JOURNAL OF TROPICAL BIOLOGY AND CONSERVATION 9(1) : 83 – 95, 2012

Research Article

Assessment of micrometeorology at selected age stands in a rehabilitated forest of Sarawak, Malaysia

Roland Kueh Jui Heng[1*], Nik Muhamad Abd. Majid[2], Seca Gandaseca[1], Osumanu Haruna Ahmed[1], Silvester Jemat[1] and Melvin Ku Kin Kin[1]

*[1]Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, Jalan Nyabau, 97008 Bintulu, Sarawak, Malaysia. *email:roland@btu.upm.edu.my*

[2]Faculty of Forestry, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.

ABSTRACT. The micrometeorological varies vertically and horizontally from the forest canopy to forest floor. An assessment of the forest micrometeorological is necessary to understand the interaction between the environment and biological activities, but such information is lacking in rehabilitated forests.The objective of this study was to assess the forest floor micrometeorology of selected age stands at a forest rehabilitation project.The study was conducted at a rehabilitated forest in Universiti Putra Malaysia Bintulu Sarawak Campus, Sarawak, Malaysia. Three study plots at (1, 10, 19-year-old) at the rehabilitated forest sites and a study plot at a natural regenerating secondary forest (± 23-year-old) were established. Davis Vantage Pro2 Weather Station was used to monitor and record micrometeorological variables (i) air temperature (°C), (ii) relative humidity (%), (iii) heat index (°C) and (iv) solar radiation (W/m^2). Data analyses showed that the micrometeorology inside forests is less extreme and more humid as compared to outside the forests. The micrometeorology among different age stands of rehabilitated forests varies and different which is unique in each study plots as compared to the outside forest. Older rehabilitated forest and natural regenerating secondary forest has less extreme micrometeorological condition as compared to outside forest. The study suggested that the development of the canopy and its layers influence the micrometeorological condition of the forest. The rehabilitated forest has yet to recover in the aspect of the micrometeorology.

Keywords: Micrometeorology, air temperature, relative humidity, heat index, solar radiation, forest rehabilitation.

INTRODUCTION

In general, both micrometeorology and microclimatology measure the average of variables such as temperature and light intensity at different time length. The former deals with short-term average micrometeorology variables while the later deals with long term average. The data collected in this study covers only one year monitoring of those variables. Therefore, the term micrometeorology was more appropriate in this context of this paper. Most literature report on the study of microclimate rather than on micrometeorology. The term microclimate would still be used to cite previous work.

Microclimate of the tropical rain forest varies vertically from the canopy to forest floor and horizontally from point to point beneath the canopy. It also varies between gap size,

Received 16 August 2011. Revision accepted 15 October 2011

between building and mature phase and between different forest types (Walsh, 1996). The distribution of light intensity affects other variables such as temperature, relative humidity and also the amount of energy available for the production and the timing of seasonal cycles of flora and fauna in the forest (Brower *et al.*, 1990; Brown, 1993; Walsh, 1996). These distributions in a canopy gap are strongly dependent on the size of the gap. Ashton (1992) reviewed that among the causes of these disturbances are single and multiple tree falls from wind, lightning strikes and pathological and entomological outbreaks that affect canopy trees. The larger tree gap has the greater the amount of solar radiation that can reach the forest floor. For this reason, the different sizes of gaps may have different microclimatic conditions (Brown, 1993).

It is also known that tropical rainforests are characterized by complex canopy structures and therefore, considerable differences exist in abiotic factors (such as light, humidity, temperature, heat index and wind velocity) in the canopy space (Walsh, 1996; Kumagai *et al.*, 2001). Kumagai *et al.* (2001) reviewed that these differences and variation within the forest stands determine greater differences of many biological activities such as photosynthesis (Carswell *et al.,* 2000), transpiration (Meinzer *et al.,*1997), growth, productivity (Longman & Jenik, 1981) and species composition (Koike & Hotta, 1996) from the upper canopy to the forest floor. Space utilization by different species in tropical rainforests is influenced by the spatial differences of abotic factors in the forest canopy (Whitmore, 2006). Therefore, measurements profiles of the microclimate factors of a forest are necessary in order to understand and evaluate biological activities in the tropical forest environment.

The importance of in-canopy microclimate data in tropical forests is reported by several researchers such as Aoki *et al.* (1978), Thompson & Pinker (1975), Longman & Jenik (1981), Shuttleworth *et al.* (1985), Ashton (1992), Cabral *et al.*(1996), Kumagai *et al.* (2001) and Ahmad & Salleh (1999). Kumagai *et al.* (2001) reported that the in-canopy environments of tropical rainforests of Southeast Asia have been poorly documented, with few existing published data on the environment within a canopy in the tropical rainforest of Borneo.

In addition to that, other forest types like rehabilitated forests lack microclimate information to fully understand the interaction between the environment and biological activities. Information on the forest floor micrometeorology can also provide an indication on the status of the recovery of the forest. The method to rehabilitate the degraded forest at the study site used the accelerating regeneration method, or Miyawaki's Method (Miyawaki, 1999). This method applied high density planting of three indigenous seedlings per square metre at the Universiti Putra Malaysia Bintulu Sarawak Campus, Sarawak, Malaysia. The objective of this study was to assess the forest floor micrometeorology of selected age stands at a forest rehabilitation project.

MATERIALS AND METHODS

Study Sites

The study was conducted at the UPM-Mitsubishi Corporation Forest Rehabilitation Project at Universiti Putra Malaysia, Bintulu Sarawak Campus, Sarawak, Malaysia. It is located about 600 kilometres northeast of Kuching (Latitude 03°12'N, Longitude 113°02'E) and 50 above sea level. Research plots of 20 x 20 m size were established at stand of a 19-year-old (Plot 1991), 10-year-old (Plot 1999), and 1-year-old (Plot 2008) (Figure 1). For the purpose of comparison, a plot was established at the adjacent natural regenerating secondary forest at Bukit Nyabau (± 23-year-old; Plot NF). Prior to the establishment of the campus in 1997, Plot NF was a logging area. Since then, the forest regenerated naturally and all anthropogenic activities ceased. The key structural characteristics of these study plots are as shown in Table 1.

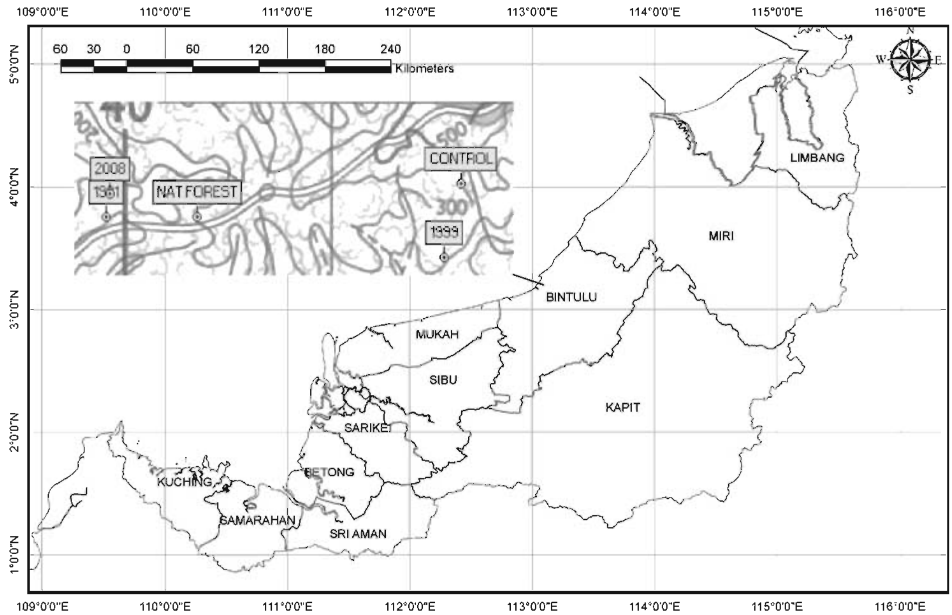

Figure 1. The locations of study plots and control weather station (enlargement at 1: 26,316) at the Universiti Putra Malaysia Bintulu Sarawak Campus, Sarawak, Malaysia.

Table 1. Structural characteristic of the forest in the study plots.

Structural Characteristics	Plot 2008	Plot 1999	Plot 1991	Plot NF
Mean dbh (cm)	0.76	6.00	8.16	3.24
Basal Area (m^2/0.04 ha)	0.02	0.80	1.56	1.64
Mean height (m)	0.46	6.15	9.30	4.02
Stand density (number of tree/0.04 ha)	321	227	205	546
Canopy Openness (%)	78	19	8	3
Dominant species	*Sandoricum borneense*	*Drybalanops beccarii*	*Shorea dasyphylla*	*Teijsmanniodendron holophyllum*
Forest stratification (%)				
Emergent (> 36m)	-	-	-	-
Main canopy (25-36m)	-	-	-	0.2
Understory (< 25 m)	100	100	100	99.8

A report by Roland *et al.* (2011) on the study site found that the older rehabilitated forest at Plot 1991 showed better performance in structural characteristics, mainly the mean basal area (61%), mean dbh (56%) and mean height (60%) of the trees as compared to the adjacent natural regenerating secondary forest. The stand development at the older rehabilitated forest had accelerated, affecting the forest canopy development, hence canopy openness (CO). Hemispherical photographs were used to assess the canopy openness. The study sites showed wide variations from 3 to 78% of CO as shown in Table 1.

Forest stratification based on Golley (1983) showed that the natural regenerating secondary forest had two layers, namely the main canopy and understory. All rehabilitated forest have monolayer of understory (Table 1). This information provided an indication that all the study areas had yet to recover in terms of their forest stratification. Whitmore (1984, 2006) reported the influence of canopy development and forest stratification on the variation of micro-environment, especially microclimate variations.

Data Collection

In this study, Davis Vantage Pro2 Weather Station was used to monitor and record micrometeorology variables namely:

(i) Air temperature (°C)
(ii) Solar radiation (W/m^2)
(iii) Relative humidity (%)
(iv) Heat index (°C) using temperature and the relative humidity to determine how hot the air actually feels. By using the WeatherLink software versions 5.2 and Vantage Pro2 in the Davis Vantage Pro2 Weather Station, the software calculates heat index. The formula is based on the lookup table presented by Steadman (1979) as reported by Davis Instruments (2011).

Measurements were recorded at the height of 1.5 m at intervals of 30 minutes in a day over 60 days throughout the study period. A control weather station was established in an open area at the adjacent study sites and another in the study plots (Figure 1) which recorded data simultaneously from 29 July 2010 to 28 July 2011 (Table 2). Simultaneous recording of data in all the study plots was not possible due to inadequate number of equipment. Therefore, only simultaneous monitoring between study plots and the control station was possible and reported in this paper.

Data Analysis

Comparisons were made between the study plots on micrometeorology variables using Analysis of Variance (ANOVA). All significant differences of means were grouped using Duncan New Multiple Range Test (DNMRT). All statistical analyses were carried out using SAS Version 9.2 statistical package software.

RESULTS AND DISCUSSION

In this study, comparison of micrometeorology of selected age forest stands and outside forest was monitored. Generally, the comparison of mean value of each variable, namely air temperature, relative humidity, heat index and solar radiation between inside forests and outside forests showed that there were significant differences between both sites.

The 60-day mean air temperature at each hour of the day at areas under forest was 1.1 to 4.3% lower as compared to outside a forest (Table 3).The distribution of hourly mean air temperature of the day over 60 days when compared to areas under forest and outside forests is shown in Figure 2. Inside forest mean air temperature peak from 30.7 to 31.3°C as compared to the outside forest which recorded 32.0 to 32.5°C. Lower minimum mean air temperature was recorded inside the forest with a range of 23.7-24.0°C as compared to 24.5-24.8°C outside the forest. Lower mean temperature recorded at the older rehabilitated forest and natural regenerating secondary forest as compared to the Control Weather Station was due to the more mature stage of canopy development where smaller canopy openness (CO) was recorded at 8-19% (Table 1). This forest canopy acts to reduce solar radiation reaching the forest floor and also to regulate extreme air temperature. For young rehabilitated forests without fully developed canopy layers, this forest was unable to regulate temperature during the observation period. The forest floor rather than the forest canopy is the main heating and radiation surface.

The heating of air temperature was due to direct solar radiation from large gaps, while during the night, the canopy layer prevented energy from being radiated out of the atmosphere. Brown (1993) reported that at forest gap of 3.8%, the mean temperature ranged from 21.2 to 28.4°C while at 17.8%, mean temperature ranged from 21.3 to 34.6°C. The results were also consistent with findings by Ahmad & Salleh (1999), where they found that the UPM Meteorological Station, Selangor, Malaysia had higher mean hourly air temperature (31.3°C) and recorded higher maximum (31.3°C) and lower minimum (22.1°C) compared to the Ayer Hitam secondary forest, Selangor, Malaysia (mean: 27.7°C; range: 22.9-27.7°C), while Ashton (1992) found that gap temperature can reach as high as 34°C in a Sri Lankan tropical rainforest. This suggested that forest cover plays an important role in lowering the mean air temperature and creates a cooler forest floor as compared to outside the forest. This is consistent with the report by Kruk *et al.* (1988) that recorded relatively lower air temperature inside forests at a range of 7-10°C lower than in an open area.

However, the mean relative humidity inside a forest was significantly higher as compared to outside the forest. The 60-day mean relative humidity at each hour of the day was1.4 to 2.4% higher than outside the forest. The hourly distribution of mean relative humidity of the day over 60 days is shown in Figure 3. Inside the forest, the mean relative humidity was higher of 96.5 to 97.0% as

Table 2. The period of simultaneous monitoring between the study plots and Control Weather Station.

No	Plot	Date of Monitoring	Total Days of Record
1	2008	29th July – 30th July, 2010; 2nd August-6th August, 2010 23rd-24th October, 2010; 30th October, 2010 1st -4th November, 2010; 5th -9th December, 2010 20th -21st December, 2010; 12th -18th January, 2011 1st -6th March, 2011; 28th -31st March, 2011 1st -3rd April, 2011; 25th -30th April, 2011 1st May, 2011; 23rd -29th May, 2011 20th -23rd June, 2011; 28th February– 6th March, 2011 28th March – 3rd April, 2011; 25th April-1st May, 2011 23rd -29th May, 2011; 20th -26th June, 2011	60
2	1999	27th August – 2nd September, 2010 28th November-4th December, 2010 5th -11th January, 2011; 21st -27th February, 2011 21st -27th March, 2011; 18th -24th April, 2011 16th -22nd May, 2011; 13th -19th June, 2011 11th -14th July, 2011	60
3	1991	8th – 14th August,2010; 21st -27th November, 2010 29th December, 2010-4th January, 2011 14th -20th February, 2011; 14th -20th March, 2011 11th -17th April, 2011; 9th -15th May, 2011 6th -12th June, 2011; 4th -7th July, 2011	60
4	NF	17th – 26th August, 2010; 15th -21st November, 2010 22nd -28th December, 2010; 7th -13th March, 2011 4th -10th April, 2011; 2nd -8th May, 2011 30th May-5th June, 2011; 27th June-3rd July, 2011 25th -28th July, 2011	60

compared to outside the forest of 94.7-96.2%. The older rehabilitated forest and natural regenerating secondary forest recorded higher mean relative humidity as compared to the Control Weather Station. The forest cover acts to maintain higher relative humidity rather than those without forest cover. In relation to this, a study by Ahmad & Salleh (1999) found that the hourly mean relative humidity was higher inside the forest area as compared to outside the forest.The inside forest of Ayer Hitam Forest Reserve, Selangor, Malaysia recorded mean relative humidity of 87.6% in contrast to an open area at the UPM Meteorological Station, Selangor, Malaysia was 80.1%. Less developed forest canopy as in young rehabilitated forest where it has a large opening has a similar mean relative humidity as compared to the Control Weather Station. This was consistent with findings reported by Whitmore (2006) that in a big gap the recorded mean minimum relative humidity was 52% but higher in a closed forest with 85%.

Table 3. Comparison of mean air temperature, relative humidity, heat index and solar radiation between study plots and control station.

Parameters		Plot	Control Station
Mean Air Temperature (°C ± S.E.)	1991	$27.0^{b} \pm 0.06$	$27.8^{a} \pm 0.06$
	1999	$26.9^{b} \pm 0.06$	$27.9^{a} \pm 0.06$
	2008	$28.0^{a} \pm 0.06$	$27.7^{b} \pm 0.06$
	NF	$26.7^{b} \pm 0.05$	$27.0^{a} \pm 0.06$
Mean Relative Humidity (% ± S.E.)	1991	$85.9^{a} \pm 0.22$	$84.7^{b} \pm 0.22$
	1999	$86.3^{a} \pm 0.21$	$84.4^{b} \pm 0.22$
	2008	$83.3^{b} \pm 0.21$	$84.4^{a} \pm 0.22$
	NF	$86.5^{a} \pm 0.22$	$84.4^{a} \pm 0.22$
Mean Heat Index (°C ± S.E.)	1991	$30.9^{b} \pm 0.09$	$32.5^{a} \pm 0.10$
	1999	$30.8^{b} \pm 0.09$	$32.6^{a} \pm 0.10$
	2008	$32.8^{a} \pm 0.10$	$32.5^{b} \pm 0.10$
	NF	$30.5^{a} \pm 0.09$	$32.6^{a} \pm 0.10$
Mean Solar Radiation (W/m^2 ± S.E.)	1991	$6.8^{b} \pm 4.67$	$149.6^{a} \pm 0.21$
	1999	$12.8^{b} \pm 0.39$	$156.2^{a} \pm 4.71$
	2008	$147.2^{a} \pm 4.58$	$143.4^{b} \pm 4.58$
	NF	$4.1^{b} \pm 0.14$	$147.8^{a} \pm 4.67$

Note: Within row having similar alphabets are not significantly different at $p \geqslant 0.05$ using Duncan New Multiple Range Test; S.E. means standard error.

Effect of the Heat Index

27–32 °C: Caution — fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps

32–41 °C: Extreme caution —heat cramps, and heat exhaustion are possible. Continuing activity could result in heat stroke

41–54 °C: Danger —heat cramps, and heat exhaustion are likely; heat stroke is probable with continued activity

Over 54°C: Extreme danger—heat stroke is imminent

Source: United States National Weather Service (2010). Heat index Available at: http://www.crh.noaa.gov/pub/heat.php

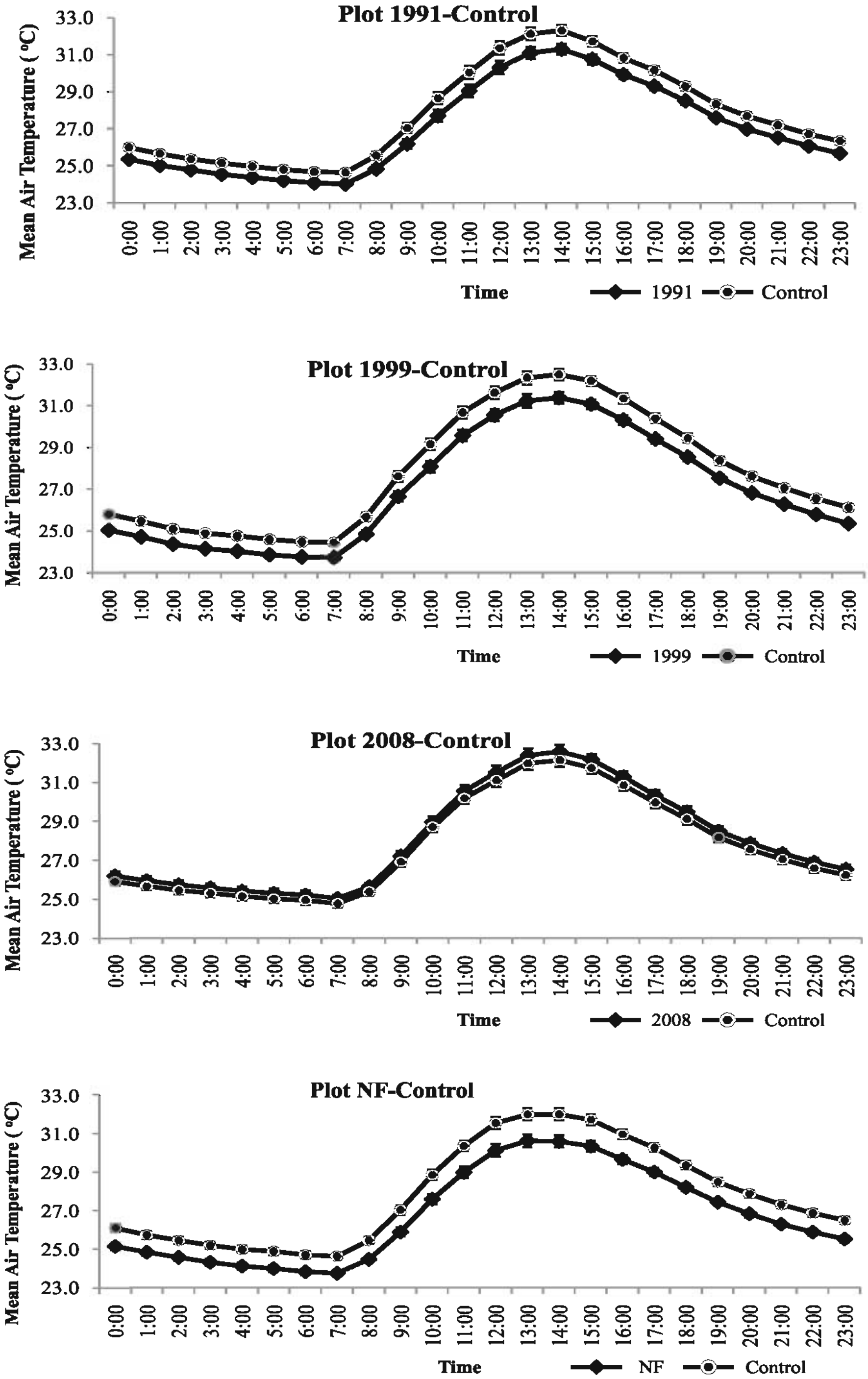

Figure 2. The 60-day mean air temperature (°C ± S.E.) at each hour of the day between study plots and control station.

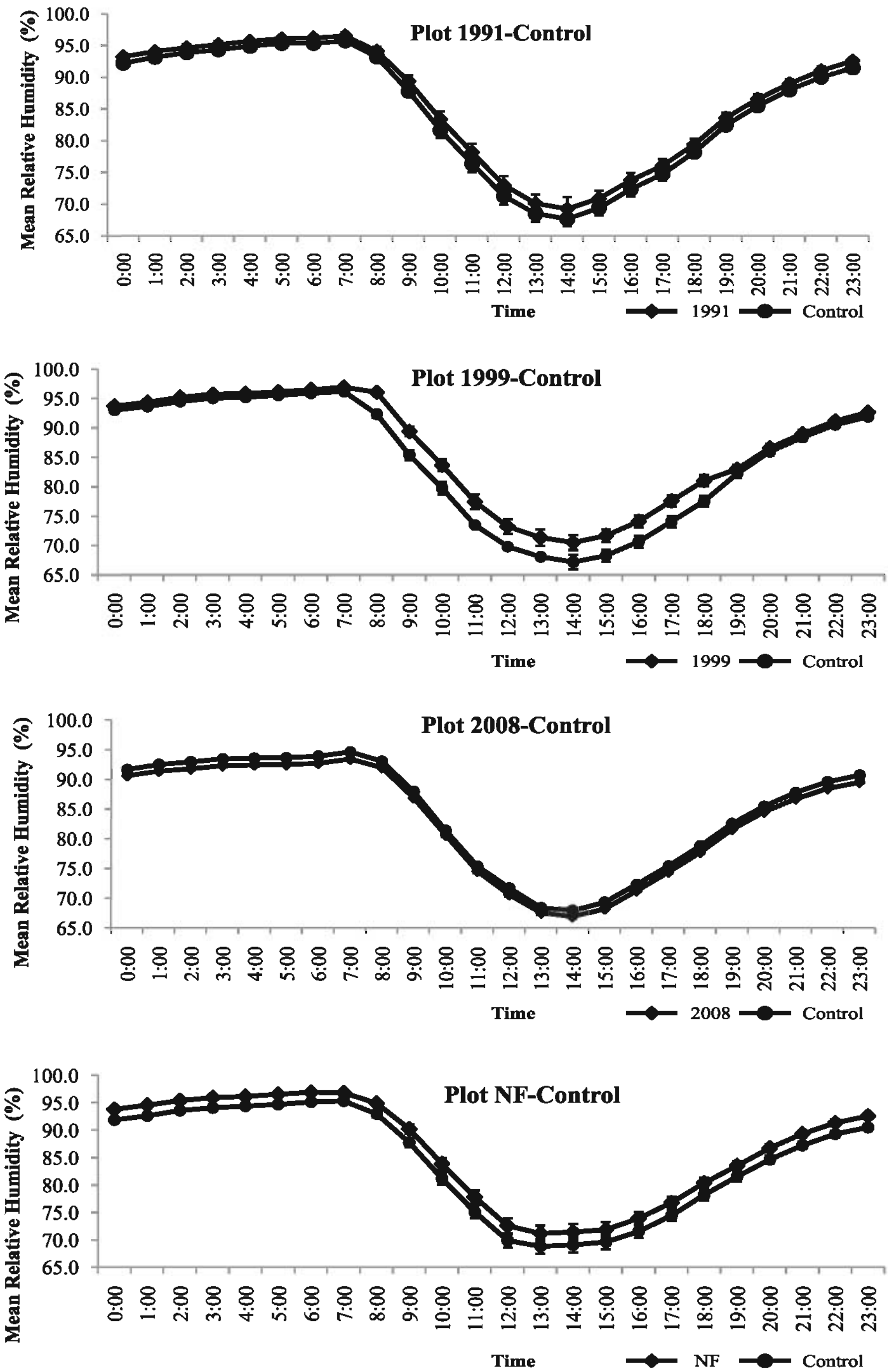

Figure 3. The 60-day mean relative humidity (% ± S.E.) at each hour of the day between study plots and control station.

With the variation in the recorded mean air temperature and mean relative humidity, heat index was recorded lower inside the forest as compared to outside the forest. The recorded 60-day mean heat index at each hour of the day for inside the forest was 5.2 to 6.4% lower as compared to outside the forest. The hourly variation of mean heat index of the day over 60 days is shown in Figure 4.The outside forest recorded higher peak mean heat index of 39.9-40.5°C as compared to inside the forest of 37.0-38.1°C. Whereas, lower minimum mean heat index of 37.0-38.1°C was recorded inside the forest as compared to 39.8-40.5°C outside the forest.

Forest canopies in older rehabilitated forests as in Plot 1991 and 1999 and natural regenerating secondary forest had regulated the air temperature and relative humidity to maintain a favourable mean heat index as compared to a more open area. Less developed forest canopy in young rehabilitated forests showed similarity value as in the open area. Based on the results, higher mean heat index (>32°C) in younger rehabilitated forest (Table 3) with large canopy opening and Control Weather Station indicated that extreme caution should be taken as it could lead to heat stroke on humans and possibly wildlife and plants under stress as compared to older rehabilitated forests. At the forest floor of natural regenerating secondary forests and older rehabilitated forests, less heat stress occurred with less temperature extremes and more humid compared to outside the forest.

Under the forest canopy cover, the inside forest recorded significant lower solar radiation intensity at the forest floor as compared to outside the forest. The 60-day mean solar radiation at each hour of the day for the inside forest was 91.8-97.2% lower as compared to the outside forest.The hourly variation of solar radiation of the day over 60 days is shown in Figure 5.The inside forest recorded lower peak mean solar radiation of 16.6-50.5 W/m^2 as compared to outside the forest of 582.7-615.6 W/m^2. The formation of canopy layers influences the solar radiation at the forest floor at all the study plots. This is consistent with Walsh (1996) who reported that at Pasoh forest, Negeri Sembilan, Malaysia, 60% of the incoming solar radiation was absorbed by the uppermost 5 metres of the forest canopy and 3.2% reached the forest floor.

As the forest canopy at a younger age rehabilitated forest has yet to fully develop with a larger gap (Table 1) and lesser canopy layer to filter light incidence at the forest floor, it leads to large light incidence which is comparable to an open area. The differences in the forest structure especially the canopy development would affect the solar radiation intensity. Walsh (1996) reported that the forest canopy and its spatial pattern of gaps, building and mature phases are responsible for most of the variation under the forest canopy. Incoming light intensity in the forest floor was only a small fraction especially in a virgin forest like Pasoh forest, Negeri Sembilan, Malaysia which recorded only 0.4 and 3.2% (Yoda, 1978; Aoki *et al.*, 1978) and Lambir forest, Sarawak, Malaysia at 5% (Kumagai *et al.*, 2001).

It could be noted that the young rehabilitated forest with less cover as Plot 2008 showed close reading value to the Control Weather Station. Based on the hourly monitoring in the day over 60 days, mean air temperature was 1.1% higher, higher mean index (0.9%) and higher solar radiation (2.6%) while lower relative humidity of 1.3%. The lack of forest cover substantiates the important role of the canopy cover of the forest that actually regulates and moderates the micrometeorology beneath the forest cover. The reading recorded in young rehabilitated forests showed significant differences as compared to outside the forest which indicates every study plot has their own unique micrometeorological variations.

The different stages of stand development as reflected by the different age stand of the rehabilitated forest affects the micrometeorological condition. Older rehabilitated forests and natural regenerating secondary forests with a developed forest

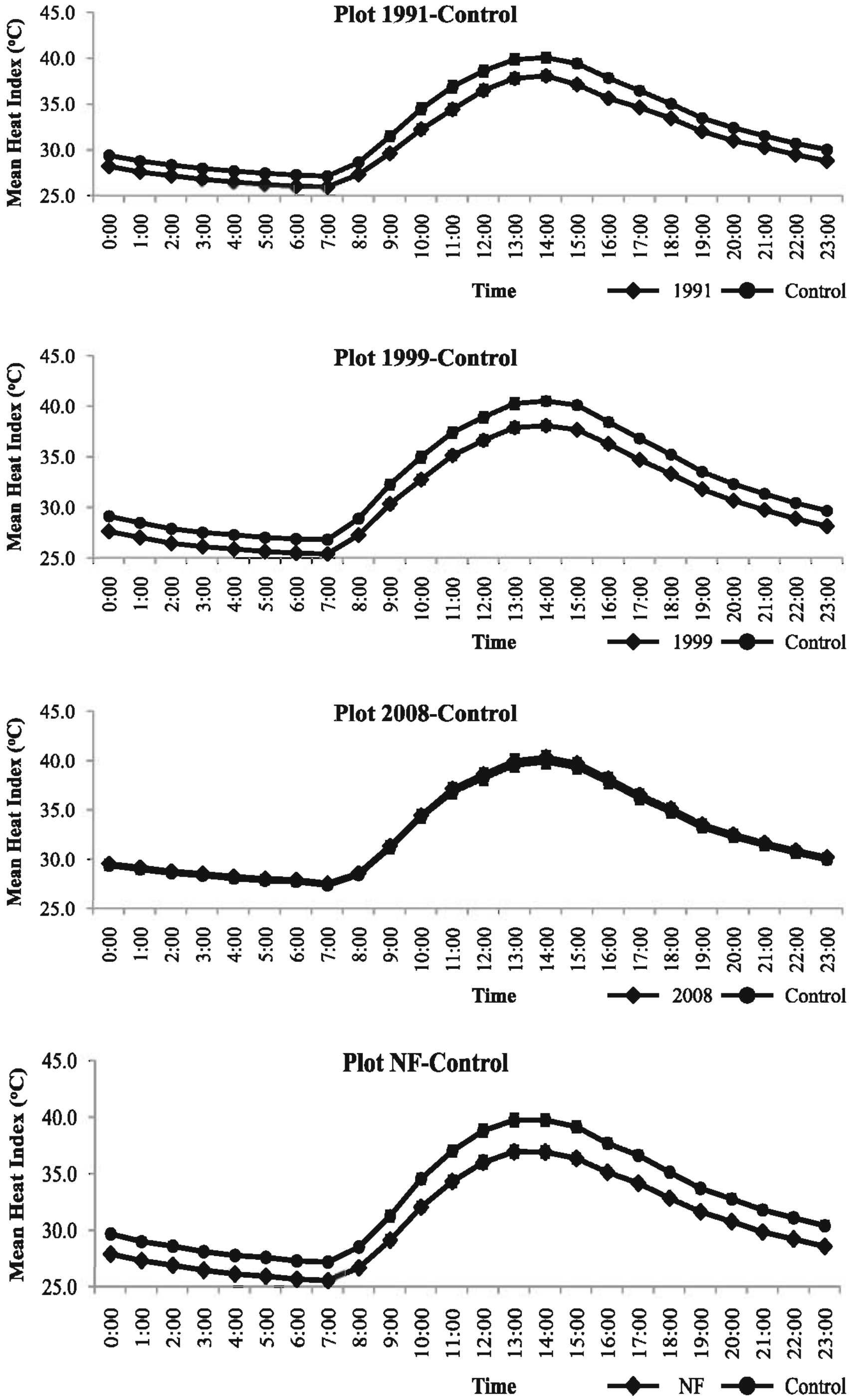

Figure 4. The 60-day mean heat index (°C ± S.E.) at each hour of the day between study plots and control station.

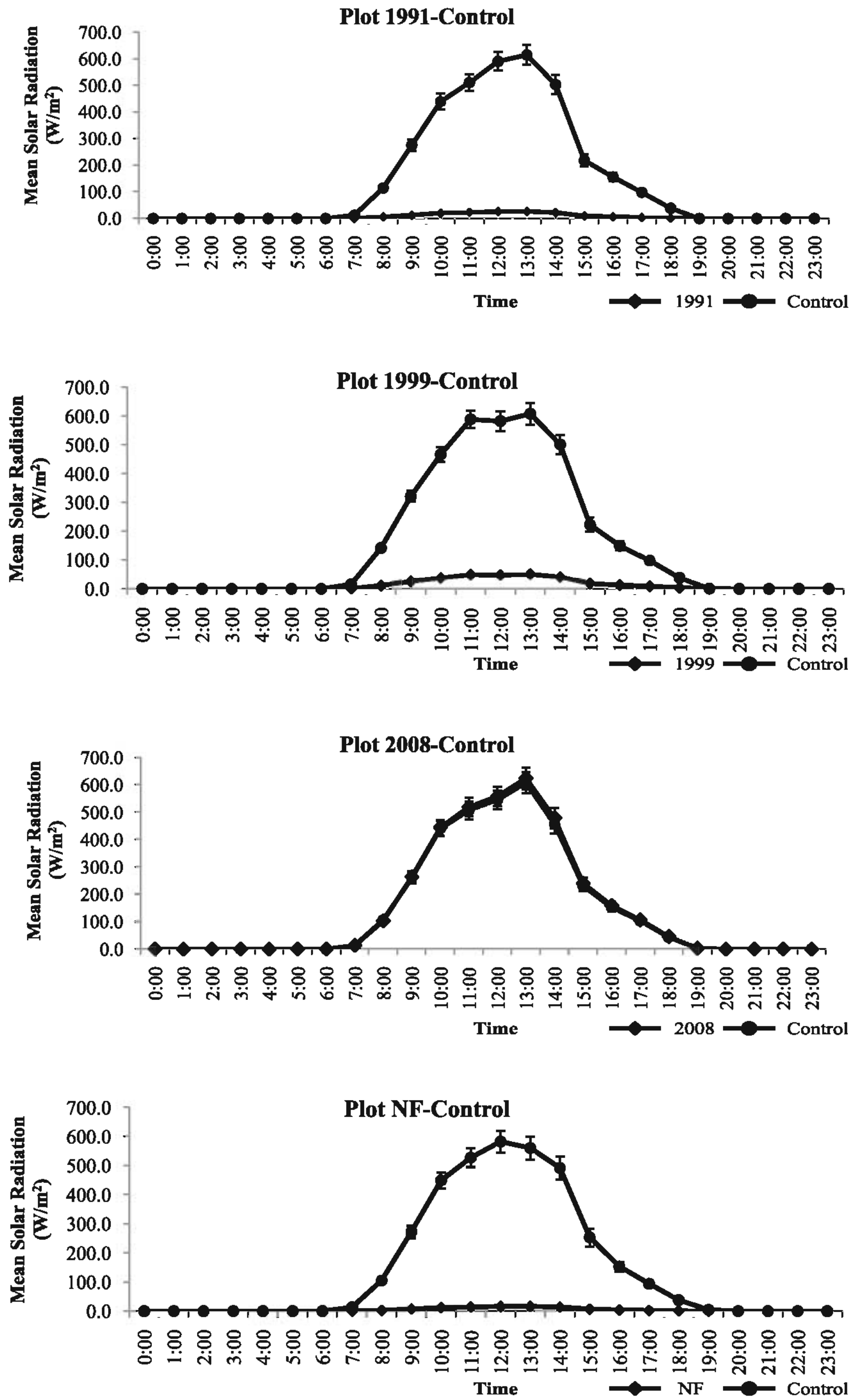

Figure 5. The 60-day mean solar radiation (W/m^2 ± S.E.) at each hour of the day between study plots and control station.

canopy that has reduced the extreme air temperature, less heat stress, more humid and less solar radiation reaching the forest floor as compared the Control Weather Station. Therefore, different age stands of rehabilitated forests has its unique micrometeorological variations.

CONCLUSION

Micrometeorological assessment is an important parameter in ecological studies. Short-term studies provide some indication of the recovery of the microenvironment. The study found that the younger age rehabilitated forest has more extreme micrometeorology which is comparable to open areas. This was due to the development of the canopy layers which influenced the level of canopy openness. Older rehabilitated forest and natural regenerating secondary forest had more tolerant micrometeorology beneath their more-closed forest canopy as the canopy layers act as a regulator. Forest stratifications do play an important role in regulating less extreme conditions. All study plots shown their own unique micrometeorological conditions which reflect the importance of monitoring individual study sites concurrently. Long term studies are particularly needed to determine the variations and the rate of micrometeorological recovery of different age stands of a rehabilitated forest.

ACKNOWLEDGMENTS

The authors would like to thank the management and field staff of the Universiti Putra Malaysia Bintulu Sarawak Campus for their kind support, assistance and cooperation during this study. This research was supported by the research grant from the Mitsubishi Corporation, Japan.

REFERENCES

Ahmad, A.N. & A. Salleh. 1999. Microclimate of Ayer Hitam Forest, Selangor. *Pertanika Journal of Tropical Agricultural Science* 22(2): 125-129.

Aoki, M., K. Yabuki&H. Koyama. 1978. Micrometeorology of Pasoh forest. *Malayan Nature Journal* 30: 149-159.

Ashton, P.M.S. 1992. Some measurements of the microclimate within a Sri Lankan tropical rainforest. *Agricultural and Forest Meteorology* 59: 217-235.

Brower, J., J. Zar & C. von Ende. 1990. *Field and laboratory methods for general ecology*. (3rd ed.). Dubuque: Wm. C. Brown Publishers.

Brown, N. 1993. The implication of climate and gap microclimate for seedling growth conditions in a Bornean lowland rain forest. *Journal of Tropical Ecology* 9:153-168.

Cabral, O.M.R., A.-L.C. McWilliam & J.M. Roberts. 1996. Incanopy microclimate of Amazonian forest and estimates of transpiration. Pp. 207-219. In: Gash, J.H.C., C.A. Nobre, J.M. Roberts and R.L. Victoria. (eds.). *Amazonian deforestation and climate*. New York: John Wiley & Sons.

Carswell, F.E., P. Meir, E.V. Wandelli, L.C.M. Bonates, B. Kruijt, E.M. Barbosa, A.D. Nobre, J. Grace & P.G. Jarvis. 2000. Photosynthetic capacity in a central Amazonian rain forest. *Tree Physiology* 20: 179-186.

Davis Instrument. 2011. Derived variables in Davis weather products. Available from http://www.davisnet.com/support/weather/support_docs.asp?dtype=3.

Golley, F.B. 1983. *Tropical rain forest ecosystems: structure and function*. New York: Elsevier Scientific Publishing Company.

Koike, F. & M. Hotta. 1996. Foliage-canopy structure and height distribution of woody species in climax forests. *Journal of Plant Research* 109: 53-60.

Kruk, R., M. Jacobs & R.A.A. Oldeman. 1988. *The tropical rain forest: a first encounter*. Berlin: Springer-Verlag.

Kumagai, T., K. Kuraji, H. Noguchi, Y. Tanaka, K. Tanaka & M. Suzuki. 2001. Vertical profiles of environmental factors within tropical rainforest, Lambir Hills National Park, Sarawak, Malaysia. *Journal of Forest Research* 6:257-264.

Longman, K.A. & J. Jenik. 1981. *Tropical forest and its environment*. New York: Longman.

Meinzer, F.C., J.L. Andrade, G. Goldstein, N.M. Holbrook, J. Cavelier & P. Jackson. 1997. Control of transpiration from the upper canopy of a tropical forest: The role of stomatal, boundary layer and hydraulic architecture components. *Plant Cell Environment* 20: 1242-1252.

Miyawaki, A. 1999. Creative ecology: restoration of native forests by native trees. *Plant Biotechology* 16(1): 15-25.

Roland, K.J.H., N.M. Abd. Majid, S. Gandaseca, O.H. Ahmed, S. Jemat & M.K.K. Ku. 2011. Forest structure assessment of a rehabilitated forest. *American Journal of Agricultural and Biological Sciences* 6(2): 256-260.

Shuttleworth, W.J., J.H.C. Gash, C.R. Lloyd, C.J. Moore, J.M. Roberts, A. de O. Marques Filho, G. Fisch,V. de P. Silva Filho, M. de N.G. Ribeiro, L.C.B. Molion, L.D. de Abreu Sa, C.A. Nobre, Cabral OMR, S.R. Patel & J.C. de Moraes. 1985. Daily variations of temperature and humidity within and above Amazonian forest. *Weather* 40: 102-108.

Steadman, R.G. 1979. The Assessment of Sultriness, Part

II: Effects of wind, extra radiation and barometric pressure on apparent temperature. *Journal of Applied Meteorology 18(7): 874-885.*

Thompson, O.E. & R.T. Pinker. 1975. Wind and temperature profile characteristics in a tropical evergreen forest in Thailand. *Tellus* 27: 562-573.

Walsh, R.P.D. 1996. Mircoclimate and hydrology. Pp. 206-236. In: Richards, P.W. (ed.) *The tropical rain forest: An ecological study*. Cambridge: Cambridge University Press.

Whitmore, T.C. 2006. *An introduction to tropical rain forests*. Oxford: Oxford Press.

Whitmore, T.C. 1984. *Tropical rain forests of the Far East.* Oxford: Oxford University Press.

Yoda, K. 1978. Three-dimensional distribution of light intensity in a tropical rain forest of West Malaysia. *Malayan Nature Journal* 30(2):161-177.