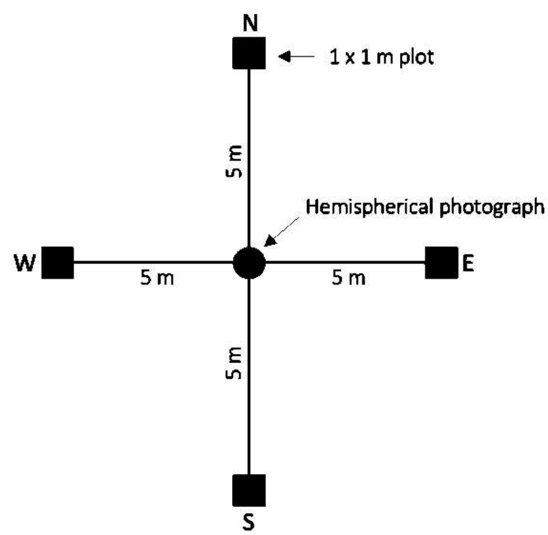

Fig. 2. Layout of transect and sampling plots (Modified from: Hammond et al 2020)

Table 1. Geographic location and tree fall characteristics of canopy gaps

Canopy gap class	Latitude	Longitude	Elevation (masl)	GPS accuracy (m)	No. of tree fall
SG1	7.88173	125.06609	433	12	0
SG2	7.88187	125.06626	412	10	0
SG3	7.88192	125.06591	422	7	0
MG1	7.88249	125.06668	409	7	1
MG2	7.88179	125.06571	409	5	1
MG3	7.88256	125.06692	408	8	1
LG1	7.88244	125.06588	382	7	4
LG2	7.88198	125.06594	427	7	3
LG3	7.88209	125.06557	400	6	2

transect line was 5 meters starting from the center of cardinal plane. 1x1 meter plots were then laid out at the ends of each transects line for the sampling plots of understory vegetation and soils. This set-up was replicated in other forest canopy gap classes.

Collection of canopy photographs: Hemispherical photographs were used to quantify the light environment below the canopy gaps. The photographs were taken during overcast skies using a digital camera (Nikon D3100) with a fish-eye lens. The camera system was set up at 1.37 m above ground, with the lens leveled and positioned vertically, and the top of the resulting image orientated to the north. The set up was laid at the intersection of the N-S and E-W transect lines (Fig. 2). Calculation of percent light transmission (% light) and photosynthetically active radiation (PAR) from the hemispherical photographs was accomplished using the software package Gap Light Analyzer (GLA version 2; Frazer et al 1999).

Vegetation and soil sampling*:* All vascular plants within each 1 m^2 plot were sampled. The taxonomic identification and number of individuals of plants were recorded. Aside from tree fall, trees adjacent to the plot were also noted. Soil samples from A horizon (30-cm depth) were taken using soil auger and other available tools. Thirty-six samples were collected from the field, airdried and then sieved to remove extraneous materials such as leaves, roots and others. Four soils samples from each gap class were grouped together for form nine composite samples. These nine samples were then brought to the laboratory for chemical analysis that included pH, percent organic matter (OM) content, extractable P, and exchangeable K.

Data analysis*:* Data from each 1 m^2 plot was pooled. Differences in species richness and abundance was analyzed using Microsoft excel. Soil properties of each gap category was in Microsoft Excel. Descriptive statistics such as means and percentages was also applied as deemed appropriate.

RESULTS AND DISCUSSION

Percent light and PAR in canopy gaps: Large gaps obtained a higher mean % light (22.25%) and mean PAR (9.13 Mol s^{-2} d^{-1}) as compared with small gaps (% light = 8.42, PAR =3.51) and medium gaps (% light = 12.27, PAR = 5.11). These are expected variations since more light can penetrate the canopy as the opening from gaps increase. PAR is strongly attenuated by foliage and canopy structure, but canopy opening in gaps can greatly increase the amount of PAR that reaches the forest floor. Kobe (1999) also found that canopy gaps had much higher levels of PAR than understory microsites due to the direct penetration of sunlight through the gap.

As depicted in the canopy photographs (Fig. 3), numerous gaps can be seen even in the small gap class. With the area classified as secondary forest (Marin and Casas 2017), it was observed that canopy gaps frequently occur in the 2-hectare permanent plot established under the Long-term Ecological Research project implemented by the Center of Biodiversity Research and Extension in Mindanao (CEBREM) of Central Mindanao University. A completely closed canopy with no small gaps or openings appear to be absent in the area. In large gaps, an average number of three fallen trees per gap was documented indicating that there was a total of nine fallen trees recorded in large gaps. This is

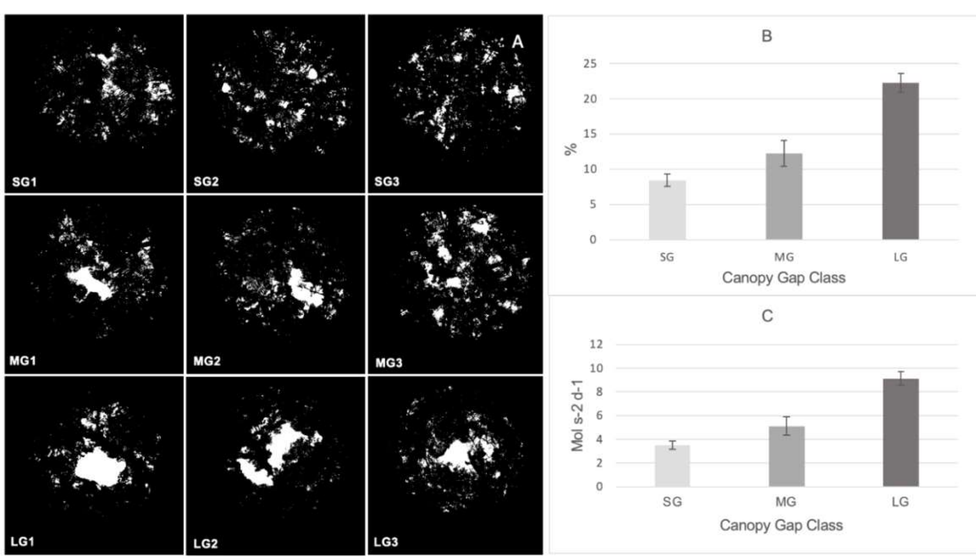

Fig. 3. Canopy gaps (A) and their variation in % light (B) and PAR (C)

higher than in medium gaps wherein only a single fallen tree was recorded per gap. The diameter of fallen trees observed in medium and large gaps ranged from 26-55 cm. It also appeared that trees downed by wind, a natural phenomenon (Amolikondori et al 2021) had led to the creation of those mentioned gaps. Gaps in the canopy bring about significant effects on the structure and dynamics of most temperate and tropical forests. Environmental changes particularly light intensity that reaches the understory can accompany gap creation (Xu et al 2016). This in turn can have an influence on plant diversity (Richards and Hart 2011) and soil nutrient cycling (Schliemann and Bockheim 2014). However, a few logs cut down using axe and saw have been observed outside the studied gaps. These were medium sized logs which may have been illegally felled. Further observations should be done to observe activities that could potentially cause disturbance in the area.

Variation in soil properties among canopy gaps: There was an observed variation in the mean pH, percent OM content, extractable P and exchangeable K among forest canopy gap classes (Fig. 4). However, the variations were not statistically significant. The mean pH was closely comparable but was highest in Small Gap (Fig. 4). Soil pH tend to increase in closed forest canopy (Tang et al 2019). Zhang & Zhao (2007) observed that soil pH under closed canopy was also higher but was not significantly different than in canopy gaps. Levia and Frost (2003) also found lower soil pH in larger canopy gaps. Soils under larger canopy gaps are more exposed to rainfall which can hasten the leaching of cations (Levia and Frost 2003). However, the relationship between canopy gap size and soil pH can be complex. Other factors including the age of the gap, the surrounding vegetation and the level of soil disturbance could also influence soil pH (Levia and Frost 2003).

Meanwhile, percent OM content was lower in small gap as compared with medium and large ap. Previous studies have suggested that soil organic matter content tend to decrease with increasing canopy gap size (Potvin and Gotelli 2008). In the same manner that it affects soil pH, exposure of the soil surface to solar radiation and rainfall hastens soil organic matter decomposition. Minerals are eventually absorbed by the growing vegetation including the understory.

Table 2. *p* values of the different soil properties

Soil properties	p value	Remarks
pH	0.94	Not significant
% OM	0.31	Not significant
Extractable P (ppm)	0.49	Not significant
Exchangeable K (ppm)	0.51	Not significant

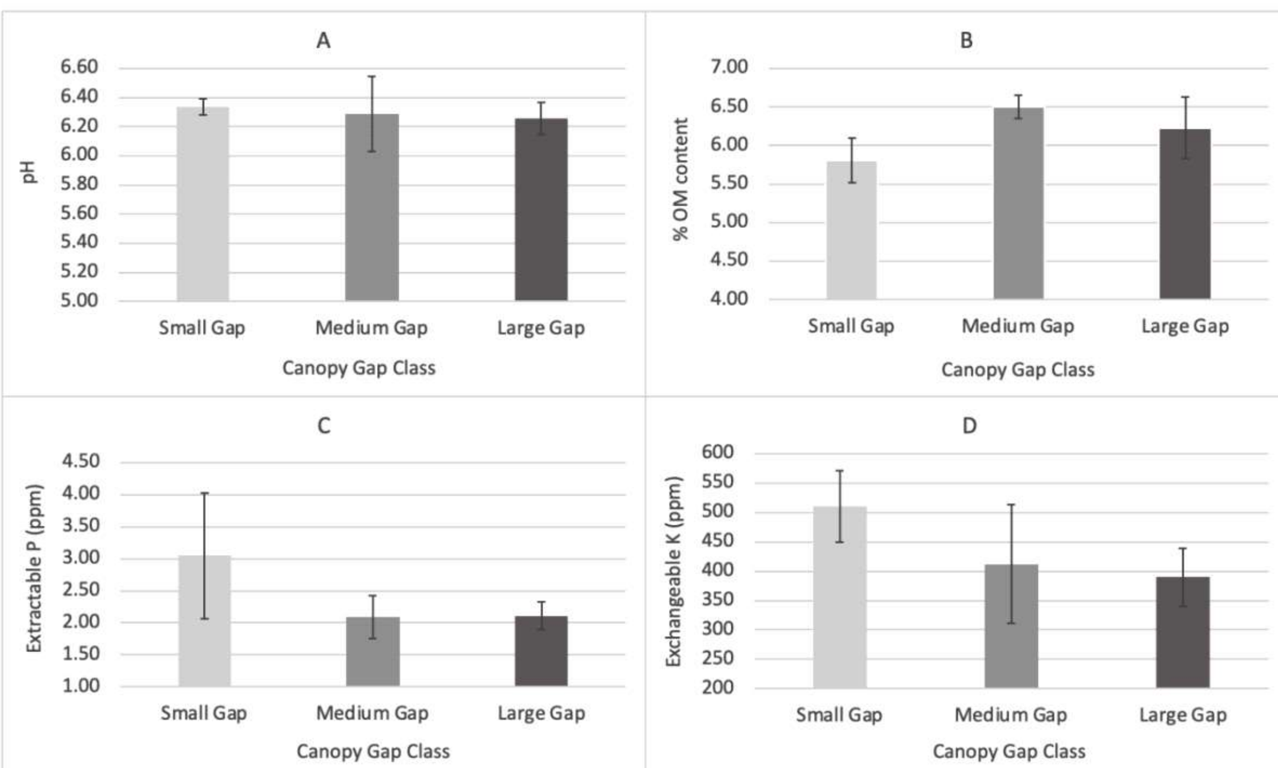

Fig. 4. Variation in mean pH (A), % OM (B), Extractable P (C), and Exchangeable K (D) among canopy gap classes

In forest ecosystems, gaps that are created by natural disturbances such as tree fall and windthrow may possibly increase soil organic matter content. Understory vegetation growing in microhabitats under canopy gaps can contribute to the accumulation of organic matter in the soil

Higher Extractable P was observed in soil under small gaps. Kaspari et al (2008) found higher soil phosphorus availability in gaps than in closed understory microsites. Chen et al (1995) also observed higher soil phosphorus availability in canopy gaps than under closed canopy. Meanwhile, there was a higher exchangeable K in small gaps than in medium and large gaps. Soil potassium availability can be influenced by canopy gaps, with gaps having higher potassium availability than in closed canopy areas (Clark et al 2001). Higher P and K in gaps could be attributed to an increased litter decomposition and nutrient cycling (Kaspari et al 2008). The previous studies suggest that phosphorus and potassium stocks increased with forest gaps, this phenomenon can also depend on other factors. The effect of gap size on P and K stocks may also depend on forest composition, with gaps having more deciduous species that contribute to litter production likely to have higher soil P and K (Clark et al 2001). This study was not able to include completely closed canopy gaps as these are absent because the study area is a disturbed secondary forest.

Species richness and abundance of understory vascular plants: Large gaps had higher species richness of trees, shrubs and vines (Fig. 5a). On average, 23 different species of vascular plants was recorded under large gaps wherein 12 are tree species. This is higher than in small and medium gaps wherein only 7 and 10 tree species were recorded respectively. The mean total number of species is also lower in small and medium gaps, only 14 and 17 respectively. Čater et al (2014) observed that gap size is a strong predictor of species composition in forest gaps. Several studies have also reported that canopy gaps can influence species diversity in forest ecosystems. Lertzman et al (2002) observed that in a temperate rainforest, gaps created by windthrow increased plant diversity and biomass.

The, mean species abundance was also higher in large gaps (81) in comparison with small (60) and medium gaps (76). Moreover, the abundance of trees, shrubs and vines increased with canopy gap size. In contrast, the abundance of palms decreased as the canopy gap size increased. Canopy gaps can also have an influence on seedling abundance in forest ecosystems. Busing and Brokaw (2002) found that seedling abundance was higher in canopy gaps than in closed canopy in a tropical rainforest in Puerto Rico. Canham and Thomas (2010) also had the similar observation on their study in a temperate deciduous forest in the northeastern United States. The enhanced light condition in gaps is exploited by different species especially the light demanding (Nagel et al 2010). Changes in light, temperature and moisture conditions caused by the creation of gaps could have affected the germination, growth and survival of tree seedlings associated with gaps.

Implications for conservation and management: Although there are more species of trees, only very few individuals are present. The top three most abundant species under different canopy gaps are *Donax canniformis* (G. frost) K. Schum., *Orania palindan* (Blanco) Merr. and *Calamus sp* (Fig. 6). These species dominate the understory in the study sites regardless of the size of the canopy gaps. The mean abundance of *O. palindan and Calamus sp.* drops as the canopy gap size increase. The mean abundance of *Calamus sp*. decreased from 18 to 15 from small to large gaps respectively. The mean abundance of *O. palindan* had a stepper drop from 21 in small gaps to only 4 in large gaps. Meanwhile, an increase in the abundance of *D. canniformis* was positively correlated with the increase in gap size.

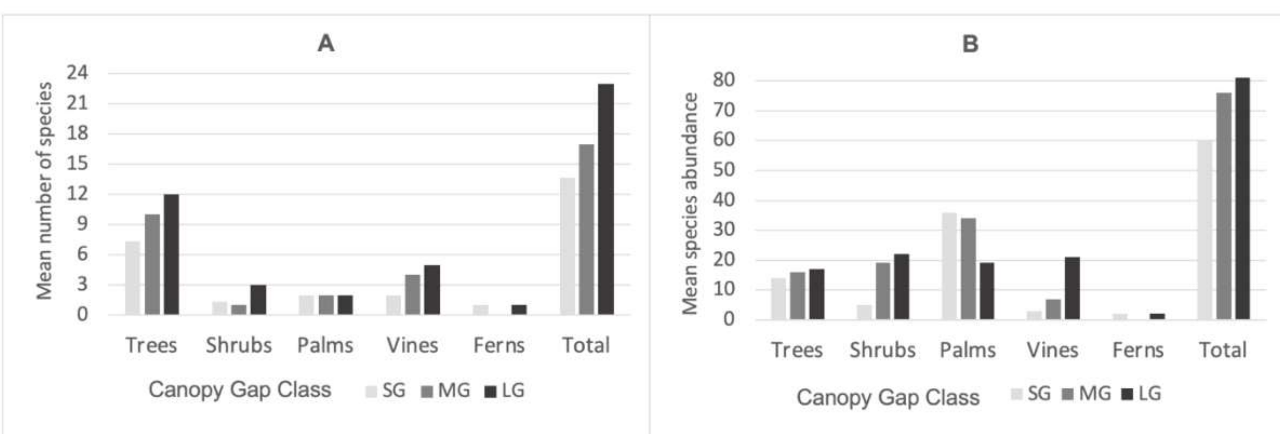

Fig. 5. Mean number of species (A) and mean species abundance (B) among canopy gap classes

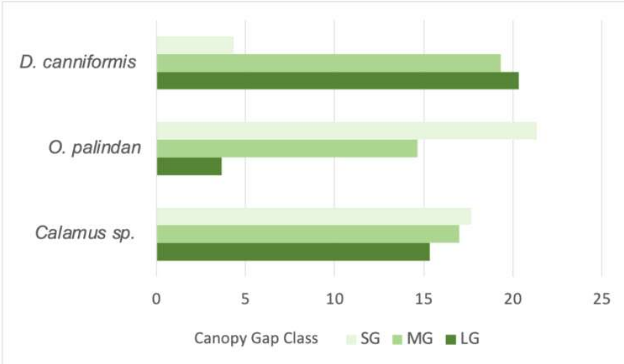

Fig. 6. Top 3 most abundant species in canopy gaps

Ardiyani et al (2010) observed that *D. canniformis* is common especially in open and disturbed places. It is common in low and medium elevation secondary forest in the Philippines and is common throughout South East Asia. This explains its observed greater abundance under canopy gaps.

D. canniformis is classified as native species. However, as observed, the species had become the dominant understory plant species in the open sites of the study area. As seen in this study, larger openings in the canopy can promote the spread of this species in other parts of the forest. The species can potentially outcompete tree regenerants for light, space and nutrients and may impact plant diversity. Natural disturbances such as windthrow can promote canopy openings. Anthropogenic activities such as timber poaching can also pose disturbance. The uncontrolled spread of some species such as *D. canniformis* may be averted by silvicultural intervention such as manual removal of individuals. Various authors have written about *D. canniformis* being used in novelty items such as placemats, baskets, and flowerpot holders (Agduma et al 2011). The stem is made into a wide range of handicrafts including hats, baskets, magazine rack and bookshelves (Teo 2003). The leaves also contain saponins, phenolics, and tannins (Hidayatullah et al 2017). These are some of the potential uses of the species to control its population.

CONCLUSIONS

This study observed the presence of canopy gaps of different sizes in the study area. % light and PAR differed among canopy gaps. There was an observed variation in soil properties, however, their differences were not statistically significant. In general, species richness increased with canopy gaps. The abundance of species, except for palms, were also greater as the gap size increased. However, three species namely; *D. canniformis*, *O. palindan*, and *Calamus sp.* dominate the understory of the canopy gaps. In particular, the mean abundance of *D. canniformis* had a steep increase from small to large gaps. This could be indicative of the potential harm that the species can pose to tree regenerates if its spread is not controlled. The findings of this study can have implications in the management of the area. Apart from strict forest protection from timber poachers, silvicultural interventions could be explored to control the population of *D. canniformis*, *O. palindan*, and *Calamus sp.* This is to allow trees and other plant species to grow and survive in the area.

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