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Evaluation of rehabilitated forest stands development using hemispheric photograph

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ABSTRACT

Most tropical rainforest tree species depends on forest gaps for their successful regeneration. Evaluation on the gap or canopy openness provides an indicator on the forest development stages. This paper reported on the canopy openness (CO) of three study plots at (1-, 9-, 18-year old) rehabilitated forest sites and one study plot at natural regenerating secondary forest (± 22-year old) in UPM-Mitsubishi Corporation Forest Rehabilitation Project, Universiti Putra Malaysia Bintulu Sarawak Campus (UPMKB). Plot of 20 x 20 m was established where dendrometric parameters were collected while Delta-T Device HemiView system was used to take the hemispherical photograph and field observation information were used to assess the CO. Qualitative analysis of the photographs suggested there were three stages of forest growth namely gap, building and mature stand development phases. These also helped the interpretation of the quantitative analysis in relation to forest dynamics. Hemispherical photographs were used for quantitative analysis of the CO. CO showed statistical significant differences among study plots which recorded a range of 3-78%. Rapid analysis of CO on the hemispherical photographs with information from the dendrometric measurement had assisted in assessing the forest stand development. The canopy openness was dependent on the age of the rehabilitated forest. Overall, the study plots were in the different stages of stand development.

Keywords:
Canopy openness, hemispherical photograph, natural regenerating secondary forest, rehabilitated forest

1. Introduction

The tropical forest growth are divided in gap, building, mature and degenerative phases. In this region, most of the tropical tree species are gap dependent for their successful regeneration [1-4]. In an undisturbed forest, the canopy strata are continuous and uniform with little radiation penetrates through the many canopy layers to ground level except where gaps occur [2]. A forest gap is a patch in a forest created by the death of a canopy tree. The composition and structure of the communities

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are the results of the species responses to the different size, frequency and distribution of gap [5] and seedlings of different species react differently to reach optimal growth under different light regimes in different sized gaps [6]. Such gap characteristics are important to study as they strongly influence the nature of forest regeneration and succession. The size of canopy gaps is more important for the natural regeneration after disturbances as these affects the microclimate [2,7]. Therefore, forest canopy is important as it regulates ecological and ecophysiological processes in the forest ecosystem [8].

Studies on gaps or canopy openness using hemispherical photograph provide a useful information for forest dynamics studies [7], [9], [10] which can: (i) explain its effect on the biophysical and ecological processes occurring in the forest ecosystem [11], (ii) measure of stand density [12], (iii) predict woody plant composition, leaf area index (LAI) [13], [14], [15] (iv) evaluate tree crown condition or forest pest damage [16], [17], (v) assess wildlife microhabitat [18], (vi) estimate direct and diffuse solar radiation transmitted by the canopy [19], [20] and (vii) assess forest structure [21], [22], [23]. Details on the application of hemiview photograph application and limitation use in the forest has be discussed by Fournier and Hall [24].

Assessment on the canopy openness based on the natural forest dynamics can provide an indicator on the stand development a forest area especially secondary and rehabilitated forests. Such information is rather limited especially in rehabilitated forest and a few researchers such as Brown [2] and Whitmore *et al*. [7] conducted gap studies using hemispherical photographs in Bornean tropical rainforest while Numata *et al*. [4] in Pasoh forest, Peninsular Malaysia. Jansson [25] assessed the effects of canopy properties on light conditions at the forest floor. These affects the regeneration of species or planted tree species. Researching the aspect of canopy openness can provide indication to the recovery status. The traditional method of measuring tree data, sketching canopy opening and profile diagram are time consuming and costly. Hemiview photography technology helps to increase field work efficiency. This paper reported on the canopy openness at different age stands of the rehabilitated forest which was to evaluate the forest stand development stages.

2. Materials and Methods

2.1 Study Sites

The study was conducted at the rehabilitated forest in Universiti Putra Malaysia Bintulu Sarawak Campus (UPMKB), Sarawak, Malaysia (Latitude 03°12'N, Longitude 113°02'E). The campus soil belongs to Nyalau and Bekenu Series. The Nyalau Series is characterized by coarse loam, yellowish brown topsoil of 9 cm deep with a brownish yellow sub-soil. The Bekenu Series is characterized by mixed fine loam, light yellowish brown top-soil of 4 to 15 cm deep and brownish yellow sub-soil [26].

The average monthly rainfall recorded from the Bintulu Meteorological Station was 308.7 mm while the average monthly relative humidity was 86.5%. The average annual recorded rainfall over 20 years was 3074 mm. The area received the most rainfall during the month of October to January. The mean relative humidity was also consistent throughout the year with a range of 85.0–88.5%. The average monthly air temperature was 26.8°C. The mean air temperature was quite consistent throughout the year but recorded increasing temperature during the dry season from the month of April to August with decreasing in the mean monthly rainfall.

2.2 Sampling design

In order to achieve the objective to evaluate the canopy openness at different age of stand development, 20 x 20 m plots were established in 2009 at three sites namely 18-year old (Plot 1991), 9-year old (Plot 1999) and 1-year old (Plot 2008) rehabilitated forests. As for the purpose of comparison, a 20 x 20 m plot was also established at a natural regenerating secondary forest at Bukit Nyabau (± 22-year old; Plot NF) which was adjacent to the forest rehabilitation project site. The plots are in such size as the annual planting area is relatively within that size only. This rehabilitation method introduced in the project are planting indigenous tree species at high density (3 seedlings/m^2).

In all the rehabilitated forests, the family Dipterocarpaceae (71-81%) dominates the species composition compared to 14% in natural regenerating secondary forest. The five most common families, in terms of numbers of stand found in Plot 1991 were Dipterocarpaceae, Sterculiaceae, Bombacaeae, Clusiaceae and Myrtaceae while in Plot 1999, were Dipterocarpaceae, Anacardiaceae, Fabaceae, Lauraceae and Mrytaceae. In Plot 2008, the five most common families were Dipterocarpaceae, Meliaceae, Clusiaceae, Myrtaceae and Sapotaceae. In contrast, in Plot NF, the five most common families were Dipterocarpaceae, Anacardiaceae, Eupborbiaceae, Sapotaceae and Ixonanthaceae.

2.3 Dendrometric Parameters

Dendrometric analysis was conducted where the diameter, height and basal area was measured. All trees in the plots were measured of their stem diameter (cm) at 1.3 m height above the ground or basal diameter for seedling of less than 1.5 m. As for trees that have plank buttresses surpassing 1.3 m in height, the stem diameter is just above the upper end of buttress will be substituted for dbh. Diameter tape was used for diameter measurements. As for tree height (m), clinometer was used for the estimation and calculation of the tree height or measured with height stick for seedlings. Basal area (m^2/tree) was also calculated.

2.4 Canopy Openness Measurement

The canopy openness in this study was measured using the Delta-T Device HemiView system. Image acquisition of hemispherical photographs involves a Canon EOS 50D digital camera with a fixed fish eye lens (7.5 mm fish-eye lens). The camera was mounted on a tripod, levelled and oriented to magnetic north. Hemispherical photographs were taken each at the centre of 5 points (4 photographs at the centre of each 10 x 10 m subplots and 1 photograph at the centre of the main 20 x 20 m plot). The work was carried out August 2009, where data was collected early in the morning (7.00 am) in the study plots as to avoid any overexposed photograph.

The images obtained were transferred to a personal computer and analyzed using Delta-T Device HemiView software. HemiView displays the image which was adjusted to align the horizon and North/South axis. Finally, the image was threshold to turn it into a black and white image. In this study, the following information was analyzed:

Qualitative analysis was conducted by visual interpretation of photographs. A set of 5 hemispherical photographs from each plot was selected on the basis of the different forest dynamic phases, namely gap, building stage and mature forest stages. These provided the information to recognise the forest stand development stages.

Quantitative analysis was conducted by geometric measurement of the canopy. This analysis would provide addition information to the dendrometric measurement concerning the structural differences among the study plots. In which, this information can be used to assess the forest stand development status. The Delta-T Device HemiView software analyzed the hemispherical photograph which generated the value of the visible sky across the hemisphere. The canopy openness was calculated as follows [27]:

Canopy openness (CO) (%) = visible sky x 100

2.5 Field Observation

In field work activities in plot established in 2008, we noted that there were large gaps without any canopy while in Plot 1999, tree canopies segregating forming the main canopy but sunlight managed to penetrate through the gaps. In the field, Plot 1991 was a stand of 18-year old *pseudo*-plantation alike with homogenous stem diameter size, closed canopies and less undergrowth. At Plot NF, field observation found high density of trees less than 10 cm dbh which is a typical secondary forest which was naturally regenerating state.

2.6 Statistical Analysis

Independent Student T-Test Analysis was tested significant differences ($p \leq 0.05$) for dendrometric parameters namely the basal area, dbh and height among the study plots. The Pearson Correlation (λ^2) Analysis was used to establish a correlation for the diameter size classes among the study plots. Descriptive statistical analysis was also conducted for the dendrometric data to determine the skewness and the coefficient of variation (CV) of the data distribution using the SPSS software for window version 16.01.

Analysis of Variance (ANOVA) was used to compare significant differences of canopy openness (CO) value recorded from the quantitative analysis in all the study plots. Means CO of the study plot were compared and grouped using Tukey Range Test. The analysis was carried out using SAS Version 9.2 statistical package software.

3. Results and Discussion

The dendrometric analysis showed significant differences in the diameter size class, diameter, height and basal area. All study plots have more than 80% of trees concentrated in Diameter Size Class below 10 cm except for Plot 1991 (75%). The inverse-J curve indicates that the forest in all the study plots is in their process of the recovering [28] which has been reported in our paper. The mean basal area (m^2/plot) distribution among study plots were shown in Table 1. The Coefficient of Variation (CV) showed high variability in the dispersal around the mean basal area of 91-165% in the rehabilitated forest compared to 13% in natural regenerating secondary forest. This could indicate the competitive environment due to the high density planting where the trees showed high variability in their basal area performance.

The mean dbh (cm) distribution among the study plots are shown in Table 1. The rehabilitated forest recorded CV of 38-68%. The lowest was in the youngest rehabilitated forest indicating less variability in the dbh sizes. As for the 9- and 18-year old rehabilitated forests, the variability increases as the tree grow into different size classes over time. The natural regenerating secondary forest recorded CV of 163% reflect variability which indicate the forest is healthy and still in the process of natural recovering.

The mean height (m) distribution among the study plots are shown in Table 1. The CV recorded in the rehabilitated forest was 31-57% while natural regenerating secondary recorded 84%. The lower CV recorded for 9- and 18-year old rehabilitated forest reflect the generally the tree height were distributed near to mean and more homogenous. The high CV at the natural regenerating secondary forest reflects the diversity of the tree height which contributes to the forest canopy stratification.

Table 1
Characteristics of the forest structure in the respective study sites

Structural characteristics	2008	1999	1991	NF
Mean dbh (cm)*	0.8 (0.04-2.6)	6.0 (0.8-15.5)	8.2 (1.3-35.1)	3.2 (0.4-59.8)
Basal Area (m^2/0.04 ha)*	0.02	0.8	1.6	1.6
Mean height (m)*	0.5 (0.01-1.4)	6.2 (1.5-10.7)	9.3 (2.0-20.5)	4.0 (0.3-26.8)
Stand density (number/0.04 ha)*	321	227	205	546
Dominant species	*Sandoricum borneense*	*Dryobalanops beccarii*	*Shorea dasyphylla*	*Teijsmanniodendron halophyllum*
Forest stratification (%)				
Emergent (> 36 m)	-	-	-	-
Main canopy (25-36 m)	-	-	-	0.2
Understory (< 25 m)	100	100	100	99.8

*Data sourced from Kueh *et al*. [28]

The visual interpretation of the photographs showed that there are three stages of stand development, namely the gap, building and mature phase.

Gap phase: Figure 1a displayed large opening where it concentrated at the centre of the photograph. The large opening was due under-development of canopy of the seedlings as the age of the seedlings were just 1-year old after planting. These seedlings were short (with mean height of 0.5 m) and small diameter (with mean diameter of 0.8 cm) in size in Plot 2008. In rehabilitated forest, the canopy opening was determined by the stand structure development especially the dbh and height.

Building stage: Figure 1b displayed older gaps in healing phase. It can be observed that there were several small openings at the canopy. Trees had grown with a mean height of 6.2 m and began to develop aggregation of continuous canopy layer in Plot 1999. At this stage in a rehabilitated forest, the canopy development has reduced the gap as the forest stand develops. Standing trees play that important role and competing with each other for survival. However, in mature forest, seedlings found in the forest gaps will compete to fill up and colonize the emergent strata. According to Richard [29], at building stage seedlings grow into saplings grow and later into poles to colonize the gap. At this stage, fierce competition as termed by Kruk *et al*. [30] occurs where the regenerating plants compete for space and nutrient for survival.

Mature stage: Figure 1c displayed dense vegetation with high canopy and less canopy opening. Trees of 18-year old had mean height of 9.3 m tall with developed canopy filling up gaps in Plot 1991. On the other hand, Figure 1d displayed more diverse structural types of mature forest with dense vegetation stratification. Small gaps were dispersed over the rest of the hemisphere. Understory plants contributed to the multi strata forest at the Plot NF. At this stage also, the forest is entering a homeostatic phase [30] and the fittest trees survive after fierce competition during building phase.

The photographs in Figure 1 were re-examined using a quantitative approach by making use of calculated value of the canopy openness (CO). The CO (%) was highest in Plot 2008 of 78 % while the lowest was in Plot NF of 3 %. The distribution of mean CO (%) among all the study plots is shown in Figure 2. There were significant differences in the mean canopy openness among the different years of the stand structure development as represented by the study plots and grouped by using Tukey Range Test.

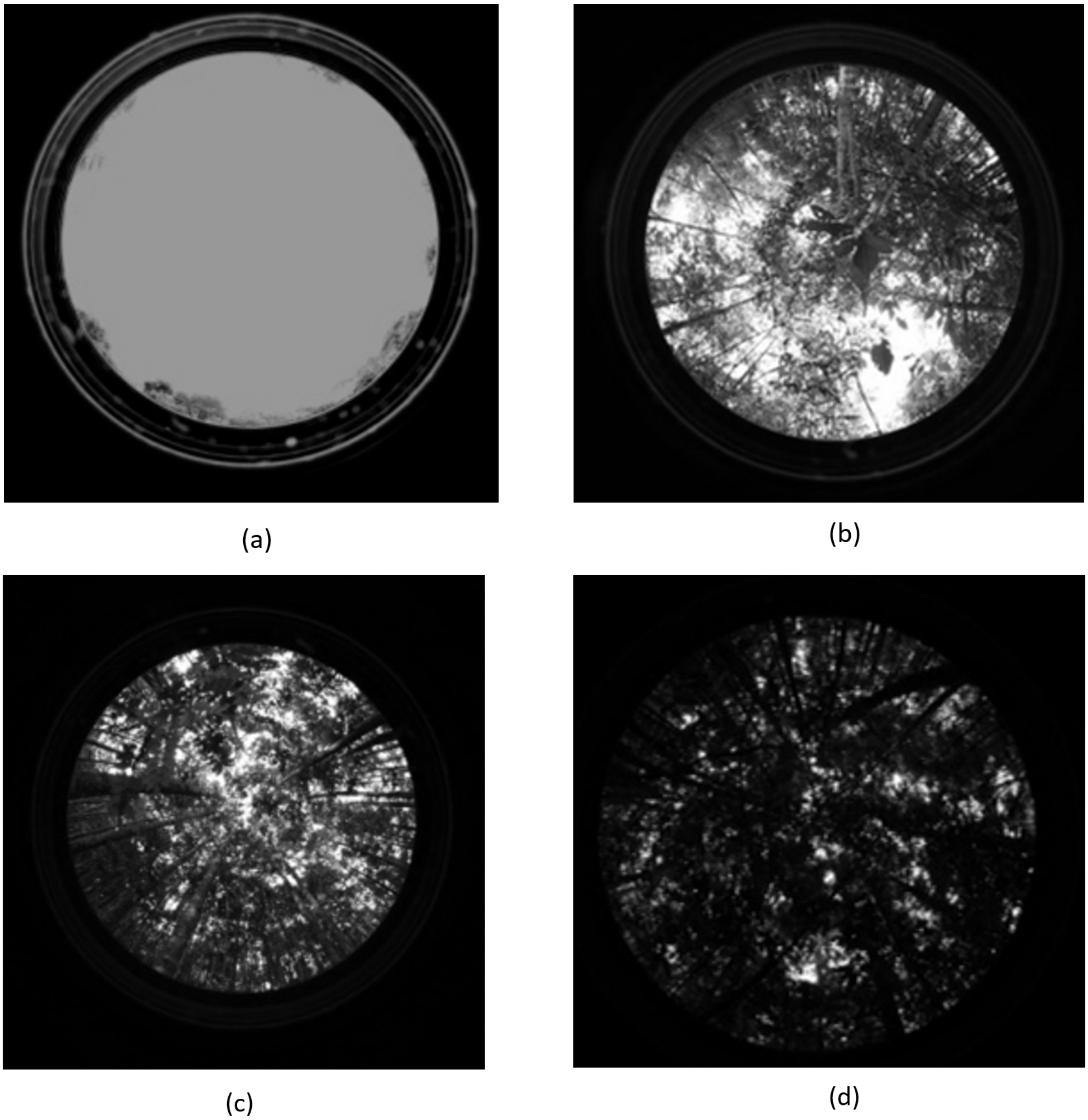
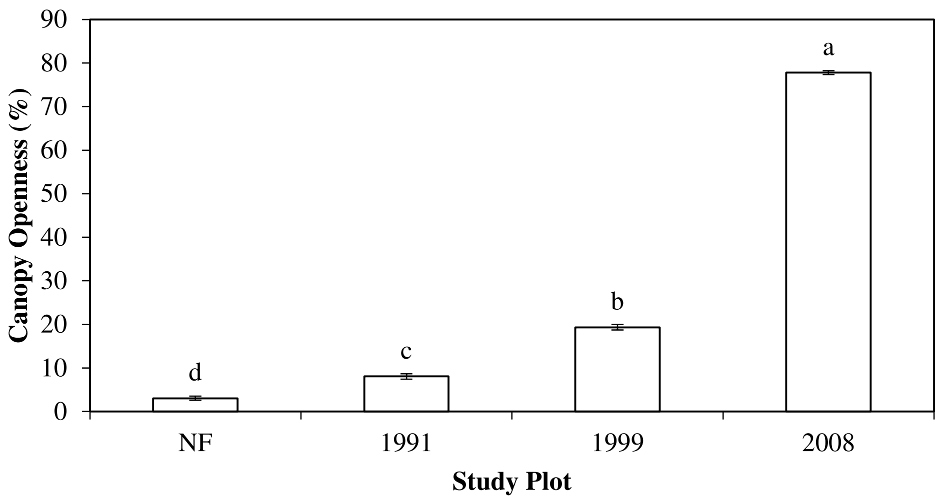


Fig. 1. Some examples of hemispherical photographs representing the different stages of recovery. Gap phase-(a) Plot 2008, Building phase-(b) Plot 1999, Mature stage-(c) Plot 1991 (d) Plot NF at UPMKB Sarawak, Malaysia

The CO is also a reflection of gap in the forest canopy. Based on analysis of the data obtained, Plot NF recorded CO ranging from 2-4 %. This reflected that the ± 22-year old natural regenerating secondary forest stand resemble a closed-forest or mature phase. As for the oldest rehabilitated forest stand of 18-year old in study Plot 1991 recorded CO ranging from 6-9%. The forest stand was between late building to mature phase. Plot 1999 recorded CO ranging from 16-23%. The 9-year old rehabilitated forest stand was at the building phase. Lastly, Plot 2008 recorded CO of 77-79 %. The stand development was still in the early stage and the area was still an open area. The Miyawaki's method to rehabilitate degraded forest area shows that forest stands has the capability to restore and develop canopy cover after 18 years as reflected in study Plot 1991.



Note: Similar alphabets are not significantly different at $p \geq 0.05$ using Tukey Range Test; S.E. means standard error

Fig. 2. Mean Canopy openness with standard error bar (% ± SE) (n=5) calculated from hemispherical photographs in Plots 2008, 1999, 1991 and NF at UPMKB

The statistical analyses of CO values provide some evidence of the differences among the study plots. These findings are discussed in light of the field experience and observation, photography observation and structural results obtained using dendrometric measurements. Based on the inventory report, the area consisted of small and short size stand where the lower mean height (0.5 m) contributed to the lower height (Table 1). These were still categorized as seedlings which has less developed canopy and contributed to the large gap. The Plot 2008 seedlings are still at the early stage of stand development. This resulted to the single forest stratification of understory strata only (less than 25 m in height). Smaller size of mean dbh (0.8 cm) would results in lowest basal area as compared to the other study plots. This leads to lower area coverage. The higher CO as reported through the hemispherical photograph analysis was recorded in Plot 2008 as compared to the other three study plots, clearly illustrating the large gap in the field. This was a 1-year old stand which was at an early stage of stand development.

Lower main canopy in Plot 1999 with mean height of 6.2 m is a typical characteristic of secondary forest. Larger mean dbh (6.00 cm) was recorded as compared to Plot 2008 which also resulted in higher basal area (Table 1). Fully developed canopies closed those gaps which resulted in a significant lower CO as compared to Plot 2008. This was a 9-year old stand which was at the building stage of stand development. Bigger mean dbh size (8.2 cm) with taller mean canopy height (9.3 m) and total basal area (1.6 m^2/0.04 ha) were recorded in Plot 1991 (Table 1). This resulted in a significantly lower CO in comparison with Plots 1999 and 2008. This was an 18-year old stand which was at the late building to mature phase stage of stand development. Despite having smaller and shorter tree mean in Plot NF, this study plots also had the tallest (26.8 m) and biggest (59.8 cm) trees (Table 1). These contributed to the understory and main canopy strata in the forest stratification. Multilayer of stratum reduces the gaps and this study plots recorded the lowest CO among all the study plots. This was a ± 22-year old natural regenerating secondary forest which was at the mature phase of stand development.

The dendrometeric and hemispherical photographs analysis with field observation are complementary methods to assess forest structure especially the canopy openness. The former method concentrated of measurement of stems which was more time consuming while the later on the photographic and phyto-element above 1.3 m which is quicker method. This helps to reduce time spent in the field and increase efficiency in data collection and analysis. Hemispherical photographs provided addition information to the conventional inventory information such as dbh, height and basal area. Incorporating all this information can provide a better understanding especially the relationship between both dendrometeric and hemispherical photographs of which is still lacking especially in rehabilitated forest. Such information can provide a platform for the assessment on the forest stand development status.

4. Conclusion

Rapid analysis of canopy openness on the hemispherical photographs with information from the dendrometric measurement had assisted in assessing the forest structure that provided an indication on the forest canopy recovery of the rehabilitated forest. The canopy openness was dependent on the age of the rehabilitated forest. Despite their structural differences among the study plots, information on canopy openness also provided some guide in the recovery status. Overall, the study plots are in the different stages of recovery from the aspects of structural characteristics.

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References

[1] T.C. Whitmore. Gaps in the forest canopy. In Tomlinson, P.B. and Zimmermann, M.H. (Eds.). Tropical trees as living systems. Cambridge University Press, 639-655, (1978).

[2] Brown, Nick. "The implications of climate and gap microclimate for seedling growth conditions in a Bornean lowland rain forest." *Journal of Tropical Ecology* 9, no. 2 (1993): 153-168.

[3] Montgomery, Rebecca A. "Effects of Understory Foliage on Patterns of Light Attenuation near the Forest Floor." *Biotropica* 36, no. 1 (2004): 33-39.

[4] Numata, Shinya, Masatoshi Yasuda, Toshinori Okuda, Naoki Kachi, and Muhammad Nor Nur Supardi. "Canopy gap dynamics of two different forest stands in a Malaysian lowland rain forest." *Journal of Tropical Forest Science* (2006): 109-116.

[5] Newton, Adrian. *Forest ecology and conservation: a handbook of techniques*. Oxford University Press on Demand, 2007.

[6] Johns, Andrew Grieser. *Timber production and biodiversity conservation in tropical rain forests*. Cambridge University Press, 1997.

[7] Whitmore, T. C., N. D. Brown, M. D. Swaine, D. Kennedy, C. I. Goodwin-Bailey, and W-K. Gong. "Use of hemispherical photographs in forest ecology: measurement of gap size and radiation totals in a Bornean tropical rain forest." *Journal of Tropical Ecology* 9, no. 2 (1993): 131-151.
[8] Nadkarni, Nalini M., Geoffrey G. Parker, and Margaret D. Lowman. "Forest canopy studies as an emerging field of science." *Annals of Forest Science* 68, no. 2 (2011): 217.
[9] Hale, Sophie E., and Colin Edwards. "Comparison of film and digital hemispherical photography across a wide range of canopy densities." *Agricultural and Forest Meteorology* 112, no. 1 (2002): 51-56.
[10] Hu, Lile, Zhiwen Gong, Junsheng Li, and Jiaojun Zhu. "Estimation of canopy gap size and gap shape using a hemispherical photograph." *Trees* 23, no. 5 (2009): 1101-1108.
[11] Guevara-Escobar, A., J. Tellez, and E. Gonzalez-Sosa. "Use of digital photography for analysis of canopy closure." *Agroforestry Systems* 65, no. 3 (2005): 175-185.
[12] Paletto, Alessandro, and Vittorio Tosi. "Forest canopy cover and canopy closure: comparison of assessment techniques." *European Journal of Forest Research* 128, no. 3 (2009): 265-272.
[13] Fassnacht, Karin S., Stith T. Gower, John M. Norman, and Ross E. McMurtric. "A comparison of optical and direct methods for estimating foliage surface area index in forests." *Agricultural and Forest Meteorology* 71, no. 1-2 (1994): 183-207.
[14] Awal, M. A., WI Wan Ishak, and S. M. Bockari-Gevao. "Determination of leaf area index for oil palm plantation using hemispherical photography technique." *Pertanika Journal of Science and Technology* 18 (2010): 23-32.
[15] Woodgate, William, John D. Armston, Mathias Disney, Simon D. Jones, Lola Suarez, Michael J. Hill, Phil Wilkes, and Mariela Soto-Berelov. "Quantifying the impact of woody material on leaf area index estimation from hemispherical photography using 3D canopy simulations." *Agricultural and Forest Meteorology* 226 (2016): 1-12.
[16] O'Brien, Renee A. "Comparison of overstory canopy cover estimates on forest survey plots." *Research paper INT-US Department of Agriculture* (1989).
[17] Bechtold, William A., Manfred E. Mielke, and Stanley J. Zarnoch. "Comparison of field methods and models to estimate mean crown diameter." *Northern Journal of Applied Forestry* 19, no. 4 (2002): 177-182.
[18] Morrison, Michael L., Bruce Marcot, and William Mannan. *Wildlife-habitat relationships: concepts and applications*. Island Press, 2012.
[19] Zorer, R., C. G. Volschenk, and J. J. Hunter. "Integrating Geographic Information Systems and hemispherical photography in the assessment of canopy light profiles in a vineyard." *Agricultural and Forest Meteorology* 232 (2017): 672-681.
[20] Jelaska, Sven D. "Analysis of canopy closure in the Dinaric silver fir-beech forests (Omphalodo-Fagetum) in Croatia using hemispherical photography." *Hacquetia* 3, no. 2 (2004): 43-49.
[21] Souza, Alexandre F., and Fernando R. Martins. "Spatial variation and dynamics of flooding, canopy openness, and structure in a Neotropical swamp forest." *Plant Ecology* 180, no. 2 (2005): 161-173.
[22] Dietz, Johannes, Dirk Hölscher, Christoph Leuschner, Adam Malik, and M. Amran Amir. "Forest structure as influenced by different types of community forestry in a lower montane rainforest of Central Sulawesi, Indonesia." *Stability of Tropical Rainforest Margins* (2007): 131-146.
[23] Leblanc, Sylvain G., and Richard A. Fournier. "Measurement of forest structure with hemispherical photography." In *Hemispherical Photography in Forest Science: Theory, Methods, Applications*, pp. 53-83. Springer Netherlands, 2017.
[24] Fournier, Richard A., and Ronald J. Hall. "Hemispherical Photography in Forest Science: Conclusions, Applications, Limitations, and Implementation Perspectives." In *Hemispherical Photography in Forest Science: Theory, Methods, Applications*, pp. 287-302. Springer Netherlands, 2017.
[25] Jansson, Joakim. "Rehabilitation in a tropical secondary rain forest in Malaysian Borneo." (2015).
[26] Peli, Mat. "Report and map of the detailed soil survey of UPM Farm, Bintulu Campus, Sarawak." *UPM Sarawak Campus Technical Paper* 1 (1984).
[27] Trichon, Valérie, Jean-Michel N. Walter, and Yves Laumonier. "Identifying spatial patterns in the tropical rain forest structure using hemispherical photographs." *Plant Ecology* 137, no. 2 (1998): 227-244.
[28] Heng, Roland Kueh Jui, Nik Muhamad Ab. Majid, Seca Gandaseca, Osumanu H. Ahmed, Silvester Jemat, and Melvin KK Kin. "Forest structure assessment of a rehabilitated forest." *American Journal of Agricultural and Biological Science* (2011).
[29] Richards, Paul Westmacott. *The tropical rain forest; an ecological study*. At The University Press; Cambridge, 1952.
[30] Remke, Kruk, Marius Jacobs and Roelof A.A. Oldeman. The tropical rain forest: a first encounter. Springer-Verlag (1988).