Journal of
TROPICAL BIOLOGY & CONSERVATION

A journal of the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah

Cover image:
Tor tambra, Rasbora cf. *rheophila, Barbodes sealei, Paracrossochilus acerus* (Photo credit: Casey Ng Keat Chuan)

Date of issue: 2017-10-15

Contents

Response of Cryptocoryne pallidinervia Engler (Araceae) on light intensity and water depth. **Isa Ipor, Md. Djzamanni Yahya, Cheksum Tawan**....................1-19

Land Use Changes and Their Effects on the Provisioning Services for 32 Years in Temiang Village, Giam Siak Kecil-Bukit Batu. **Vera Budi Lestari Sihotang, Bayu. A. Pratama, M. Fathi Royyani, Joeni S. Rahajoe, Lin Zhen**..21-35

The Application of Citizen Science Approach in an Ichthyofaunal Survey at Tagal Sites in Upper Moyog River, Sabah, East Malaysia. **Casey Ng Keat Chuan**..37-53

Notes on the genus *Chilocoristes* Weise (Coleoptera: Chrysomelidae: Alticinae) in Malaysia. **Haruo Takizawa**..55-68

Seasonal variation of temperature dependent physico-chemical parameters of a coastal River Bhadra, Bangladesh. **Mosummath Hosna Ara, Md. Nazim Uddin, Subhas Chandra Sarkar, Uttom Kumar**..69-81

Beach Morphology Changes during the Northeast and Southwest Monsoons at Mantanani Besar Island, Sabah (Malaysia). **Russel Felix Koiting, Ejria Saleh, John Madin, Md Nizam Bin Ismail**..83-94

Diversity of *Pteroptyx* Fireflies (Coleoptera: Lampyridae) and Their Display Trees at Klias Peninsula, Sabah, Malaysia. **Kevin Foo, Mahadimenakbar M. Dawood**....95-103

Evaluation of Spatial and Seasonal Variations of Dissolved Organic Matter in Maliau Basin, Sabah, Malaysia. **Tan Sin Yee, Sahana Harun, Kueh Boon Hee, Arman Hadi Fikri**..105-124

Tree diversity at Payeh Maga Montane Forest, Sarawak, Borneo. **Roland Kueh Jui Heng, Nixon Girang Mang, Ong Kian Huat , Muaish Sait, Sylvester Sam, George Bala Empin, Thashwini Rajanoran, Cassy Rechie Sinus**.........................125-150

Journal of Tropical Biology and Conservation 14:1–19, 2017 ISSN 1823-3902

Research Article

Response of *Cryptocoryne pallidinervia* Engler (Araceae) on light intensity and water depth

Isa Ipor*, Md. Djzamanni Yahya, Cheksum Tawan

Department of Plant Science and Environmental Ecology
Faculty of Resource Science and Technology, University Malaysia of Sarawak
94300 Kota Samarahan, Sarawak, Malaysia
*Corresponding author: ibipor@frst.unimas.my

Abstract

The study of the effect of different light intensities and water depths on the growth pattern, biomass allocation and photosynthetic rate of *Cryptocoryne pallidinervia* collected from Sungai Prasak, Keranji, Lundu, Sarawak, Malaysia, was conducted. Plants grown under tree canopy condition produced more leaves and lateral shoots than those grown under 50 % and 75 % shading. By increasing shade to 75 % level, the plants grew taller with larger leaves. The expansion of individual leaves at 75 % shade required 51 days to reach maximum size. The growth pattern such as leaf weight ratio (LWR), petiole weight ratio (PWR), rhizome weight ratio (RhWR) as well as root weight ratio (RWR) and biomass allocation such as specific leaf area (SLA), leaf area ratio (LAR), dry matter production (DMP), leaf area duration (LAD) and net assimilation rate (NAR) were significantly affected by shading. Plants grown in the depth of 15 cm were significantly taller and required a longer period to achieve maximum leaf expansion than those grown at 0 cm and 7 cm water depth. Growth pattern and biomass allocation were also significantly affected by water depths. Plants grown under 75 % shading and those grown at 0 cm water depth resulted in higher maximum quantum yield. However, plants at 75 % shade and those at 7 cm water depth had higher photosynthetic production at 300 μmol quanta $m^{-2}s^{-1}$ than those from other shade regimes and water depths.

Keywords: *Cryptocoryne pallidinervia*, light intensity, water depth, growth pattern, photosynthesis.

Introduction

Species of *Cryptocoryne*, also known as Keladi Air by locals in Sarawak, are mostly endemic aquatic plants. According to Jacobsen (1985), ten species of *Cryptocoryne* were recorded from Sarawak viz. *C. auriculata* Engl., *C. bullosa* Engl., *C. ciliata* (Roxb.)Kunth, *C. ferruginea* Engl., *C. grabowskii* Engl., *C. keei* N. Jacobsen, *C. lingua* Engl., *C. pallidinervia* Engl., *C. striolata* Engl. and *C. zonata* De Wit. Another four new species of *Cryptocoryne* recently found in

Received 14 July 2015
Reviewed 16 December 2015
Accepted 07 November 2016
Published 15 October 2017

Sarawak were *C. uenoi* Sasaki (Sasaki, 2002), *C. yujii* Bastmeijer (Bastmeijer, 2002), *C. zaidiana* Ipor & al. (Ipor et al., 2005a), *C. fusca* De Wit (Ipor & al. 2006), and a new interspecific hybrid *C. ×batangkayanensis* Ipor & al. (Ipor & al. 2015).

Jacobsen (1985) described three different habitats in which the *Cryptocoryne* grow, *vis.* the inner tidal zone as an amphibious life form, slow to fast running water as an aquatic life form and at the bank of smaller rivers as a rheophytic life form. Most of the *Cryptocoryne* are evergreen perennial herbs with procumbent to erect rhizomes and short to long subterranean runners.

Cryptocoryne pallidinervia is characterized by the limb of the spathe that has prominent, red protuberances and a broad, yellow collar zone with red spots, and on the spadix the male and female flowers are adjacent to each other (Arends et al., 1982; Bastmeijer, 2015). The leaves are cordate in shape and often somewhat bullate.

The physical appearance possessed by the species of *Cryptocoryne* have promoted the potential of these plants as aquarium plants. Species of *Cryptocoryne* are some of the commercially important aquatic species used in the aquarium plant trade, which have made them marketable products on the global market (Rataj & Horeman, 1977; Mansor, 1994). Besides that, the *Cryptocoryne* species are of great importance in aquatic ecology. In their natural habitats, they provide nutrients to other aquatic organisms. During the photosynthetic process, oxygen is supplied to the water thus lowering the BOD (biological oxygen demand) of the water. To some extent there is also an uptake of excessive nutrients from the water if not too contaminated and thus helps to clean it. The occurrence of *Cryptocoryne* in a stream is to some extent also an indication of a certain level of cleanness of the water. According to Jacobsen (1985), many *Cryptocoryne* can grow well under a thick canopy. The condition of low light intensity and high humidity level under the canopy promotes growth of these particular species. *Cryptocoryne* can even grow at high intensity of shading (approximately 90 % shading).

Cryptocoryne pallidinervia is mainly found in peat swamp areas (Figure 1). However, swamp areas have been substantially destroyed and transformed for agriculture and extensive forest harvesting. These activities have significantly destroyed its habitats and obviously caused drastic decline on populations. Ipor et al. (2007) had briefly attempted using polymerase chain reaction M13 universal primer of DNA fingerprinting of *C. pallidinervia* in Sarawak. The

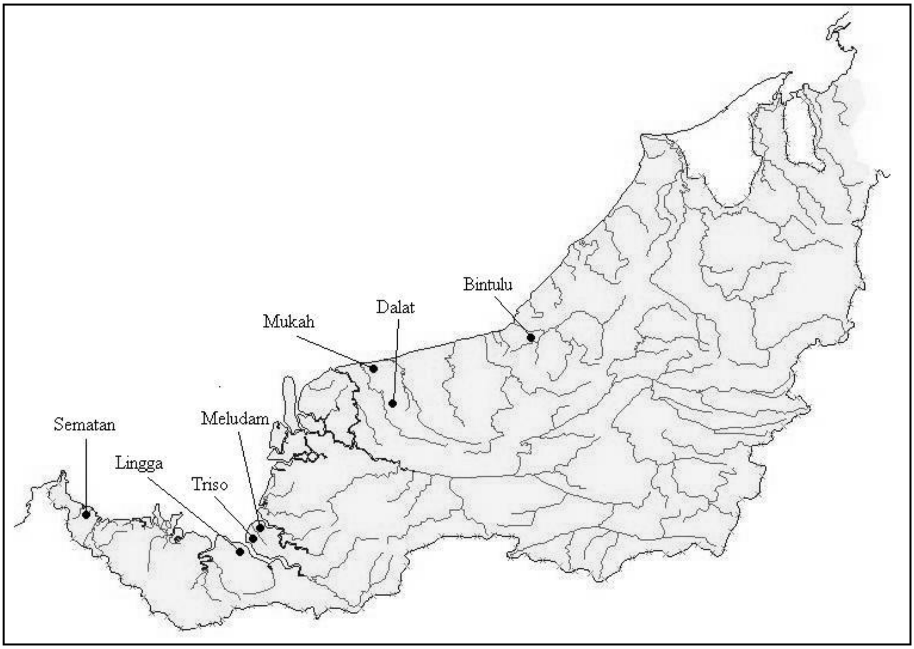


Figure 1. Seven areas of *C. pallidinervia* natural habitats found in Sarawak, Malaysia.

objective of this study is to determine the effects of different light intensities and water depth levels on the growth pattern of *C. pallidinervia*. The study also included the assessment of growth pattern, biomass allocation, photosynthetic rate, growth measurement and individual leaf expansion of *C. pallidinervia*.

Materials and Methods

Sampling and Study Area

Sampling of *C. pallidinervia* plants and soil was made at Sungai Prasak, near Kampong Keranji, Lundu, Sarawak, Malaysia. The plant and soil samples were then brought back to Universiti Malaysia Sarawak (UNIMAS) for plant material preparation for greenhouse experiments.

Propagation of planting materials

The lateral shoots were raised from mother plants throughout the entire study. The potting was a mixture of sandy loam soil and peat swamp soil from the sampling site. The selected lateral shoots were transplanted in pots (14 cm diameter and 9 cm height) and placed inside trays (47 cm x 24 cm). Two weeks after transplanting, placement of selected uniform plants to respective shade levels and water depths was carried out.

Light intensity

Three different light regimes which were under tree canopy shading condition, 50 % and 75 % shading conditions. Different intensity of lathe netting was used to obtain the 50 % and 75 % shading conditions. The pots were placed at 10 cm water depth (water depth measured from water surface to the media surface in the pot) for all light regimes. The plants were then subjected to growth assessment and biomass allocation analysis.

Growth measurement

Twenty uniform plants from every different shade level were labeled prior to growth assessment. The parameters that included plant height and total leaf number were taken every two weeks.

Development of individual leaves

In another assessment, the development of individual leaves was also studied. Each individual leaf was measured every 3 days using LI-3000A Portable Area Meter without severing the leaves. The measurement was continuously carried out until the consistent area obtained from three consecutive readings.

Biomass allocation

Five plants from each light regime were selected randomly and harvested after 30 days of transplanting. The leaf area of the individual plants was determined before drying the samples using the AT Delta-T scan equipment. The leaf, root, petiole and rhizome were separated prior to oven drying at 60°C for seven days to determine their dry weight. Similar harvest or assessment was done after 60 days of transplanting. The biomass allocation assessment was determined using the method described by Patterson & Flint (1983).

Water depth

Three different water depths used in this experiment were 0 cm, 7 cm and 15 cm. The depths were measured from the media surface to the water surface. For each treatment, 20 plants were placed in the designated water depth. All water containers containing plants at the respective water depth were placed under 50 % shade condition. The designated water levels were maintained and monitored every day. Similar assessment as in the light response experiment such as growth assessment and biomass allocation was conducted for their response to different water depths.

Photosynthesis measurement

The photosynthesis measurements were done in both light intensity and water depth experiments. In measuring the photosynthetic rates, "WALZ Diving-PAM Flourometer" equipment was used. Three uniform leaves were selected from each plant to determine their maximal fluorescence yield. Each light regime and water depth comprised five plants. Each leaf was dark-adapted for 10 minutes prior to photosynthetic measurements. The light curve (electron transport rate vs. photosynthetic active radiation) was also determined. The light curve experiment was done in a darkened room. Leaves were dark-adapted using dark-leaf clip for 10 minutes prior to measurement.

Data analysis

The experiments were conducted twice in completely randomized blocks with five replicates. The data were pooled and statistically subjected to least significant difference or Tukey's test. Significance in the text refers to the 95 % confidence level.

Results

Response to shading

It was observed that tree canopy shading and 75 % shading has approximately similar light intensity within the 13–hour-measurements, only that at 1400 hours the light intensity for tree canopy shading increased to a higher level than that under the 50 % and 75 % shading due to direct penetration of sunlight on the samples. The light regime of 0% shading was not applied in this study as the direct sunlight condition was not favourable for *C. pallidinervia* cultivation. It was observed that *C. pallidinervia* was a heat sensitive plant as it was not tolerant to direct sunlight.

Plants grown under tree canopy and 75 % shade regime were significantly taller than those at 50 % shade regime. From the 4th week, plants under tree canopy condition were significantly taller than those under 50 % and 75 % shading. Between the second and fourth weeks, plants under 75 % shade regime experienced a great change of plant height, however, it also grew well after week 4 (Figure 2).

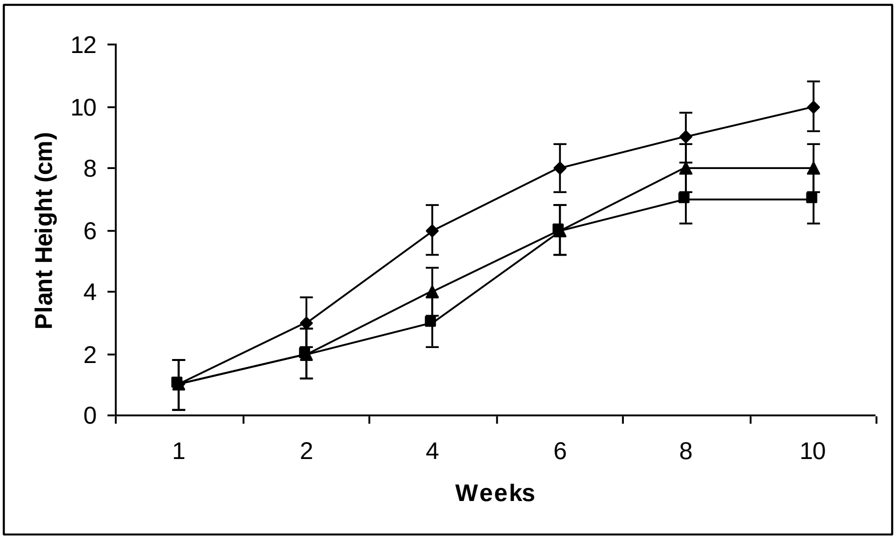


Figure 2. Effect of shading on the plant height of C. pallidinervia. Under tree canopy shading ( ), 50% shading ( ) and 75% shading ( ). Vertical bars are values of LSD = 0.05. Water level 0 cm.

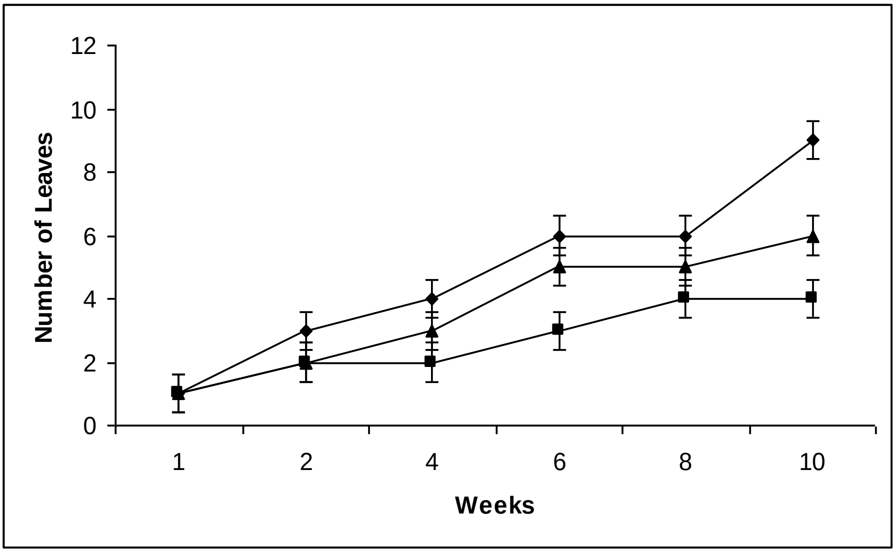


Figure 3. Effect of shading on leaf number of *C. pallidinervia*. Under tree canopy shading (—◆—) 50% shading (—■—) 75% shading (—▲—). Vertical bars are values of LSD at 0.05.

Plants under tree canopy shading produced significantly more leaves compared to the other two light regimes (Figure 3). Plants under 75 % shading had the least number of leaves. However, there was no significant difference on the number of leaves for plants under 50 % and 75 % shade during the first 4 weeks. Plants under all light regimes were not significantly different in terms of leaf numbers in week 2. The expansion and maturity of individual leaves varied between shade regimes. By increasing level of shading, larger leaves with delay in their maturity was observed (Figure 4). Leaves from 75 % shade required 51 days to obtain full and maximum expansion where as 50 % shade and under canopy condition required 42 and 39 days respectively.

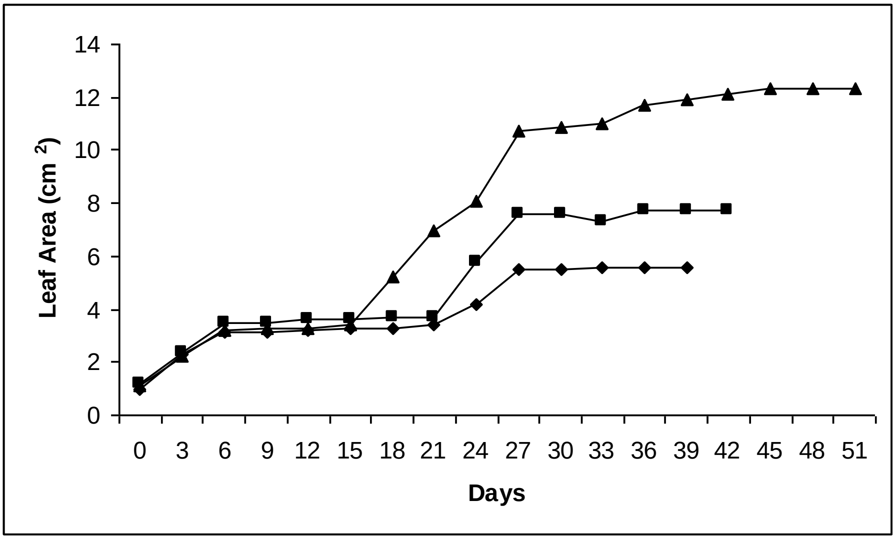


Figure 4. Effect of shading on individual leaf area of *C. pallidinervia*. Under tree canopy shading (—◆—), 50% shading (—■—) and 75% shading (—◆—).

Leaf weight ratio (LWR) of plants under 50 % shading was significantly lower than those under the tree canopy shading (Figure 5a). Petiole weight ratio (PWR) was not significantly differed between shade regimes (Figure 5b). Plants at 75 % shade had highest PWR. Rhizome weight ratio (RhWR) of plants under tree canopy shading was significantly lower than those under 50 % shading (Figure 5c). However, these plants had a significantly higher root weight ratio (RWR) than those from other light regimes (Figure 5d). The SLA of plants grown under 75 % shading was significantly higher than those from plants under tree canopy shading (Figure 5e). There was no significant difference of SLA between 50 % and 75 % shading and between 50 % shading and under tree canopy shading. Leaf area ratio (LAR) of plants under 50 % shading was significantly decreased compared to those under tree canopy and 75 % shading (Figure 5f).

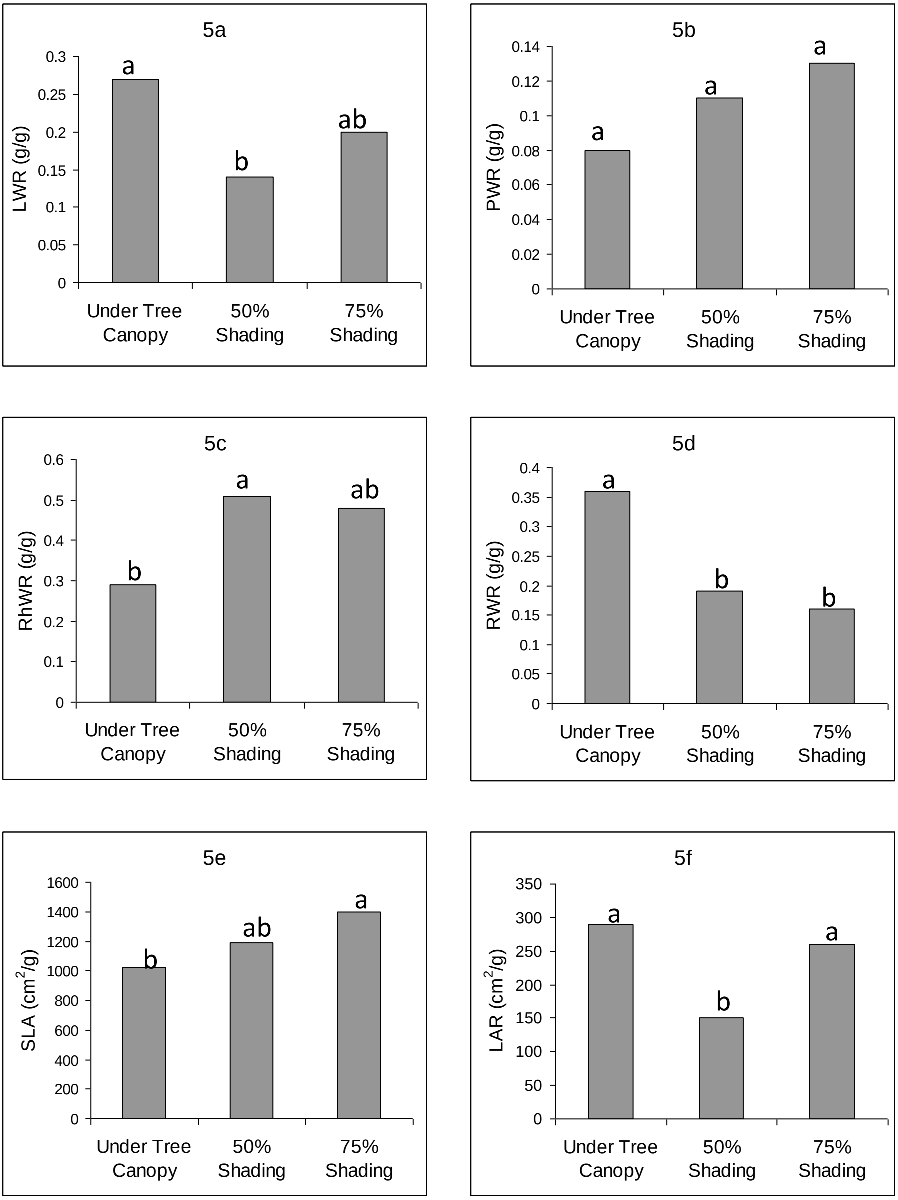


Figure 5. Effect of shading on vegetative growth, leaf area production and biomass allocation in *C. pallidernivia* (30^{th} harvest) (5a = Leaf Weight Ratio (g/g), 5b = Petiole Weight Ratio (g/g), 5c = Rhizome Weight Ratio (g/g), 5d = Roots Weight Ratio (g/g), 5e = Specific Leaf Area (cm^2/g), 5f = Leaf Area Ratio (cm^2/g)). Values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Both dry matter production (DMP) and leaf area duration (LAD) were significantly higher under tree canopy than those from 50 % and 75 % shading (Table 1). Plants under the 50 % shading regime showed a significantly higher value of net assimilation rate (NAR) than the other light regimes.

Table 1. Effect of shading on dry matter production (DMP), net assimilation rate (NAR) and leaf area duration (LAD) of *C. pallidinervia* during the 30^{th} to 60^{th} day interval after transplanting. Within each column, values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Shading	DMP	NAR	LAD
Under tree canopy	0.20a	0.00014b	1588.92a
50%	0.14b	0.00039a	420.55c
75%	0.11b	0.00017b	737.80b

Water depth response

Plants grown in the water depth of 15 cm were significantly taller than the other two water depth regimes. However, plant height of plants in the water depth regimes of 0 cm and 7 cm was not significantly differed throughout the study (Figure 6). A similar trend was observed for leaf number from different water depths (Figure 7).

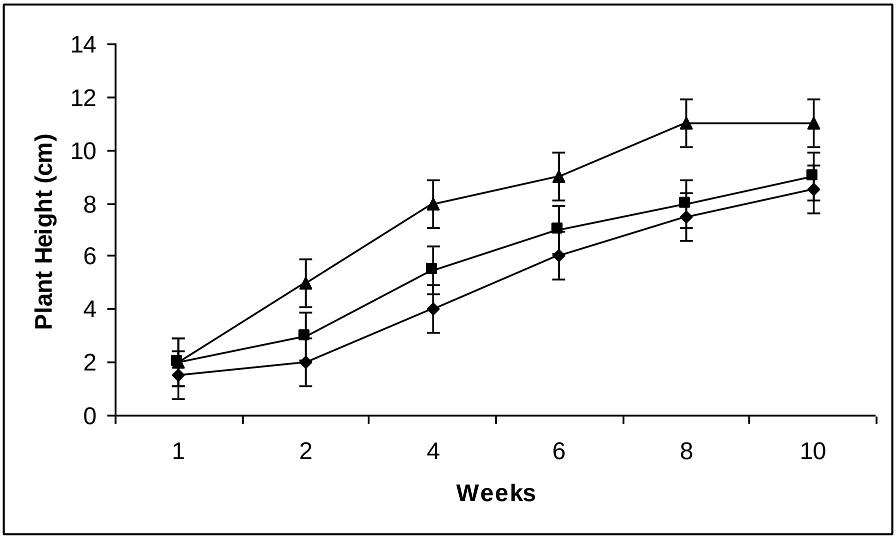


Figure 6. Effect of water depth on plant height in *C. pallidinervia*. 0 cm depth ( ), 7 cm depth ( ) and 15 cm depth ( ).Vertical bars are values of LSD = 0.05.

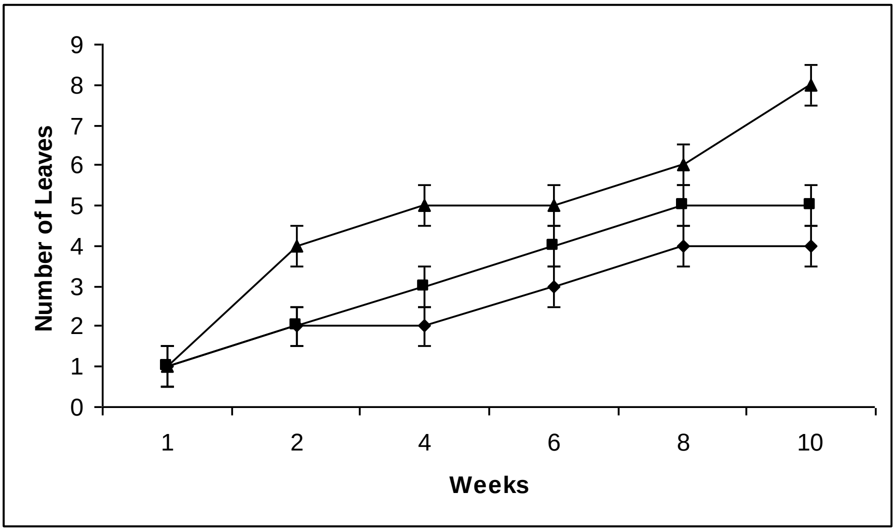


Figure 7. Effect of water depth on number of leaves in *C. pallidinervia*. 0 cm depth (—◆—), 7 cm depth (—■—) and 15 cm depth (—◆—).Vertical bars are values of LSD = 0.05.

The placement of plants at the depth of 15 cm had produced larger leaves and required a longer period to obtain maturity. It took 54 days to reach the maximum size. Both 0 cm and 7 cm water depth regimes had produced smaller leaves and required 36 and 42 days to obtain maximum size respectively (Figure 8).

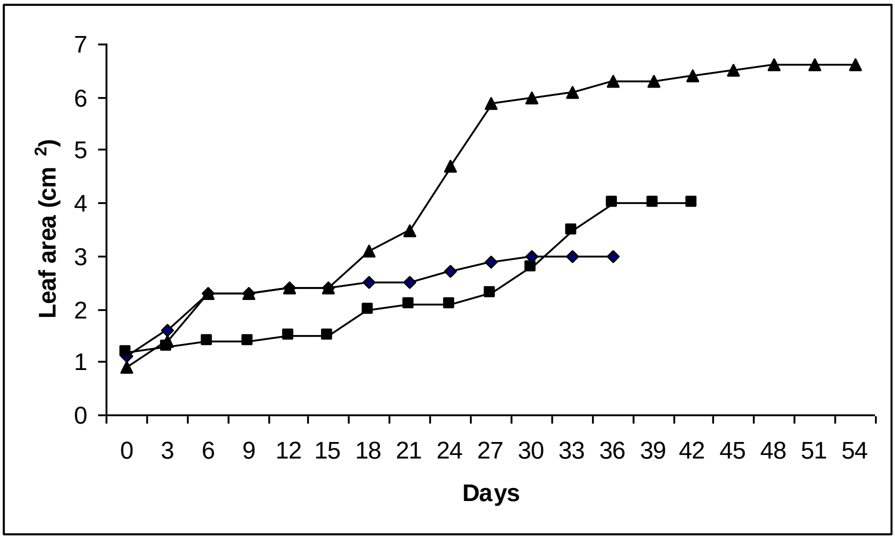


Figure 8. Effect of water depth on individual leaf area in *C. pallidinervia*. 0 cm depth (—◆—), 7 cm depth (—■—) and 15 cm depth (—◆—).

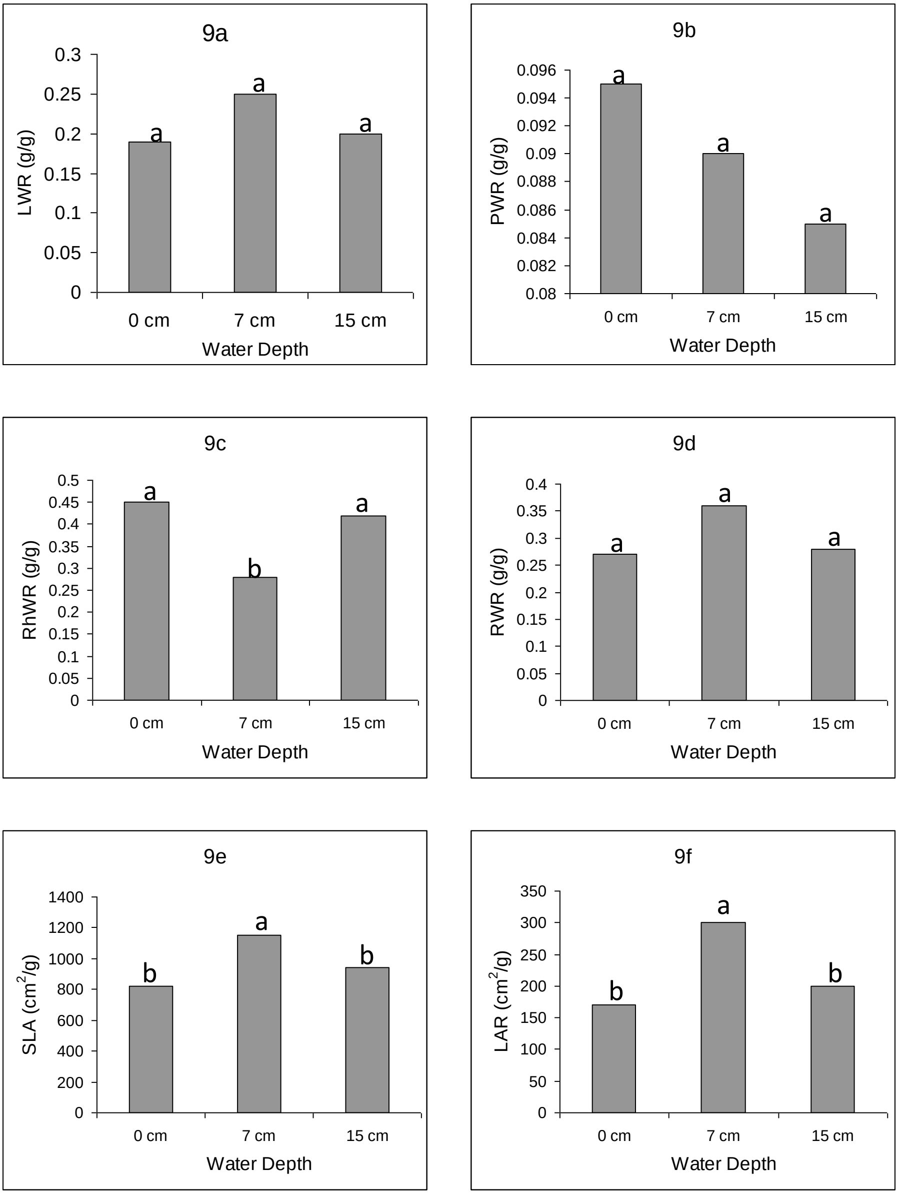


Figure 9. Effect of water depth on vegetative growth, leaf area production and biomass allocation in *C. pallidernivia* (30th harvest) (9a = Leaf Weight Ratio (g/g), 9b = Petiole Weight Ratio (g/g), 9c = Rhizome Weight Ratio (g/g), 9d = Roots Weight Ratio (g/g), 9e = Specific Leaf Area (cm^2/g), 9f = Leaf Area Ratio (cm^2/g)). Values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

There was no significant difference in the leaf weight ratio (LWR), petiole weight ratio (PWR) and root weight ratio (RWR) between water depths (Figure 9). Plants grown in the water depth of 7 cm had a significant decrease in rhizome weight ratio (RhWR) compared to the other two depth regimes. However, leaf area ratio (LAR) of those from 7 cm water depth was significantly higher than those from 0 cm and 15 cm water depths (Figure 9).
Dry matter production (DMP) was significantly different among the three different water depths (Table 2). The leaf area duration (LAD) of plants in the 7 cm water depth was significantly lower than the other depth regimes. Net assimilation rate (NAR) was not significantly differed among the water depth regimes.

Table 2. Effect of water depth on dry matter production (DMP), net assimilation rate (NAR) and leaf area duration (LAD) of *C. pallidinervia* during the 30^{th} to 60^{th} day interval after transplanting. Within each column, values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Water Depth	DMP	NAR	LAD
0 cm	0.10440a	0.00006a	1731.23a
7 cm	0.05667c	0.00005a	1250.59b
15 cm	0.08755b	0.00005a	1792.82a

Placement of plants at 75 % shading resulted in significantly higher maximum quantum yield than those from 50 % shading (Figure 10). It had no significant difference to those under tree canopy shading and in field condition.

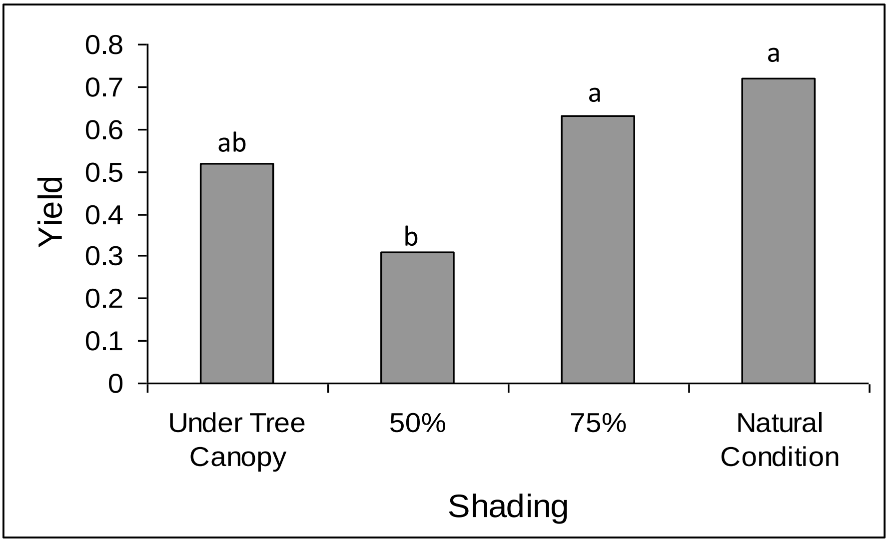


Figure 10. Effect of shading on maximal quantum yield of *C. pallidernivia*. Values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Plants grown under 75 % shading had a higher photosynthetic production at 300 µmol quanta m^{-2} s^{-1} than those grown under the tree canopy and the 50 % shading regimes (Figure 11).

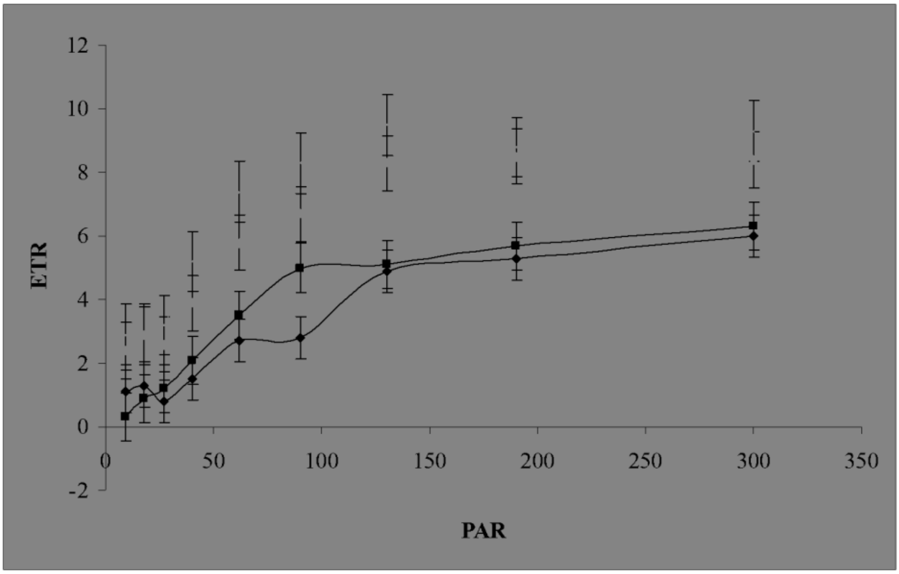


Figure 11. Effect of shading on light curve (electron transport rate (ETR, µmol. Protons $m^{-2}.s^{-1}$) vs. photosynthetic active radiation (PAR, $\mu mol.m^{-2}.s^{-1}$)) of *C. pallidinervia*. Tree canopy shading (—◆—), 50 % shading (—■—), 75 % shading (—◆—) and natural habitat (—✶—). Vertical bars are LSD = 0.05.

The maximum quantum yield tended to decrease as water depth increased under greenhouse conditions (Figure 12). Plants grown in the water depth of 0 cm had a significantly higher maximum quantum yield than those in the 15 cm depth regime. However, it was not significantly different from those at the 7 cm depth regime. The rate at the water depth of 7 cm in natural condition was almost similar to those from the 0 cm depth in the green house condition. Plants grown in the water depth of 7 cm recorded higher photosynthetic production at 300 µmol quanta m^{-2} s^{-1} than those grown in the 0 cm and the 15 cm water depth regimes (Figure 13).

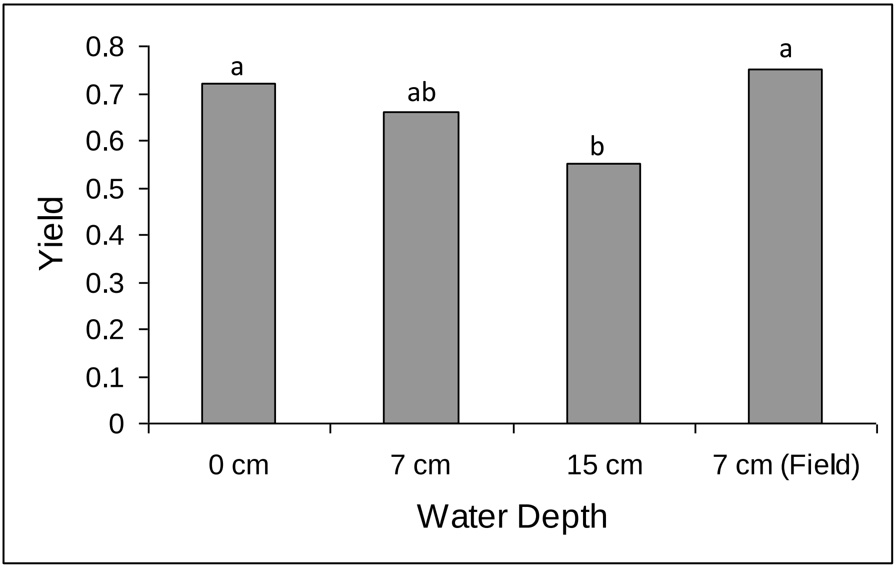


Figure 12. Effect of water depth on maximal quantum yield in *C. pallidernivia*. Values sharing the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

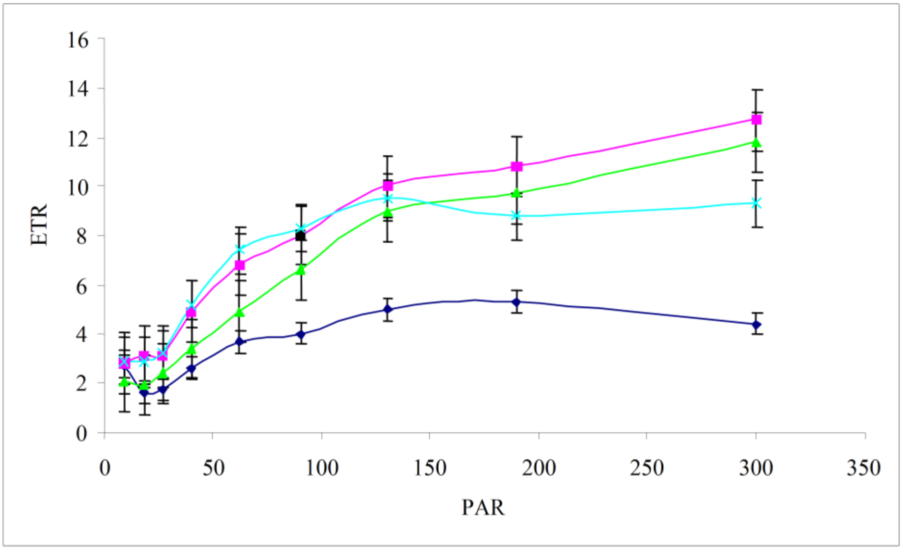


Figure 13. Effect of water depth on light curve (electron transport rate (ETR, µmol. Protons $m^{-2}.s^{-1}$) vs. photosynthetic active radiation (PAR, µmol.$m^{-2}.s^{-1}$)) in *C. pallidinervia*. 0 cm depth ( ), 7 cm depth ( ), 15 cm depth ( ) and natural habitat ( ). Verical bars are LSD = 0.05.

Discussion

For *C. pallidinervia* plants grown under the tree canopy and the 75 % shading regimes, no significant difference in their height was recorded. Plants under those shading regimes were significantly higher than that under the 50 % shading regime. A similar pattern was observed for *C. zaidiana* being exposed to different light intensities (Ipor et al. 2009). This was due to the intensity of light received by plants under the tree canopy and the 75 % shading regimes being lower than the 50 % shading. Plants stretch themselves in order to reach for a sufficient light source.

According to Bjorkman (1968) and Ishimine et al., (1985), reduced light levels to a certain degree would result in an increased stem extension of *Solidago virgaurea* L. and height of *Paspalum urvillei* Steud. However, a further reduction of light suppressed plant growth. In addition, *Cryptocoryne* species are capable of growing well under a thick canopy (Jacobsen, 1985). In the study of water depth effect on *C. pallidinervia*, different water depths significantly affected the plant height. Plants grown at a depth of 15 cm of water were significantly taller than the 0 cm and 7 cm depth regimes. This might be due to the phototropism of the plants, where the plant grew taller to reach the light source on the surface of the water. Ipor et al., (2005b) observed that *C. striolata* Engler that grew in deeper water had longer leaves and therefore were taller plants.

C. pallidinervia plants grown under tree canopy shading had significantly more leaves than that under the 50 % and 75 % shading regimes. However, plants under the 75 % shading regime generally developed larger leaves. Higher light intensity condition promoted the plants to produce more leaves and the number decreased significantly with larger leaves under lower light condition (Ipor, 1992; Ipor & Price, 1991; Ipor & Tawan, 2002). In this study, it was observed that light penetration under the tree canopy shading was at a lower level compared to the 50 % shading regime and may sometimes be even at a lower level than the 75 % shading condition. On the contrary, based on light intensity measurements on those three light regimes, shading under the tree canopy allowed higher light penetration than 50 % and 75 % shading regimes at about 1400 hours during clear sunny days. This obviously affected the growth of the plants under the tree shading condition. Short exposure of plants to high light intensity may have triggered the plants in enhancing their physiological activities such as photosynthetic activities.

Plants grown under tree canopy condition were significantly higher in lateral shoot production on the tenth week. The delay in production of lateral shoots experienced by plants under the 75 % shading regime showed that the condition was not favourable for lateral shoot production. There was no significant difference on lateral shoots produced. According to Ipor & Naim (2003), the *Rottboellia exaltata* Lour. plants cultivated under 75 % shading regime had lower production of tillers. Kobayashi et al., (2001) in their study of *Plantago asiatica* L. reported the percentage of reproductive plants in shaded plant populations was less than that in exposed populations at all size classes. This was similar to the *C. pallidinervia* as plants under 75 % shading conditions produced fewer lateral shoots. However, plants under the tree canopy shading produced more lateral shoots. The periodic high light intensity in the tree canopy shading regime may have contributed to the higher lateral shoots production than those under the 50 % and 75 % shading regimes.

Based on the biomass allocation assessment of *C. pallidinervia*, the highest leaf weight ratio (LWR) was recorded from plants grown under the tree canopy shading which was significantly higher than those under the 50 % shading regime. There was no significant difference on petiole weight ratio (PWR) among the three light regimes. Partitioning of biomass to root and rhizome differed significantly among light regimes. Root weight ratio (RWR) of plants under tree canopy shading regime recorded significantly higher than that under the 50 % and 75 % shading regimes. Rhizome weight ratio (RhWR) of plants under the tree canopy shading regime was significantly lower than that under the 50 % shading regime, but not significantly different to that under the 75 % shading regime. Although there was no significant difference among light regimes on the specific leaf area (SLA), plants under 75 % shading recorded the highest value of SLA. The plants under a light-limited regime invested more to the production of light-harvesting apparatus rather than other components of plant biomass (Patterson, 1980). The tree canopy shade regime possessed significantly higher leaf area ratio (LAR) than that under 50 % shading.

The biomass allocation assessment in different water depths showed that there was no significant difference in leaf weight ratio (LWR), petiole weight ratio (PWR), root weight ratio (RWR) or specific leaf area (SLA) among the three different depths. Plants grown in the water depth of 7 cm were significantly differed on rhizome weight ratio (RhWR) compared to the other two depth regimes. Plants grown in the 7 cm water depth regime showed highest value in LWR, RWR, SLA and LAR.

DMP and LAD of *C. pallidinervia* were highest at the tree canopy shade. The values were significantly higher than that under 50 % and 75 % shading. DMP and LAD values among the three light regimes showed significant difference. The NAR value was recorded significantly higher at 50 % shade than the other two light regimes. For the assessment of DMP, NAR and LAD at three different water depths, it was shown that there was a significant difference among the three depths on the DMP values. However, the NAR values did not indicate a significant difference among the three different depths. Data showed that at a water depth of 7 cm, the value of LAD was significantly lower than the other two depths.

Plants under the 75 % shading regime resulted in a higher value of the maximal quantum yield. There was no significant difference on maximum quantum yield value of plants under the tree canopy shading and the 75 % shading. This may be due to the light intensity received by plants under both light regimes that were almost similar. Plants in water of 0 cm and 7 cm depths were significantly taller than those in 15 cm depth. A higher value of maximum quantum yield showed that plants had a higher photochemical efficiency of photosystem II (PSII) primary reaction centres (Krause & Weis, 1991).

Plants grown under the 75 % shading regime and the 7 cm water depth regime had higher electron transport rate (ETR) value at 300μmol quanta m^{-2} s^{-1}. Both samples indicated a higher photosynthetic production rate. Sample at the 75 % shading regime received a lower amount of light. This also happened to the sample from the 7 cm water depth regime, where the water was dark.

Conclusion

Based on the study, cultivation of *C. pallidinervia* under different light intensities showed different growth patterns. Placing the plants under the tree canopy regime resulted in higher number of leaves and lateral shoots than those under the 50 % and 75 % shade regimes. However, a lower light intensity would cause the plants to grow longer and produce larger leaves. The water depth levels of 0 cm, 7 cm and 15 cm did not affect the number of leaves produced, plant height growth and the number of lateral shoots produced. Different light intensities and water depths significantly affected the photosynthesis rate and biomass partitioning of *C. pallidinervia*. Similar pattern of and biomass allocation and growth response for *C. ferruginea* Engler was observed in different conditions of shading and water depth (Ipor et al. 2006).

Acknowledgement

The authors are grateful to Universiti Malaysia Sarawak for providing financial support. The authors express their utmost appreciation to Meekiong Kalu, Norasmah Saupi, Sekudan Tedong, Angelin Simon and Mohd. Rizan Abdullah, for their assistance. Appreciation is also extended to Prof. Niels Jacobsen for his comments and suggestions during the preparation of this paper.

References

Arends JC, Bastmeijer JD, Jacobsen N. 1982. Chromosome numbers and taxonomy in *Cryptocoryne* (Araceae) II. *Nordic. Journal of Botany,* **2:** 453-463

Bastmeijer JD. 2002. *Cryptocoryne yujii* Bastmeijer (Araceae). eine neue Art aus Sarawak. *Aqua Planta,* **26:** 145-146

Bastmeijer JD.2015. The Crypts pages http://crypts.home.xs4all.nl/Cryptocoryne/

Bjorkman O. 1968. Further studies on differentiation of photosynthetic properties in sun and shade ecotypes of *Solidago virgaurea* L. *Physiolgia Plantarum,* **21:** 84-89

Ipor I.B., Tawan, C.S. (2002). Growth, biomass allocation and response to glyphosate of *Imperata cylindrica* (L.) Raeuschl. Grown under different light conditions. **Journal of Bioscience,** 12(1): 33-38

Ipor IB, Meekiong K, Tawan CS, Simon A. 2009. Response of *Cryptocoryne zaidiana* Ipor & Tawan (Araceae) to shading and water depth. *Journal of Tropical Biology and Conservation,* **5(1):** 15–29

Ipor IB, Naim ML. 2003. Response of *Rottboellia exaltata* (Lour.) to shading. In Adam, J.H., Ali, Z.M, Ibrahim, N. Md-Zain, B.M. & Omar R. (Eds.), *Prosiding Simposium Biologi Gunaan ke-7, Universiti Kebangsaan Malaysia, Selangor* (pp. 350-354)

Ipor IB. 1992. Shading effects on growth and partitioning of plant biomass in *Paspalum conjugatum* Berg. *Biotropia,* **6:** 55-65

Ipor, I.B., C.S. Tawan & M. Basrol (2006). Growth pattern, biomass allocation and response of *Cryptocoryne ferruginea* Engler (Araceae) to shading and waterdepth. Jurnal Biosains, 17(2): 55–78

Ipor, I.B., Price, C.E. (1991). The effect of shade on the growth and development of *Mikania micrantha* H.B.K. **Malaysian Applied Biology**, 20(1): 57-63

Ipor, I.B., Tawan, C.S., Jacobsen, N. (2005a). New species of *Cryptocoryne* (Araceae) from Sarawak. **Garden Bulletin Singapore**, 57: 1-6

Ipor, I.B., Tawan, C.S., Tagor, F.S. (2005b). Ecophysiology and Growth Patterns of *Cryptocoryne striolata* Eng. at Sg. Stuum Toman, Bau, Sarawak. **Journal of Bioscience**, 16(1): 97-109

Ipor, I.B., W.S. Ho, C.S. Tawan, M.S. Salmizana & M. Moryatimah (2007). Ecology and DNA fingerprinting of Cryptocoryne pallidinervia Engler (Araceae) accessions using polymerase chain reaction M13 universal primer. Malays. Appl. Biol. 36(2): 21-31

Ishimine, Y.K., Miyazato, K., Matsumoto, S. (1985). Physiological and ecological characteristics of weed of sugarcane fields in Ryukus Islands. Effects of shading on growth and seed production of *Paspalum urvellei* Steud. **Weed Res.** 19: 321-327

Jacobsen N. 1985. The Cryptocoryne (Araceae) of Borneo. *Nordic Journal of Botany* **5:** 31-50

Kobayashi, T. Okamoto, K., Hori, Y. (2001). Variation in size structure, growth and reproduction in Japanese plantain (*Plantigo asiatica* L.) between exposed and shaded population. *Plant Species Biology,* **42:** 123-128

Krause GH, Weis E. 1991. Chlorophyll fluorescence and photosynthesis: the basics. *Annual Review Plant Physiology,* **42:** 313-349

Mansor M. 1994. Kemandirian beberapa spesies *Cryptocoryne* endemic di sungai-sungai Malaysia. In Rohani A, Aminah A, Mohd. Khan, Ayub, S. Fatimah A. (Eds): *Kesatuan Dalam Kepelbagaian Penyelidikan Biologi*, Universiti Kebangsaan Malaysia, Selangor (pp. 412-417)

Patterson DT, Flint EP. 1983. Comparative water relation, photosynthesis and growth of soybean (*Glycine max*) and seven associated weeds. *Weed Science,* **31:** 318-322

Patterson DT. 1980. Shading effects on growth and partitioning of plant biomass on cogon grass (*Imperata cylindrical* L.) from shaded and exposed habitat. *Weed Science*, **28:** 735-740

Rataj R, Horeman TJ. 1977. *Aquarium Plants*. T.F.H. Publications, Inc., Neptune City, NJ. p 448

Sasaki Y. 2002. *Cryptocoryne uenoi* Y. Sasaki (Araceae), eine neue Art aus Sarawak. *Aqua Planta,* **27:** 147-149

Journal of Tropical Biology and Conservation 14:21–35, 2017 ISSN 1823-3902

Research Article

Land Use Changes and Their Effects on the Provisioning Services for 32 Years in Temiang Village, Giam Siak Kecil-Bukit Batu

Vera Budi Lestari Sihotang[1]*, Bayu. A. Pratama[1], M. Fathi Royyani[1], Joeni S. Rahajoe[1], Lin Zhen[2]

[1]Botany Division, Research Center for Biology-Indonesian Institute of Sciences
Jl. Raya Jakarta - Bogor Km. 46 Cibinong, West Java
[2]Institute of Geographic Science and Natural Resources Science, Chinese Academy of Sciences, 11A Datun Rd, Beijing 100101
Corresponding author: verbudl@gmail.com

Abstract
Research on land use change in Temiang Village is important as it is a part of Giam Siak Kecil-Bukit Batu Biosphere reserve conservation area which protects and conserves the ecosystem and the biological resources and genetic resources in it. This research was conducted to determine land use changes and their effects in Temiang village, Bukit Batu. Effects of changes in land use in Temiang village can be seen in provisioning services. Provisioning services are the benefits obtained from the supply of food and other resources from ecosystems. To collect primary data, a field trip was conducted, in addition to in depth interview and Focus Group Discussion method. The land uses in Temiang village are driven mainly by local societal preferences and practices which are rubber and oil palm plantations. The other factors that drive land use change are conversion for housing and village facilities which is also the result of population growth and the arrival of migrants.

Keywords: Temiang Village, land use change, ecosystem services, provisioning service.

Introduction
The natural world provides benefits through the ecosystems. Humans are part of the ecosystem and each person depends on the ecosystem for their welfare. Ecosystems are the source of obvious necessities such as food and fresh water. The Millennium Ecosystem Assessment (MEA) shows that over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period in human history, largely to meet fast-growing demand for food, fresh water, timber, fiber, and fuel (Azapagic 2010: 141). There are

Received 23 May 2016
Reviewed 21 June 2017
Accepted 08 August 2017
Published 15 October 2017

many other things that cause people to overuse environmental resources to survive from day to day. That is why there is strong relationship between ‘people’ and ‘nature’, between ‘the economy’ and ‘the environment’, or between ‘human well-being’ and ‘ecosystems’.

The five most important groups of indirect factors in changing the ecosystem are (1) population change (demographic drivers), (2) change in economic activity (economic drivers), (3) sociopolitical drivers, (4) cultural and religious drivers and, (5) technological changes. Important direct drivers to consider are (1) habitat change driven through land use/cover change (2) physical modification of rivers, or water withdrawal from rivers, (3) over exploitation, (4) invasive alien species, (5) pollution, and (6) climate change (Tomich, et.al. in Ash 2010:89).

Land use change, which is one of the direct drivers of the changing ecosystem, has happened in Temiang Village Riau. Similar to other provinces, Riau is also home to various ethnic groups who arrive because of employment opportunities, as tradesmen, or for other reasons. They are from Minangkabau, Java, Melayu, Tapanuli, and other areas. They went to Riau when Japan colonized Indonesia around 1942, as forced labour, known as romusha. The Japan military government in Indonesia needed manpower in strengthening defense against attacks. Apart from the Java people, the Batak and other ethnic groups also come to Riau to work as labourers and as public servants.

Temiang village is one of 14 urban villages in the districts located in Bukit Batu, Bengkalis, Riau. The area is part of Bukit Batu Biosphere Reserve in Riau. The central government and the provincial government established Giam Siak Kecil-Bukit Batu in Riau as biosphere reserves. This biosphere reserve is in Bengkalis and Siak, as proposed by The Man and Biosphere (MAB)-Indonesia Committee and Sinar Mas Forestry, which allocates 72,255 hectares of forest production for permanent conservation. This area is part of ecological corridors that combines two wildlife reserves, Giam Siak Kecil (84. 967 ha) and Bukit Batu (21. 500 ha) (Profil Desa Temiang, 2011). The concept of biosphere reserve, an integrated and comprehensive management system, enables sustainable use and community involvement in management.

Material and Methods

To collect primary data, field trips were conducted on July 2nd to 8th, 2012 in the area of the Giam Siak Kecil-Bukit Batu Biosphere Reserve, Riau and close to the village of Temiang which is located at 1°23'53.3" East Longitude and 101°54'17.2" South Latitude, at altitude of 375 meters above sea level. Secondary data on Temiang Village was collected 2 years prior to the field trip.

Materials collected were about the history of the village, livelihood of the rural people, population, village borders, and the education level of Temiang villlagers. This village is one of the 'basecamps' for a joint research between our Institution (LIPI-Indonesian Institute of Sciences) and Kyoto University.

The first method of collecting primary data was in depth interviews with the village Secretary and community leader. The in depth interview method is used to identify the structure of society and their perspective about the environment. The second method is FGD (*Focus Group Discussion*). In this activity, there were 30 respondents made up of young people, old people, and village officer. The FGD was used to make a village sketch related to the changing land use and other ecosystem services. The sketches that we made were of the past (32 years ago), present and future plans of village management related with the ecosystem. This method is part of visual anthropology.

The last method of this research was to give questionnaires to 30 respondents in Temiang Village. The age range was based on the participants of the FGD. We divided these participants into 3 groups. The first group had respondents in the 69 to 84 years old age group (4 people) to make a village sketch of the past. The second group covered ages 53 to 68 years (2 people) who made a village sketch of the present, and the third group that had people in the 29 to 52 years age group (24 people) made a village sketch based on the future plan. Most of the participants are farmers, others work in business, rubber plantations, and fisheries. Some are housewives and drivers. The questionnaire focused on comparisons between the past and present and what changes have happened to Temiang village for 32 years, related to land use change. Based on the village sketch, we analyzed and compared the difference between the past, present and the future. From raw data of questionnaires, we made graphics of statistic distribution.

Results

Background Information of FGD Participants

From the questionnaire, the demographics data of FGD participants in Temiang Village (Figure 1), we know that the participants work as farmers and most were educated up to Senior High School (11 persons).

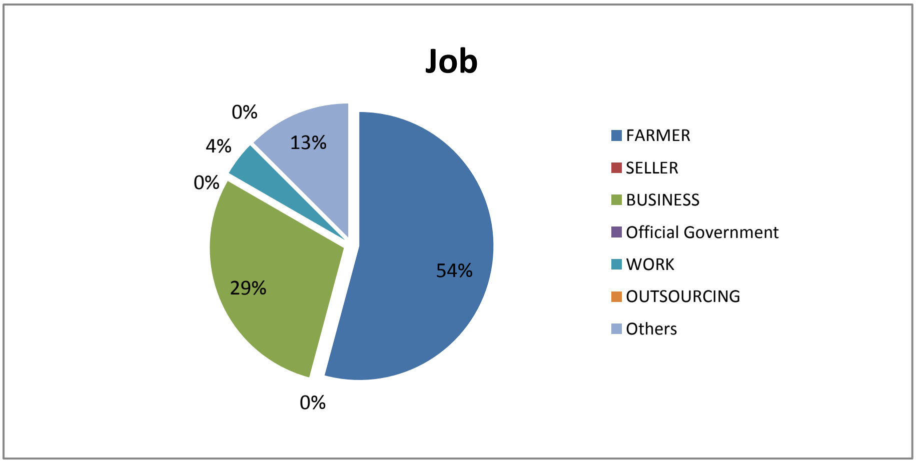


Figure 1. Graphic of demographic data of FGD Participants in Temiang Vilage

From the questionnaire, results showed that in the previous twelve months the communities earned income from planting rice, rubber, and palm trees (Figure 2). In addition, the society also received income from breeding chickens, cows and pigs. Others are self-employed, government employees or involved in private business. This result shows they work mostly on rubber plantations.

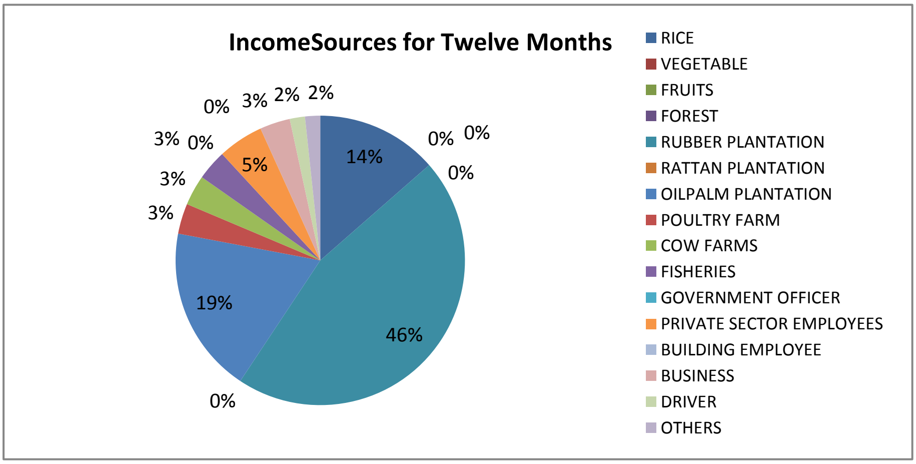


Figure 2. Graphic of Income Sources for Last Twelve Months of FGD Participants in Temiang Village

In terms of family property, most people now have a motorcycle. Previously traffic could only be traversed by rivers, so they had to rent or own a small boat (Figure 3).

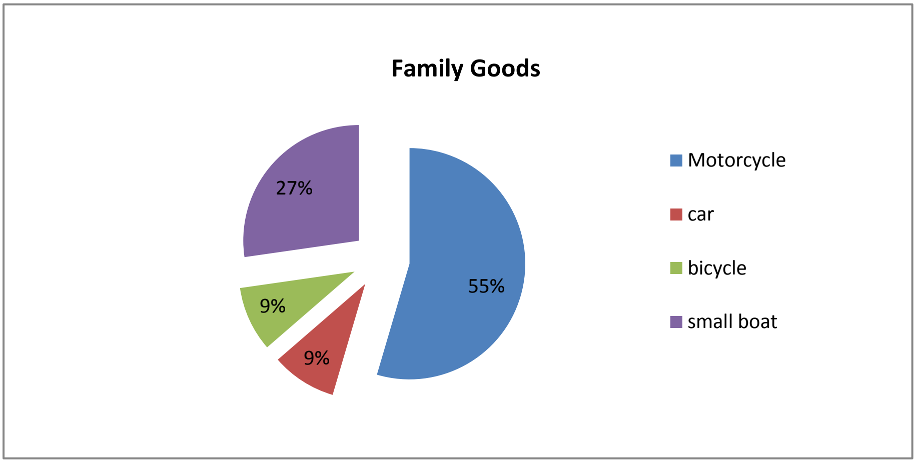


Figure 3. Graphic result of family goods own

A Brief Description of Temiang Village

Temiang village, a historic village, is a conservation model village established in 2004. A total of 300 households live in this village. The village used to be part of the Temiang forest and called 'the village of the grass' (*kampung si alang*). Temiang village began to develop when some companies came to this area before 1945, i.e. before the Dutch came to this area. At that time, the streets were still filled with soil and bushes. Before the Dutch came, nut trees are also found in Temiang, but after that, orders were given for rubber planting. With a high sale price, eventually people preferred rubber over nuts. Around the 1950s there was a group of people come who came from the Siak River into an area through Bukit Batu area. The group was deliberately moved by Datuk Laksmana to open plantations by cutting down forests around rivers. Datuk Laksmana was most feared and his word was an order - and he gave the order to keep the forest. Datuk Laksmana then gave the area to Maadun, the village head in Temiang (Profil Desa Temiang, 2011).

Previously this village only had 4 families. Some groups had also lived and bathed around the river and then felt that their skin had become itchy (*Miyang-Miyang*). After that, these people called the area they occupied as Miyang. When the district asked for the name of the village, community

leaders deliberated and said the name of the village is Temiang village. Temiang village is located 30 km north of Bukit Batu and 48 km from the capital. The village has a total area of 2,400 ha with limits as follows:The North is bordered by the village of Api-ap;
-The South is bordered by Sukajadi village;
-The East border is with Parit Satu Api-api village;
-The West border is with a company (PT SPM/BBHA)

In 2012, Temiang Village had a population of about 1,344 people scattered in two village areas. Of this number, 692 were male and 652 were female. People in Temiang depend on from agriculture (54 %), plantation and fisheries sector (17 %), and business (29 %). The Temiang village is an area surrounded by forest, plantation and Bukit Batu River, where education levels are Elementary School (SD) (33 %), Junior High School (SMP) (21 %), and Senior High School (SMA) (46 %).

Land Use Change in Temiang Village
Bukit Batu area included in the Bengkalis District has not escaped from land use changes. To report the land use change in Temiang village, we use an approach from Leslie, Barson, and Smith, by identifying areal change which is presented graphically with identified changes compared and trends observed (Byron & Lesslie 2008: 46).

The Temiang village in the recent past (32 years ago) was still filled with primary or secondary forest and shrubs (Figure 4). Most forest areas that have been converted to other land types have become rubber plantations. In terms of land use change, land use change patterns of other uses (forest, shrub, open land and fields) into a rubber plantation, fields and road construction are very dominant in Temiang Village (Figure 5); the ownership of land was also unbundling and limited. The function of forest around the village started to change drastically i.e. for plantation, fields, as well as housing.

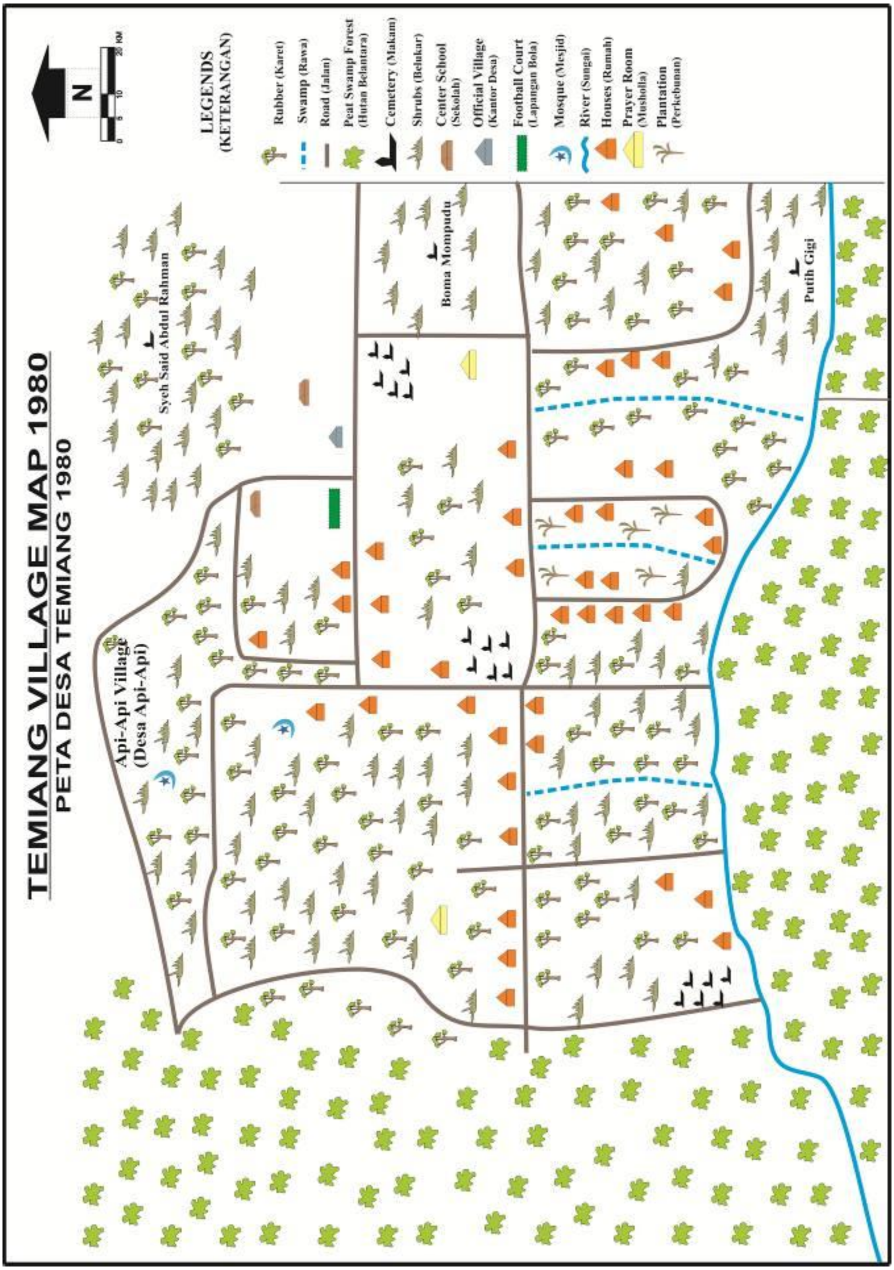


Figure 4. Temiang Village Map 1980 (sketched by Suhendra based on FGD)

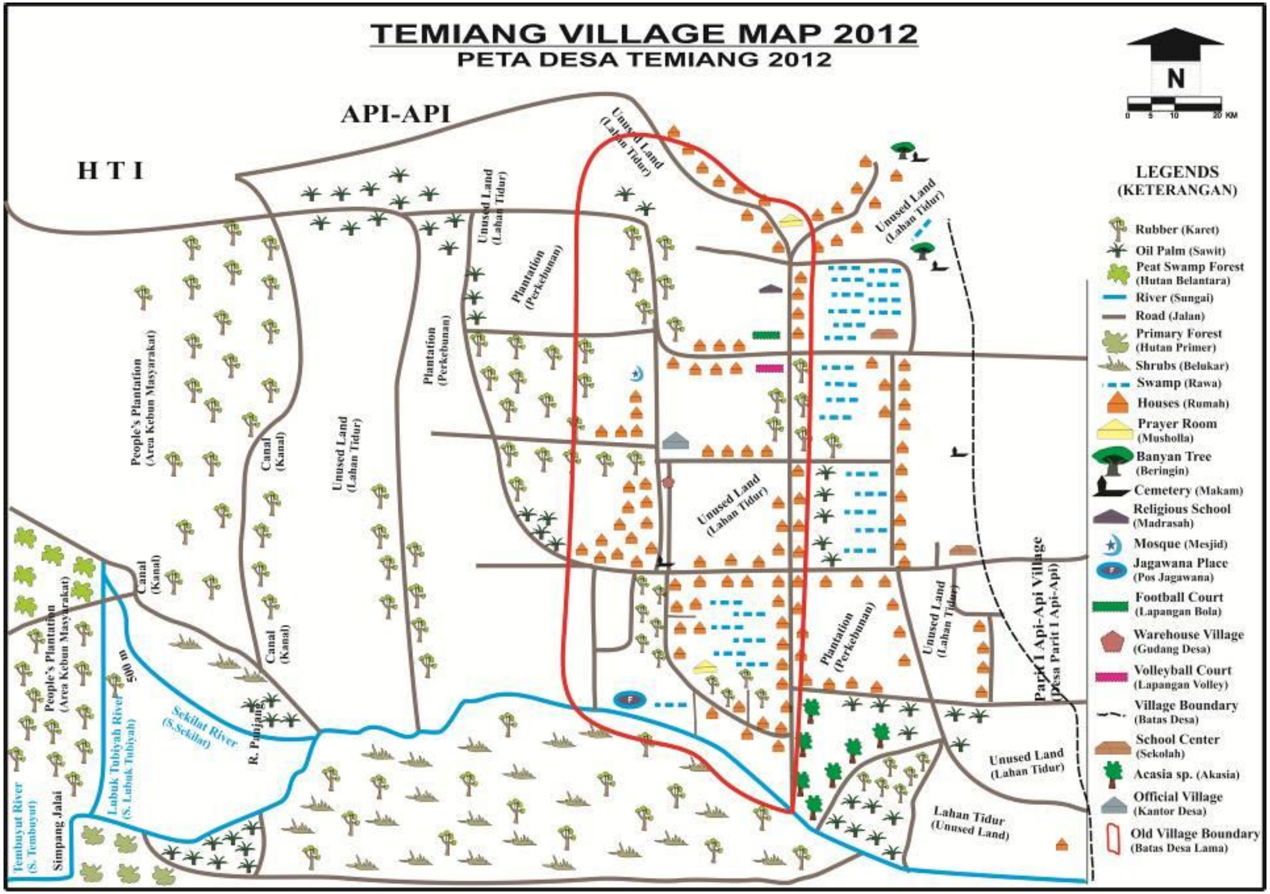


Figure 5. Temiang Village Map 2012 (sketched by Suhendra based on FGD)

Land use (LU) term entails the manner in which human beings employ the land and its resources (Ramachandra & Kumar, 2004 in Joshi & Priyanka 2011: 52). Land use changes are driven mainly by multi-scale driving forces including local societal preferences and practices (food, farming, livelihood etc.), the global economy, environmental conditions, land policies, various development programmes, and feedback between these factors, including past human activity on the land (Joshi & Priyanka 2011: 55). In general land use change has been the main driver of terrestrial biodiversity loss during the past century (Trisurat, Shrestha & Alkemade 2011: 2). Land use is a key human activity, which, through the exploitation of natural resources, fosters socio-economic development and alters structures and processes in the environment. Direct drivers of land use change are activities such as logging, cropland expansion, road building, and other types of infrastructure development (Tomich, et.al. in Ash 2010:88).

Based on the result of the Focus Group Discussion that we conducted, there are three types of land use in Temiang village; rubber, oil palm and, agricultural lands, forest areas, and village facilities (Figure 6). Apart from being used for agriculture and housing, land in Temiang village is also used for village facilities such as a mosque, football court, volleyball court, and also school. It can be seen in the map of 2012 (Figure 5).

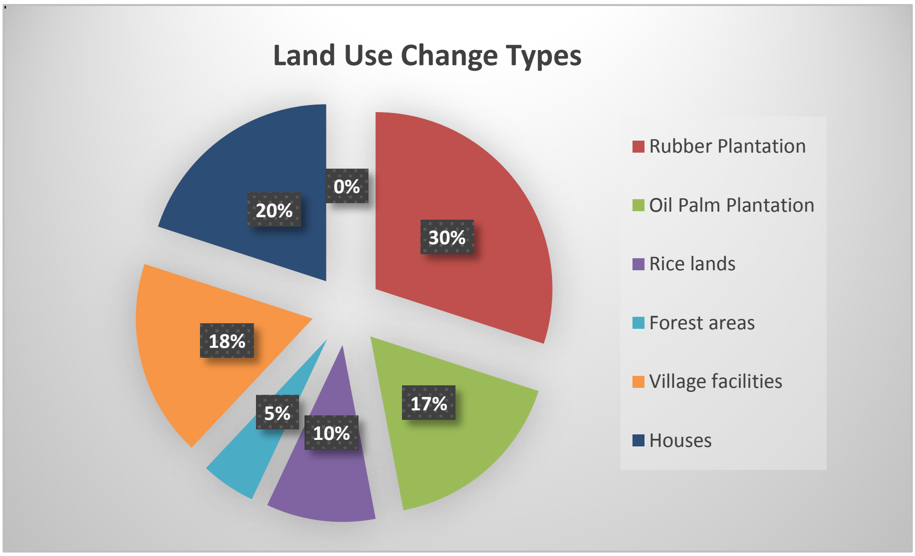


Figure 6. Graphic result of land use in Temiang Village in 2012

Land use in Temiang village is driven mainly by multi-scale driving forces including local societal preferences and practices (food, farming, livelihood etc.) such as rubber and oil palm plantations. Land use for rubber plantation is dominant in Temiang village. It also can be seen when the two maps of Temiang Village in 1980 and 2012 are compared (Figure 4 & Figure 5). In 1980 we can see that Temiang village consisted mostly of peat swamp forest (Figure 4). By 2012, the forest area was converted into rubber plantation (Figure 5). The opening of the land was not only to meet need for land but also for the value of selling timber. The entry of the plantation company in this area not only changed land use from natural forest to plantation but also triggered people to encroach the forest. The damage was uncontrollable. Change of land use in the region has an impact on the lives of local people; it also impacts climate change that has swept the world. The change of land use and loss of forests impact fisheries. Compared to 32 years ago, people have to go to further to find fish. Degradation of traditional values also happened. Unfortunately, changes in land use can lead to a number of environmental problems, including water scarcity, water pollution, soil erosion and biodiversity loss (personal communication, 2012)

Forest conversion is mainly due to the spread of agriculture (including plantations), urbanisation and mining exploration. Based on the village history, a plantation company had entered the area before 1945. This company had altered land use from forests to plantations. In the process of land clearing, the company did not pay attention to historical aspects and traditional land ownership. Even the boundary with the land owned by the company is traditionally one which is managed by the community as an area of their fields. From a map made by the company, it appears that the village is surrounded by large companies involved in plantations (Figure 7).

When the plantation first opened, there were conflicts between people and companies because the fields that people have traditionally used became the territory of the company. The presence of companies and land clearing do not only change the area but also the culture of the local people, especially related to ecosystem services. Medicinal plants, sacred sites, and a variety of cultural practices that were usually done are now rarely found, because the main factors in supporting culture (environment) has changed. Medicinal plants are hard to find, and gradually change to medical treatment. Rituals associated with land clearing, respect for tigers, and other rituals associated with the environment are now rare.
The other forces which drive land use changes in Temiang village are various development activities (agricultural programmes, road building, zoning, construction). Peoples' homes and road construction are part of land use changes that occurred in the Temiang village (Figure 5). Rubber and palm oil

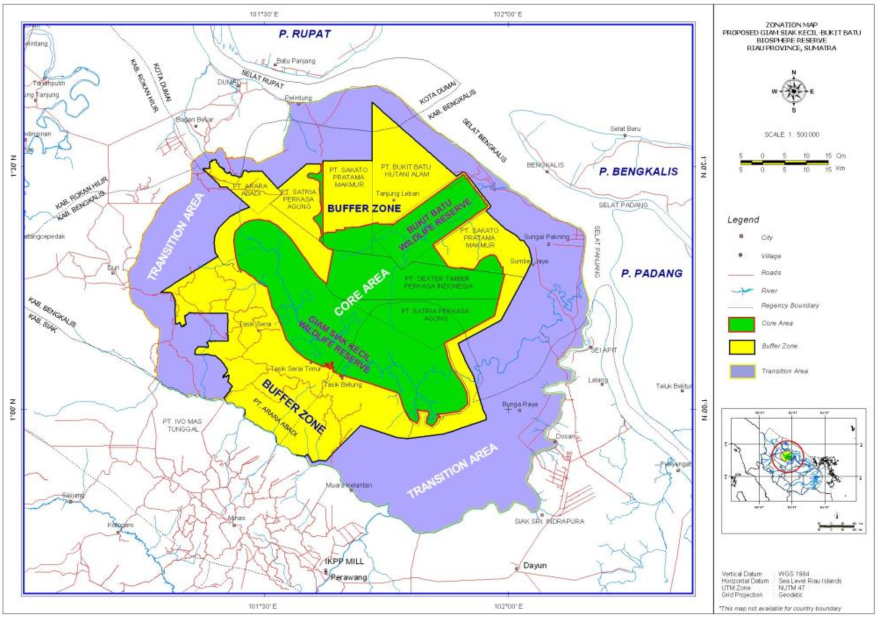


Figure 7. Map made by company described the village is surrounded by large companies

harvests need to be transported. Based on questionnaires; the road is now also more developed. It makes it easier for people to travel and transportation and infrastructure allows Temiang people to carry out activities in other regions and obtain a new lifestyle, such as the ownership of mobile phones. Mobile phones have became significant items in village of Temiang. This is the same case with television - the public wants to acquire more and information and this can be seen with the increasing number of people who have a television, and decline in the number of radios.

As a daily activity, agriculture is one of the factors of land use change. Over a period of 45 years from 1961 to 2006, growth of agricultural output (crop and livestock agriculture) in Indonesia was 3.6 per cent per annum; between 1968 and 1992 it was 4.8 per cent per annum (Booth et.al 2012: 52). Outside Java, the expansion of land under smallholder cultivation is the result of population growth leading to more land being used for food crops, and the growing world demand for a range of products including rubber, cocoa, palm oil, coffee, and spices, which has led to more land being brought under tree crop cultivation (Booth et.al 2012: 58). According to Anna Booth, apart from large estates, which now mainly produce palm oil, virtually all agricultural production in Indonesia is carried out by “smallholder” producers. The agricultural household is a household where at least one household member undertakes activities which produce agricultural output for the market or for exchange or which yield income or profit at the person's own risk (Booth et.al 2012: 61). Agricultural area expansion and transmigration had three effects on forest cover in the outer islands: forest was converted for agricultural and pressure was placed by the transmigrants on the land and forest managed by local people. In Temiang village, the community is no longer raising fish or relying on forests, but work in the agricultural sector.

The other factors that drive land use change is for more lucrative use for people, especially in areas which are close to growing urban areas. There is much cropland has been used for housing and village facilities which is also the result of population growth. In Temiang Village, housing is one of the land use changes that has happened. As we see in Figure 5, many houses were built around rubber plantations. Besides housing, people in Temiang village also build facilities (Figure 5) such as volley ball court, school, and religious facilities.

Discussion

One of services mostly affected by the land use change in Temiang village is provisioning services. Provisioning services are services in providing food, water, wood, and fiber (Ash, et.al, 2010: xi). In Temiang village, there are changes in terms of provisioning to water. With many forests turned into rice paddies; it is hard to get ground water. In terms of usage and water resources, people use water from rain and wells for cooking, farming, washing, and drinking. Rain water and wells become more widely used as a source of water for the community, which is one of the results of land use change. The loss of open areas reduced the absorption area, so that the community would have to find other sources of water. People in Temiang Village depend on ground water and rain water for their daily lives (Figure 8). For Temiang people, clean water is not too important; they are more concerned with practicality in obtaining water. Nowadays people prefer water gallons which are sold to homes, because they do not need to boil water for drinking.

One of the land-use changes that could affect people's behaviour in water resources acquisition is the development of oil palm plantations. The development of oil palm plantation area has a significant impact on the environment such as the decreasing availability of water. Palm oil plants need lots of water in the process of growth. The change of land use from natural forests to monoculture systems (oil palm) will change the balance of water in the region. Because of the mechanism of monoculture crops, either directly or indirectly, there is effect on water balance of land and water availability in the region.

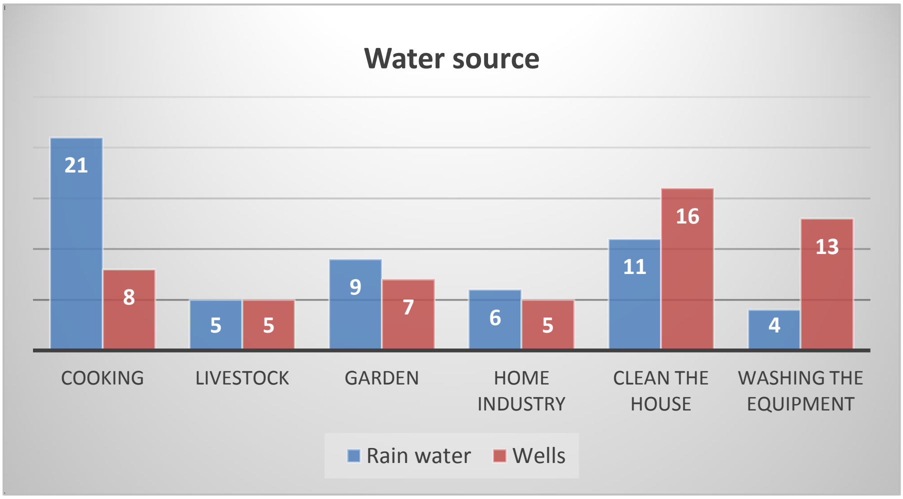


Figure 8. Graphic result of water management in Temiang Village in 2012

In addition to an effect on water, land-use changes also impact provisioning service in timber. Since the beginning, Temiang villagers use timber species such as meranti (*Shorea* sp.), punak (*Tetramerista glabra*), and ramin (*Baccaurea javanica*) in their daily lives. Based on the interview about the types of wood that are used now, ramin (*Baccaurea javanica*) is a type of wood that is very rarely used because it is hard to find. It is directly related with the effect on biodiversity. Generally biodiversity can be divided into three hierarchical categories - gene, species and ecosystems that describe different aspects of living organisms. In conjunction with this study, the category of biodiversity that has impact form land use change is species diversity. Species diversity refers to the variety of species within a region. It is the most commonly considered aspect of biological diversity. Basically species diversity can be measured in many ways, such as species richness and species diversity (Trisurat et.al 2011: 4). The simplest measure often used to describe biodiversity is 'species richness', i.e. the number of species found for a given area (Cochard 2011: 26).

Land use change in the Temiang village also gives effect on provisioning in food. Human security covers a wide range of issues including basic elements, such as food to eat, homes to live, good health, education, freedom from violence, safety during natural and human-caused disasters, democracy, good governance, and respect for human rights (Ravjanshi & Mathur 2010: 68). One of the factors responsible for hunger and poverty today is the unprecedented loss of biodiversity associated with ecological deterioration (Ravjanshi & Mathur 2010: 70).

According to interviews, people in Temiang village utilize cassava (*Manihot esculenta*) as a food supplement. Today besides cassava, palas (*Licuala spinosa* Thunb.) and galam also use as food supplements. Increasing variety of plants that can be used as supplements associated with increased knowledge of people about the species can be eaten. The arrival of migrants is part of the changing demographics of the population which can also lead to land use change in the region. The migrants would build their homes and open land for plantations to meet their basic needs. Many migrants who come to this village and bring knowledge from their native place are one of the factors of the increasing of the people knowledge about the utilization of plant as food.

Conclusions

Land use change in Temiang village gives effect to provisioning service in water, timber, food. The land uses in Temiang village are driven mainly by the development of rubber and oil palm plantations, agricultural programmes, road building, housing, village facilities, which are also the result of population growth and the arrival of migrants.

Acknowledgments

We would like to thank the project on Land Use Change which is a collaboration between LIPI-APN (Asia Pacific Network for Climate Change Research, grant number: ARCP2011-15NMY-Zhen). Without financial support from this project, this study would not be possible. Sincere thanks for Ms.Yayah who has identified the herbarium specimen from the field trip and the specimen from the local government that has been sent to our herbarium, Suhendra, who assisted with the village sketches, local people who helped with information and also elder people who shared information with us.

References

Ash N. 2010. *Ecosystems and human well-being: a manual for assessment practitioners*. Island Press.

Azapagic A. 2010. Life Cycle Assessment as a Tool for Sustainable Management of Ecosystem Services. In: Hester RE, Harrison RM (eds.) *Ecosystem Services* (Vol. 20). The Royal Society of Chemistry, Cambridge: 140-168

Booth A. 2012. The performance of the Indonesian agricultural sector: twelve questions and some tentative answers. *Land, Livelihood, the Economy and the Environment in Indonesia: Essays in Honour of Joan Hardjono*: 51-84

Byron I, Robert L. 2008. Spatial Methodologies for Integrating Social and Biophysical Data at a Regional or Catchment Scale. In: Richard J. Aspinall, Michael J. Hill (Eds.), *Land Use Change Science, Policy and Management*. CRC Press, Boca Raton: 43-61

Cochard R. 2011. Consequences of Deforestation and Climate Change on Biodiversity. In: Yongyut T, Rajendra P. Shrestha, Rob A. (Eds.). *Land Use, Climate Change and Biodiversity Modeling: Perspectives and Applications*. IGI Global, United States of America: 24-51

Joshi PK, Neena P. 2011. Geo-Informatics for Land Use and Biodiversity Studies. In: Yongyut T, Rajendra P. Shrestha, Rob A. (Eds.). *Land Use, Climate Change and Biodiversity Modeling: Perspectives and Applications*. IGI Global, United States of America: 52-77

***Profil Desa Temiang*. 2011.** Kecamatan Bukit Batu, Kabuaten Bengkalis, Propinsi Riau.

Trisurat et al. 2011. Linkage between Biodiversity, Land Use Informatics and Climate Change. In: Yongyut T, Rajendra P. Shrestha, Rob A. (Eds.). *Land Use, Climate Change and Biodiversity Modeling: Perspectives and Applications*. IGI Global, United States of America: 1-25

Journal of Tropical Biology and Conservation 14: 37-53, 2017 ISSN 1823-3902

Research Article

The Application of Citizen Science Approach in an Ichthyofaunal Survey at Tagal Sites in Upper Moyog River, Sabah, East Malaysia

Casey Ng Keat Chuan

Forever Sabah, HG01B Ground Floor, Hawaii Court Waikiki Condominium, Tanjung Aru 88100 Kota Kinabalu, Sabah, Malaysia
Corresponding author: casey@foreversabah.org

Abstract

This study explores and describes the effects of citizen science and the application of traditional ecological knowledge in data collection. A monthly survey of 10m transact were conducted in Kibunut Bawah and Notoruss tagal sites during the period of February to May 2016 to determine the fish species composition for setting the biological baselines for river monitoring purposes. A total of 279 individuals representing 8 species from 3 families were recorded and the dominant species was *Tor tambra*. Shannon Index of Diversity (H') in Kibunut Bawah and Notoruss was 0.747 and 0.825 respectively. Deeper waters were found to host higher abundance. Local participants' familiarity with local habitats and species were the key factors that influenced the sampling results. Some site observations and community responses are also discussed to guide future studies.

Keywords: Fish, *tagal*, citizen science, community-based, conservation

Received 20 June 2016
Reviewed 08 September 2016
Accepted 06 October 2016
Published 15 October 2017

Introduction

Traditional communities of Sabah have long recognized the perils of "tragedy of the commons" (Hardin, 1968). As a response, the *tagal* community-based conservation approach was conceived to ensure fish stock is not overfished in the rivers. Thus, through Section 58 of the Sabah Native Courts Rules of 1995 (Native Customary Law) and Sections 35, 36 and 37 of the Sabah Inland Fisheries and Aquaculture Enactment 2003, the *tagal* fish refugia system was introduced. Sometimes known as *managal* or *bombon* depending on local dialect, it aims to empower the local community to conserve and harvest fish stock from the *tagal* sites in a sustainable manner (Foo &Noor, 2012; Selvadurai, 2012; Halim et al., 2013). Section 35 recognizes indigenous practices for natural resource management and Sections 36-37 outline the Community Fisheries Zone framework to empower locally elected committees to manage *tagal* sites. Perpetrators who violate the *tagal* rulings can be penalized in accordance to the Sabah Native Courts Rules of 1995 (Native Customary Law).

A typical *tagal* site is demarcated by traffic light colours to depict the degree of prohibitions in *tagal* sites. Critical fish spawning grounds are designated as "red zone" while the "yellow zone" is allocated for periodical *buka tagal*, or a communal fish harvesting period, which is decided by the local *tagal* committee (Wong et al., 2009). There is no fishing restriction in the "green zone" but local communities usually forego this privilege to increase the fish population. Fishes acquired during *buka tagal*, usually a one day affair, are customarily divided equally among members of the local community.

In recent years, fish population is not only reduced by uncontrolled fishing, it is also affected by pollution in the rivers arising from human population growth and socio-economic activities. In Malaysia, 1,475,444 point sources of water pollution were identified by the Department of Environment (DOE, 2013) in 2013 alone. Left unchecked, there is a high possibility of *tagal* sites eventually losing their viability as refugia. Therefore, the process of fish diversity monitoring needs to be stepped up and it is timely that the local communities are included in the process. This can be attained by enriching the traditional *tagal* practice with modern scientific rigour based on the concept of citizen-science (Couvet et al., 2008; Dickinson et al., 2012).

The UK Environmental Observation Framework (UK-EOF) defines citizen science as a data collection exercise that involves local volunteers and it is expected to contribute to knowledge expansion of the natural environment (Tweddle et al., 2012). It is a valuable approach that combines research with environmental education for local communities who are involved in the study projects. The application of citizen science and participation of indigenous communities in conserving biodiversity is not new in Malaysia. It has been highlighted as early as 2004 (Nicholas & Lasimbang, 2004) and traditional ecological knowledge (TEK) (Berkes et al., 2000) is now widely practiced in fishery mapping and studies (Drew, 2005; MacLean et al., 2009). Naturally, local artisanal fishermen who exploit the species are the best informants. They are skilful assessors of fish composition and distribution patterns in relation to local hydrological variances. Without doubt, indigenous knowledge can enrich science and this study is inspired by such notions.

The Moyog River (5° 53' 59.8914", 116° 11' 29.544") is located at the western foothills of Crocker Range within the Penampang district that has a population of 122,388 (Department Of Statistics, 2010). Besides ichthyofaunal integrity, the river is selected based on its importance in supplying water to households, agriculture and industrial applications to nearby Kota Kinabalu city. Fish composition in Kibunut Bawah and Notoruss are expected to reflect the "best of what is left" (Karr, 1999). Therefore the objectives of this study are to generate a species list to set the biological baseline for river monitoring and to examine the implications of adopting citizen science and traditional ecological knowledge when collecting data in Moyog River.

Material and Methods

Prior to the study, a series of traditional *sumuku* sessions, or communal consultation gatherings, were carried out to ensure that free, prior and informed consent (FPIC) (FAO, 2014) were obtained from the villagers. Field data was collected by the selected artisanal fishermen and elders from the local communities between February and May in 2016 (covering a period of four months). They were chosen by showing them fish images and assessing whether they knew and could identify the species with vernacular names. Their responses indicating familiarity of fish habitats, seasonality and feeding guilds were also taken as traditional ecological knowledge competency. No two persons were spoken to at the same time to ensure one informant could not influence the answers of the other.

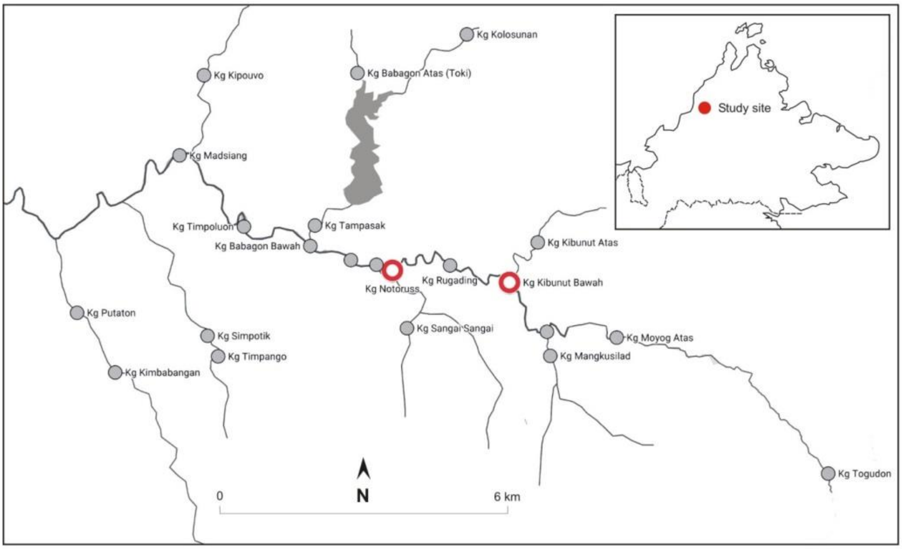


Figure 1. The study sites Notoruss and Kibunut Bawah and other *tagal* sites around them.

Sampling was supervised by the author and physically executed by selected locals during the day along 10m length transects at four locations in each *tagal* site on a monthly basis (Figure 1 & 2).

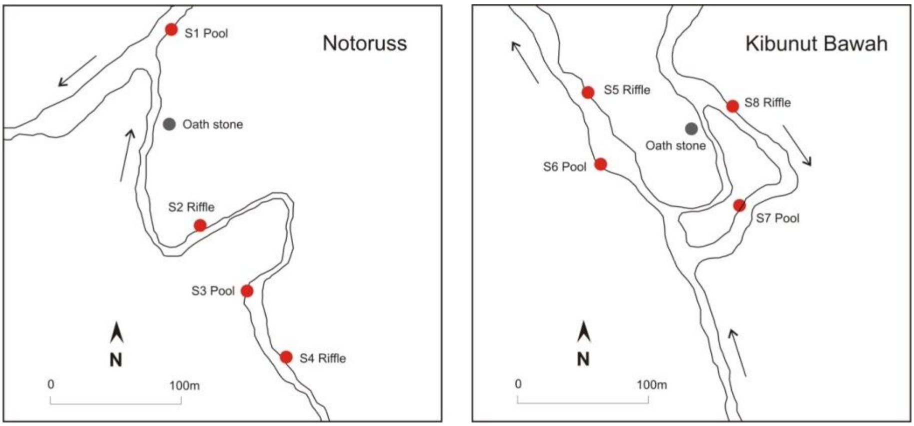


Figure 2. GPS coordinates of sampling transacts are as follow, S1= N 5° 53' 56.868", E 116° 11' 55.5714"; S2= N 5° 53' 48.2994", E 116° 11' 57.8034"; S3= N 5° 53' 45.636", E 116° 11' 59.2434"; S4= N 5° 53' 42.54", E 116° 12' 0.504"; S5= N 5° 53' 49.02", E 116° 13' 13.6194"; S6= N 5° 53' 47.076", E 116° 13' 14.484"; S7= N 5° 53' 46.1394", E 116° 13' 17.832"; S8= N 5° 53' 48.3354", E 116° 13' 17.04". Kibunut Bawah and Notoruss are located 124m and 98m above sea level respectively.

Sampling transacts in each *tagal* site were also stratified to two fast-turbulent unidirectional shallow riffles and two non-turbulent deeper pools to examine which hydraulic-habitat hosts a higher abundance. Respecting the *tagal* custom, non-depletive sampling practices were applied and specimens were released back to the river unharmed after assessment.

Only freshly caught adults with mature morphology were photographed to ensure that the natural colours and body patterns were recorded. Specimens were captured manually using 0.5m diameter round handnets (mesh size 5mm) and 2.5m diameter *rambat* (castnet mesh size 15mm). Publications by Martin-Smith & Tan (1998), Inger & Chin (1962), Tan (2006) and Ambak et al. (2012) were referred to when identifying specimens caught to species level, when possible. *Tagal* sites' hydrological characteristics were also mapped and documented to assist in result interpretation.

The Simpson index (D) is calculated as;

$$D = \Sigma p_i^2$$

where p_i is the faction of individuals corresponding to the *i*th species (Simpson, 1949). In this study, the Simpson index is expressed as 1-D to limit the value between 0 (poor) to 1 (excellent) to indicate diversity.

The Shannon index (H') is calculated as;

$$H' = -\Sigma p_i \ln p_i$$

where p_i is the ratio of individuals corresponding to the *i*th species (Shannon &Weaver,1949; Magurran, 2004).

Results and Discussion

A total of 288 individuals were caught representing eight species and three families. Food species *Tor tambra* is the dominant species in Kibunut Bawah and Notoruss (Table 1).

Table 1. List of species encountered during the study period. View appendix for images of specimens.

Family / Species	Kibunut Bawah	Notoruss
GASTROMYZONIDAE		
1. *Gastromyzon* cf. *introrsus*	13	23
CHANNIDAE		
2. *Channa striata*	0	4
CYPRINIDAE		
3. *Lobocheilos ovalis*	18	21
4. *Nematabramis borneensis*	3	7
5. *Paracrossochilus acerus*	4	27
6. *Barbodes sealei*	11	17
7. *Rasbora* cf. *rheophila*	25	26
8. *Tor tambra*	32	48
Total number of individuals	106	173
Relative abundance of *Tor tambra*	30.2%	27.7%
Simpson Diversity Index (1-D)	0.804	0.837
Shannon Diversity Index (H')	0.747	0.825
Pielou Evenness Index (J')	0.884	0.913

An independent sample t-test reveals there is a significant difference for abundance, $t(30) = 3.13$, $p = 0.004$, with Notoruss ($M = 10.44$, $SD = 4.13$) hosting a higher fish population than Kibunut Bawah ($M = 6.62$, $SD = 2.58$). As both sites are roughly just 2km apart, abundance data are combined and results show a mean population of 8.53 (n=32, $SD = 3.90$) per transect of 10m. This can be regarded as the population density of upper Moyog River based on the two *tagal* sites sampled.

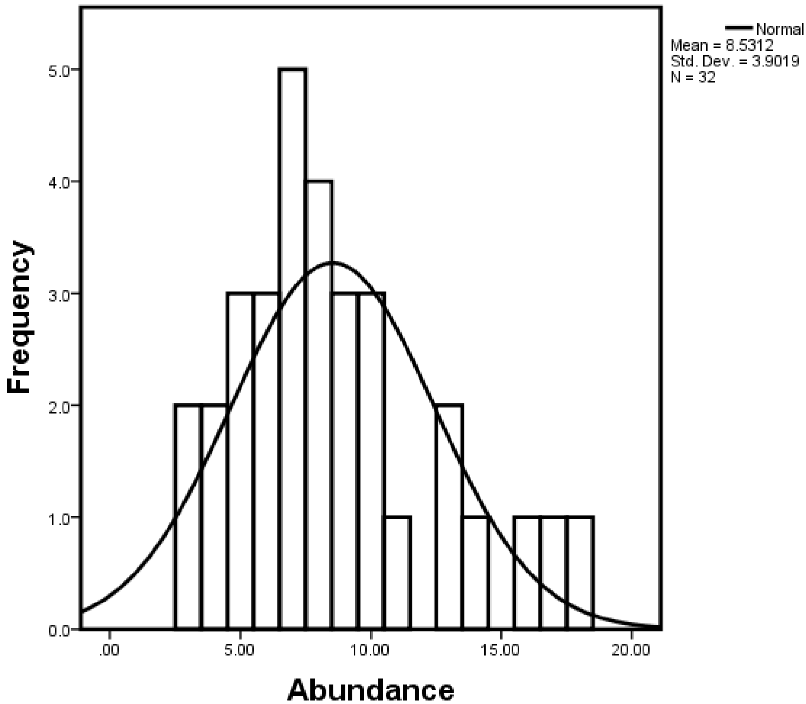


Figure 3. Histogram of combined abundance data of all species sampled in Kibunut Bawah and Notoruss.

Not surprisingly, the distribution curve is noticeably left-skewed (Figure 3). More low values were recorded and this was expected. In nature, tropical fishes are not evenly distributed for many reasons. Native species in small tributaries have evolved to be highly adaptable in their micro-habitats to prevent predation. It was observed that they tend to hide under rocks and underwater snags, especially the smaller species.

Fishes also gather in spots which provide more feeding opportunity. For example, frugivores will gather in waters underneath a fruiting tree that grows on the water edge. Therefore, the aggregating behaviours may skew the distribution curve and contradict with the fundamental of statistical analysis which generally calls for distribution homogeneity. Because it is by no means an easy task to capture the fishes, undoubtedly, here lies the advantage of adopting local community participation and traditional ecological knowledge. If it was not for the persistency and skills of locals in searching and capturing the fishes, the distribution curve would have been more left-skewed.

Correspondingly, it is often in such short-term exercises that the sampling results are possibly biased toward species that are bigger and easier to catch in open waters, for example *Tor tambra*. Because these are typically food species, locals have more relevant experience in finding their habitats and capturing them. Evidently, this shows that indigenous knowledge and species familiarity have an effect on fish assessment results. Additionally, nocturnal and benthic (which prefer crevices under rock, or with burrowing habit) species may be under-represented in this study.

Table 2. Data recorded in Notoruss

Month	Sampling point	Flow (m/s)	Depth (m)	Abundance (Number of individuals captured)
February	S1	0.76	1.89	14
	S2	1.48	0.45	7
	S3	0.55	2.22	18
	S4	1.68	0.54	6
March	S1	0.56	1.93	10
	S2	1.35	0.65	8
	S3	0.62	2.13	13
	S4	1.74	0.8	7
April	S1	0.71	2.2	10
	S2	1.64	0.73	8
	S3	0.34	2.5	17
	S4	1.52	0.65	6
May	S1	0.66	1.93	16
	S2	1.58	0.62	7
	S3	0.61	2.32	13
	S4	1.81	0.82	7

Table 3. Data recorded in Kibunut Bawah

Month	Sampling point	Flow (m/s)	Depth (m)	Abundance (Number of individuals captured)
February	S5	1.43	0.7	5
	S6	0.51	2.34	9
	S7	0.54	2.68	11
	S8	1.84	0.54	6
March	S5	1.24	0.67	4
	S6	0.64	1.93	8
	S7	0.52	2.12	10
	S8	1.64	0.58	5
April	S5	1.21	0.34	5
	S6	0.64	1.83	7
	S7	0.42	2.39	9
	S8	1.69	0.45	3
May	S5	1.63	0.64	3
	S6	0.61	1.83	9
	S7	0.68	2.12	8
	S8	1.74	0.72	4

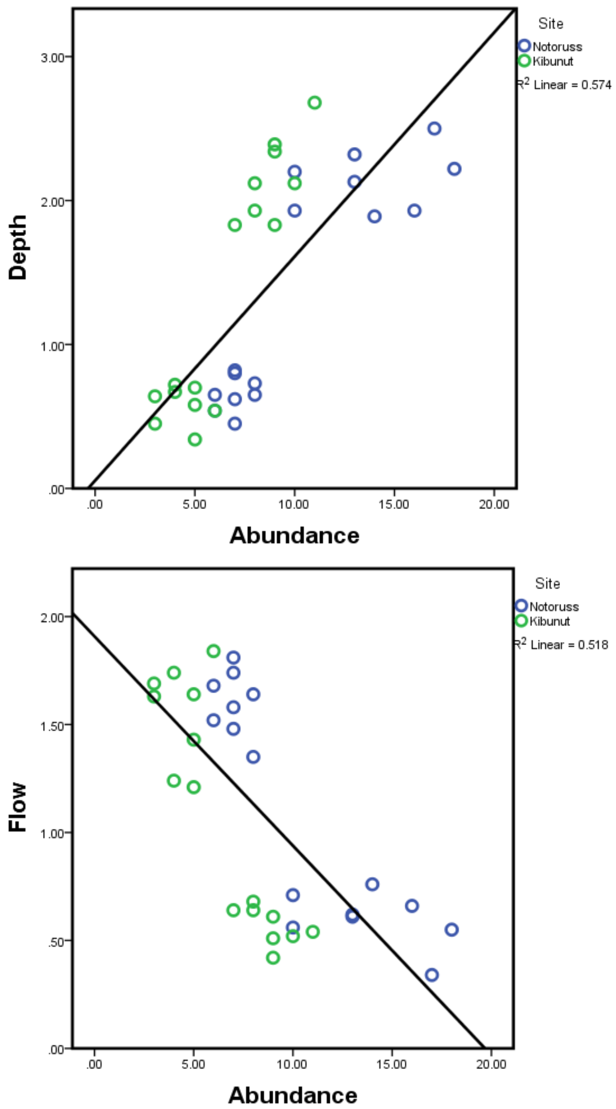


Figure 4. Two clusters are presented in the scatter plots to demonstrate correlation between abundance with river depth (m) and flow (m/s). This is expected because sampling points were intentionally stratified to two riffles and two pools in each sampling points for reasons explained in methods.

A Pearson product-moment correlation analysis was conducted between population abundance with river flow speed and depth. As shown on Figure 4, there is a strong positive correlation between abundance and depth (r = .758, n = 32, p < .001) and strong negative correlation between abundance and flow speed (r = -.720, n = 32, p < .001). Relationships showed linear trends and this implies that habitats with deeper and slower waters are more favourable in sustaining higher population. However, this study does not suggest that fast-turbulent shallow riffles should be excluded when assessing species inventory. In fact, riffles are a natural feature of most hillside rivers and Sabah is home to many torrent specialists such as *Gastromyzon* spp., *Protomyzon* spp. and *Paracrossochilus* spp. Riffles must be assessed to yield the best result to reflect species diversity of a particular site.

When interviewed and shown the results, Vitalis Galasun felt vindicated. He is the founder of the Notoruss *tagal* initiative in 1994, possibly the first formalized *tagal* site in Sabah. When the *tagal* scheme was first planned for Notoruss, he insisted that pool areas must be conserved as oral tradition dictates that deep pools are ecological refugia in times of monsoonal flooding. The move faced fierce opposition because pools were well known as the best fishing grounds. Local villagers perceived that such a move would reduce their fishing yield per effort. Eventually, traditional wisdom, and now empirical evidence, have shown everyone in the villages that their elders and forefathers were right. It is a best practice to designate pool areas for spawning and therefore a strictly non-fishing area (red zone) at *tagal* sites. This is consistent with many other studies which have found long held oral tradition embedded in indigenous society to be a plausible source of guidance for fishery conservation (UNESCO, 2007; Eicken, 2010; Berkes, 2012; Roy et al., 2012; Thornton & Maciejewski Scheer, 2012).

For the record, on 12th March 2016, Kibunut Bawah's *buka tagal* (a one-day open fishing event) yielded 168kg of fishes. Surprisingly, sampling results in the following month April 2016 did not show a substantial drop in abundance. Hydrologically, Kibunut Bawah is connected to upriver *tagal* sites of Kibunut Atas, Moyog Atas and Moyog Bawah. At downriver, Kibunut Bawah is connected to *tagal* sites of Notoruss and Tinopikon. Moreover, the Moyog River is interlinked with multiple tagal sites (Figure 1).

This implies that the Moyog ecohydrological unit has high integrity and allows a free flow of metapopulation dynamics to occur. When a site experiences depletion, the void is quickly repopulated by fishes from neighbouring *tagal* sites. This tells us that the speed of population recovery can be taken as a biology indicator for ichthyofaunal metapopulation rigour and resilience.

During the *buka tagal* event, locals interviewed also claimed that an eel with a distinctive mottled body pattern was encountered. This fits the description of *Anguilla marmorata* (Arai & Ryon, 2012). However, because the eel is not regarded as a food species, it was released without photographic records. This may warrant further investigation to ensure that the latest local fish checklist does not miss out any possible species.

The *Anguilla* genus consists of 18 species/subspecies and are all catadromous (Tesch, 1977; Aoyama, 2009). Although the adults live in freshwater, they migrate to spawning areas in the ocean. Juveniles grow up in stages in estuaries, mangroves and slowly make their way back to freshwater as adults. The coast is roughly 28km from Kibunut Bawah. If the eel was indeed *A. marmorata,* it raises the question of how the upper parts of Moyog River are still somehow ecologically linked to sea although a weir is present in Babagon Bawah (Figure 1). The Petagas-Putatan rivermouth is also considered polluted due to surrounding dense human settlement and would likely inhibit migration of catadromous species. Are *A. marmorata* specimens captured in March 2016 the last of their kind after the Babagon Bawah weir was constructed? Can the residual population be saved? Due to the awareness created from participating in this study, local communities are interested to keep a close watch on *A. marmorata* presence.

Other endemic species namely *Barbodes sealei, Nematabramis borneensis, Gastromyzon* cf. *introrsus* and *Lobocheilos ovalis* were also recorded in both *tagal* sites. When interviewed, locals did not know they were rare or endemic species. This was not surprising as the key motivation for *tagal* implementation in the villages was to conserve food species. Small and non-food species were typically overlooked. Owing to the short duration, this study is not exhaustive and the local community has plans to continue searching for more species to update their checklist. This includes organizing night searches to look for nocturnal species. Nets with finer mesh should also be used to capture smaller species.

Indeed, there were many insights that are interesting to science. More investigations are needed in the future as a follow up. As a spin off, the citizen-science approach has widened the local communities' perspective and managed to spur critical thinking. On the other hand, science has also learned and benefited from local traditional ecological knowledge. This is a desirable outcome because an ecology-friendly "collective thinking" within the communities and scientists is needed to create resilience to counter the perils of "tragedy of the commons". Locals who participated in this study are also beginning to appreciate the notion that the freshwater ecosystem and species composition should be interlinked and balanced. Big or small, rare or common, all species are important.

Conclusion

In line with the objectives outlined earlier, this study has produced a basic species inventory checklist with the application of citizen science. Subsequently, the study also revealed the advantages and issues in adopting citizen science. Although citizen science is a plausible tool for collecting data, it may not always be the best approach to take due to some biases as highlighted in this study. Data collected during the study can only be regarded as a preliminary baseline and it should be further supported with empirical study that includes the appropriate taxonomy and molecular analysis. Any absence or presence of species in the future can be used to indicate levels of integrity of the Moyog River system. Rivers and streams where we stand to lose the most aquatic biodiversity to anthropogenic pressure are currently under-researched in Sabah. It is hoped that this study will spark off a strong and continuous citizen-science movement to resolve the predicament. Traditional wisdom has vast potential and it should be further explored in a systematic manner to unearth more hidden knowledge. Certainly, questions arising from this study suggest that we still have much to learn.

Acknowledgements

The author is thankful to Shared Earth Foundation for funding this study. Special appreciation also goes to the Penampang District Office, Department of Fisheries (Penampang), Penampang Tagal Association, Kg Kibunut Bawah and Kg Notoruss tagal committees for the kind support and partnership. The author is especially grateful to Dr. Tan Heok Hui and the anonymous reviewers who have kindly assisted in improving the manuscript.

References

Ahmad A, Nek ASR, Ambak MA. 2006. Preliminary study on fish diversity of Ulu Tungud, Meliau Range, Sandakan, Sabah. *Journal of Sustainability Science and Management* **1(2):**21-26

Ambak MA, Mat Isa MM, Zakaria MZ, Ghaffar MA. 2012. *Fishes of Malaysia, 2nd edition*. Terengganu: Penerbit UMT

Aoyama J. 2009. Life History and Evolution of Migration in Catadromous Eels (Genus Anguilla). *Aqua-BioScience Monographs* **2(1):**1-42

Arai T, Siow R. 2013. First Documented Occurrence of the Giant Mottled Eel, *Anguilla marmorata* in Peninsular Malaysia, Malaysia. *World Applied Sciences Journal* **28 (11):**1514-1517

Berkes F, Coldings J, Folke C. 2000. Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications* **10:**1251-1262

Berkes F. 2012. Implementing ecosystem-based management: evolution or revolution? *Fish and Fisheries* **13:**465–476

Couvet D, Jiguet F, Julliard R, Levrel H, Teyssedre A. 2008. Enhancing citizen contributions to biodiversity science and public policy. *Interdisciplinary Science Reviews* **33(1):**95-103

Department of Environment, Malaysia 2013. *Environmental Quality Report 2013* [Online]. Available at: https://enviro.doe.gov.my/view.php?id=15791

Department Of Statistics, Malaysia 2010. *Population And Housing Census Of Malaysia.* Available at: https://www.statistics.gov.my/mycensus2010/images/stories/files/Laporan_Kiraan_Permulaan2010.pdf

Dickinson JL, Shirk J, Bonter D, Bonney R, Crain RL, Martin J, Phillips T, Purcell K. 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment.* **10(6):**291-297

Drew JA. 2005. Use of Traditional Ecological Knowledge in Marine Conservation. *Conservation Biology* **19:**1286-1293

Foo J, Noor HM. 2012. Local community respond to indigenous management of aquatic resources: The case of Tagal system. *Malaysia Journal of Society and Space* **8(2):**30-37

Food and Agriculture Organization of the United Nations, 2014. *Respecting free, prior and informed consent, Governance Of Tenure Technical Guide No. 3.* Rome: United Nations

Eicken H. 2010. Indigenous knowledge and sea ice science: What can we learn from indigenous ice users? *SIKU: Knowing our ice - documenting Inuit sea-ice knowledge and use*, New York: Springer

Halim AA, Jawan JA, Ismail SR, Othman N, Masnin MH. 2013. Traditional Knowledge and Environmental Conservation among Indigenous People in Ranau, Sabah. *Global Journal of Human-Social Science* **13(3)**

Hardin G. 1968. The Tragedy of the Commons. *Science, New Series* **162 (3859):**1243-1248

Inger RF, Chin PK. 1962. *The freshwater fishes of North Borneo*. Kota Kinabalu: Natural History Publications

Karr JR. 1999. Defining and measuring river health. *Freshwater Biology* **41:**221–234

MacLean M, Breeze H, Doherty P. 2009. Using Fish Harvesters' Local Ecological Knowledge (LEK) in Support of Identifying Ecologically and Biologically Significant Areas (EBSAs) on the Offshore Eastern Scotian Shelf. Oceans and Habitat Report 2009. *Fisheries and Oceans Canada*, Nova Scotia

Magurran A. 2004. *Measuring Biological Diversity*. Oxford: Blackwell Publishing Company

Martin-Smith KM, Tan HH. 1998. Diversity of freshwater fishes from eastern Sabah: annotated checklist for Danum Valley and a consideration of inter- and intra-catchment variability. *The Raffles Bulletin of Zoology* **46(2):**573-604

Ministry of Natural Resources and Environment, Malaysia. 2016. *Riparian Guideline* [Online]. Available at: http://www.nre.gov.my/ms-my/PustakaMedia/Penerbitan/National%20Policy%20on%20biological%20Diversity%202016-2025%20Brochure.pdf [Accessed: 24 May 2016]

Nicholas C, Lasimbang J. 2004. *Biodiversity And Indigenous Knowledge Systems In Malaysia*. Subang Jaya: Center for Orang Asli Concerns (COAC)

Roy HE, Pocock MJO, Preston CD, Roy DB, Savage J, Tweddle JC, Robinson LD. 2012. *Understanding Citizen Science & Environmental Monitoring. Final Report on behalf of UK-EOF*. NERC Centre for Ecology & Hydrology and Natural History Museum. UK Environmental Observation Framework

Shannon CE, Weaver W. 1949. *The mathematical theory of communication*. Illinois: University of Illinois Press

Simpson EH, 1949. Measurement of diversity. *Nature* 163-688

Tan HH. 2006. *The Borneo Suckers*. Kota Kinabalu: Natural History Publications

Tesch FW. 1977. *The Eel, Biology and Management of Anguillid Eel*s. London: Chapman & Hall

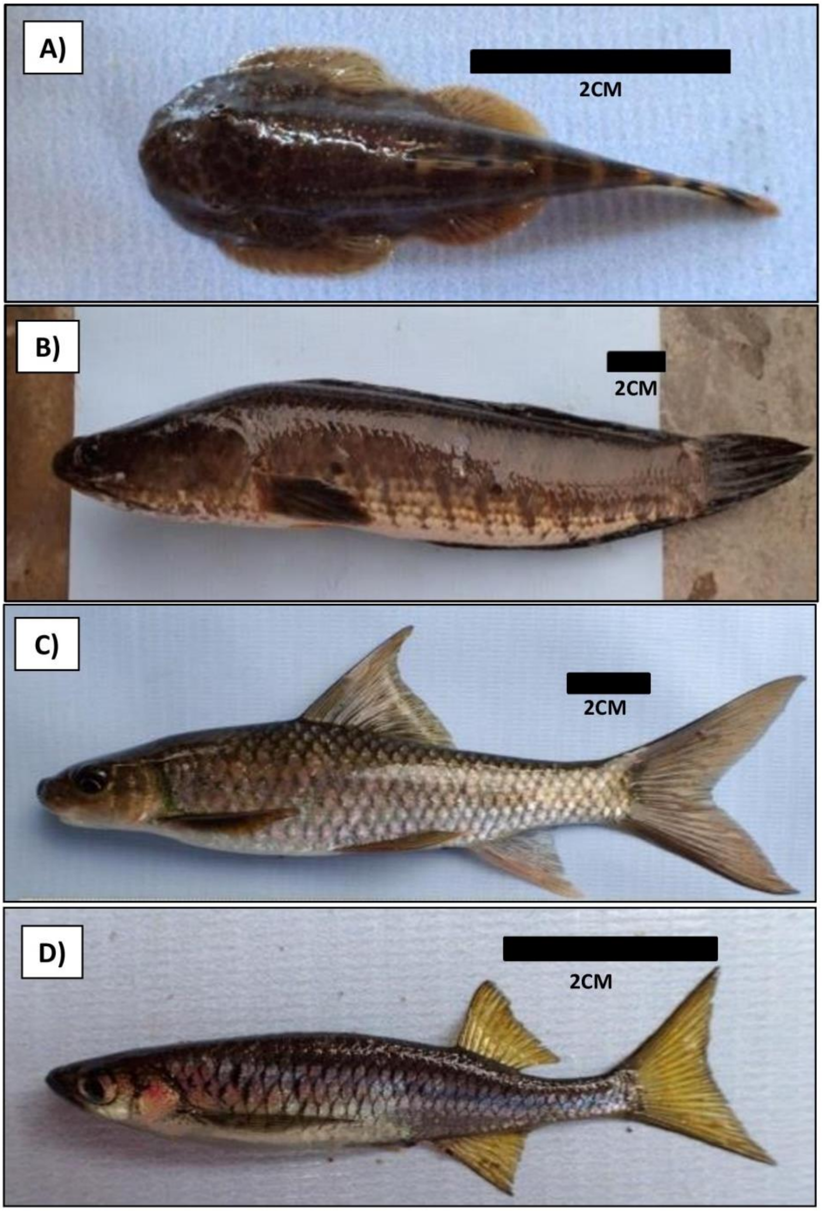
Thornton TF, Maciejewski Scheer A. 2012. Collaborative engagement of local and traditional knowledge and science in marine environments: A review. *Ecology and Society* **17(3):**8

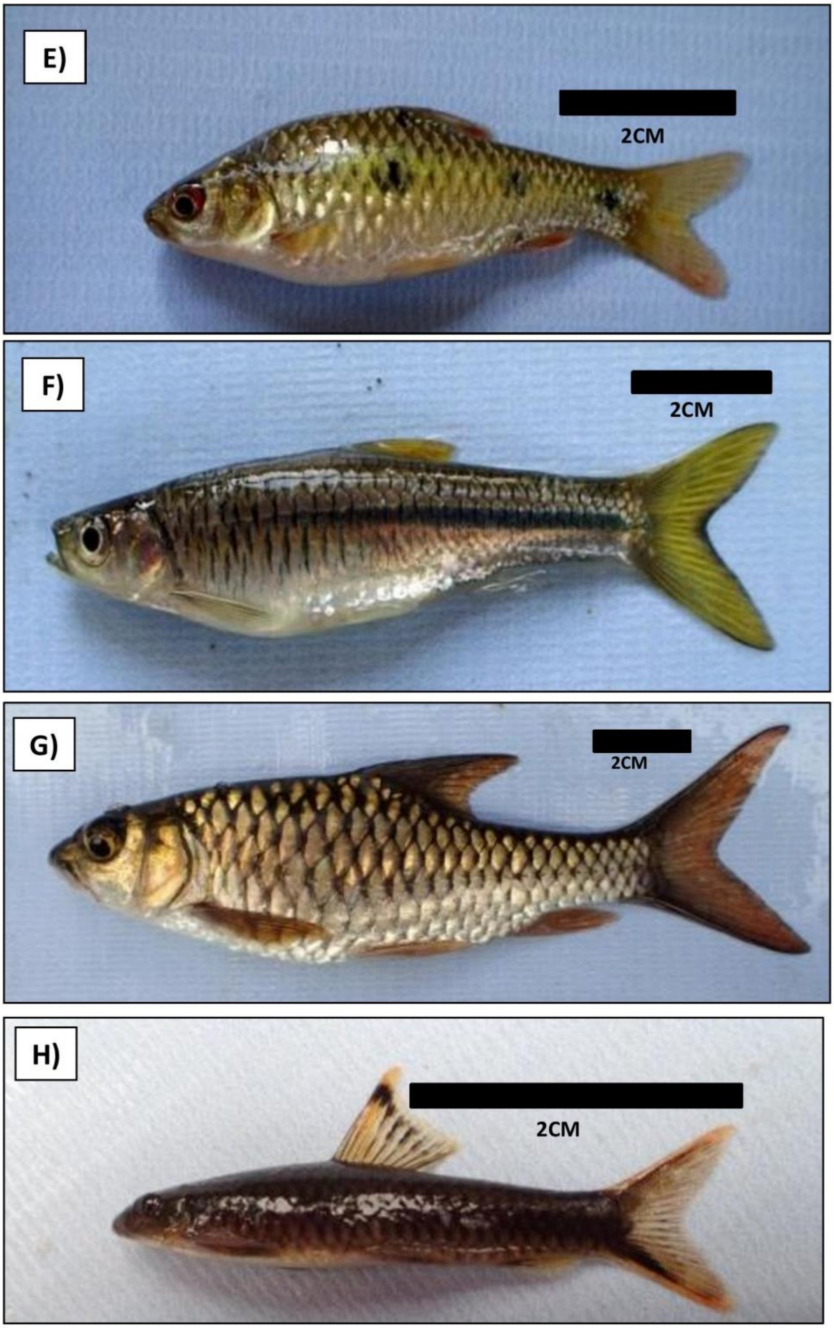
Tweddle JC, Robinson LD, Pocock MJO, Roy HE. 2012. *Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK*. Natural History Museum and NERC Centre for Ecology & Hydrology for UK-EOF

United Nations Educational, Scientific and Cultural Organization (UNESCO) 2007. *Fishers' Knowledge in Fisheries Science and Management*. Bonchamp-lès-Laval: UNESCO Publishing

Wong JZ, Etoh S, Sujang AB. 2009. Towards Sustainable Community-based Fishery Resources Management: The Tagal System of Sabah, Malaysia. *Fish For People*. Southeast Asian Fisheries Development Center. Available at: http://www.mahseertrust.org/downloads/Scientific_Publications/Wong%20et%20al%202009.pdf [Accessed: 8 September 2016]

Appendix





A) *Gastromyzon* cf. *introrsus* **B)** *Channa striata* **C)** *Lobocheilos ovalis*
D) *Nematabramis borneensis* **E)** *Barbodes sealei* **F)** *Rasbora* cf. *rheophila*
G)*Tor tambra* **H)** *Paracrossochilus acerus*

Journal of Tropical Biology and Conservation 14: 55–68, 2017 ISSN 1823-3902

Research Article

Notes on the genus *Chilocoristes* Weise (Coleoptera: Chrysomelidae: Alticinae) in Malaysia

Haruo Takizawa[1,2]

[1]*Nodai Research Institute, Tokyo University of Agriculture, Japan*
[2]*Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia*
Corresponding author: cpirka12@gmail.com

Abstract
The small Oriental genus of Chrysomelidae, *Chilocoristes* Weise, 1895 in Malaysia was studied. As a result, four new species: *Chilocoristes besar*, *C. justinahae*, *C. moyogensis* and *C. nigromarginatus* n. spp. are described from Sabah. A key to 12 known species occurring in Malaysia is provided.

Keywords: *Chilocoristes* Weise, Alticinae, Chrysomelidae, New species, Malaysia

Introduction
The small Oriental genus *Chilocoristes* was established by Weise in 1895 on the basis of *Argopistes bistripunctatus* Duvivier from India. The genus is easily distinguished by its body shape, which resembles the coccinelid genus *Chilocorus*, with strongly developed and vertical epipleura of the elytra. This alticine genus belongs to a group which has the third tarsal segment in its entire, not bi-lobed. Further characteristics defining *Chilocoristes* are: body ovate, smaller than 10 mm; vertex evenly convex, without deep furrows along eyes; eyes normal, widely separated; clypeus entire, not emarginate at anterior margin; maxillary palpi with 2 apical segments strongly incrassate; antennae with first segment long, sometimes as long as 2nd to 4th combined; elytral epipleura strongly developed and vertical; hind femora only incrassate; hind tarsi with 1st segment distinctly shorter than half the length of hind tibia; hind tibiae normal without acute process apically.

In recent years, Medvedev (1998, 2009, 2011) extensively studied this genus from the Oriental region. Mohamedsaid (2004) listed from Malaysia only 3 species of the genus, namely *Chilocoristes mohamedsaidi* Medvedev, *C. pallidus* (Baly) and *C. punctatus* Weise.

Received 13 September 2016
Reviewed 07 November 2016
Accepted 20 January 2017
Published 15 October 2017

Result and Discussion

During my survey of the leaf beetle fauna of Malaysia, I found 8 species of the genus from Borneo and 1 species from Peninsular Malaysia. A further 3 species were recorded from Malaysia, of which I could not examine the specimens. These 12 known species from Malaysia, including 4 new species, are treated in this paper. All the holotypes and a series of representative specimens will be deposited in the BORNEENSIS collection of the Institute of Tropical Biology and Conservation (IBTP), Universiti Malaysia Sabah, Kota Kinabalu, Sabah.

Figure 1. Habitus of *Chilocoristes* spp.: **1)** *C. besar* n. sp. (Holotype); **2)** *C. justinahae* n. sp. (Holotype); **3)** *C. mohamedsaidi* Medvedev (Lojing, Kelantan); **4)** *C. moyogensis* n. sp. (Holotype); **5)** *C. nigromarginatus* n. sp. (Holotype); **6)** *C. obscurus* Medvedev (Kinabalu Park, HQ, Sabah); **7)** *C. septemmaculatus* Chen (Kinabalu Park, HQ, Sabah); **8)** *C. trilineatus* Medvedev (Kinabalu Park, HQ, Sabah); **9)** *Chilocoristes* sp. nr. *thailandica* Medvedev (Mamut Mine, Sabah)

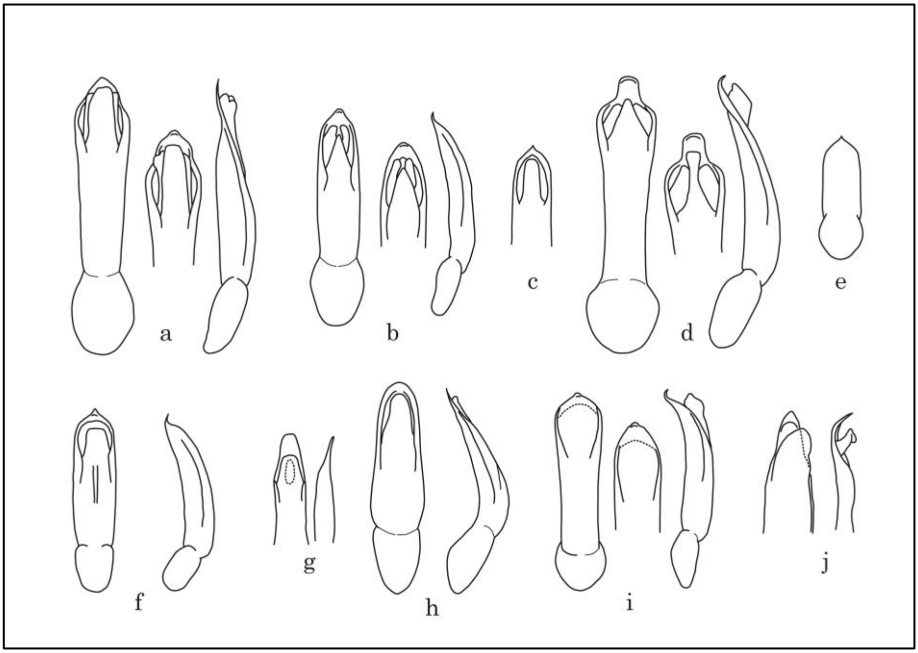


Figure 2. Aedeagus (left: dorsal view, middle: apical portion, right: lateral view) of: **a)** *Chilocoristes besar* n. sp. (Ulu Kimanis, Papar); **b)** *C. justinahae* n. sp. (Manggis subst., Ranau); **c)** *C. mohamedsaidi* Medvedev (after Medvedev, 1998); **d)** *C. moyogensis* n. sp. (Mamut Mine, Ranau); **e)** *C. obscurus* Medvedev (Kinabalu Park, HQ, Sabah); **f)** *C. pallidus* Baly (after Medvedev, 1998); **g)** *C. sabahensis* Medvedev (after Medvedev, 2011); **h)** *C. septemmaculatus* Chen (Kinabalu Park, HQ, Sabah); **i)** *C. trilineatus* Medvedev (Kinabalu Park, HQ, Sabah); **j)** *Chilocoristes* sp. nr. *thailandica* Medvedev (Mamut Mine, Sabah).
(a-j: on the same scale)

Descriptions

Chilocoristes besar n. sp. (Figures 1-1, 2a)

Male. Body large, ca. 5.0 mm; brownish red, with metathoracic sternum and antennae on 5 or 6 apical segments dark brownish red.

Head finely punctate; frontal tubercles strongly oblique, well demarcated on both anterior and posterior margins; clypeus with median carina and lateral edges obtusely raised; antennae widened on 7 apical segments; 1st segment slightly shorter than 2nd to 4th combined. Prothorax rather roundly narrowed anteriorly on lateral margins; disc densely covered with distinct large and small punctures, of which interspaces almost as wide as diameter of large punctures; both the anterior and posterior angles rounded. Elytra covered with large and small punctures, of which interspaces are distinctly wider than the diameter of large ones; large punctures with tendency to arrange themselves in longitudinal rows; lacking longitudinal rows of larger punctures near lateral margins. Fifth visible abdominal sternite weakly tri-lobed apically, and median longitudinal dark line weakly marked. Aedeagus gradually widened from subapical constriction to apical 1/6th, thence narrowed to rounded triangular apical process; ventral side with distinct longitudinal depression medially on apical 1/3; apical process straight in lateral view (Figure 2a).

Female. Body 5.0-6.0 mm; antennae with 1st segment distinctly shorter than 2nd to 4th combined; 5th visible abdominal sternite simply produced at posterior margin.

Holotype. Male, Ulu Kimanis substation, Papar, Sabah, Malaysia, 26-28.II.2010, H. Takizawa leg. (IBTP). Paratypes. 2♀, data same as the holotype; 1♀, Crocker Range Park, Headquarters*, Keningau, Sabah, 9.VIII.2008, H. Takizawa leg.; 1♀, Kg. Guramboi, Jln. Tambunan, Penampang, Sabah, 15.III.2009, H. Takizawa leg.; 1♂1♀, Muaya waterfall, Kg. Muaya, Sipitang, 7-9.III.2009, H. Takizawa leg. *Headquarters area

Host. *Smilax* sp. (Liliaceae).

Distribution. Borneo (Sabah).

Remarks. This species is similar to *C. pallidus* Baly (unspotted form), but is easily distinguished from the latter by the shape of the aedeagus, which is distinctly widened from the basal constriction to the subapical area.

The species is distinguished from similarly coloured *C. justinahae* and *moyogensis* n. spp. by the body being slightly larger, the pronotum roundly narrowed on the lateral margins, and the aedeagus straight at the apex in lateral view. The species is found feeding on leaves of *Smilax* sp. along trails in secondary forests at an altitude of 100 to 1,000m.

Its specific name comes from a Malay adjective meaning “large” which refers to its body size.

Chilocoristes justinahae n. sp. (Figures 1-2, 2b)

Male. Body small, ca. 4 mm; brownish red with antennae blackish brown on 6 apical segments.

Head with vertex finely punctate; frontal tubercles obliquely situated, with both the anterior and posterior margins well demarcated; clypeus narrowly triangular, with median and lateral edges narrowly keeled; antennae short, widened and thickly pubescent on apical 6 segments; 1st segment almost as long as 2nd to 4th combined; 4th weakly widened, shorter than 5th. Pronotum rather roundly narrowed anteriorly on lateral margins; posterior angles broadly rounded, anterior ones roundly thickened; disc densely punctate, with their interspaces narrower than diameter of punctures at median portion. Elytra densely covered with large and smaller punctures; larger punctures with tendency to arrange themselves longitudinally; two rows of punctures present below humerus along imaginary limits of expanded epipleuron; with distinct punctures near lateral margin; 5th visible abdominal sternite weakly produced at posterior margin, slightly depressed along median line. Aedeagus subparallel-sided, widened at sub-basal portion, gently narrowed on apical 1/5, broadly rounded at apex with roundly triangular apical process which is strongly curved upward (Figure 2b).

Female. Body ca. 4mm; similar to males; 5th visible abdominal sternite rather flat, gently arched on apical margin.

Holotype. Male, Manggis substation, Ranau, Sabah, Malaysia, 9-10.XII.2009, H. Takizawa leg. (IBTP). Paratypes: 1♂1♀, Poring Park, Ranau, Sabah, 29-30.IX.2007, H. Takizawa leg.

Host. Unknown.

Distribution. Borneo (Sabah).

Remarks. This smaller species looks like *C. punctatus* Weise from Borneo, but is easily distinguished from the latter by bi-coloured antennae. The species is characterized by a brownish red dorsum and by the subparallel-sided aedeagus. It was found, so far, at hills of 300 to 700m altitude. Its host plant is still unknown.

Its specific name is dedicated to Ms. Justinah Parantis, a researcher on butterflies, of the Poring Substation, Ranau, who accompanied me to the Manggis substation in December, 2009.

Chilocoristes mohamedsaidi Medvedev, 1998 (Figures 1-3, 2c)

Chilocoristes mohamedsaidi Medvedev, 1998, Russian Entomology Journal, 7: 151 (Malaysia: Pahang)

Body 3.8-4.5 mm; reddish, with head posteriorly, antennae, pronotum and legs black; vertex distinctly punctate; pronotum covered with moderately dense punctures; elytra confusedly punctate; aedeagus subparallel-sided, with apex ending in acute triangle (Figure 2c).

Specimens examined. 1 ex., Lojing, Gua Musang, Kelantan, Malaysia, 10.VII.2008, H. Takizawa leg.

Host. Unknown.

Distribution. Peninsular Malaysia (Pahang, Kelantan).

Remarks. On account of the dorsal colouration, this species is easily distinguished from other congeners of the genus. Medvedev (1998) gave a figure of the aedeagus.

Chilocoristes moyogensis n. sp. (Figures 1-4, 2d)

Male. Body 4.2-4.5 mm; brownish red with antennae on 6 apical segments black; metathoracic sternum dark brownish red.

Head smooth; frontal tubercles obliquely situated and well demarcated on both anterior and posterior margins; clypeus transversely triangular, rather short, weakly edged on lateral margins; antennae widened on 7 apical segments; 1st segment shorter than 2nd to 4th combined. Pronotum as in *C. justinahae* n. sp.; disc densely covered with large and smaller punctures; anterior angles round, posterior angles rounded but smaller; lateral margin straight. Elytra covered with large and smaller punctures; large punctures with weak tendencies to arrange themselves in longitudinal rows; 2 rows of large punctures present along imaginary limits of epipleuron; metathoracic sternum densely punctate, with weak transverse wrinkles medially; 5th visible abdominal sternite weakly tri-lobed, with dark brownish longitudinal line medially. Aedeagus gently widened posteriorly from sub-basal constriction, then almost subparallel-sided on apical half, widest before apex; apex strongly produced in subquadrate shape, with roundly triangular apical process, which is strongly curved upward at apex (Figure 2d).

Female. Body 4.0-5.0mm; similar to males; 5th visible abdominal sternite archedly produced at apical margin, without dark median longitudinal line.

Holotype. Male, Mamut Mine, Ranau, Sabah, Malaysia, 21.VII.2011, H. Takizawa leg. (IBTP). Paratypes. 1♀, Kg. Moyog, Jln. Tambunan, Penampang, Sabah, 3.V.2014, H. Takizawa leg.; 1♀, ditto, 8.V.2010, H. Takizawa leg.; 1♂1♀, Kundasang, Ranau, Sabah, 16.VIII.2008, H. Takizawa leg.

Host. *Smilax* sp. (Liliaceae).

Distribution. Borneo (Sabah).

Remarks. This reddish brown species, with the apical 7 antennal segments black, is closely similar to *C. pallidus* Baly (unspotted form), but is easily distinguished from the latter by the shape of the aedeagus with subquadrate apical process.

This species is similar to *C. justinahae* n. sp., but is slightly larger, with metathoracic sternum much more densely punctate, antennae with 1st segment shorter than 2nd to 4th combined. Furthermore, the aedeagus is differently shaped with distinct subquadrate apical process. The species is found feeding on leaves of *Smilax* sp. along trails in forest at 100-1,300m altitude.

Its specific name refers to one of the collected localities, Kg. Moyog near Donggongon, Penampang.

Chilocoristes nigromarginatus n. sp. (Figures 1-5)

Female. Body large, 5 mm; black with dirty yellow elytra which are margined with black; sutural and lateral margins rather widely black; antennae brown on four basal segments.

Head with narrow frontal carina not reaching anterior margin; vertex punctate; frontal tubercles obliquely situated; antennae widened on 7 apical segments. Pronotum evenly convex, densely covered with weak punctures, roundly narrowed from base to apex; both angles distinctly rounded. Elytra densely covered with weak punctures, with a row of strong punctures below humerus to basal 2/3; another widely spaced punctate row present in middle of lateral black margin. Abdomen with 5th visible sternite evenly arched at posterior margin.

Holotype. Female, Gunung Alab, Crocker Range Park, Tambunan, Sabah, Malaysia, 29.VII.2011, H. Takizawa leg. (IBTP).

Host. Unknown.

Distribution. Borneo (Sabah).

Remarks. This new species is uniquely characterized by its colouration, viz. black body with dirty yellowish elytra, which are margined with black. *C. trilineata* Medvedev from Sabah has elytra with black stripes at suture and laterally, but has frontal tubercles broader and situated less obliquely.

Its specific name refers to the colouration of elytra.

Chilocoristes obscurus Medvedev, 2011 (Figures 1-6, 2e)

Chilocoristes obscurus Medvedev, pp. 92 in Telnov (ed.) Biodiversity, Biogeography and Nature Conservation in Wallacea and New Guinea, Vol. 1 (Zoological Institute, St. Petersburg: Mt. Kinabalu, Sabah).

Body small, 2.5-3.5 mm; black, with antennae, legs and venter reddish brown; meso- and metasternum, and 1st abdominal segment partially blackish.

Head with antennal grooves well developed; antennae with 1st segment long, longer than 2nd to 4th segments combined; pronotum rather densely and finely punctate, almost straight on lateral margins; elytra with eleven regular rows of punctures, with interstices finely and sparsely punctulate; expanded lateral area with larger punctures; aedeagus subparallel-sided, gently narrowed distally on apical 1/8, with a small apical tooth, which is bent upward (Figure 2e).

Specimens examined. 1 ex., Kinabalu Park, HQ, Ranau, 20-24.II.2009, H. Takizawa leg.; 3 exs., ditto, 14.III.2012, H. Takizawa leg.; 6 exs., ditto, 23-25.III.2010, H. Takizawa leg.; 1 ex., 26.III.2016, H. Takizawa leg.; 2 exs., ditto, 2.V.2014, H. Takizawa leg.; 3 exs., 27-28.V.2008, H. Takizawa leg.; 1 ex., 13.VI.2010, H. Takizawa leg.; 2 exs., ditto, 8.VII.2010, H. Takizawa leg.; 1

ex., ditto, 20.VII.2011, H. Takizawa leg.; 2 exs., ditto, 19-20.VIII.2008, H. Takizawa leg.; 1 ex., ditto, 11.IX.2007, H. Takizawa leg.; 1 ex., ditto, 17-19.X.2008, H. Takizawa leg.; 1 ex., ditto, 28.IX.2008, H. Takizawa leg.; 1 ex., ditto, 7.XI.2015, H. Takizawa leg.; 2 exs., ditto, 16-17.XI.2007, H. Takizawa leg.; 2 exs., ditto, 15-16.XII.2014, H. Takizawa leg.; 1 ex., ditto, 23-24.XII.2008, H. Takizawa leg.; 1 ex., Gn. Alab, Crocker Range Park, Tambunan, 6.IV.2016, H. Takizawa leg.

Host. a species of undetermined fern.

Distribution. Borneo (Sabah).

Remarks. This small species is a montane species, feeding on a species of undetermined fern at the open understorey of undisturbed forest. Though the expanded and vertical epipleuron of elytra is suggestive of the present genus, its food plant is exceptional for this genus, of which members usually feed on *Smilax* spp. Elytra are also exceptionally furnished with regular punctate striae. Elytra with punctate striae and feeding on ferns are suggestive of an affinity to the genus *Schenklingia*. Furthermore, the antennae are a characteristic with the first segment longer than the three following combined. Thus, it may be better to place this species in the latter genus. The genus *Schenklingia*, however, is not well defined in regards to the Bornean species at present and will be the theme of another paper.

Chilocoristes punctatus Weise, 1895

Chilocoristes punctatus Weise, 1895, Deutsches entomologische Zeitschrift, 1895: 337 (Borneo)

Body including antennae wholly reddish yellow brown, ca. 4 mm; frontal tubercles well demarcated; pronotum densely covered with distinct small punctures; elytra with strong punctures in longitudinal rows, with interstices sparsely punctate.

Host. Unknown.

Distribution. Borneo, Philippines.

Remarks. No specimen was examined. The original description is somewhat vague with regard to the elytra, “die Fld. mit stärkeren, gereihten Punkten und in den großsen Zwischenräumen sparsam punktiert” [in German]. I am not sure whether this applies to the disc or the expanded area of elytra. However, the entirely yellowish brown antennae well characterizes this species.

Chilocoristes sabahensis Medvedev, 2011

Chilocoristes sabahensis Medvedev, 2011, pp. 92 in Telnov (ed.) Biodiversity, Biogeography and Nature Conservation in Wallacea and New Guinea, vol.1 (Mt. Kinabalu, Sabah).

Body small, ca. 3.2 mm; fulvous with five black spots on elytra; antennae black on 5th to 10th segments; elytra with a large subquadrate humeral spot, and with sutural spots on both elytra united, confusedly punctate, with 4 or 5 rather regular rows of punctures in outer part; aedeagus subparallel-sided and short, ending in a sharp triangular tooth (Figure 2g).
Host. unknown.
Distribution. Borneo (Sabah).
Remarks. This species was described on the basis of a single male specimen collected at Mt. Kinabalu. No specimen was examined by me. However, this species is well characterized by its fulvous body with 5 black spots on the elytra, especially by the disposition of large humeral spot.

Chilocoristes septemmaculatus Chen, 1934 (Figures 1-7, 2f)
Chilocoristes pallidus var. *septemmaculatus* Chen, 1934. Stylops 3(4): 73 (Quap, Sarawak); Medvedev, 2011, pp. 95, in Telnov (ed.) Biodiversity, Biogeography and Nature Conservation in Wallacea and New Guinea, vol. 1.
Body large, 4.5-5.5 mm; brownish red, with a pair of spots on pronotum, and 3 pairs of spots on elytra black; elytra with mid-lateral spots situated in line of sutural spots; antennae wholly reddish brown; thoracic sterna largely blackish to dark brown; abdomen more or less dark brown on median portion; sometimes dark area restricted to first and last visible sternites; fore and middle femora basally blackish brown, hind one largely blackish brown; antennae wholly reddish brown; aedeagus strongly curved in lateral view, subparallel-sided on apical half in dorsal view, with apex roundly produced; apex with minute tip curved upward (Figure 2h).
Specimens examined. 1 ex., Kinabalu Park, HQ, Ranau, Sabah, 22-23.I.2010, H. Takizawa leg.; 1 ex., ditto, 23.III.2010, H. Takizawa leg.; 1 ex., ditto, 25.III.2010, H. Takizawa leg.; 1 ex., ditto, 23-25.III.2010, H. Takizawa leg.; 1 ex., ditto, 2.IV.2016, H. Takizawa leg.; 3 exs., ditto, 8.VII.2010, H. Takizawa leg.; 3 exs., ditto, 20.VII.2011, H. Takizawa leg.; 1 ex., 15.XII.2014, H. Takizawa leg.; 3 exs., 23-24.XII, 2008, H. Takizawa leg.; 1 ex., Mesilau, Ranau, Sabah, 11.IX.2007, H. Takizawa leg.; 1 ex., Kundasang, Ranau, Sabah, 28.XII.2008, H. Takizawa leg.; 1 ex., Kg. Tarian – Inobong, Salt trail, Penampang, 14.XI.2009, H. Takizawa leg.
Host. *Smilax* sp. (Liliaceae).
Distribution. Borneo (Sabah).
Remarks. This species is closely similar to the maculated type of *C. pallidus*, but is distinguished from the latter by frontal tubercles weakly demarcated posteriorly, by much denser punctuation on elytra. Further the aedeagus is simply rounded at apex, and strongly curved in lateral view.

This seems to agree with *C. quinquemaculatus* (sensu Medvedev, 1998) from Java and Vietnam, especially in the disposition of elytral spots. The population in Sabah is characteristic, with sutural spots of the elytra always separated from each other, while the nominate form from Sarawak has both the sutural spots fused together. Nevertheless, the shape of its aedeagus agrees well with that of *quinquemaculatus* (sensu Medvedev). I tentatively treat the population in Sabah as *C. septemmaculatus* Chen. This species might prove to be identical with *quinquemaculatus* (sensu Medvedev), although Weise's *quinquemaculatus* is characterized according to the original description by 5 black spots on the dorsum, viz. 2 basal ones on the pronotum and 3 more arranged in a single row on the elytra. Its relation to the present species remains unclear.

This is a montane species, collected at Kinabalu Park, Headquaters area (1500-1800m altitude), Kundasang (1300m), Mesilau (1700-1800m) and Gunung Alab (1600-1700m), but also collected at the Kg. Tarian – Inobong area of the Crocker Range Park (500-600m). The species was found feeding on leaves of *Smilax* sp. at Kinabalu Park and Gunung Alab.

Chen described another taxon from Sarawak in 1934, *Chilocoristes pallidus* var. *nigrofasciatus* Chen, which is characterized by a spot and a longitudinal stripe on each elytron. Medvedev (2011) suggested that it may be a good species. Since I have never seen such specimens, I refrain from giving any decision on its status.

C. pallidus Baly was cited in the list of Mohamedsaid from Borneo, based on these two varieties. Though this species does not actually occur in Borneo, a figure of the aedeagus is shown for the sake of reference (Figure 2f).

Chilocoristes trilineatus Medvedev, 2007 (Figures 1-8, 2i)

Chilocoristes trilineatus Medvedev, 2007, Stuttgarter Beiträge zur Naturkunde, Serie A, No. 702: 14 (Sapulut, Sabah)

Male. Body large, 4.2-5.0mm; yellowish brown; antennae blackish brown on 3rd to 9th segments, yellowish white on 2 apical segments; elytra with 3 black narrow stripes, common sutural one reaching apex, lateral one occupying 2 or 3 lateral longitudinal punctate striae not reaching apical margin; tibiae and tarsi infuscate.

Head with frontal tubercles rather transverse and convex; frontal carina indistinct anteriorly; clypeus distinctly granulate; antennae rather slender, almost half as long as body. Pronotum almost impunctate, roundly narrowed anteriorly on lateral margins; anterior angles broadly rounded; the posterior obscure. Elytra finely punctate, with 3 punctate-striae laterally, starting below humerus, not reaching apical 1/3rd. Aedeagus gently narrowed from base, subparallel-sided medially, gently narrowed on apical 1/4 to obtuse apex; apex with a small tooth which is acutely curved upward (Figure 2i).

Female. Body 4.5-5.5 mm; last visible abdominal sternite rather flat, with apical margin rather straight medially.

Specimens examined. 1 ex., Peak, 26 km to Keningau, Jln. Kimanis, Papar, Sabah, 24.III.2012, H. Takizawa leg.; 1 ex., ditto, 24.VIII.2013, H.Takizawa leg.; 1 ex., ditto, 5.XII.2014, H. Takizawa leg.; 1 ex., Gunung Alab, Crocker Range Park, Tambunan, Sabah, 15-16.I.2008, H. Takizawa leg.; 1 ex., ditto, 21-23.III.2010, H. Takizawa leg.; 1 ex., ditto, 25.V.2008, H. Takizawa leg.; 2 exs., ditto, 17.VI.2007, H. Takizawa leg.; 1 ex., ditto, 8.VII.2010, H. Takizawa leg.; 2 exs., ditto, 18.VIII.2007, H. Takizawa leg.; 1 ex., Bundu Tuhan, Kundasang, Ranau, Sabah, 17.I.2007, H. Takizawa leg.; 1 ex., Kinabalu Park, HQ, Ranau, Sabah, 18-20,23.I.2008, H. Takizawa leg.; 2 exs., ditto, 1.II.2010, H. Takizawa leg.; 1 ex., ditto, 20-26.II.2009, H. Takizawa leg.; 3 exs., ditto, 31.III-1.IV.2016, H. Takizawa leg.; 1 ex., ditto, 23-25.VII.2008, H. Takizawa leg.; 1 ex., ditto, 27.VII.2007, H. Takizawa leg.; 2 exs., 19-20.VIII.2008, H. Takizawa leg.; 1 ex., ditto, 27.IX.2007, H. Takizawa leg.; 2 exs., Mesilau, Kundasang, Ranau, Sabah, 11.IX.2007, H. Takizawa leg.

Host. *Smilax* sp. (Liliaceae).

Distribution. Borneo (Sabah).

Remarks. This species is uniquely characterized by its dorsal colouration, that is, yellowish brown body with 3 black stripes on elytra. This is, too, a montane species and is so far collected at Kg. Bundu Tuhan (1200-1300m), 26 km peak, Jln. Kimanis (1300m), Gunung Alab (1600-1900m), Mesilau (1600-1800m) and Kinabalu Park, Headquarters area (1600-1800m). Beetles are found feeding on leaves of *Smilax* sp. in the understorey of undisturbed forests almost year round.

Chilocoristes sp. near *thailandicus* Medvedev (Figures 1-9, 2j)

Male. Body large, ca. 5 mm; brownish red, with a pair of black spots on pronotum and 3 pairs of black spots on elytra; metathoracic sternum dark brown; antennae, abdomen and legs reddish brown.

Frontal tubercles well demarcated on both anterior and posterior margins; elytra with mid-lateral black spots distinctly behind the level of anterior margin of sutural spots; aedeagus weakly curved in lateral view, with apex produced and strongly curved upward in shape of obtuse triangle (Figure 2j).

Female. Unknown.

Specimens examined. 1 ex., Mamut Mine, Ranau, Sabah, 21.VII.2011, H. Takizawa leg.

Host. Unknown.

Distribution. Borneo (Sabah).

Remarks. This species is very close to *C. thailandicus* Medvedev, but the pronotum is rather weakly rounded on the lateral margins. Its aedeagus is strongly curved upwards at the apex. Since the single specimen examined is teneral with its aedeagus distorted, I refrain from identifying this specimen until I examine further material.

This species is also similar to *C. septemmaculatus* Chen in colouration, but is clearly distinguished from the latter by the frontal tubercles which are well demarcated, elytra with different position of lateral spots and by the aedeagus being strongly and broadly curved upward at apex.

Conclusion

In conclusion, the 12 known species of the genus *Chilocoristes* from Malaysia are distinguished by the following key.

Key to Malaysian species of the genus *Chilocoristes* Weise

1. Elytra confusedly punctate; yellowish to reddish brown, sometimes with black spots, stripes or margins ---------- 2

- Elytra regularly punctate-striate; body black with abdomen, antennae and legs reddish brown --------- *Chilocoristes obscurus* Medvedev

2.Body largely yellowish to reddish brown, with/without black markings ---------- 3

- Body black; yellowish elytra narrowly margined with black ---------- *Chilocoristes nigromarginatus* n. sp.

3. Elytra with black markings ---------- 4

- Elytra without black markings ---------- 8

4. Elytra with three longitudinal black stripes; aedeagus as in Fig. 2i ---------- *Chilocoristes trilineatus* Medvedev

- Elytra with black spots ---------- 5

5.Elytra with a median spot and a black stripe ---------- *Chilocoristes pallidus* var. *nigrofasciatus* Chen

Elytra with black spots only ---------- 6

6.Elytra with 5 black spots; antero-lateral spot situated at humeral area; sutural spots on both elytra fused into a common large spot; pronotum without black markings ------------------------------------ *Chilocoristes sabahensis* Medvedev

- Elytra each with 3 black spots; sutural spots generally separated from each other; pronotum with 2 black spots -- 7

7. Elytra densely punctate, with mid-lateral spots situated in line of sutural spots; aedeagus round at apex as in Fig. 2h ------------------------------------ *Chilocoristes septemmaculatus* Chen

- Elytra sparsely punctate, with mid-lateral spots situated distinctly behind the level of sutural ones; aedeagus with apical process curved upward as in Fig. 2j -- *Chilocoristes* sp. near *thailandicus* Medvedev

8. Pronotum and head posteriorly black; elytra largely red with lateral margin infuscate; frontal carina not reaching to anterior margin ------------------------ *Chilocoristes mohamedsaidi* Medvedev

- Pronotum and head yellowish to reddish brown -- 9

9. Antennae dark to blackish brown on apical 4 or 6 segments --- 10

-Antennae entirely yellowish brown ------------------------ *Chilocoristes punctatus* Weise

10.Pronotum rather straightly narrowed anteriorly on lateral margins; aedeagus widened to apex, with subquadrate apical process as in Fig. 2d ------------ *Chilocoristes moyogensis*, n. sp.

-Pronotum roundly narrowed anteriorly on lateral margins --- 11

11. Body slightly larger, 5mm in length; aedeagus gently widened to apical 1/6th as in Fig. 2a -------------------- *Chilocoristes besar*, n. sp.

-Body smaller, 4mm in length; aedeagus subparallel-sided as in Fig. 2b ------------------------------ *Chilocoristes justinahae* n. sp.

Acknowledgement

This work was started at the Institute of Tropical Biology and Conservation, Universiti Malaysia Sabah, where I stayed for almost 3 years as a volunteer researcher sent by Japan International Cooperation Agency (JICA). I wish to express my sincere thanks for the authorities of both the organizations. I am also deeply indebted to Dr. L. N. Medvedev in Moscow, who kindly gave suggestions on taxonomy of the genus.

References

Baly JS. 1876. Descriptions of new genera and species of Galerucidae. *Entomologist's Monthly Magazine* **13:** 224-227

Chen SH. 1934. On some species of Chrysomelidae (COL.) in the British Museum. *Stylops* **3:** 66-78

Medvedev LN. 1998. To the knowledge of Oriental Alticinae (Coleoptera, Chrysomelidae). Genera *Euphitrea* Baly, 1875, *Chilocoristes* Weise, 1895, *Pentamesa* Harold, 1876, and *Maulikia* Basu & Sengupta, 1980. *Russian Entomology Journal* **7(3-4):** 147-156

Medvedev LN. 2007. New and poorly known Oriental Chrysomelidae (Coleoptera) of the Staatliches Museum für Naturkunde, Stuttgart. *Stuttgarter Beiträge zur Naturkunde, Serie A* **No. 702:** 1-19

Medvedev LN. 2009. Alticinae of Indochina, 224 pp. KMK Scientific Press, Moscow.

Medvedev LN. 2011. New species of Alticinae (Coleoptera: Chrysomelidae) from insular systems of SE Asia, in Telnov, D. ed. Biodiversity, Biogeography and Nature Conservation in Wallacea and New Guinea, vol. 1: 89-95.

Mohamedsaid MS. 2004. *Catalogue of the Malaysian Chrysomelidae (Insecta: Coleoptera*). 239 pp., Pensoft, Sofia-Moscow.

Weise J. 1895. Neue Chrysomeliden. *Deutsches entomologische Zeitschrift,* **1895:**327-352

Journal of Tropical Biology and Conservation 14: 69-81, 2017 ISSN 1823-3902

Research Article

Seasonal variation of temperature dependent physico-chemical parameters of a coastal River Bhadra, Bangladesh

Mosummath Hosna Ara*, Md. Nazim Uddin, Subhas Chandra Sarkar, Uttom Kumar

Chemistry Discipline, Khulna University, Khulna, Bangladesh
*Corresponding author: hosnaara1@gmail.com

Abstract

This analysis observed the seasonal variation in the temperature dependent physico-chemical parameters [pH, Transparency, Salinity, Electrical conductivity (EC), Total Dissolved Solid (TDS), Total Alkalinity, Total Acidity, Dissolved Oxygen (DO) and Free Dissolved CO_2] of surface water in a coastal river in Bangladesh. Composite samples from four different sampling points that considered high and low tides were collected and analyzed in three main consecutive seasons: rainy, winter and summer. The study has revealed that most physico-chemical parameters are not a serious problem for Bhadra River eco-system and water quality shows significant seasonal changes. The statistical analysis unveiled a positive correlation of temperature with pH, Transparency, Salinity, EC, TDS, Total Alkalinity, Total Acidity and Free Dissolved CO_2 but only negative correlation with DO.

Keywords: Bhadra River, physico-chemical, water quality and Statistical analysis.

Introduction

Water is undoubtedly the most precious natural resource that exists on the planet. It is the most valuable and vital resource for sustenance of life and also for any development activity (Kumar et al., 2010). Temperature is an important factor to consider when assessing water quality. In addition to its own effects, temperature influences several parameters and can alter the physical and chemical properties of water. These influencing parameters are called temperature correlated parameters (Wilde, 2006). Such as pH, Transparency, Salinity, EC, TDS, Total Alkalinity, Total Acidity, DO and Free Dissolved CO_2. Water temperature can affect the metabolic rates and biological activity of aquatic organisms (Wetzel, 2001). For most fishes, a 10°C increase in water temperature will approximately double the rate of physiological function (Bais et al., 1992). Increased metabolic function can be noticed in respiration rates and in digestive responses in most species.

Received 02 November 2016
Reviewed 18 June 2017
Accepted 10 July 2017
Published 15 October 2017

Increased respiration rates at higher temperatures lead to increased oxygen consumption, which can be detrimental if rates remain raised for an extended period of time. Furthermore, temperatures above 35°C can begin to denature or breakdown enzymes, reducing metabolic function (Pearson Education, 2011). Temperature fluctuations can affect the behaviour choices of aquatic organisms, such as these moving to warmer or cooler water after feeding, predator-prey responses and resting or migrating routines (Bais et al., 1992). Plants are also affected by water temperature. Temperature can also inhibit plant respiration and photosynthesis. In general, algal photosynthesis will increase with temperature, though different species will have different temperatures for optimum photosynthetic activity (Wetzel, 1975).

Bangladesh is a land of rivers. Around 230 rivers flow in the country including 53 international rivers. Bhadra River is one of the most important rivers of the river system network across the coastal belt of Khulna, Bangladesh. The River Bhadra is a very old river, which flows through Batiaghata upazila and separates “Zolma” union from Batiaghata. It starts from Solmari River and finally flows into the Salta. The river has several tributaries and adjacent villages. This makes the geographical location of this river very significant apart from the ecological perspective. People use land for various purposes. Due to these activities, water characteristics can be influenced through agricultural runoff and other unwanted wastes. Moreover, assessment of water quality in a region is an important aspect of developmental activities, as rivers are used for water supply to domestic, industrial and agricultural purposes (Jackher & Rawat, 2003). Keeping these aspects in mind, the present study was designed to investigate seasonal variation of water quality, which could adversely affect plants and animals, including aquatic habitat in Bhadra River, Khulna.

Methodology

Study area:

Bangladesh has a tropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures, and high humidity. Regional climatic differences in this flat country are minor. Three seasons are generally recognized: a hot, muggy summer from March to June; a hot, humid and rainy season from June to November, about 80 % of Bangladesh's rain falls during the rainy season; and a warm-hot, dry winter from December to February. In general, summer records the highest temperature and while the lowest temperature is in the winter season (The Washington Post, 2015). The study area, Bhadra River, is located in the Southwest part of Bangladesh and within 22°38'50.3" to 22°45'55.6" North latitude and 89°25'56.6" to 89°28'19.0" East longitude (figure 1). The Southwest coastal region is the most disaster-prone area in Bangladesh and is very vulnerable to the effects of climate change. The region is part of an inactive delta of large Himalayan rivers and is protected from tidal surge by the Sundarban mangrove forest. Cyclones, tidal surges, floods, repeated water-logging and land subsidence are common in this part of Bangladesh.

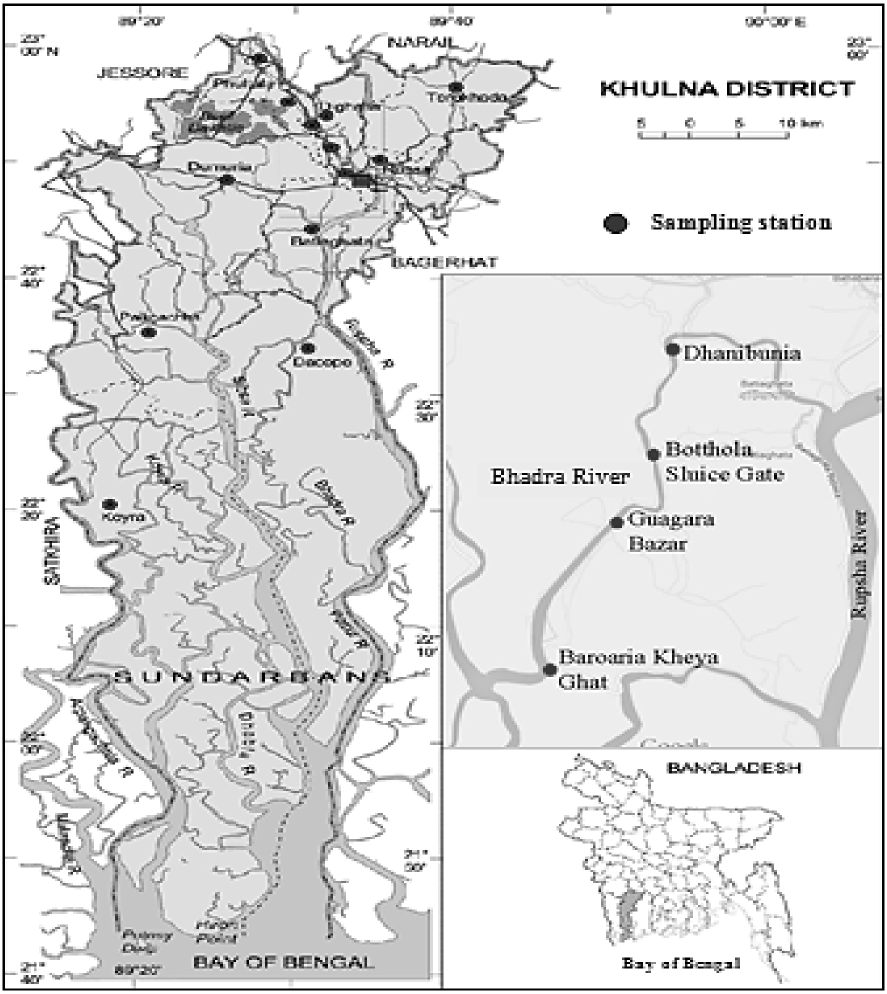


Figure 1. Map of the study area indicating the sampling station (source: Banglapedia)

The average temperature and rainfall in this area is 26.1°C and 1,736 mm respectively. The river Bhadra is about 15.5 km long. Being a coastal river, it faces diurnal tidal fluctuation that sees sea water mixing with fresh water. Water samples were collected from four stations along Bhadra River. The selected sampling sites were Baroaria kheyaghat, Gaugara bazaar, Botthola sluice gate and Dhanibunia. These stations are described in Table 1.

Table 1. Location, Latitude, Longitude and sample ID of the sampling points

Sl. No	Location	Latitude (North)	Longitude (East)	Sample ID
1	Baroaria kheyaghat, Khulna	22°38'50.3"N	89°25'56.6"E	Station-1
2	Gaugara bazaar, Khulna	22°42'06.1"N	89°27'14.5"E	Station-2
3	Botthola sluicegate, Khulna	22°43'37.4"N	89°27'55.8"E	Station-3
4	Dhanibunia, Khulna	22°45'55.6"N	89°28'19.0"E	Station-4

Sample collection and Preservation:

Water samples were collected from four different sites based on characteristics of the location along the Bhadra River; rainy season (July, 2015 to August, 2015), winter season (December, 2015 to February, 2016) and summer season (May, 2016 to June, 2016) with fortnightly variations. The samples were collected from each site both during high tide and low tide from close to about 10 cm depth from the surface of the Bhadra River. For the determination of Dissolved Oxygen, water samples were collected in different BOD bottles and the sample was kept "Fixed" on the spot by some prescribed reagents such as Manganase sulfate $MnSO_4.4H_2O$, concentrated H_2SO_4 and Alkali Iodide Azide (APHA, 1992). In the case of other parameters, one liter capacity clean plastic bottle was used for the collection of samples. To avoid direct sunlight, all the collected samples were placed in a black bag.

Analytical Method set-up and Statistical analysis:

In the experimental work, all of the Physical and Chemical parameters were measured in situ. All physical parameters such as Temperature (Centigrade mercury thermometer), pH (pH-5011, HANNA), Transparency (Secchi disc), Salinity (Refractometer, REF-201 bp), EC and TDS (HI-8733, HANNA) were measured by instrumentally and chemical parameters- Total Alkalinity, Total Acidity, DO and Free Dissolved CO_2 were analyzed by the standard titration method of APHA (APHA, 1992). Replicate analysis of blank, standards and water samples were performed during the study to avoid errors. For statistical analysis, Q-test and ANOVA (Software SPSS-15) were used to compare the mean values of the tested parameters for different sampling seasons. The coefficient of correlation of temperature along with other physico-chemical parameters was calculated through the Pearson correlations test (Software SPSS-15).

Results and Discussion

The results obtained from some temperature dependent physicochemical parameters of the Bhadra River water samples in various season are presented in Tables 2, 3 and 4. Table 5 exposes the summary of seasonal variation with standard deviation and range of those physicochemical parameters in Bhadra River. Table (5) showed wide variation among seasons through the study period. During the study period, temperature varied from 20^{o}C to 33^{o}C with an average of 27.56±4.52^{0}C at the Bhadra River. Water temperature is generally low, ranging from 5^{0}C-36^{0}C which is standard for fisheries (Boyd & Tucker, 1998). The range of water temperature of Bhadra River was found within the standard range and higher in summer season due to low water level and high air temperature. The present observation is similar to the seasonal fluctuation in temperature studied by Sharma et al. (Sharma et al., 2007). Water temperature has a significant correlation with most of these parameters.

Aquatic organisms are affected by pH because most of their metabolic activities are dependent on it. pH of an aquatic system is an important indicator of water quality and the extent of pollution in watershed areas (Kumar et al., 2010). The mean pH was found to be 7.675 ± 0.74 at the Bhadra River which indicates the river water is slightly alkaline in nature. The alkaline nature of river water values may be due to sewage discharged by surrounding villages and agricultural fields. In the rainy season, the highest average pH is observed (7.68 ± 0.28) because in this season, sewage and agricultural discharges increase. Sewage and agricultural discharges are generally a complex combination of natural organic and inorganic materials and man-made compounds. It usually contains many fertilizers, metals, sediments, pesticides, nutrients, salt, sodium, calcium, potassium, chlorine, phosphate, bicarbonate etc. (Ongley, 2004). Water with pH ranging from 6.0 to 9.0 is generally regard as suitable for growth of organism (Huq, 2002) and results showed that pH values were within the permissible limit.

Table 2. physicochemical parameters in Bhadra River during rainy season

Sampling Site	time	T (^{0}C)	pH	Tra (cm)	Sal (ppt)	EC (mS/cm)	TDS (ppt)	T alka (mg/L)	T acid (mg/L)	DO (mg/L)	F d CO_2 (mg/L)
Station 1	LT	28.50	7.70	10.25	4.38	6.23	3.99	110.0	9.0	6.15	3.63
	HT	29.50	7.83	11.13	4.88	6.75	4.32	115.0	10.15	5.75	4.22
Station 2	LT	28.50	7.68	10.38	2.88	4.52	2.89	98.75	8.83	5.0	4.18
	HT	29.50	7.78	11.25	3.13	4.94	3.16	106.25	9.40	4.60	4.73
Station 3	LT	28.50	7.50	11.0	1.80	2.74	1.75	95.0	6.50	4.60	2.75
	HT	29.50	7.58	11.75	1.93	2.96	1.89	102.50	7.25	4.35	3.19
Station 4	LT	28.50	7.63	10.63	3.13	4.88	3.12	98.75	7.93	5.35	4.033
	HT	29.50	7.73	11.13	3.38	5.23	3.35	105.0	8.83	5.0	4.45

Table 3. physicochemical parameters in Bhadra River during winter season

Sampling Site	time	T (^{0}C)	pH	Tra (cm)	Sal (ppt)	EC (mS/cm)	TDS (ppt)	T alka (mg/L)	T acid (mg/L)	DO (mg/L)	F d CO_2 (mg/L)
Station 1	LT	21.00	7.35	11.70	6.75	12.01	7.68	96.25	19.13	5.77	8.42
	HT	22.00	7.81	11.90	6.88	12.03	7.70	101.25	20.38	5.53	8.96
Station 2	LT	21.00	7.26	10.40	6.75	11.48	7.34	89.38	18.37	5.38	8.08
	HT	22.00	7.36	11.03	6.88	11.75	7.52	95.63	19.13	5.22	8.42
Station 3	LT	21.00	6.92	9.93	6.50	11.09	7.10	85.63	16.63	5.27	7.32
	HT	22.00	6.99	10.45	6.50	11.22	7.18	88.75	17.88	5.19	7.87
Station 4	LT	21.00	7.42	10.91	6.75	11.62	7.43	89.37	18.25	5.44	8.03
	HT	22.00	7.49	11.06	6.75	11.86	7.59	93.13	19.13	5.36	8.42

Table 4. physicochemical parameters in Bhadra River during summer season

Sampling Site	time	T (^{0}C)	pH	Tra (cm)	Sal (ppt)	EC (mS/cm)	TDS (ppt)	T alka (mg/L)	T acid (mg/L)	DO (mg/L)	F d CO_2 (mg/L)
Station 1	LT	32.25	7.02	12.55	17.75	26.4	16.89	112.50	20.25	4.64	9.68
	HT	32.25	7.12	12.51	17.75	26.27	16.81	110.00	22.25	4.28	10.74
Station 2	LT	31.75	7.07	12.47	17.50	25.35	16.22	115.63	19.25	4.59	10.12
	HT	32.00	7.10	12.54	18.75	25.97	16.62	115.63	22.00	4.89	10.12
	LT	31.75	7.00	12.52	17.50	25.12	16.07	113.13	20.00	3.87	9.79
Station 3	HT	32.5	7.12	12.49	18.75	25.52	16.33	111.25	20.50	4.54	9.90
	LT	32.00	7.10	12.50	17.75	25.25	16.16	114.37	20.75	4.28	9.79
Station 4	HT	32.75	7.22	12.53	18.75	26.38	16.88	122.50	23.00	4.18	10.23

NOTES: LT: Low tide; HT: High tide; SD: Standard deviation; T: Temperature; Tra: Transparency; Sal: Salinity; TDS: Total dissolved solid; T alka: Total alkalinity; T acid: Total acidity; F d CO_2: Free dissolved CO_2.

Table 5. Seasonal variation of physicochemical parameters in Bhadra River

Samp. Time	Stat. Para.	T (^0C)	pH	Tra (cm)	Sal (ppt)	EC (mS/cm)	TDS (ppt)	T alka (mg/L)	T acid (mg/L)	DO (mg/L)	F d CO_2 (mg/L)
Rainy Season	Mean	29.00	**7.68**	10.56	3.38	4.77	3.05	103.91	8.31	5.19	3.89
	SD	±0.72	±0.28	±1.31	±3.28	±5.19	±3.32	±12.09	±2.42	±1.44	±1.13
	Range	28-30	7.3-8.3	10-13	0.2-10	0.3-16.9	1.85-4.3	80-125	4.7-12.6	2.2-7.2	2.2-5.28
Winter Season	Mean	21.56	7.32	10.49	6.72	11.63	7.44	92.42	18.61	**5.38**	8.19
	SD	±0.84	±0.41	±1.63	±2.23	±2.57	±1.64	±6.07	±2.98	±0.62	±1.31
	Range	20-23	6.7-8.7	9.2-13	3.5-10	7.8-15.9	6.8-8.03	85-110	12-23	4-6.5	5.3-10.2
Summer Season	Mean	**32.12**	7.09	**12.52**	**18.13**	**25.78**	**16.49**	**114.37**	**21.00**	4.40	**9.85**
	SD	±0.79	±0.11	±0.06	±0.91	±0.89	±0.57	±7.24	±1.74	±0.46	±1.18
	Range	31-33	6.9-7.3	12.4-12.6	17-20	24.3-27.3	16-16.7	90-117.5	18-24	3.7-5.4	4.8-11.4
Yearly Average	**Mean**	27.56	7.675	11.19	3.18	14.06	8.99	103.56	15.97	5.1	3.89
	SD	±4.52	±0.74	±1.52	±0.74	±9.40	±1.84	±12.57	±6.03	±0.43	±1.13

Samp. time: Sampling time; Stat. para: Statistical parameter; SD: Standard deviation; T: Temperature; Tra: Transparency; Sal: Salinity; T alka: Total alkalinity; T acid: Total acidity; F d CO_2: Free dissolved CO_2.
Bold value: Maximum average value.

Table 6. The correlation coefficients (r) among the parameters of Bhadra River.

Parameter	Tem.	pH	Trans	Salinity	EC	TDS	T alka	T acid	DO	F d CO_2
Temp	1	-.077	.476**	.498**	.412**	.412**	.723**	-.049	-.36**	.032
pH		1	-.228*	-.522**	-.553**	-.553**	-.030	-.460**	.376**	-.472**
Trans			1	.581**	.550**	.550**	.482**	.396**	-.243*	.416**
Salinity				1	.987**	.987**	.567**	.769**	-.183	.799**
EC					1	1.00**	.516**	.812**	-.178	.842**
TDS						1	.516**	.812**	-.178	.842**
T alka							1	.193	-.027	.225*
T acidity								1	.009	.944**
DO									1	-.029
F d CO_2										1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 7. The ANOVA analysis of temperature dependent parameters of Bhadra River.

Statistical parameters	Tem.	pH	Tra (cm)	Sal (ppt)	EC (mS/cm)	TDS (ppt)	T alka (mg/L)	T acid (mg/L)	DO (mg/L)	F d CO_2 (mg/L)
F	0.467	2.362	4.606	0.881	0.726	0.728	2.322	0.246	0.986	0.647
Sig. figure	0.628	0.10	0.012	0.418	0.486	0.485	0.104	0.782	0.377	0.526

Sig. figure: Significant figure; Tem: Temperature; Tra: Transparency; Sal: Salinity; TDS: Total dissolved solid; T alka: Total alkalinity; T acid: Total acidity; F d CO_2: Free dissolved CO_2.

Conductivity is a measure of the ability of water to conduct electricity. It is dependent on the ionic concentration and water temperature. The total load of salts in a water body is directly related to its conductivity (Mane et al., 2013; Delince, 1992). The EC value of the study area varied from 2.74 mS/cm to 26.4 mS/cm with mean 14.06 ± 9.40 mS/cm. According to the Federal Environmental Protection Agency (FEPA), the sustainable EC value for aquatic organism is 10.77 mS/cm to 12.30 mS/cm (Aina et al., 1996). Another parameter, Transparency, is determined by the depth that sunlight penetrates in water (Chesapeake Bay Program., 2012). The mean Transparency for Bhadra River was found to be 11.19± 1.52 mS/cm with maximum transparency value 12.6 cm in the summer season. The Transparency of the fresh water is 35 to 45 cm which is suitable for the aquatic environment (Hossain et al., 2011). A higher transparency value was observed during summer due to absence of rain, runoff and flood water as well as gradual settling of suspended particles (Khan & Chowdhury, 1994). The observed EC value is slightly higher and Transparency value is lower than the standard value but Transparency and EC has less effect on aquatic life.

Total Dissolved Solid (TDS) is a measurement of inorganic salts, organic matter and other dissolved materials in water (Phyllis et al., 2007).The values of TDS in the study area ranged from 1.85 to 16.70 ppt and mean TDS value was found to be 8.99 ± 1.84 ppt. Water with total dissolved solids concentration within 0.1 ppt to 20 ppt is considered as suitable for aquatic life (ENVIRO SCI INQUIRY, 2000-2011). The TDS levels recorded in the entire sample points were within the standard guideline for the protection of fisheries and aquatic life. If the TDS levels are high due to dissolved salts, many forms of aquatic life are affected. The salts act to dehydrate the skin of aquatic animal which can be fatal (Johnson et al., 1999). In our study area, the TDS value was high in the summer season because the parameter TDS showed positive correlation with water temperature not exceeding the standard level (Shinde & Deshmukh, 2008). This means the TDS value of river Bhadra is not harmful for aquatic life.
Water Salinity indicates the presence of ionic substances that may come from the reaction of metals and acids present in the water. It is observed that in Bhadra River, the mean valve of Salinity was 3.18± 0.74 ppt. For good aquatic growth and survival, Salinity range should be 0.0 to 25 ppt (Bhatnagar & Devi, 2013). The minimum Salinity value was obtained in the study area during the rainy season. River water salinity decreases in the rainy season due to excessive rainfall and soft water entering the river from the surrounding villages (Furumai et al., 2007).

Water Alkalinity is a measure of its capacity to neutralize acids. Water with high alkalinity is undesirable. The obtained alkalinity ranged from 80.0-125.0 mg/L with a mean of 103.56±12.57 mg/L. The standard value of alkalinity for river water is (100-200) mg/L for fisheries activities (Boyd & Tucker, 1998). On the other hand, Acidity is a measure of the capacity of water to neutralize bases. The average Total Acidity content varied from 8.0 mg/L to 24.15 mg/L. The mean Total Acidity content of the river was 15.97 ± 6.03 mg/L. The standard value of acidity for river water is less than 19 mg/L (Yisa & Jimoh, 2010). The maximum Total Alkalinity and Total Acidity value were obtained during the summer season and minimum value during the winter and rainy seasons, respectively. During the summer season the water temperature was high and the parameter of Total Acidity and Total Alkalinity show positive correlation with water temperature. For this reason, Total Alkalinity and Total Acidity values were maximum in the summer season (Tripathi et al., 2014; Shashi et al., 2009). The values obtained for alkalinity and acidity were within the standard range and these make the river suitable for aquatic life.

Dissolved Oxygen (DO) and Free Dissolved CO_2 are present in water in the form of a dissolved gas. Dissolved Oxygen is one of the most vital parameters in water quality assessment and reflects the physical and biological processes prevailing in the water (Trivedi & Goel, 1984). The mean DO was found to be 5.1 ± 0.43 mg/L during the study period. The level of DO was lower in the summer season, compared to the rainy and winter seasons. During our research, high oxygen was dissolved in winter due to low temperature, high wind speed and high brightness (Shinde & Deshmukh, 2008). At the same time the DO level is higher in LT than HT because at low temperature and low salt level the amount of Dissolved Oxygen is higher (Wetzel, 2001). The optimum DO level should be 5.0 mg/L or more for fish and various aquatic lives (Bhatnagar & Singh, 2010). The lower values of Dissolved Oxygen in summer season occurs due to higher rate of decomposition of organic matter and limited flow of water in a low holding environment can be noticed due to high temperature (Rani et al., 2004). The mean Free Dissolved CO_2 was found to be 3.89±1.13 mg/L. The maximum Free Dissolved CO_2 value was observed during the summer season (Chatap et al., 2016). The optimum level of free carbon dioxide level for the survival of organisms is less than 5 mg/L (Huq, 2002). When the water is polluted with large amounts of organic matter, a lot of dissolved oxygen will be rapidly consumed. And Free Dissolved CO_2 in the biological aerobic decay will affect the water quality and aquatic life (Dara, 2007). From the data and above discussion it is clear that the various physical and chemical parameter ranges of Bhadra River fall within standard range and are able to maintain the productivity of water and normal physiology of aquatic life.

The study shows that the temperature dependent parameters are linearly correlated to a large extent. Table 6 shows the correlation matrix of water sample, which describes significantly positive correlation between water temperature with Transparency (r = 0.476), Salinity (r = 0.498), EC (r = 0.412), TDS (r = 0.412), Total Alkalinity (r = 0.723), Free Dissolved CO_2 (r = 0.032) and significantly negative correlation with DO (r = -0.366). pH (r = -0.077) and Total Acidity (r = -0.049) show negative correlations with temperature but not significantly. Another statistical one-way ANOVA analysis shows a significant seasonal change of Transparency, at the 0.01 level of significance but other proposed parameters are not significant at this level of significance (Table 7).

Q-test is used for identification and rejection of outliers. From the calculated Q values, we can see that more than 50 % values of Q are greater than the standard value of the Q_{table}. So, there is an outlier among the values and the test shows (90 % sure) that 50 % of the values of temperature dependent parameters are not the same. From statistical analysis ANOVA-test, Q-test and standard deviation, it is concluded that there are changes in almost all the parameters but changes in one parameter Transparency were significant with seasonal variation and in other parameters changes are insignificant.

Conclusion

From the water quality analysis, it can be observed that there is seasonal variation in water quality with respect to temperature dependent physico-chemical parameters. The statistical analysis Pearson correlation exposed that Transparency, Salinity, EC, TDS, Total Alkalinity, Total Acidity and Free Dissolved CO_2 increase with temperature but DO decreases with a rise in water temperature. The water quality parameters of the Bhadra River found most of the parameter values (except EC and Transparency) between the standard ranges of river water for aquatic life. However, it is not easy to characterize the water quality fully by measuring these certain temperature dependent parameters. However, the findings of the present study would be helpful as baseline information for developing monitoring, management and conservation of the Bhadra River ecosystem in future.

References

Aina EOA, Adedipe NO, 1996. Water Quality Monitoring and Environmental Status in Nigeria. FEPA, Monograph 6, FEPA, Abuja, Nigeria, 239

APHA, 1992. Standard Method for the Examination of water and Waste Water, (14th edition), American public Health Association, New York.

Bais VS, Yatheesh S, Agrawal NC, 1992. Benthic macro-invertebrates in relation to water and sediment chemistry. *J. Fresh Water Biol.,* **4:** 183-191

Bhatnagar A, Devi P. 2013. Water quality guidelines for the management of pond fish culture. *International Journal of Environmental Science* **3(6):** 1980-2009

Bhatnagar A, Singh G. 2010. Culture fisheries in village ponds: a multi-location study in Haryana, India. *Agriculture and Biology Journal of North America* **1(5):** 961-968

Boyd CE, Tucker CS. 1998. Pond Aquaculture water quality Management, Kluwer Academic publisher, London, 87-148 pp.

Chatap PB, Telkhade PM, Khinchi PJ. 2016. Physico-Chemical Investigation of River Penganga at Kodsi Village, Taluka korpana, District Chandrapur. *International Journal of Researches in Biosciences, Agriculture and Technology:* 5-7

Chesapeake Bay Program, 2012. Water Clarity, In the Bay Ecosystem, retrieved from https://www.chesapeakebay.net/discover/bayecosystem/waterclarity.

Dara SS. 2007. A text book of environmental chemistry and pollution control, (7th ed.), S. Chand and Company Ltd., Ram Nagar, New Delhi, India, 44-75 pp.

Delince G. 1992. The Ecology of Fish and Ecosystem with Special Reference to Africa, Academic Publishers, Dordrecht, Netherland, 230 p.

ENVIRO SCI INQUIRY, 2000-2011. Lehigh Environmental Initiative at Lehigh University.

Furumai H, Kurisu F, Katayama H, Satoh H, Ohgaki S, Thanh NC. 2007. Southeast Asian Water Environment, IWA publishing, Alliance House, 12 Caxton Street, London, 86 p.

Hossain MU, Farzana S, Mia MY. 2011. Assessment of Aquatic Environmental Parameters in the Louhajang River, Tangail, Bangladesh. *Journal of Science and Technology* **1(1):** 65-71

Huq ME. 2002. A complication of environmental causes of Bangladesh Administered by the Department of environment, BEMP, 60-63 pp.

Jackher GR, Rawat M. 2003. Studies on physicochemical parameters of a tropical lake, Jodpur, Rajasthan, India. *Journal of Aquaculture Biology* **18:** 79-83

Johnson RL, Holman S, Holmquist DD. 1999. Water Quality with CBL Vernier Software, Oregon.

Khan MAG, Choudhary SH. 1994. Physical and chemical limnology of lake Kaptai: Bangladesh, *Tropical Ecology* **35:** 35-51

Kumar GNP, Srinivas P, Chandra JK, Sujatha P. 2010. Delineation of groundwater potential zones using remote sensing and GIS techniques: a case study of

Kurmapalli Vagu basin in Andhra Pradesh, India. *International Journal of Water Resources and Environmental Engineering* **2(3):** 70-78

Mane AV, Pardeshi RG, Gore VR, Walave RL, Manjrekar SS, Sutar GN. 2013. Water quality and sediment analysis at selected locations of Pavana River of Pune district, Maharashtra. *Journal of Chemical and Pharmaceutical Research* **5(8):** 91-102

Ongley ED. 2004. Control of water pollution from agriculture, FAO Irrigation and Drainge Paper 55: 6-13

Pearson Education, Inc., Lab Bench Activity, 2011. In Measuring Temperature & Metabolic Rate,Retrieved from http:/www.phschool.com/science/biology-place/ labbench/lab10/tem.

Rani R, Gupta BK, Srivastava KBL, 2004. Studies on water quality assessment in Satna city (M.P): Seasonal parametric variations. *Nature environment and pollution technology* **3:** 563-565

Sharma KK. 2007. Some immunological investigations in Ganga stream, katra. *Jammu & Kashmir state Aquatic Biology* **22(1):** 105-109

Shashi J. Singh, Dwivedi AK. 2009. Numerical interdependence in pH, acidity and alkalinity of a polluted river water. *Journal of Environmental Biology* **30(5):** 773-775

Shinde AH, Deshmukh BD. 2008. Seasonal Changes in Physico-Chemical Characteristics of Zirpurwadi Lake, The 12th World Lake Conference, 1794-1795 pp.

The Washington Post, 2015. Hundreds Dead in Bangladeshi Cold Spell,14 p. https://en.wikipedia.org/wiki/Geography of Bangladesh, 13 June 2017.

Tripathi B, Pandey R, Raghuvanshi D, Singh H, Pandey V, Shukla DN. 2014. Studies on the Physico-chemical Parameters and Correlation Coefficient of the River Ganga at Holy Place Shringverpur, Allahabad. *Journal of Environmental Science, Toxicology and Food Technology* **8(10):** 29-36

Trivedi RK, Goel PK, 1984. Chemical and biological methods for water pollution studies, Environmental Publications Karad, India, 250 p.

Weber-Scannell, PK, Duffy LK. 2007. Effects of total dissolved solids on aquatic organism: a review of literature and recommendation for salmonid species. In *American Journal of Environmental Sciences*.

Wetzel RG, Limnology WB, 1975. Sunders Co. Philadephia, London and Toronto, 743 p.

Wetzel RG. 2001. Limnology: Lake and River Ecosystems (3rd ed.), San Diego, CA.

Wilde F. 2006. Temperature in USGS Field Manual, Retrieved from, htt://water.Usgs.gov/ owq/Field Manul/Chapter6/6.1 ver2.pd.

Yisa J, Jimoh T. 2010. Analytical studies on water quality index of river landu. *American Journal of Applied sciences* **7(4):** 453-458

Journal of Tropical Biology and Conservation 14: 83-94, 2017 ISSN 1823-3902

Research Article

Beach Morphology Changes during the Northeast and Southwest Monsoons at Mantanani Besar Island, Sabah (Malaysia)

Russel Felix Koiting[1]*, Ejria Saleh[1], John Madin[1], Md Nizam Bin Ismail[2]

[1]*Borneo Marine Research Institute, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.*
[2]*Department of Marine Park Malaysia, Ministry of Natural Resources and Environment, 62574 Putrajaya, Malaysia*
*Corresponding author: russel.felix.k@gmail.com

Abstract

Mantanani Besar Island is a tourism and island that also has communities and is located in the west coast of Sabah. The island coastline is dominated by sandy beaches that tend to change due to direct exposure from natural phenomenon (waves, wind, current and periodic storm) and anthropogenic activities. The seasonal monsoon (NEM and SWM) is an important factor that intensifies the natural phenomenon leading to major beach changes in a short period of time. Therefore, this study aims to determine the beach morphology changes (profile, width, angle and volume) and to identify short-term beach changes trends at different seasonal monsoons. This study was conducted annually between 2013 and 2015. Beach profiling and field measurements were done in May and November 2013, March and September 2014 and January and May 2015 at 5 selected stations around Mantanani Besar Island. Further analysis of beach width, angle and volume were calculated based on beach profile data. The result of beach profile shows St. 1, St. 2 and St. 5 undergoing erosion while St. 3 and St. 4 are experiencing accretion. Averages of beach morphology were higher during the NEM than in SWM indicating more sediment accumulation on the beach of Mantanani Besar Island during the NEM and vice versa in SWM. The findings of this study are useful for local communities, tourist operators and the local government as a guide for any development and to produce shoreline management plans for Mantanani Besar Island.

Keywords: beach morphologies, beach changes, seasonal monsoons, Mantanani Besar Island

Received 12 January 2017
Reviewed 18 May 2017
Accepted 04 July 2017
Published 15 October 2017

Introduction

Shoreline changes have been documented by many researchers around the globe and it is dominated with erosion especially at coastal areas where at least 70 % of the world's sandy beaches are affected (Bird, 1985; Zhang et al., 2004). In Malaysia, almost 30 % of its coastline experienced critical coastal erosions (shore-based facilities or infrastructures are in danger of collapse/damage) especially in Sabah which experienced the longest coastal erosion compared to other states (DID, 2007). Major erosion in Sabah (significant to critical) occurred along the coastline in the west coast (Papar and Kimanis) and east coast (Sandakan).

Shoreline changes related to beach processes (accretion and erosion) happen along the shore. These can be classified into three parts which are long-term changes, short-term changes and episodic changes. These classifications provide a picture on how the shoreline has changed in a certain period of time and illustrate the most dynamic areas along the shoreline (Gibeaut et al., 2001). Long-term beach changes occur for between ten to thousands of years. It is caused by any activity that can significantly alter the sea level (rise or fall) and tectonic activities which lead to subsidence or emergence of coastal land (Prasetya, 2007). Short-term changes occur within 5 to 10 years or several seasons. The beach responds to smaller scale events such as winds, coastal waves, currents and tides. Episodic changes only occur in response to a single storm and it usually causes more beach changes compared to long-term and short-term changes (Gibeaut et al., 2001).

Mantanani Besar Island is an important island for both tourism and communities in the west coast of Sabah. Tourist arrivals has increased yearly (RCM, 2012) ande the island is also inhabited by local communities mainly from the Bajau Ubian ethnicity (Rosazman et al., 2015). The island coastline is dominated by sandy beaches and a small portion of cliff. The shape and size of the beach is constantly changing due to the continuous interaction of sandy beaches (loose granular sediments) with the natural phenomenon (wave action, tides and the wind) and human activities (boating, beach activities and clearance of beach vegetation). The beach change is further intensified by the presence of seasonal monsoons.

Malaysia is affected by yearly two major monsoon regimes which are the Northeast Monsoon (NEM) and the Southwest Monsoon (SWM). A different energy of waves, currents and winds occur at different directions depending on the type of monsoon. Coastal currents during NEM that occur from November to March flow southward and usually bring heavy rainfall contributing to a major rainy season and rough seas. The monsoon systems are developed in conjunction with cold air outbreaks from Siberia which produce heavy rains that often cause severe floods along the east coast states of Peninsular Malaysia (Kelantan, Terengganu, Pahang and East Johor) and in the state of Sarawak (Met Malaysia, 2015). Coastal currents during SWM (late May to September) flow northwards with calmer weather (Nakajima et al., 2015). Most states in Peninsular Malaysia experience minimum rainfall and dry conditions due to the rain shadow effect of the Sumatran Mountain range. In contrast, Sabah experiences wetter weather conditions during the SWM due to the tail effects of typhoons during their journey from islands in the Philippinesacross the South China Sea and beyond (Diman & Tahir, 2012; Met Malaysia, 2015).

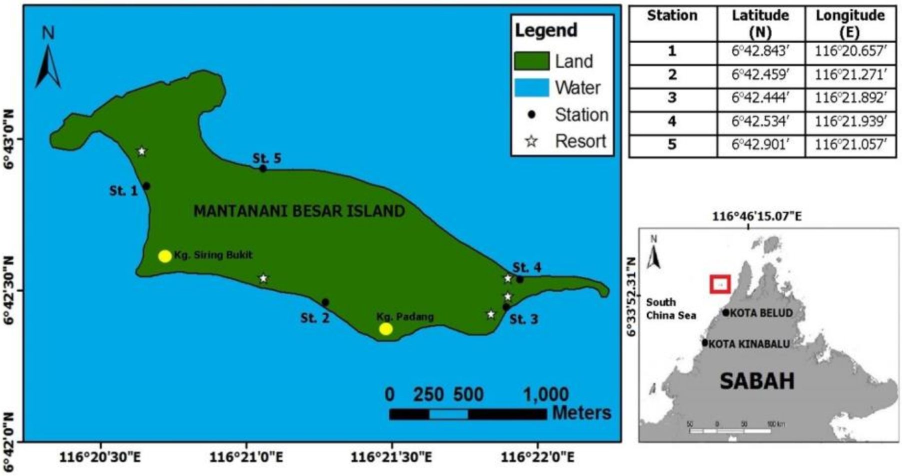
Effects of monsoons on shoreline changes vary locally (Mohd Lokman et al., 1995). Based on Wong (1981), erosion usually occurs during NEM and accretions during SWM. Mantanani Besar Island is also known to experience a major problem of beach erosion which affects communities and infrastructure along the coastline (Koiting et al., 2015). Limited baseline data especially physical data means there is less information on beach changes which lead to difficulties for communities and tourist operators in managing livelihoods as well as finding suitable places for houses/chalets construction. Further, continuous erosion may happen if the island is not protected which eventually could lead to the loss of island areas.

Therefore, this study aims to determine the beach morphology changes (profile, width, angle and volume) and to identify the short term trends of beach changes (erosion and accretion) at different seasonal monsoons in Mantanani Besar Island. Seasonal variation (short-term) of beach changes (erosion and accretion) and the evolution of beach profile provides useful information for coastal processes understanding and management (Andrade & Ferreira, 2006; Gujar et al., 2011; Dora et al., 2012).

Materials and Methods

Study Area

Mantanani Besar Island is one of the three islands (others are Mantanani Kecil and Linggisan) that make up the Mantanani Island cluster. It is located at the northwest of Sabah facing the South China Sea (Figure 1) within Kota Belud distrct. Mantanani Besar Island is the biggest and only inhabited island in this cluster. Most of the man-made infrastructure (villages and tourism infrastructures) are found along the eastern, southern and western parts of the coastline (Figure 1).



Station	Latitude (N)	Longitude (E)
1	6°42.843′	116°20.657′
2	6°42.459′	116°21.271′
3	6°42.444′	116°21.892′
4	6°42.534′	116°21.939′
5	6°42.901′	116°21.057′

Figure 1. Mantanani Besar Island and location of measurement stations

Methods and Measurements

Measurements of beach morphologies were done using beach profiling method at different seasonal monsoons (NEM and SWM) between 2013 and 2015 [2nd May 2013 (SWM), 13th November 2013 (NEM), 13th March 2014 (NEM), 12th September 2014 (SWM), 19th January 2015 (NEM) and 20th May 2015 (SWM)]. Five stations (St.) were selected for the beach profiling measurement (Figure 1). Locations of the stations were chosen by considering the presence of anthropogenic activities. St. 1 is located near Kg. Siring Bukit (KSB) with the presence of one resort, St. 2 is located near Kg. Padang (KP) with two resorts, St. 3 and St. 4 are located near four tourism resorts while St. 5 is located at an undeveloped area (north). The coordinates of each sampling station are shown in Figure 1.

Materials used for beach profiling are a tripod, auto level, staff, measuring tape and Global Positioning System (model: Garmin GPSmap 60CSx). A tripod was set up at the vegetation area that grows near the beach at all stations. Permanent solid structures that were selected as a control point in this study are tall trees, boulders and houses available at the vegetation area. Coordinates of each station were recorded by GPS to mark the location and as one of the precautions taken in case the control point was damaged by natural causes or human intervention. The auto level was placed onto the tripod to ensure its stability by adjusting the air bubbles to be positioned in the middle for better accuracy of reading. A measuring tape was pulled perpendicular from the tripod to the low water line. The staff was placed and held in an upright position and the measurement of the height differences between the auto level and the staff were taken at every 5m interval along the tape.

Data Analysis

Beach profiles were obtained by plotting the graph of beach elevation versus distance. The calculations of each beach width, angle and volume were based on the beach profile readings elaborated by Dora et al. (2012). Beach width was the distance of the beach from vegetation area to the low water line.

The beach angle is known as the gradient of the beach that shows the potential of beach changes in different steepness of the beach. It was calculated based on the height and width of the measured beach by adopting the right angle triangle trigonometric formula as below (1):

$$\sin(\theta) = \frac{H}{W}$$

$$\theta = \sin^{-1}\left(\frac{H}{W}\right) \quad (1)$$

Where,

H is the height (m) or elevation, W is the width (m) and θ is the degree of beach angle.

Volumes of sediment within the beach profile were calculated in each station to determine beach irregularities and total sediment gain and loss during the study period. The beach sediment volumes were calculated based on trapezoid formula as given below (2):

$$\text{Volume per unit length } (\text{m}^3/\text{m}) = A = \left[\frac{(LI + L2)}{2}\right] * H \quad (2)$$

Where,

L1 and L2 are the length (m) of each beach profile base while H is the height (m) or elevation.

Results

Beach profile

The trend of beach profile patterns at the western (St. 1), southern (St. 2) and northern (St. 5) sections of Mantanani Besar Island were almost the same in all sampling periods (Figure 2abe). These three stations also show decreasing pattern of profile and beach width at the end of the sampling period. Only St. 2 displays a drop of beach elevation at the beginning of 2015 (January) (Figure 2b). Northern beach profile (St. 5) shows increase of sedimentation on the beach within the period of May 2013 and November 2013 and then gradually decreased until May 2015 (Figure 2e). The eastern beach profile (St. 3 and St. 4) are varied (Figure 2cd). Nonetheless, these stations displayed an increase of profile patterns and beach width from May 2013 to May 2015.

The average of beach profiles was higher during the NEM than in SWM at all stations except St. 5 (Figure 3). A small portion of beach profile for SWM was seen slightly higher at beach width 8-12 m for St. 1 (Figure 3a) and at the end of the beach width for both St. 3 and St. 5 (Figure 3ce). In contrast, the average profiles at St. 4 were lower during NEM than the SWM (Figure 3d). The SWM profile was almost the same with NEM profile at width 8-12 m.

Beach width, angle and volume

The volumes of sediment on the beach at all stations were higher during NEM than in SWM (Figure 4c). The highest and lowest beach sediment volumes were at St. 4 and St. 2 respectively. Width average at each station in Mantanani Besar Island were wider during the NEM than SWM except for St. 5 (Figure 4a). The longest beach width was at St. 4 during both NEM and SWM with an average of more than 25 m while shorter beach width (< 20 m) was found at St. 5 (NEM) and St. 2 (SWM). Total average for width is slightly higher in NEM than SWM (Figure 4a).

Beach angle was varied in the NEM and the SWM. St. 1 and St. 2 have higher beach angles during the NEM while other stations are vice versa. The NEM beach angle was ranged from 4^{o} to 10^{o} whereas the SWM from 3^{o} to 8^{o}. There were high differences of beach angles at St. 5 compared to the other stations. Overall, the total averages of beach angle were higher in NEM (Figure 4b).

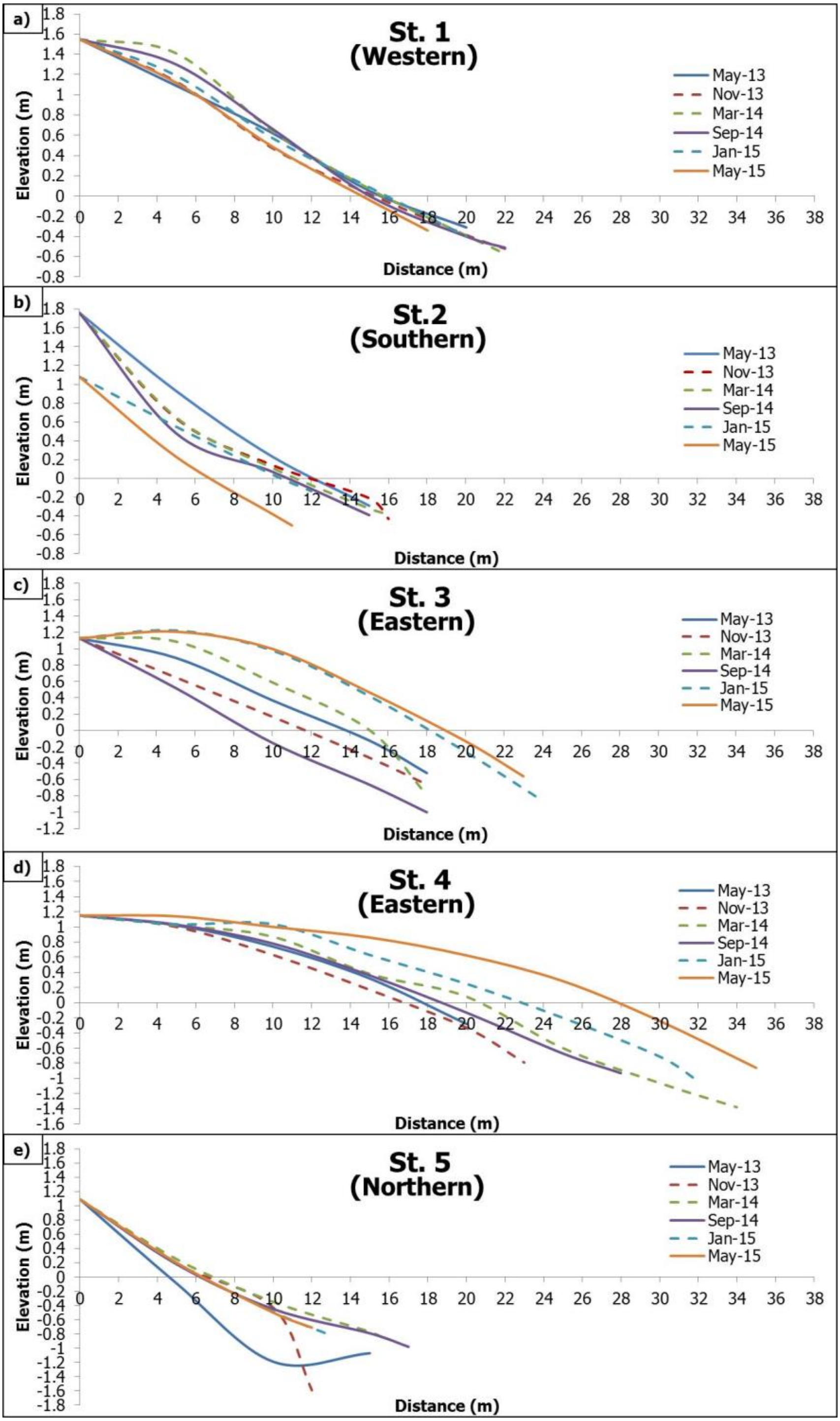


Figure 2. Seasonal of beach profiles at Mantanani Besar Island with five stations (a) St. 1; (b) St. 2; (c) St. 3; (d) St. 4 and; (e) St. 5.

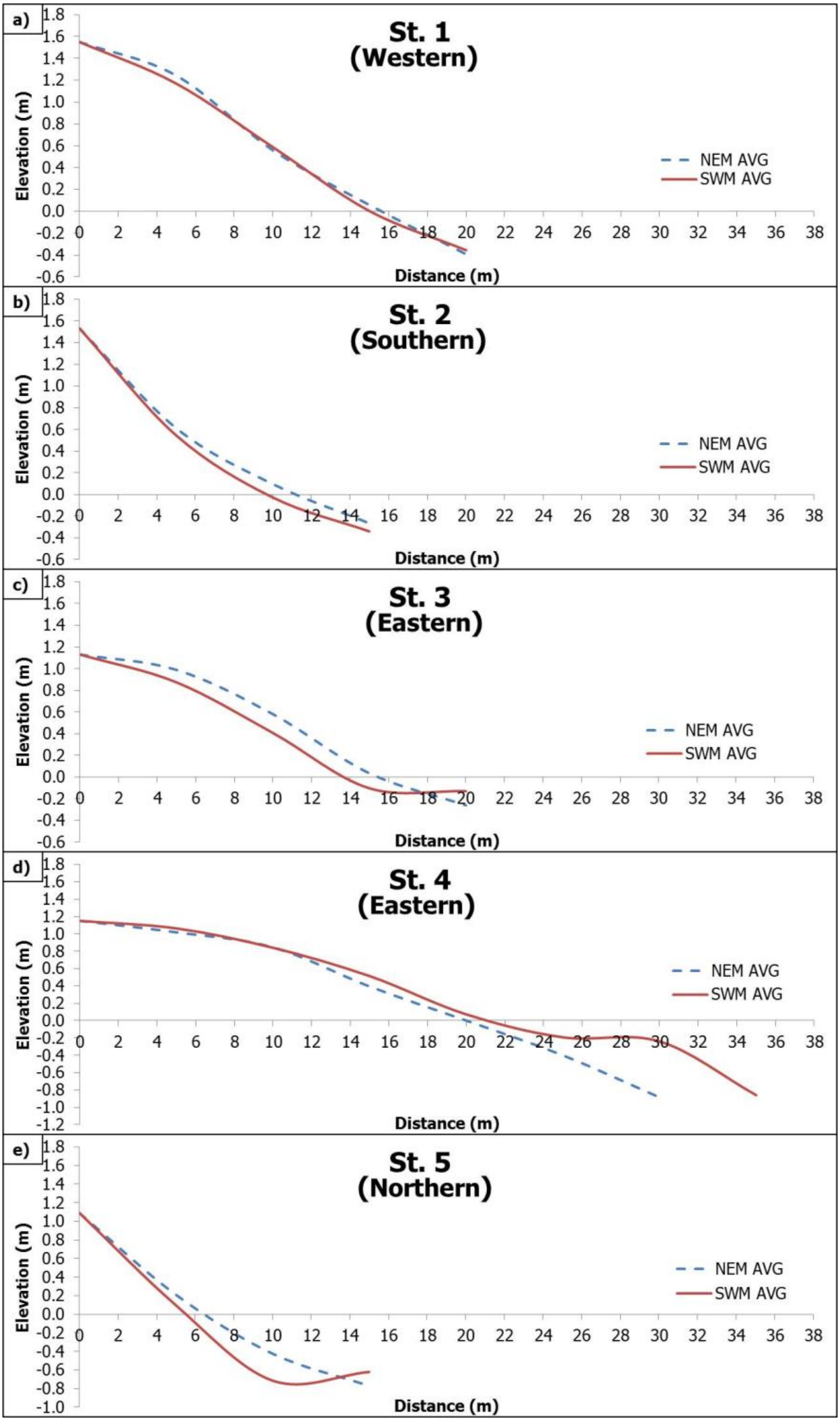


Figure 3. Seasonal average of beach profiles at Mantanani Besar Island during NEM and SWM with five stations (a) St. 1; (b) St. 2; (c) St. 3; (d) St. 4 and; (e) St. 5.

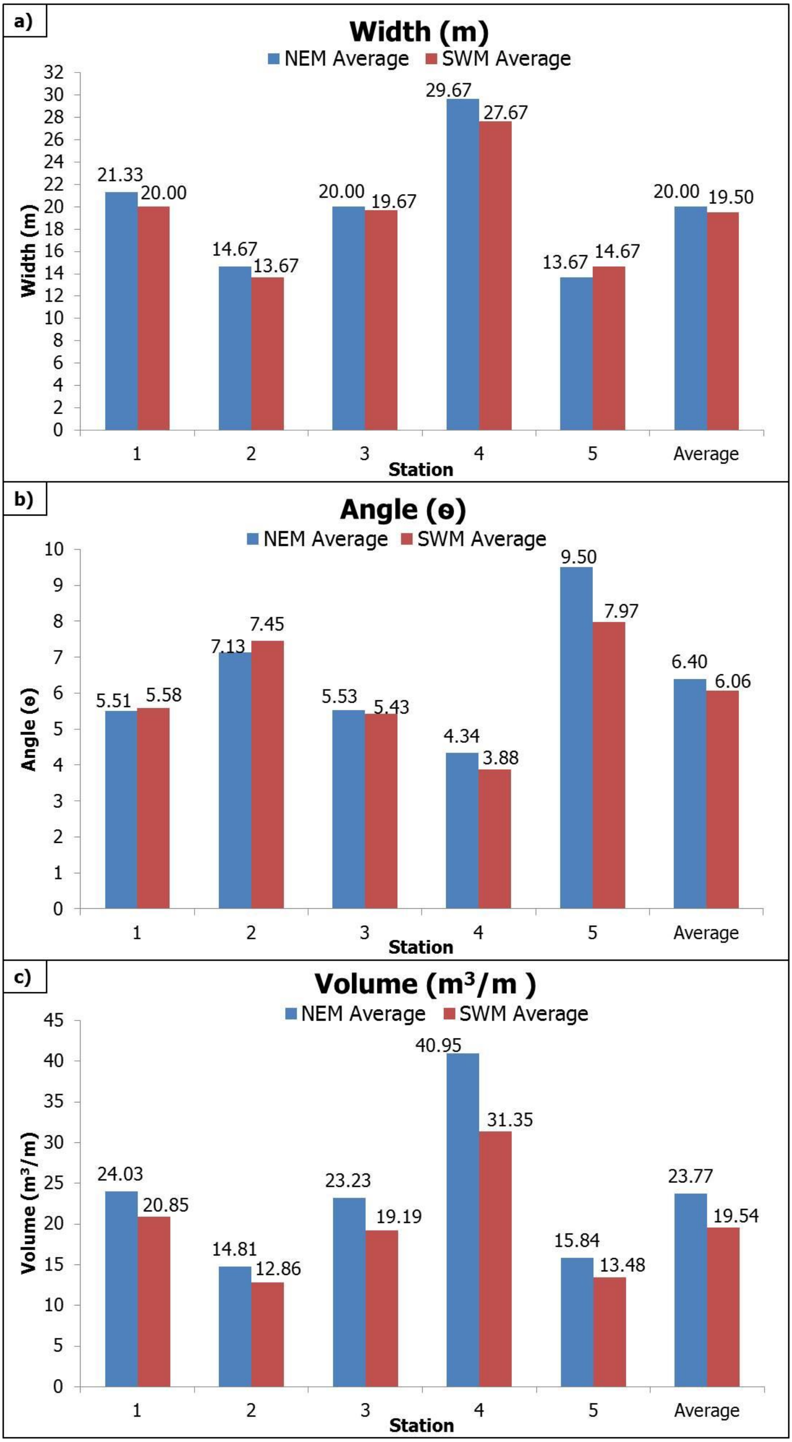


Figure 4. Seasonal average of beach morphology at Mantanani Besar Island during NEM and SWM with (a) beach width; (b) beach angle and; (c) beach sediment volume.

Discussion

Beach profiles of Mantanani Besar Island (2013 to 2015) showed that St. 1, St. 2 and St. 5 were undergoing erosion while St. 3 and St. 4 experienced accretion (Figure 2). High sedimentation increased on St. 5 beach within the period of May 2013 and November 2013 is an example of episodic beach changes where the beach experienced massive changes (high sediment deposition) due to the tail effect of Typhoon Haiyan that hit the Philippines (3-11 November 2013). Based on Gibeaut et al. (2001), extreme events have the tendency to change the shoreline by more than 30 m. The averages of beach morphologies were higher during the NEM than the SWM indicating that most sediment accumulated on the beach at the end of the year while sediment washed out after the first quarter of the year (Figure 3 and Figure 4).

Beach profiles can be related to the changes in beach width and beach sediment volume. The increase in beach width will cause sediment volume to increase as well. Therefore, beach profiles will rise if beach width and volume increases. The beach angles depend on the beach elevation and width. Based on Dora et al. (2011), the difference of beach angles are associated with beach erosion and accretion processes that happen along the beach. Deposition in both elevation and width leads to a small increase of angle while the increase of only elevation (or erosion on low tidal area) causes the beach to have a major increase in its angle (Koiting et al., 2015). Furthermore, studies done by Maryam et al. (2011) shows that smaller beach angle causes more land loss than a bigger beach angle. This is due to the bigger coverage of the area during wave breaks or tidal process at flat slopes rather than at steep ones.

Studies on short-term coastline changes (<10 years) is difficult to understand and predict. It is probably because one part of the beach may experience erosion while otherparts are accreting, or vice versa throughout the year. Apart from that, if a particular beach shows advancing or stablity for a few years but has a history of erosion in the previous decade, and then the erosion will eventually continue (Gibeaut et al., 2001).

Conclusion

Mantanani Besar Island has experienced erosion especially at the western (St. 1), southern (St. 2) and northern (St. 5) areas and accretion at the eastern part of the island (St. 3 and St. 4). The occurrence of beach erosion at western and southern Mantanani Besar Island has affected local community houses, jetties and also tourist facilities. The average of beach profile, width and sediment volume are higher during the NEM indicating that the island undergoes deposition during the NEM and then erosion takes place during the SWM while the varieties of beach angles within the monsoons are due to the process of beach erosion and accretion occuring at the different tidal areas. Studies on hydrodynamic forces (waves, winds and current) around Mantanani Besar Island are recommended to identify the influence of environmental forces on the beach. Both hydrodynamic forces and beach morphology changes would be very useful to get a better understanding of the beach processes of the island. Nonetheless, this study is still very useful as a guide for local communities and tourist operators for any development on the island. Considerable knowledge is also provided for the local government to produce relevant and effective shoreline management plans for Mantanani Besar Island.

Acknowledgements

This project was funded by Department of Marine Park, Ministry of Natural Resources and Environment, Malaysia (grant GL00102). Appreciations are given to Borneo Marine Research Institute supporting staff for their assist in the field. I would also like to thanks to the undergraduate students (UMS), practical students and mdm. Fazliana Mustajap for their help and accompanying throughout the sampling at Mantanani Besar Island shoreline area.

References

Andrade F, Ferreira MA. 2006. A simple method of measuring beach profiles. *Journal of Coastal Research* **22:** 995-999

Bird ECF. 1985. *Coastline Changes*. New York: John Wiley & Sons Ltd.

DID (Department of Irrigation and Drainage. 2007. Kompendium Data dan Maklumat Asas. Retrieve from http://redac.eng.usm.my/EAD/EAD511/JPS%20Compendium%202007.pdf

Diman CP, Tahir W. 2012. Dam Flooding Caused A Prolonged Flooding. *International Journal of Civil & Environmental Engineering* **12:** 71-75

Dora GU, Kumar VS, Johnson G, Philip CS, Vinayaraj P. 2012. Short-term observation of beach dynamics using cross-shore profiles and foreshore sediment. *Journal of Ocean Coastal Management* **67:** 101-112

Gibeaut JC, Hepner T, Waldinger R, Andrews J, Gutierrez R, Trembley TA, Smyth R, Xu L. 2001. *Changes in Gulf Shoreline Position, Mustang and North Padre Islands, Texas.* A Report of the Texas Coastal Coordination Council Pursuant to National Oceanic and Atmospheric. University of Texas. United States of America.

Gujar AR, Ganesan P, Iyer SD, Gaonkar SS, Ambre NV, Loveson VJ, Mislankar PG. 2011. Influence of morphodynamic variability over seasonal beach sediments and its probable effect on coastal development. *Journal of Ocean and Coastal Management* **54:** 514-523

Kilibarda Z, Shilinglaw C. 2014. A 70 year history of coastal dune migration and beach erosion along the southern shore of Lake Michigan. *Journal of Aeolian Research* **17:** 263-273

Koiting RF, Saleh E, Madin J, Aung T, Mustajap F. 2015. Morphologies changes during pre- and post- Southwest Season in Mantanani Besar Island, Kota Belud, Sabah. *Journal of Borneo Science* **36:** 21-32

Maryam DS, Weliyadi A, Aung T. 2011. Method to estimate the land loss from sea level rise due to gradual warming in Kota Kinabalu, Sabah. *Journal of Borneo Science* **28:** 18-28

MetMalaysia (Malaysian Meteorological Department). 2015. *Monsoon*. http://www.met.gov.my/index.php?option=com_content&task=view&id=6 9 &Itemid=160&lang=english

Mohd Lokman H, Rosnan Y, Shahbudin S. 1995. Beach Erosion Variabiltiy during a Northeast Monsoon: The Kuala Setiu Coastline, Terengganu, Malaysia. *Journal of Science and Technology* **3:** 337-348

Nakajima R, Yoshida T, Othman BHR, Toda T. 2015. Monsoonal changes in the planktonic copepod community structure in a tropical coral-reef at Tioman Island Malaysia. *Regional Studies in Marine Science* **2:** 19-26

Prasetya G. 2007. Chapter 4: Protection from coastal erosion. In Braatz S, Fortuna S, Broadhead J, Leslie R(eds). *Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forest and trees*. Proceeding of the Regional Technical Workshop, Khao Lak, Thailand. Regional Office for Asia and the Pacific, 39 Phra Atit Road, Bangkok, Thailand, 28-31 August 2006.

RCM (Reef Check Malaysia). 2012. *Status of Coral Reefs of the Mantanani Islands.* Organized by Reef Check Malaysia Bhd.

Rosazman H, Kunjumaran V, Weirowski F. 2015. Work transformation from fisherman to homestay tourism entrepreneur: A study in Mantanani Island Kota Belud, Sabah, East Malaysia. *Jurnal Kemanusiaan* **24:** 15-29

Wong PP. 1981. Beach Changes on a monsoon coast, Peninsular Malaysia. *Journal of Geological Sociology Malaysia* **14:** 59-74

Zhang K, Douglas BC, Leatherman SP. 2004. Global warming and coastal erosion. *Journal of Climate Change* **64:** 41-58

Journal of Tropical Biology and Conservation 14: 95–103, 2017 ISSN 1823-3902

Research Article

Diversity of *Pteroptyx* Fireflies (Coleoptera: Lampyridae) and Their Display Trees at Klias Peninsula, Sabah, Malaysia.

Kevin Foo, Mahadimenakbar M. Dawood*

Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88450 Kota Kinabalu, Sabah, Malaysia.
*Corresponding author: menakbar@ums.edu.my

Abstract

Congregating fireflies are among the most marvellous organisms that fill the mangrove forests with "living fireworks". These dainty creatures emit bioluminescence to attract mates by nightfall. Fireflies from the genus *Pteroptyx* aggregate on mangrove trees lighting up the riverine of several places in Malaysia, and this natural phenomenon provides local communities with lucrative business opportunity. Unsustainable management can bring disastrous consequences to the natural population of these graceful beetles. Without information on the current status of *Pteroptyx* fireflies in Klias Peninsula, any variation of this population in the future would be untraceable. This study was carried out to document the diversity of *Pteroptyx* fireflies and to identify their display trees in Klias Peninsula which is known as a firefly watching hotspot in Sabah. A total of four firefly species are found in Klias Peninsula, namely *Pteroptyx tener* Olivier, *Pteroptyx malaccae* Gorham, *Pteroptyx valida* Olivier, and *Pteroptyx bearni* Ballantyne. *Pteroptyx tener* is the dominant species in both Weston and Garama rivers while *Pteroptyx bearni* is the dominant species in Teratak River. The overall sex ratio on the display trees in Klias Peninsula was significantly biased towards the male. Seven mangrove species were selected as display trees by the congregating fireflies, particularly *Excoecaria indica* L. (Family Euphorbiaceae), *Hibiscus tiliaceus, Nypa fruticans, Rhizophora apiculata, Avicennia alba, Excoecaria agallocha* L.*, and Sonneratia alba* J. Smith (Family Lythraceae)-IUCN Red List. Information on the display tree species provides indispensable information for conservation and rehabilitation purposes while information on the *Pteroptyx* firefly species composition and abundance can be used as reference to track the spatial and temporal variation of firefly communities.

Keywords: Congregating fireflies, Klias Peninsula, Ecotourism, *Pteroptyx tener, Pteroptyx malaccae, Pteroptyx valida, Pteroptyx bearni,* Display trees

Received 11 April 2017
Reviewed 19 June 2017
Accepted 24 July 2017
Published 15 October 2017

Introduction

Congregating fireflies from the genus *Pteroptyx* are primarily associated with the aquatic-terrestrial ecotone at the edge of mangrove forests. Their bioluminescence ability and aggregative behaviour that light up mangrove trees never fail to fascinate whoever has the opportunity to see this natural phenomenon. These congregating fireflies also provide benefit to local communities involved in ecotourism activities. At the same time, contemporary anthropogenic activities and global climate change are expected to result in various unprecedented ecological impacts on mangrove ecosystems as well as the survival of these fireflies. There is a remarkable decline in the abundance of the congregating firefly observed in Kampung Kuantan, Selangor (Nallakumar, 2003). The observation in Peninsular Malaysia warns us to prepare for rapid decline of this natural capital if it is not managed in a sustainable manner. Despite their economic importance for ecotourism purposes, there is inadequate research carried out to document the current status of *Pteroptyx* fireflies in Klias Peninsula which is one of the firefly watching hotspots in Sabah. Furthermore, it is unclear how the congregating fireflies' population might respond to the current ecotourism practices in Klias Peninsula. The knowledge gained from this study might potentially act as a reference for future comparisons to determine spatial-temporal variations of the firefly communities in this area. In order to sustain and conserve the congregating firefly population in their natural habitat, their diversity and ecological information must be acquired. For these reasons, this study was carried out to determine the diversity of *Pteroptyx* fireflies and their display trees in Klias Peninsula.

Method and Materials

Study site and identification of display tree

Three rivers that are known to have high population of *Pteroptyx* fireflies were selected as sampling sites, namely Garama River, Teratak River and Weston River (Figure 1). Garama River lies within the centre of the Klias Peninsula. The river is 5.4 km long (N 05°24'37.32", E 115°31'54.54"), located in the Padas Damit Forest Reserve while parts of the river flows outside the forest reserve. Teratak River (N 05°19'38.9"; E 115°31'06.7"), located within the Padang Teratak wildlife sanctuary was also selected as one of the three sampling sites. Weston River (N 05°11'37.82", E 115°34'38.54") flows towards a wide estuary and the riverine is surrounded by mangrove vegetation and nypa palms. Field sampling was carried out from January 2015 to August 2015. There were five sampling occasions in each river.

A total of 15 display trees were selected in each river for sampling purposes (selected display trees were indicated by red dots on Figure 1). The display trees where the congregating fireflies perched on were identified to species level.

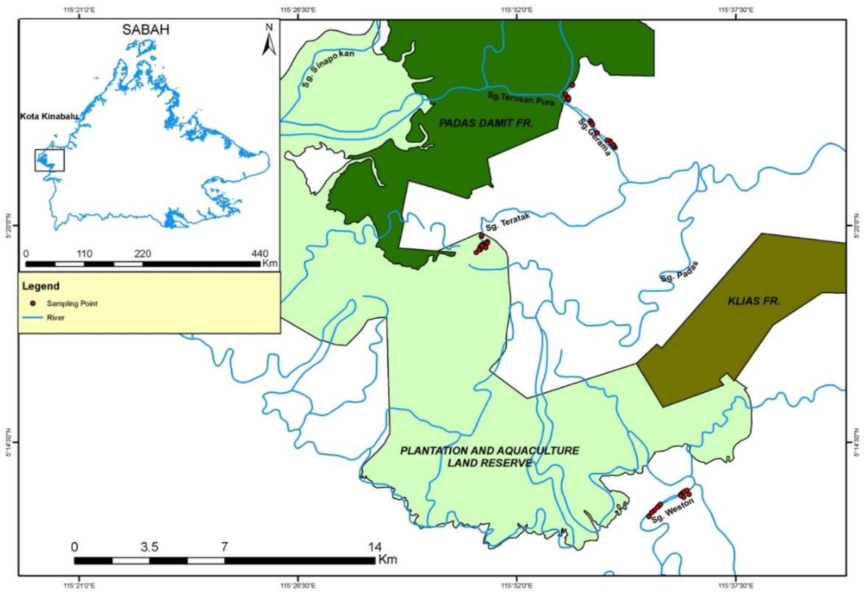


Figure 1. Map presenting three sampling sites, namely Sg. Garama, Sg. Teratak and Sg. Weston. The blue line indicates the river structure and red spots indicate the sampling sites in different rivers.

Firefly diversity assessment and statistical analysis

Visual estimation technique was utilized to determine the firefly density on each display tree by referring to modified percentage cover comparison chart employed from “Field Manual for Describing Terrestrial Ecosystems: Land Management Handbook number 25, 1998, from British Columbia Ministry of Environment, Lands, and Parks” (Province of British Columbia, 1998). Firefly specimens were collected through net sweeping technique for two minutes on each individual display tree. Firefly species identification was done by referring to the taxonomy description published by Ballantyne & Lambkin (2013). Temporal variation on the abundance of fireflies between sampling occasions was compared by Kruskal-Wallis *H*-test (Mahadimenakbar et al., 2007). The abundance of male and female fireflies was analysed using the Mann-Whitney non-parametric *U*-test.

Results

Firefly diversity and abundance

Approximately 1,750 individuals representing four species were recorded from the three sampling rivers (Garama River, Teratak River and Weston River). Weston River exhibited the highest abundance while Garama River had the lowest (Figure 2). Kruskal-Wallis test showed the abundance of fireflies collected at all stations of Weston River were significantly different among the five sampling occasions ($H = 11.88$, *d.f.* = 4, $p < 0.05$). However, there were no significant variations ($p > 0.05$) observed in Garama River and Teratak River.

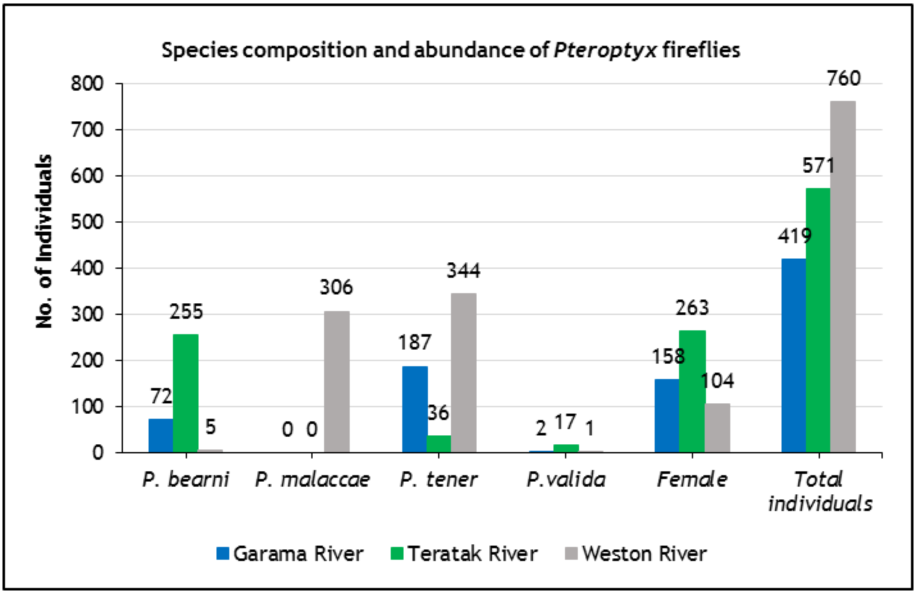


Figure 2. Species composition and abundance of *Pteroptyx* fireflies in Garama River, Teratak River and Weston River.

Male-female composition

Of the 1,750 firefly individuals collected (all species combined), 1,225 individuals (70.0 %) were male while 525 (30.0 %) were female. Results from the Mann-Whitney *U*-test showed that abundance of males was significantly higher than females in all samples (Mann-Whitney $U = 6162.0$, $Z = -7.814$, $p < 0.05$). Except for Teratak River that had almost an 1: 1 sex ratio, both Garama and Weston rivers showed that the male abundance was significantly higher than that of the female ($p < 0.05$) (Table 2).

Table 1: Sex composition and Mann – Whitney *U* test result from Garama River, Teratak River and Weston River.

	Overall	Garama River	Teratak River	Weston River
Male	1225 (70.0 %)	261 (62.3 %)	308 (53.9 %)	656 (86.3 %)
Female	525 (30.0 %)	158 (37.7 %)	263 (46.1 %)	104 (13.7 %)
Male–Female Ratio	2.33 : 1	1.65 : 1	1.17 : 1	6.31 : 1
Mann – Whitney *U*	6162.0	449.5	1126.5	492.5
Z-score	-7.814	-2.845	-1.169	-8.103
Sig. *P*	0.000	0.004	0.242	0.000

Coverage on display trees

Fifteen display trees with high flashing visibility were selected in Garama River, Teratak River and Weston River. The percentage cover of fireflies on selected display trees in Garama River was within the range of 0.5 to 5 %, Teratak River within the range of 0 to 3 %, and Weston River ranged between 0 to 5 %. It was found that fireflies in Weston River displayed their light on a single mangrove species, *Sonneratia alba*, with an average firefly coverage of 1.66 %. Interestingly, this plant species was not selected as a display tree by firefly communities at the Garama River and Teratak River. Both Garama River and Teratak River had a higher coverage of fireflies on plant species of *Excoecaria* (~2.1 %), and lower coverage on *Rhizophora apiculata* (<1 %).

Table 2. Percentage covers of fireflies (mean ± standard deviation) on main display mangrove plant species in Garama River, Teratak River, and Weston River

Plant Species	Garama River	Teratak River	Weston River
Avicennia alba		1.06 ± 0.64	
Excoecaria agallocha		2.13 ± 1.18	
Excoecaria indica	2.15 ± 0.89		
Hibiscus tiliaceus	1.88 ± 1.39		
Nypa fruticans	1.89 ± 1.40		
Sonneratia alba			1.66 ± 1.26
Rhizophora apiculata	0.75 ± 0.29	0.5 ± 0.71	

Discussion

Among the three sampling rivers, the highest species richness was recorded from Weston River. Four *Pteroptyx* firefly's species were found in Weston, namely *Pteroptyx bearni* Ballantyne, *Pteroptyx malaccae* Gorham, *Pteroptyx tener* Olivier, and *Pteroptyx valida* Olivier. The dominant species in Weston River was *Pteroptyx tener* (n = 344, 52.4 %) but *Pteroptyx malaccae* was just slightly lower in abundance compared to *P. tener* (n = 306, 46.6 %). On the other hand, *Pteroptyx tener* was also the dominant species in Garama River (n = 187, 71.6 %). Studies carried out in Peninsular Malaysia show that *Pteroptyx tener* was the dominant species in several localities, namely Rembau-Linggi Estuary (Wan Jusoh et al., 2010a), Sepetang Estuary (Wan Jusoh et al., 2010b), Kampung Kuantan (Ballantyne and Menayah, 2000) and Sungai Johor (Norela et al., 2015; Sahara et al., 2017 (in press)). Interestingly, the dominant species in Teratak River was *Pteroptyx bearni* (n = 255, 82.8 %). Previous documentation suggested that *Pteroptyx bearni* was the dominant species across the mangrove forests of Sabah, especially in Paitan (Chey, 2006), Garama River (Mahadimenakbar et al., 2007), Sepilok (Chey, 2008), Tuaran (Chey, 2009), Pulau Sakar (Chey, 2011). In addition, *P. bearni* was also recorded in Kerteh River at Terengganu (Wan Jusoh et al., 2011). Hence, *P. bearni* is not endemic to Sabah. This indicates that Klias Peninsula harbours an interesting species composition of *Pteroptyx* fireflies.

Combining the result from current study with findings from Mahadimenakbar et al. (2007), the data indicated that the *Pteroptyx valida* is comparatively rare in Klias Peninsula. Surprisingly, *Pteroptyx malaccae* that was previously documented in Garama and Teratak Rivers (Mahadimenakbar et al., 2007; Foo & Mahadimenakbar, 2015) is not recorded in this study. This could not be due to seasonal emergence because a large population of this species was found in Weston River around the same period. The temporal fluctuation of *Pteroptyx* fireflies was tested by Kruskal-Wallis *H*-test and statistical analysis determined significant temporal variations of firefly abundance in Weston River ($H = 11.88$, $d.f. = 4$, $p < 0.05$), but no significant ($p > 0.05$) temporal variations were observed in other sampling rivers. This result leads us to assume that the firefly population at the sampling sites is considerably stable in terms of abundance. In addition, this suggests that ecotourism that utilizes congregating fireflies as an attraction can operate throughout the year without worrying about a sudden sharp decline of the firefly population.

In terms of abundance, the male fireflies (70 %) outnumber the female fireflies (30 %) on the display trees (Table 1). However, this number does not emphasize the sex ratio within the entire mangrove habitat. The Mann-Whitney *U*-test revealed that the abundance of males was significantly higher than females in the entire sample (Mann-Whitney $U = 6162.0$, $Z = -7.814$, $p < 0.05$). Combining the findings from the current study and sex ratio results published by Koji et al. (2012), we suggest that the males are most probably the primary signaler that are retained on the display tree after mating, subsequently resulting in significantly higher male abundance on the display tree. Identifying display trees species that are utilized by congregating fireflies is essential for the purpose of rehabilitation. In Garama River, four mangrove tree species were selected as display trees, such as *Excoecaria indica, Hibiscus tiliaceus, Nypa fruticans*, and *Rhizophora apiculata*. For Teratak River, three mangrove species were selected as display trees, namely *Avicennia alba, Excoecaria agallocha,* and *Rhizophora apiculata*. The display tree species selected by fireflies as their perching tree during the night are different between sites except for *Rhizophora apiculata* that was selected as the display tree in both Garama and Teratak rivers (Table 2). There is only one mangrove species selected as the display tree by *Pteroptyx* fireflies in Weston, that is the *Sonneratia alba*. The exact reason behind the selection of specific mangrove species at different localities remains unclear. We suspect the antimicrobial chemical secretes by certain mangrove species might act as a factor that governs the selection of display trees, for example the *Sonneratia alba* was proven to exhibit antimicrobial activities (Saad et al., 2012). The highest firefly coverage was identified on *Excoecaria indica* (2.15 ± 0.89 %) and *Excoecaria agallocha* (2.13 ± 1.18 %). We suspect that the leaf arrangement and large surface area that is suitable for mating are the main factors influencing the selection of these display trees.

Collectively, the findings from this study on the diversity of *Pteroptyx* fireflies can be used as a reference for future studies to determine the spatial-temporal variation of these congregating firefly communities in Klias Peninsula. The information on the display tree species in different rivers provides input for rehabilitation projects.

Acknowledgement

This project was supported by KPT under the grant FRGS0357-STWN-2/2013. We would like to express our deepest appreciation to Sabah Wildlife Department for allowing us to conduct research at Padang Teratak. We would like to thank Simon Kuyun, Hong Men Chin, and Vickly Mobilim for their assistance during field sampling.

References

Ballantyne LA, Lambkin CL. 2013. Systematics and phylogenetics of Indo-Pacific Luciolinae fireflies (Coleoptera: Lampyridae) and the description of new genera. *Zootaxa* **3653(1):** 1-162

Ballantyne LA,Menayah R. 2000. Redescription of the synchronous firefly *Pteroptyx tener* Olivier (Coleoptera: Lampyridae) of Kampong Kuantan, Selangor. *Malayan Nature Journal* **54(4):** 323–328

Chey VK. 2006. Fireflies of Sungai Paitan. *Sepilok Bulletin* **5**: 1-6

Chey VK. 2008. Fireflies of Sepilok. *Sepilok Bulletin* **9**: 3-11

Chey VK. 2009. Fireflies of Tuaran. *Sepilok Bulletin* **10**: 25-33

Chey VK. 2011. Fireflies of Pulau Sakar. *Sepilok Bulletin* **13** & **14**: 27-32

Foo K, Mahadimenakbar MD. 2015. Diversity of fireflies (Coleoptera: Lampyridae) of Sungai Teratak, Sabah, Malaysia. *Journal of Tropical Biology and Conservation* **12**: 1-11

Kathiresan K, Salmo III SG, Fernando ES, Peras JR, Sukardjo S, Miyagi T, Ellison J, Koedam NE, Wang Y, Primavera J, Jin Eong O, Wan-Hong Yong J, Ngoc Nam V. 2010. *Sonneratia alba*. The IUCN Red List of Threatened Species 2010: e.T178804A7611432.

Koji S, Nakamura A, Nakamura K. 2012. Demography of the Heike firefly *Luciola lateralis* (Coleoptera: Lampyridae), a representative species of Japan's traditional agricultural landscape. *Journal of Insect Conserv*ation **16**: 819-827

Mahadimenakbar MD, Hairul HM, Mazidi AG. 2007. The distribution and phenology of *Pteroptyx* fireflies (Coleoptera: Lampyridae) along Garama River, Sabah, Malaysia. *Journal of Tropical Biology and Conservation* **3**: 1-9

Nallakumar KA. 2003. The synchronously flashing aggregative fireflies of Peninsular Malaysia. *Biodiversity* **4(2):** 11-16

Norela, S., Shahril, M.H., Mohd. Noh, A., Maimon, A., and Khairunnisa, S. 2015. Abundance of Lampyridae in relation to the vegetation and abiotic conditions along the Sungai Johor, Johor, Malaysia. *Malayan Nature Journal* **67**(4): 395-402.

Province of British Columbia. 1998. Field manual for describing terrestrial ecosystems. British Columbia Minestry of Environment, Lands, and Parks and British Columbia Minestry of Forests. Vitoria, British Columbia. *Handbook* **25**.

Saad S, Taher M, Susanti D, Qaralleh H, wang AFI. 2012. *In vitro* antimicrobial activity of mangrove plant *Sonneratia alba*. *Asian Pacific Journal of Tropical Biomedicine* pp. 427-429

Shahara A, Nura AMR, Maimon A, Norela S. 2017. Assessment of firefly abundance at a new ecotourism site of Sungai Bernam, Selangor, Malaysia. Malayan Nature Journal **69**(2). June 2017 (in press).

Wan Jusoh WFA, Hashim NR, Ibrahim ZZ. 2010a. Distribution and abundance of *Pteroptyx* firelfies in Rembau-Linggi Estuary, Peninsular Malaysia. *Environment Asia* **2**: 56-60

Wan Jusoh WFA, Hashim NR, Ibrahim ZZ. 2010b. Firefly distribution and abundance on mangrove vegetation assemblages in Sepetang Estuary, Malaysia. *Wetlands Ecology and Management* **18**: 367-373

Wan Jusoh WFA, Wong C-H, Hashim NR. 2011. Zonation of firefly species and their display trees along Kerteh River, Terengganu. *Serangga* **16(2):** 59-66

Journal of Tropical Biology and Conservation 14: 105–124, 2017 ISSN 1823-3902

Research Article

Evaluation of Spatial and Seasonal Variations of Dissolved Organic Matter in Maliau Basin, Sabah, Malaysia

Tan Sin Yee[1], Sahana Harun[1,2]*, Kueh Boon Hee[1], Arman Hadi Fikri[1,2]

[1]*Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, 88400 Jalan UMS, Kota Kinabalu, Sabah, Malaysia.*
[2]*Water Research Unit, Universiti Malaysia Sabah, 88400 Jalan UMS, Kota Kinabalu, Sabah, Malaysia.*
*Corresponding author: sahana@ums.edu.my

Abstract
The characteristics dissolved organic matter (DOM) and surface water quality in Maliau Basin, Sabah, Malaysia, were determined from December 2014 to September 2015. The objectives of this study were: (i). to distinguish the surface water quality of rivers which consisted of different types of land use: primary forest (PF), secondary forest (SF), main river (MR) and altered habitat (AH); (ii). to assess seasonal variations of the water quality. A total of 36 water samples were collected during the fieldwork campaign that extended over high and low rainfall periods. The water quality physico-chemical parameters such as water temperature, pH, dissolved oxygen (DO), conductivity, and salinity were measured *in-situ* with the YSI-multiparameter instrument, while dissolved organic carbon (DOC) concentration was evaluated using Shimadzu TOC-V-SCH analyzer with auto-sampler TOC-ASI-V equipped. Dissolved organic matter (DOM) was determined optically in the laboratory at 254 (a_{254}), 340 (a_{340}) and 410 (a_{410}). Discriminant analysis (DA) was employed to organize independent variables into mutually-exclusive groups. The outcome of DA indicated that water temperature, total suspended solid (TSS), and conductivity were dominant at AH, whilst a_{340} was dominant at MR in March 2015. Our results also showed seasonal variations for water quality parameters. The highest mean concentrations of pH and a_{340} were found during the dry period (March 2015) and dissolved oxygen (DO) during the wet season (December 2014), suggesting spatio-seasonal variations of DOM and water quality parameters were determined by environmental factors such as precipitation, water velocity and discharge amount. UV-vis absorptions a_{254} and a_{340} show significant positive correlation with dissolved organic carbon (DOC), suggesting that it could be a suitable proxy for DOC concentration for tropical flowing water.

Keywords: Water quality, dissolved organic matter (DOM), Maliau Basin.

Received 10 July 2017
Reviewed 31 July 2017
Accepted 08 August 2017
Published 15 October 2017

Introduction

Tropical river systems are mainly characterized by marked annual cycles in precipitation, rain periods and high solar radiation (Saigusa et al., 2008) and also low in aquatic primary production and nutrients (Davies et al., 2008). These streams or rivers occur in complex variety with seasonal differences in velocity of flow, water chemistry, and metabolic rates. Spatial and seasonal variations of tropical rivers biogeochemistry are mostly driven by local topography that surround the river (Allan, 2004) and it can also be altered by anthropogenic activities such as logging and road construction (Dudgeon, 2012). Forest canopy coverage also was found to play an essential role in determining the turbidity and total suspended solids in the fluvial system (Singh & Mishra, 2014). The presence of vegetation can stabilize riverbanks to prevent erosion, filter nutrients and sediments, moderate water temperature by governing light availability and provide various other ecological services (Iwata et al., 2013).

Several studies had demonstrated that the spatial and seasonal variations of river water chemistry, for instance, Zakeyuddin et al. (2016) found that the concentration of dissolved oxygen, water temperature, electrical conductivity, and total dissolved solids in Bukit Merah Reservoir, Malaysia displayed variations from December 2012 until January 2014. Udoh et al. (2013) revealed seasonal variation in several physico-chemical parameters, more specifically between the wet and dry seasons. Furthermore, da Costa et al. (2015) reported that the water temperature, salinity, and pH were higher during the long dry season. In addition, Harun et al. (2016) suggested that there were significant seasonal and spatial variations in dissolved organic matter (DOM) in the tropical catchment of North Borneo, and the concentration of DOM was mainly determined by the types of land use and precipitation rate.

Dissolved organic matters (DOM) are an important source of energy in the aquatic environment; the quality and quantity of DOM can determine the productivity of the local fluvial ecosystem (Carlson, 2002; del Giorgio & Davis, 2003). From a catchment perspective, streams at the upper area which receive more terrestrial-derived DOM tend to have higher dissolved organic carbon (DOC) concentrations (Dalzell et al., 2009; Mayorga et al., 2005). DOC is the carbon component of DOM; therefore, determining the DOM flux is essential for a better understanding of the aquatic ecosystem (Hopkinson & Vallino, 2005). There are numerous techniques in evaluating the quality and quantity of DOM (Coble, 2007), while the optical parameters method is currently increasingly used in water quality related research due to its lower application costs and lower operational knowledge (Hansen et al., 2016). The absorption coefficient at 340 nm was considered as an effective proxy for dissolved organic matter concentration for natural water (Allpike et al., 2005), while the spectral slope can be used to reveal the molecular weight and aromaticity of the DOM (Helms et al., 2008). In freshwater, DOM mainly derived from leaf litter, plants and soil organic matter (allochthonous) and in-situ heterotrophic production (autochthonous) (Pagano et al., 2014). In tropical regions, DOM plays a crucial role in surface water quality to indicate anthropogenic and land use activities that influence stream water DOM concentrations (Harun et al., 2016; Holbrook et al., 2006; Williams et al., 2010; Yamashita et al., 2011; Lu et al., 2013; Burrows et al., 2013). Consequently, DOM has been shown to vary seasonally in the tropical river catchment of Kinabatangan, Sabah, Malaysia (Harun et al., 2016), undisturbed rainforest sub-catchment in Australia (Bass et al., 2011) and sub-tropical bay in Florida, USA (Maie et al., 2012).

In tropical forest stream ecosystems, very little work is published on the characterization of water quality and dissolved organic matter (DOM) according to spatial and seasonal variations. Maliau Basin Conservation Area (MBCA) is a pristine tropical forest situated in Sabah, Malaysian Borneo. The basin is drained by Maliau River, which flows and joins Kuamut River at the southeastern part of the basin, and eventually joins the largest waterway in Sabah: Kinabatangan River (Hazebroek, 2004; YS, 2014). The objectives of this study were twofold: (i). to distinguish the surface water quality of rivers which consisted of different types of land use: primary forest (PF), secondary forest (SF), main river (MR) and altered habitat (AH); and (ii). to assess seasonal variations of the water quality. To-date, only four water quality assessments have been carried out at the MBCA within a period of two decades: Mykura, 1989; Anton & Alexander, 1998; Mokhtar et al., 2009; Harun et al., 2010. The data regarding to river water quality in this area has not been updated since 2006 (Mokhtar et al. 2009). Therefore, we would like to provide the latest data on the water quality status of the rivers.

Methodology

Study Site

Maliau Basin is located in Sabah in the northeastern part of Borneo Island (Figure 1). It occupies an area of about 390 km^2 and is surrounded by a formidable ridge reaching over 1,675 m above sea level (Webb & Ali, 2002). The area is a Class I (Protection) Forest Reserve which means it is totally protected and not for logging activities. The area is also covered entirely by an evergreen tropical rainforest, which consists of a mixture of tree species with at least 12 distinct forest types (Hazebroek et al., 2004). The basin is a huge water catchment drained by the main river: Maliau River (MR). Figure 1 illustrates the location of each sampling station at the Maliau Basin. Four streams consisting of four types of land use were investigated in this study: altered habitat (AH), Maliau River (MR), secondary forest (SF) and primary forest (PF). PF is situated within the core area of the forest reserve which is supposed to receive minimal disturbance, while SF is located in the buffer zone of MBCA which consists of lowland mixed dipterocarp forest. MR could be regarded as a high order river, as it is a single massive water catchment area that is connected and drained by a set of radiating tributaries. It drains the heath forest which attributes to the tea-colouration of the river water (Mykura, 1989). Stream at AH may have been subject to deterioration as there was a road construction project adjacent to the AH stream during the sampling periods. It was perceived that logging activities in the 1970s and mid-1990s (Ewers et al., 2011) would disturb the natural habitats of SF, MR and AH, as these three streams are located in the buffer zone area of Maliau Basin.

The area is influenced by monsoon winds (YS, 2014) and typically record heaviest rainfall from August to September (Maral, 2002; Hazebroek et al., 2004). The sampling campaign was conducted from December 2014 to September 2015. Two periods corresponded to the wet season (WS): December 2014 and March 2015; and another two corresponded to the dry season (DS): May 2015 and September 2015.

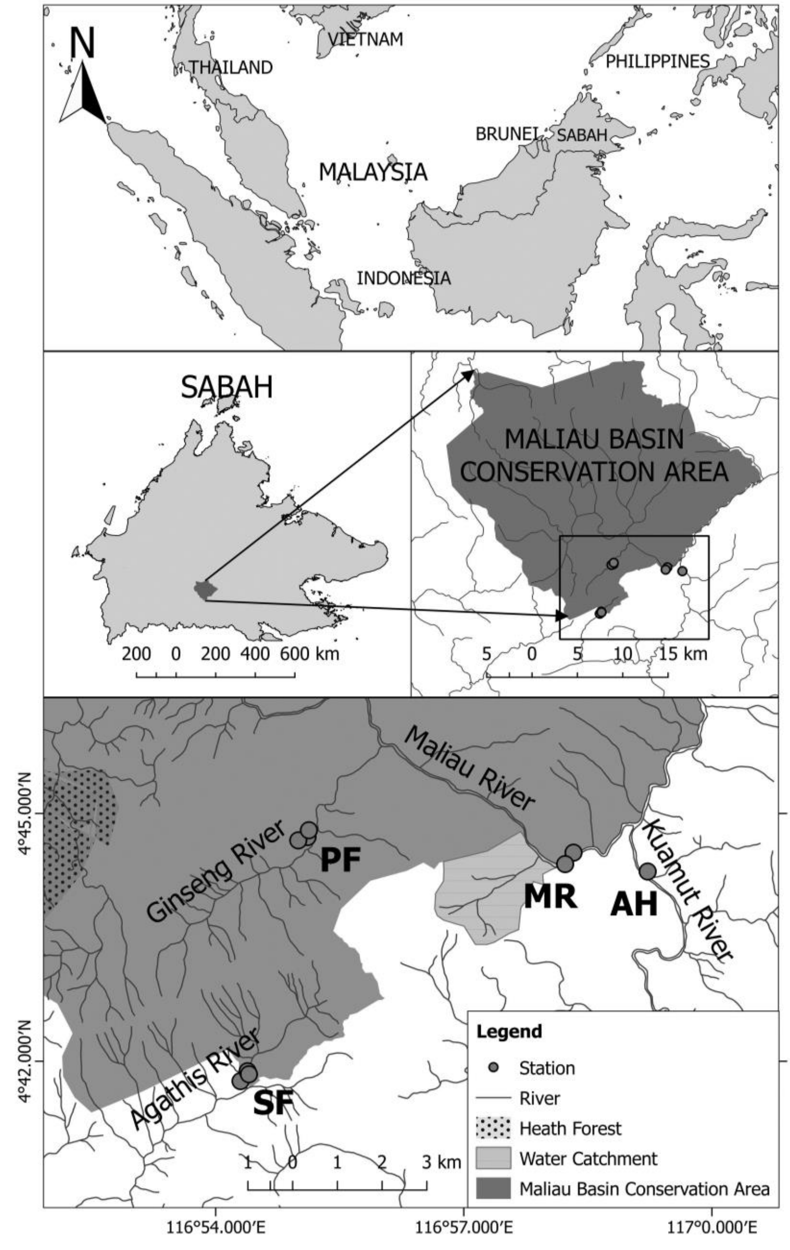


Figure 1. The locations of sampling stations at Maliau Basin, Sabah.

Surface Water Analysis

Physico-chemical parameters such as pH, water temperature, conductivity, total dissolved solids (TDS), and dissolved oxygen (DO) were recorded *in-situ* by using YSI Profesional Plus (ProPlus) (Model 6026 S/N Y5173) multiparameter. To analyze total suspended solids (TSS) and optical parameters (a_{254}, a_{340}, $a_{410,}$ and $S_{275-295}$), water samples were randomly collected from each stream into 250 mL high-density polyethylene (HDPE) bottles. Sampling bottles were pre-washed with 10 % hydrochloric acid (HCl) and rinsed with deionized water to avoid contamination from metal and non-metal ions (Perera et al., 2016). During the water sample collection, the water bottles were rinsed with river water three times before the samples were collected (Perera et al., 2016). Water samples were immediately filtered after sampling using Whatman GF/F filters (pore size 0.7 µm). The Whatman GF/F filters were used as these can achieve higher particle retention efficiency when filtering large volumes of less turbid water and provide a more accurate measurement of the TSS for less turbid water like those at Maliau rivers. Filtered samples were kept in a dark area and stored at 4°C for further analysis at Universiti Malaysia Sabah (UMS).

Spectral Measurement and DOC

Several studies demonstrated the applicability of using the absorption coefficients in determining the DOM concentration (Baker et al., 2008; Peacock et al., 2014). A study carried out by Peacock et al. (2014) elucidated that absorbance in the Ultraviolet or visible spectrum can act as a proxy for the DOM concentration in stream water. In addition, several UV-Vis spectrums were used as a proxy for DOM concentration, for example, absorbance coefficient at wavelength 254 nm (Allpike et al., 2005; Baker et al., 2008; Burrows et al., 2013), 340 nm (Baker & Spencer, 2004; Baker et al., 2008), and 410 nm (Baker et al., 2008).

The optical properties of the stream water were identified by UV-Visible spectroscopy technique performed with Agilent Cary 60-Vis Spectrophotometer (Agilent Technologies, California, United States) and referenced to deionized water. Two hours prior to analysis, the filtered water samples were taken out from the cooler to ensure the water samples were restored to room temperature (Loginova et al., 2016). The water samples were then transferred into 1 cm quartz cuvettes with 2 mL volume. The water samples were scanned with a spectrophotometer with a wavelength range of 200 nm to 800 nm, at one nm intervals (Cooper et al., 2016). The absorbance for each water sample was recorded and used for the calculation of absorption coefficients and spectral slopes. The absorbance spectra for these three wavelengths were converted to Napierian absorption coefficients using the following equation (Helms et al., 2008):

$$a = 2.303 \bullet A / l$$

where a is Napierian absorption coefficient, A is the absorbance provided by a spectrophotometer, and l is the path length of the cuvette in meters. The spectral slope for the interval of 275 to 295 nm ($S_{275-295}$) was calculated by linear regression of the log-transformed a spectra (Helms et al., 2008).
Dissolved organic carbon (DOC) was acquired by high-temperature catalytic combustion method using Shimadzu TOC-VCSH analyzer with auto-sampler TOC-ASI-V (Zigah et al., 2012). Samples were acidified with hydrochloric acid (HCl) after the filtration processes. Two hours prior to lab analysis, the water samples were taken out from the refrigerator, and allowed to warm to room temperature (Loginova et al., 2016). Samples were acidified to pH ~2 and then sparged for 8 minutes at 75 or 100 mL/min with ultra-pure oxygen to remove all inorganic carbon from samples prior to measurement (Zigah et al., 2012). Due to equipment and technical constraints, only one sample set (September 2015) was used for DOC analysis in this study.

Statistical Analysis

Discriminant analysis is a multivariate statistical modeling technique, which can be used as a tool for pattern recognition. Objects can be classified into mutually-exclusive groups according to a set of independent variables (Gazzaz et al., 2012). Discriminant analysis has been employed using the statistical software of SPSS (Version 20) to discriminate the water quality data in different habitat types where the water samples were collected, as well as the seasonal variations of the stream water quality into mutually-exclusive clusters. To increase the ability to identify important parameters, water quality parameters that covaried strongly ($r > 0.7$) were removed, retaining those with most direct ecological interpretation. For instance, salinity and TDS were removed as they covaried strongly with conductivity while absorption coefficients, a_{254} and a_{410} were also not included in this analysis. The standardized coefficient represents the partial contribution of the variable and ranks the importance of each variable to the discriminant function. Wilks' Lambda test is to test which variables contribute significantly to the function. The closer Wilks' Lambda is to 0, the more the variable contributes to the function. The significance of Wilks' Lambda is tested by the Chi-Square statistic. The corresponding function explains the group membership well if the *p*-value is less than 0.05.

Results and Discussion

Suitability of UV-Vis absorption coefficients as proxy for DOM concentrations

In many aquatic systems, particularly in freshwater systems, UV-vis absorbance values have been showed to positively correlate with dissolved organic carbon (DOC) (Baker et al., 2008; del Vecchio & Blough, 2004) and estimate DOC concentrations (Cook et al., 2017). The spectral reading from the wavelength absorption is a good substitute in identifying the concentration of the DOC (Cook et al., 2017; Kwak et al., 2013). Figure 2 exhibits scattergram of optical parameters (a_{254}, a_{340}, and a_{410}) and dissolved organic carbon (DOC) concentrations. UV-vis absorption coefficients at 254 and 410 nm also showed positive correlations with DOC. Highest correlations were found between a_{254} and DOC, followed by a_{340} and DOC, and the lowest were found between a_{410} and DOC. This result suggests that the absorption coefficient at 254 nm and 340 nm is suitable to act as the proxy for DOM concentration for tropical flowing water. These two wavelengths are also commonly used in the water treatment industry (Allpike et al., 2005) and natural water studies (Baker et al., 2008; Hernes & Benner, 2003; Tipping et al., 2009).

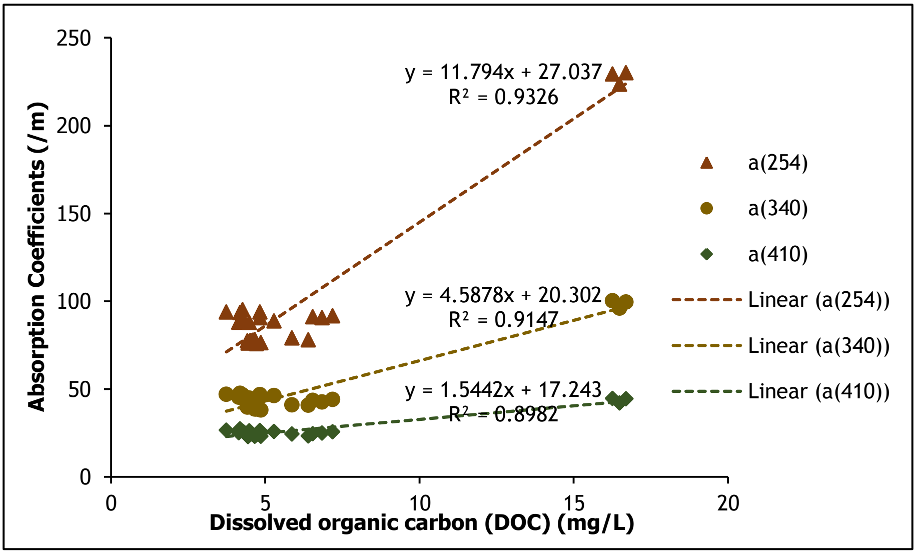


Figure 3. UV-vis absorption coefficients at 254 nm, 340nm and 410 nm (a_{254}, a_{340}, and a_{410}) against dissolved organic carbon (DOC) concentration.

Spatial Variations of Water Quality

Physico-chemical and optical properties of the four streams in Maliau Basin showed significant variations (Table 1). The ordination plot of discriminant analysis (DA) for water quality data set based on land use type is demonstrated in Figure 4a. Based on the DA plot, sampling stations at the primary forest (PF) and secondary forest (SF) both indicated higher resemblance in their physical and chemical characteristics. However, segregation of altered habitat (AH) and main river (MR) revealed that these two streams differed distinctively from other streams in their water quality properties. It has been found that water temperature, total suspended solids (TSS), and conductivity were higher in AH, while dissolved organic matter concentrations (a_{340}) were higher in MR (Figure 4a; Table 2). Spatial variations of water quality are determined by several local environmental conditions such as solar radiation, ambient temperature, water velocity and discharge amount (Qadir et al., 2008), and influenced and enhanced by the seasonal precipitation rate.

The varied water temperature at different sampling locations can be attributed to riparian vegetation shading, topographic variable of elevation, shape of the channel (i.e. wide and shallow channels more easily heated and cooled) (Poole et al., 2001), and river water circulation that is influenced by heat exchange on the earth's surface (Mokhtar et al., 2009). Higher water temperature was recorded at AH and MR (27.07 ± 1.408 °C and 24.28 ± 1.229°C respectively), characterized by a wider channel which increased the surface area exposed to solar radiation that consequently resulted in higher water temperature.

The suspended-sediment loads in tropical streams are highly variable with soil type, local precipitation rates, topography, riparian vegetation and human activities (Jacobsen, 2008). Even without the presence of anthropogenic disturbances at the upper stream, a heavy flow can give rise to higher TSS levels (Jacobsen, 2008). In addition, it has been reported that increment of sediment loads at Maliau River during flood flow was due to constant erosion of soft mudstone at steep valley slopes in the upstream area (Mykura, 1989). These processes could take part during the study period as well, as indicated by high sediment concentrations at MR during high rainfall periods. The constant erosion possibly provided sediment input to the Maliau River, however, this assumption needs further confirmation through geological analysis on soil properties and the erosion rate needs further confirmation. Moreover, road construction at Maliau Basin was suspected to be the causative factor that resulted in a high value of TSS in AH.

Results from this study show that lower conductivity was observed at PF (33.73 ± 13.42 μS/cm) and SF (46.32 ± 14.427 μS/cm). On the other hand, a comparatively higher conductivity (99.04 ± 27.149 μS/cm) was determined at Kuamut River (termed AH), where the earthwork operation for road construction adjacent to the river may cause high conductivity values as recorded in this study. Anthropogenic activities like logging and agricultural activities were reported to cause remarkable disruption to the nutrient cycle (i.e. calcium fixation) in the natural habitat. Nutrient leaching followed by the interruption of forest activities and land clearing can result in higher river water conductivity in the affected regions (Singh & Mishra, 2014). Meanwhile, lower river water conductivity, in general, is associated with riparian forests characterized by higher vegetation densities (de Souza et al., 2013), the low conductivity and TDS at MR (21.69 μS/cm and 13.38 mg/L, respectively) could be caused by the acidity of the water and this is because the water conductivity is highly dependent on the ionic concentration of the water bodies (Balance, 1996). Apart from that, blackwater rivers typically have lower dissolved solids and exhibit low values for conductivity (Duncan & Fernandes, 2010), for instance, the Negro River in Amazon Basin recorded a mean conductivity of 14.4 μS/cm.

DOM concentrations were the highest at Maliau River (MR), the main river of Maliau Basin, and lower DOM concentrations were observed at forest habitats (for both PF and SF). Aiken et al. (2011) revealed that DOM concentrations were lower in pristine forest habitats. This could be due to the root mat of pristine/undisturbed forests that provides efficient service in recycling plant nutrients and non-humic substances into the living biomass, and at the same time retaining organic matters that are released from the litter layer before entering the groundwater and draining into the river system (Foster & Bhatti, 2006; Tank et al., 2010). The nutrients recycling and organic matter retention abilities of pristine forest were believed to reduce the amount of organic matter leaching into the fluvial ecosystem, thus we observed a relatively low DOM concentration within the rivers located at PF and SF. The existence of heath forest vegetation at the upstream of Maliau River was believed to result in high DOM concentration of water samples from MR (the downstream of Maliau River). This could be due to the heath forest vegetation being less efficient compared to the dipterocarp forest in trapping humic compound (Mykura, 1989).

Table 1. Mean ± SE of physico-chemical and optical parameters in the four tropical streams of Maliau Basin.

	Altered Habitat (AH)	Main River (MR)	Secondary Forest (SF)	Primary Forest (PF)
Physico-Chemical Parameters				
PH	7.2 ± 0.6	5.8 ± 1.4	7.1 ± 0.4	7.2 ± 0.5
Temperature (°C)	27.1 ± 1.4	24.3 ± 1.2	23.5 ± 0.3	22.5 ± 0.4
Conductivity (μS/cm)	99.0 ± 27.2	21.7 ± 2.0	46.3 ± 14.8	33.7 ± 13.4
DO (mg/L)	7.6 ± 1.6	8.4 ± 1.8	7.0 ± 0.4	8.4 ± 2.8
TDS (mg/L)	60.1 ± 20.0	13.4 ± 2.2	27.5 ± 11.4	20.4 ± 10.4
TSS (mg/L)	48.1 ± 61.4	72.2 ± 113.1	11.3 ± 5.2	9.1 ± 4.9
Optical Parameters				
a_{254} (/m)	72.1 ± 7.8	167.8 ± 49.8	82.4 ± 21.6	95.8 ± 32.2
a_{340} (/m)	36.4 ± 4.2	76.4 ± 17.6	42.2 ± 10.2	46.7 ± 13.5
a_{410} (/m)	22.3 ± 2.1	35.6 ± 5.9	24.1 ± 3.7	25.6 ± 4.9
$S_{275-295}$ (10^{-3}/nm)	8.7 ± 0.4	9.3 ± 1.0	8.1 ± 0.1	8.7 ± 0.6

Seasonal Variations of Water Quality

Rainfall data for each month were obtained from the Meteorological Department of Maliau Basin Studies Centre, Sabah (Figure 3). The second sampling occasion (March 2015) recorded the lowest rainfall, while the rest of the sampling occasions recorded rainfall above the mean monthly rainfall. In terms of seasonal variations, water samples collected in December 2014 were discriminated from other sampling months (Figure 4b; Table 2); water samples collected during this period was characterized by a higher dissolved oxygen (DO) concentrations (10.29 ± 2.244 mg/L). Water temperature plays an important role in determining the DO concentration by influencing the solubility of oxygen in water (Rajwa-Kuligiewicz et al., 2015). Several studies have shown that higher DO was observed in association with lower water temperature (Zaidi et al., 2015; Dienye & Woke, 2015). Discriminant analysis performed in this study indicated a negative correlation between DO concentration and water temperature. The lowest mean water temperature observed in December 2014 at all sampling sites (23.56 ± 1.226 °C) possibly increased the solubility of oxygen in the water bodies (Hosseini et al., 2017).

Water samples from the month with the lowest rainfall (March 2015) were discriminated from other sampling occasions with higher pH values and DOM concentrations (Figure 4b; Table 2). The seasonal variations of pH were mainly contributed by the water samples from the main river (MR), as other sampling stations exhibited relative consistency in pH values throughout the study period. Notably, pH in MR was as low as 5.79 indicating MR as having acidic river water characteristics (Table 1). The acidity of river water at Maliau Basin has been reported in previous studies carried out at Maliau River (Mykura, 1989), Eucalyptus River (Mokhtar et al., 2009), Giluk River and Takob-Akob River (Harun et al., 2010). The acidic river water recorded in this study could be caused by humic substances leached from vegetation in the heath forest zone as indicated in Figure 1 (Mykura, 1989; Hazebroek et al., 2004). Besides that, the main river (MR) was found to be associated with high values of a_{340}. UV-vis absorption coefficient at 340 nm was positively correlated with dissolved organic carbon (DOC), thus could indicate high dissolved organic matter (DOM) concentration (Figure 2). Consequently, the high concentration of DOM probably caused the acidity of river water at MR due to the acidic properties of most DOM (i.e. humic and fulvic acids found in organic contents) (Findlay & Sinsabaugh, 2003). Therefore, neutral pH values observed at MR during the low rainfall month (March 2015) could be due to low input of dissolved organic matter.

UV-vis absorption coefficients at 340 nm (a_{340}) displayed seasonal variations and the fluctuations patterns vary among sampling locations. Highest mean DOM concentrations were determined at both primary and secondary forests (PF and SF respectively) during the dry month (March 2015), while the lowest mean for DOM concentration was observed at altered habitat (AH) and the main river (MR) during the sampling occasion performed in the same month (Table 1). The result from this study indicated a higher concentration of DOM at PF and SF during the low rainfall month possibly due to the condensation process by evaporation. Research carried out by Aiken et al. (2011) revealed that a higher DOM concentration was associated with the dry month, primarily due to the evaporation of surface water, and lower concentration was commonly observed during the period of higher rainfall caused by dilution by rain water. Inversely, lower DOM concentration observed at AH and MR during the dry month may reflect low in-situ production of DOM (both allochthonous and autochthonous). Wantzen et al. (2008) stated that the primary source of organic matter in streams/rivers is plant litter from the riparian zone and the retentiveness capacity of leaf litter influences the organic decomposition rate. However, leaf litter data was not collected in this study, thus, we are not able to evaluate whether the density of leaf litter influenced the DOM concentration for both AH and MR. On the other hand, flow/discharge rate that determines the transportation of DOM from one locality to another might also influence the DOM concentration in the fluvial system (Larsen et al., 2010). Meanwhile, the flow and discharge rates are governed by liquid precipitation, canals, and groundwater discharge rates (Njogu & Kitheka, 2017). During the period with lower rainfall rate, the export of DOM might be reduced thus resulting in a lower concentration of DOM at both AH and MR during the dry month.

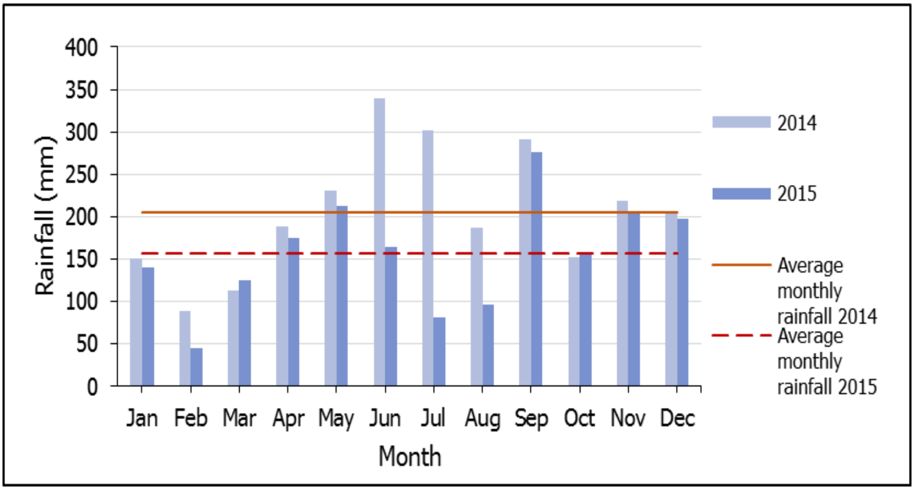


Figure 3. Monthly rainfall data recorded at the Maliau Basin from January 2014 to December 2015. (Source: Meteorological Centre of Maliau Basin Studies Centre, Sabah).

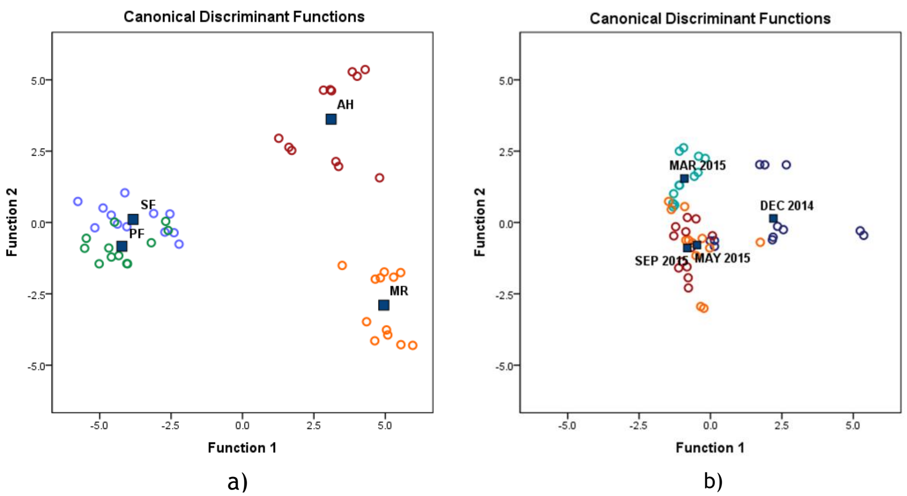


Figure 4. (a) Discriminant analysis functions for each type of land use at the Maliau Basin (PF – Primary forest, SF – Secondary forest, MR – Main river, and AH – Altered habitat). (b) Discriminant analysis functions for each sampling month (December 2014, March 2015, May 2015, and September 2015).

Table 2. Standardized canonical discriminant function coefficients, eigenvalue, cumulative percent of the variance, and Wilk's Lambda from the discriminant analysis that employed to examine the spatial and seasonal variations of water quality at Maliau Basin.

Variables	Spatial Variations		Seasonal Variations	
	DF1	DF2	DF1	DF2
pH	0.126	-0.004	-0.280	**1.200**
Temperature	**2.309**	-0.002	-0.546	-0.038
Conductivity	-0.729	**1.002**	0.558	0.469
Dissolved Oxygen (DO)	**1.038**	0.150	**1.065**	0.077
Total Suspended Solids (TSS)	**1.417**	0.237	-0.065	-0.127
a_{340}	**1.339**	-0.620	-0.210	**1.178**
$S_{275-295}$	0.033	-0.097	-0.213	-0.082
Eigenvalue	18.160	6.056	1.790	1.042
Cumulative % of Variance	74.3	99.1	46.7	73.9
Wilk's Lambda	0.006	0.117	0.088	0.244
(Sig. p)	(0.00)	(0.00)	(0.00)	(0.00)

Conclusions

Based on the surface water quality physico-chemical and optical assessment, we concluded that the water quality from all sampling stations at Maliau Basin was clean as indicated by most parameters, in accordance with the Interim National Water Quality Standards for Malaysia (INWQS). The water quality at PF and SF were categorized as Class I, thus suitable for conservation of the natural environment. However, our findings showed that the rivers located in the buffer zone of Maliau Basin (such as AH) are likely subjected to water quality deterioration. Both the physico-chemical and optical parameters demonstrated spatial and seasonal variations, where UV-vis absorbance a_{340} was dominant at the main river (MR), followed by primary forest (PF), secondary forest (SF) and altered habitat. Seasonally, the respective UV-vis absorbance was dominant during sampling in December 2014 and the least in March 2015. This also suggests that the quality of dissolved organic matter (DOM) varies in different types of land use, and is also altered by the monsoonal cycle. Significant positive correlation of UV-vis absorption coefficients at 254 and 340 nm with dissolved organic carbon (DOC) suggests its suitability as a proxy for DOC concentration in tropical regions. Consequently, further studies are needed to investigate the spatial and seasonal trends in surface water quality in catchments at Maliau Basin for a better understanding of this precious natural capital.

Acknowledgement
The authors thank Universiti Malaysia Sabah for providing financial support under UMS Research Grant (SBK0104-STWN-2013). We also would like to thank Mr. Faizal, Mr. Masliadi, and Mr. Edizam for their help with sampling.

References
Allpike BP, Heitz A, Joll CA, Kagi RI, Abbt-Braun G, Frimmel FH, Brinkmann T, Her N, Amy G. 2005. Size exclusion chromatography to characterize DOC removal in drinking water treatment. *Environmental Science & Technology* **39(7):** 2334-2342

Aiken GR, Gilmour CC, Krabbenhoft DP, Orem W. 2011. Dissolved organic matter in the Florida Everglades: Implications for ecosystem restoration. *Critical Review in Environmental Science and Technol*ogy **41(S1):** 217-248

Allan JD. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. *Annual Review of Ecology, and Evolution Systematics* **35:** 257-284

Anton A & Alexander J. 1998. Limnology of Maliau Rivers. *In* Mohamed M, Sinun W, Anton A, Dalimin MN & Hamid AH (eds.). *Maliau Basin Scientific Expedition*. Kota Kinabalu: Universiti Malaysia Sabah.

Armijos E, Laraque A, Barba S, Bourrel L, Ceron C, Lagane C, Magat P, Moquet JS, Pombosa R, Sondag F, Vauchel P, Vera A & Guyot JL. 2013. Yields of suspended sediment and dissolved solids from the Andean basins of Ecuador. *Hydrological Sciences Journal* **58(7):** 1478-1494

Avagyan A, Runkle BRK, Kutzbach L. 2014. Application of high-resolution spectral absorbance measurements to determine dissolved organic carbon concentration in remote areas. *Journal of Hydrology* **517:** 435-446

Baker A & Spencer RGM. 2004. Characterization of dissolved organic matter from source to sea using fluorescence and absorbance spectroscopy. *Science of the Total Environment* **333:** 217-232

Baker A, Bolton L, Newson M, Spencer RGM. 2008. Spectrophotometric properties of surface water dissolved organic matter in an afforested upland peat catchment. *Hydrological Processes* **22 (13):** 2325-2336

Balance, R. 1996. Field testing methods. *In* Balance R, Bartram J. (Eds). *Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. Great Britain: E and FN Spon.

Bass AM, Bird MI, Liddell MJ, Nelson PN. 2011. Fluvial dynamics of dissolved and particulate organic carbon during periodic discharge events in a steep tropical rainforest catchment. *Limnology Oceanography* **56(6):** 2282-2292

Burrows RM, Fellman JB, Magierowski RH, Barmuta LA. 2013. Allochthonous dissolved organic matter controls bacteria carbon production in old-growth and clearfelled headwater streams. *Freshwater Science* **32(3):** 821-836

Carlson CA. 2002. Chapter 4: Production and removal processes. *In* Hansell, D. A. and Carlson, C.A. (ed.). *Biogeochemistry of Marine Dissolved Organic Matter*. pp. 91-151. Elsevier Science: USA

Coble PG. 2007. Marine optical biogeochemistry: The chemistry of ocean color. *Chemical Reviews* **107:** 402–418

Cook S, Peacock M, Evans CD, Page SE, Whelan MJ, Gauci V, Lip KK. 2017. Quantifying tropical peatland dissolved organic carbon (DOC) using UV-visible spectroscopy. *Water Research* **115:** 229-235

Cooper KJ, Whitaker FF, Anesio AM, Naish M, Reynolds DM, Evans EL. 2016. Dissolved organic carbon transformations and microbial community response to variations in recharge waters in a shallow carbonate aquifer. *Biogeochemistry* **129:** 215-234

da Costa KG, Pereira LCC, da Costa RM. 2008. Short and long-term temporal variation of the zooplankton in a tropical estuary (Amazon region, Brazil). *Boletim do Museu Paraense Emilio Goeldi Ciencias Naturais, Belem*, **3(2):** 127-141

Dalzell BJ, Minor EC, Mopper KM. 2009. Photodegradation of estuarine dissolved organic matter: a multi-method assessment of DOM transformation. *Organic Geochemistry* **40:** 243-257

Davies PM, Bunn SE, Hamilton SK. 2008. Primary production in tropical streams and rivers. *In* Dudgeon, D. (Ed.), *Tropical Stream Ecology*. Academic Press, New York, pp. 24-42

de Souza ALT, Fonseca DG, Libório RA, Tanaka MO. 2013. Influence of riparian vegetation and forest structure on the water quality of rural low-order streams in SE Brazil. *Forest Ecology and Management* **298:** 12-18

del Giorgio PA, Davis J. 2003. Patterns in dissolved organic matter lability and consumption across aquatic ecosystems. *In* Findlay SEG, Sinsabaugh RL. (Eds.). *Aquatic Ecosystems: Interactivity of Dissolved Organic Matter*, pp. 399-424. Academic Press: Elsevier Science, USA.

del Vecchio R, Blough NV. 2002. Photobleaching of chromophoric dissolved organic matter in natural waters. Kinetics and modeling. *Marine Chemistry* **78(4):** 231-253

Dienye HE, Woke GN. 2015. Physico-chemical parameters of the Upper and Lower reach of the New Calabar River Niger Delta. *Journal of Fisheries and Livestock Production* **3(154):** 2

Dudgeon D. 2012. Threats to biodiversity globally and in the Indo-Burma biodiversity hotspot. *In* Allen DJ, Smith KG, Darwall WRT.(eds.) *The Status and Distribution of Freshwater Biodiversity in Indo-Burma*, Cambridge, UK: IUCN, 2012. Pp. 1-28

Duncan WP, Fernandes MN. 2010. Physicochemical characterization of the white, black, and clearwater rivers of the Amazon Basin and its implications on the distribution of freshwater stingrays (Chondrichthyes, Potamotrygonidae*). Pan-American Journal of Aquatic Sciences* **5(3):** 454-464

Ewers RM, Didham RK, Fahrig L, Ferraz G, Hector A, Holt RD, Kapos V, Reynolds G, Sinun W, Snaddon JL, Turner ECA. 2011 large-scale forest fragmentation experiment: the Stability of Altered Forest Ecosystems Project. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* **(366):** 3292-3302

Findlay SEG, Sinsabaugh RL. 2003. *Aquatic Ecosystems: Interactivity of Dissolved Organic Matter*. Academic Press, USA

Gazzaz NM, Yusoff MK, Ramli MF, Aris AZ, Juahir H. 2012. Characterization of spatial patterns in river water quality using chemometric pattern recognition techniques. *Marine Pollution Bulletin* **64(4):** 688-698

Grayson RP, Holden J. 2016. Improved automation of dissolved organic carbon sampling for organic-rich surface waters. *Science of the Total Environment* **543:** 44-51

Hansen AM, Kraus TEC, Pellerin BA, Fleck JA, Downing BD, Bergamaschi BA. 2016. Optical properties of dissolved organic matter (DOM): Effects of biological and photolytic degradation. *Limnology and Oceanography* **61(3):** 1015-1032

Harun S, Abdullah Mohd H, Mohamed M, Fikri AH, Jimmy EO. 2010. Water Quality Study of Four Streams within Maliau Basin Conservation Area, Sabah, Malaysia. *Journal of Tropical Biology and Conservation* **6:** 109–113

Harun S, Baker A, Bradley C, Pinay G. 2016. Spatial and seasonal variations in the composition of dissolved organic matter in a tropical catchment: the Lower Kinabatangan River, Sabah, Malaysia. *Environmental Science: Processes & Impacts* **18(1):** 137-150

Harun S, Dambul R, Abdullah MH, Mohamed M. 2014. Spatial and seasonal variations in surface water quality of the Lower Kinabatangan River Catchment, Sabah, Malaysia. *Journal of Tropical Biology and Conservation* **(11)**: 117-131

Hazebroek HP, Adlin TZ, Sinun W. 2004. *Maliau Basin: Sabah's Lost World*. Kota Kinabalu: Natural History Publications (Borneo). Pp. 235

Helms JR, Stubbins A, Ritchie JD, Minor EC. 2008. Absorption spectral slopes and slope ratios as indicators of molecular weight, source, and photobleaching of chromophoric dissolved organic matter. *Limnology and Oceanography* **53(3):** 955-969

Hernes PJ, Benner R. 2003. Photochemical and microbial degradation of dissolved lignin phenols: Implications for the fate of terrigenous dissolved organic matter in marine environments. *Journal of Geophysical Research* **108(C9):** 3291

Holbrook RD, Yen JH, Grizzard TJ. 2006 Characterizing natural organic material from the Occoquan Watershed (Northern Virginia, US) using fluorescence spectroscopy and PARAFAC. *Science of the Total Environment* **361:** 249-266

Hopkinson Jr, CS, Vallino JJ. 2005. Efficient export of carbon to the deep ocean through dissolved organic matter. *Nature* **433(7022):** 142

Hosseini N, Johnston J, Lindenschmidt K-E. 2017. Impacts of climate change on the water quality of a regulated prairie river. *Water* **9:** 199

Iwata T, Nakano S, Inouse M. 2003. Impacts of past riparian deforestation on stream communities in a tropical rainforest in Borneo. *Ecological Applications* **13(2):** 461-473

Jacobsen D. 2008. Tropical high-altitude streams. *In* Dudgeon D. (ed.).*Tropical Stream Ecology*. Pp. 219-253

Kwak J, Khang B, Kim E, Kim H. 2012. Estimation of biochemical oxygen demand based on dissolved organic carbon, UV absorption, and fluorescence measurements. *Journal of Chemistry* **2013:** Article ID 243769.

Larsen L, Aumen N, Bernhardt C, Engel V, Givnish T, McCormick P, McVoy C, Noe G, Nungesser M, Rutchey K, Sklar F, Troxler T, Volin J, Willard D. 2011. Recent and historic drivers of landscape change in the Everglades Ridge, Slough, and Tree Island Mosaic. *Critical Reviews in Environmental Science and Technology* **41(S1):** 344-381

Loginova AN, Thomsen S, Engel A. 2016. Chromophoric and fluorescent dissolved organic matter in and above the oxygen minimum zone off Peru. *Journal of Geophysical Research: Oceans* **121:** 7973-7990

Lu Y, Bauer JE, Canuel EA, Yamashita Y, Chambers RM, Jaffé R. 2013. Photochemical and microbial alteration of dissolved organic matter in temperate headwater streams associated with different land use. *Journal of Geophysical Research: Biogeosciences* **118(2):** 566-580

Maie N, Yamashita Y, Cory RM, Boyer JN, Jaffé R. 2012. Application of excitation emission matrix fluorescence monitoring in the assessment of spatial and seasonal drivers of dissolved organic matter composition: Sources and physical disturbance controls. *Applied Geochemistry* **27:** 917-929

Maral N. 2002. *Technical Assistance Report, Maliau Basin Climate 2000-2001*. Yayasan Sabah.

Mayorga E, Aufdenkampe AK, Masiello CA, Krusche AV, John I, Hedges JI, McGroddy ME, Baisden WT, Hedin LO. 2008. Stoichiometry of hydrological C, N and P losses across climate and geology: and environmental matrix approach New Zealand primary forests. *Global Biogeochem Cycles* **22:** GB3005

Mokhtar M, Aris AZ, Abdullah MH, Yusoff MK, Abdullah Md.P, Idris Abd. Rahim, Raja Uzir RI. 2009. A pristine environment and water quality in perspective: Maliau Basin, Borneo's mysterious world. *Water and Environmental Journal* **23:** 219–228

Mykura, Hamish F. 1989. Hydrology, Geomorphology and Erosion Potential. *In* Marsh, Clive W. (Ed.). *Expedition to Maliau Basin, Sabah. April – May 1988. Final Report*. Yayasan Sabah

Njogu IN, Kitheka JU. 2017. Assessment of the influence of rainfall and river discharge on sediment yield in the Upper Tana Catchment in Kenya. *Hydrology Current Research* **8(1):** 1000263

Pagano T, Bida M, Kenny JE. 2014. Trends in levels of allochthonous dissolved organic carbon in natural water: A review of potential mechanisms under a changing climate. *Water* **6:** 2862-2897

Peacock M, Evans CD, Fenner N, Freeman C, Gough R, Jones TG, Lebron I. 2014. UV-visible absorbance spectroscopy as a proxy for peatland dissolved organic carbon (DOC) quantity and quality: Considerations on wavelength and absorbance degradation. *Environmental Science: Processes & Impacts* **16(6):** 1445-1461

Perera PACT, Sundarabarathy TV, Sivananthaweri T, Kodithuwakku SP, Edirisinghe U. 2016. Arsenic and cadmium contamination in water, sediments and fish is a consequence of paddy cultivation: *Evidence of river pollution in Sri Lanka. Achievements in the Life Sciences* **10:** 144-160

Poole G, Risley J, Hicks M. 2001. *Issue paper 3 – Spatial and temporal patterns of stream temperature*. EPA-910-D-01-003 United States Environmental Protection Agency.

Qadir A, Malik RN, Hussain S. 2008. Spatio-temporal variations in water quality of Nullar Aik-Tributary of the River Chenab, Pakistan. *Environmental Monitoring and Assessment* **140(1-3):** 43-59

Rajwa-Kuligiewicz A, Bialik RJ, Rowiński PM. 2015. Dissolved oxygen and water temperature dynamics in lowland rivers over various timescales. *Journal of Hydrology and Hydromechanics* **63:** 353-363

Saigusa N, Yamamoto S, Hirata R, Ohtani Y, Ide R, Asanuma J, Gamo M, Hirano T, Kondo H, Kosugi Y, Li SG, Nakai Y, Takagi K, Tani M, Wang H. 2008. Temporal and spatial variations in the seasonal patterns of CO2 flux in boreal, temperate, and tropical forests in East Asia. *Agricultural and Forest Meteorology* **148(5):** 700-713

Singh S, Mishra A. 2014. Spatiotemporal analysis of the effects of forest covers on stream water quality in Western Ghats of peninsular India. *Journal of Hydrology* **519:** 214-224

Tank JL, Rosi-Marshall EM, Griffiths NA, Entrekin SA, Stephen ML. 2010. A review of allochthonous organic matter dynamics and metabolism in streams. *Journal of the North American Benthological Society* **29(1):** 118-146

Tipping E, Corbishley HT, Koprivnjak JF, Lapworth DJ, Miller MP, Vincent CD. 2009. Quantification of natural DOM from UV absorption at two wavelengths. *Environmental Chemistry* **6(6):** 472-476

Udoh JP, Ukpatu JE, Otoh AJ. 2013 Spatial variation in physico-chemical parameters of Eastern Obolo Estuary, Niger Delta, Nigeria. *Journal of Environment and Earth Science* **3(12):** 163-171

Wantzen KM, Yule CM, Mathooko JM, Pringle CM. 2008. Organic matter processing in tropical streams. *In* Dudgeon D. (Ed.), *Tropical Stream Ecology*. Pp. 44-64

Webb CO, Ali S. 2002. Plant and vegetation of the Maliau Basin Conservation Area, Sabah, East Malaysia. *Final Report to Maliau Basin Management Committee*

Williams CJ, Yamashita Y, Wilson HF, Jaffé R, Xenopoulos MA. 2010. Unraveling the role of land use and microbial activity in shaping dissolved organic matter characteristics in stream ecosystems. *Limnology and Oceanography* **55(3):** 1159-1171

Yamashita Y, Kloeppel BD, Knoepp J, Zausen GL, Jaffé R. 2011. Effects of watershed history on dissolved organic matter characteristics in headwater streams. *Ecosystem* **14:** 1110-1122

Yayasan Sabah (YS). 2014. *Maliau Basin Conservation Area: Strategic Management Plan 2014-2023.* Kota Kinabalu, Sabah: Yayasan Sabah

Zaidi J, Pal A. 2015. Influence of temperature on physico-chemical properties of freshwater ecosystem of Bundelkhand region of Uttar Pradesh, India. *International journal of current research in chemistry and pharmaceutical sciences* **2(3):** 1-8

Zakeyuddin MS, Md. Sah ASR, Mohammad MS, Mohd Fadzil NF, Hashim ZH, Wan Omar WM. 2016. Spatial and temporal variations of water quality and trophic status in Bukit Merah Reservoir, Perak. *Sains Malaysiana* **45(6):** 853-863

Zigah PK, Minor EC, Werne JP. 2012. Radiocarbon and stable-isotope geochemistry of organic and inorganic carbon in Lake Superior. *Global Biogeochemical Cycles* **26(1)**

Journal of Tropical Biology and Conservation 14: 125–150, 2017 ISSN 1823-3902

Research Article

Tree diversity at Payeh Maga Montane Forest, Sarawak, Borneo

Roland Kueh Jui Heng[1*], Nixon Girang Mang[2], Ong Kian Huat[1], Muaish Sait[1], Sylvester Sam[1], George Bala Empin[1], Thashwini Rajanoran[1], Cassy Rechie Sinus[1]

[1]*Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, Jalan Nyabau 97008 Bintulu, Sarawak Malaysia*
[2]*Forest Department Sarawak, Bangunan Wisma Sumber Alam, Jalan Stadium, Petra Jaya 93600 Kuching, Sarawak, Malaysia*
*Corresponding author: roland@upm.edu.my

Abstract
Tree species composition and diversity were determined at 1,600 m Payeh Maga Highland in Lawas, Sarawak, Borneo. Five study plots (20 x 20 m) were established at five transect lines (1 ha). The study shows that the forest was represented by 40 families, 68 genera and 151 species. Fagaceae represented 26 % of the families recorded, followed by Myrtaceae (16 %) and Clusiaceae (12 %) which are a typical family of montane forest in this region. Important Value Index (IV) showed *Lithocarpus urceolaris* as the most important species (IV=294 %), followed by *Gymnostoma sumatranum* (IV=273 %) and *Tristaniopsis microcarpa* (IV=194 %). There are no significant differences among transects for number of species and diversity indices. This forest is important for biodiversity conservation as it is as rich as those reported for lowland forests elsewhere in this region. The continued accumulation of species is an indication that this highland could support and provide habitat for larger tree species communities.

Keywords: Highland, Payeh Maga, Montane forest,·Tree diversity, ·Sarawak

Introduction
Tree species in the tropical forest differs in terms of composition and diversity due to heterogeneity in the environment and biogeography (Whitmore, 1988). The important factors affecting are the communities' structure, composition that are biotic, abiotic, edaphic, and historical factors (Suratman et al., 2015). Altitudinal vegetation classifications in Malaysia are Lowland Dipterocarp Forests (0-300 m), Hill Dipterocarp Forests (300-750 m), Upper Dipterocarp Forests (750–1,200 m), Lower Montane Forests/Montane Oak Forests (1,200–1,500 m), Upper Montane Forests/Montane Ericaceous Forests (1,500-3,000 m) (Symington, 1943; Whitmore, 1993). The montane forest is represented by

Received 11 May 2016
Reviewed 21 June 2017
Accepted 04 July 2017
Published 15 October 2017

Fagaceae-Lauraceae and Ericaceae families with present of thick moss layer and bryophytes (Whitmore, 1984).

The highland forest ecosystems of Sarawak are unique as there are no distinct forest types with changes in altitude (Asthon, 1995; MNS, 1998; Pearce, 2006) as changes in floristic composition of the forests with altitude are gradual and continuous. Such uniqueness contributes to high plant endemism. In general, highland forests are important ecosystems due to their unique biological, hydrological aspects (Bruijnzeel et al., 2010) and carbon storage (Spracklen & Righelato, 2014). These forests are isolated due to the altitudinal factor and hence sensitive to changes in climate and land use. In addition, the steep mountain slopes are susceptible to erosion when forest canopies are removed. Among issues related to global highland ecosystems are fragmentations by road construction, logging and development associated with tourism, temperate agriculture as well as township and telecommunication facilities (Bruijnzeel et al., 2010).

The Heart of Borneo (HoB) initiative was initiated in 2007 across Malaysia, Brunei and Indonesia. The objective is to conserve the biodiversity for the benefit of the people through sustainable management practices and protected areas. The HoB in Sarawak covers an area of 2.1 million hectares (ha) stretching from Batang Ai in the SouthWest to Merapok in the NorthEast (FDS, 2014). The upland and montane forest ecosystems are important as these cover an area of 13.08 million ha out of 17.4 million ha of forest cover in the HoB area. It has been reported that between 2007 and 2012, approximately 600,000 ha of upland forests were deforested while 300,000 ha of montane forests were lost between 2007 and 2010 within the HoB area. These trends have resulted in about 26 % and 20 % of upland and montane forests respectively being fragmented (WWF, 2014).

The urgency to address the conservation initiative in these forest ecosystems is a priority to ensure that their functions in providing ecological products and services are maintained. This paper reports a study which was conducted to assess the tree diversity found in the montane forest in Sarawak. Payeh Maga Highland in Lawas, Sarawak has three peaks namely Gunung Doa (570 m-lower peak), Gunung Tuyo (1,752 m) and Gunung Matallan (1,828 m) (Ampeng et al., 2013). These highlands are part of the forest network of the HoB initiative site in Sarawak. Information gathered will provide the baseline data of this forest. This could help forest managers in developing conservation programmes towards more sustainable use of natural resources and protection of these highlands ecosystems.

Materials and methods

The study was conducted at Payeh Maga Highland (N 4°27'10.27" & E 115°33'34.1") in Lawas, Sarawak, Borneo. At an elevation of 1,600 m, five study plots (20 x 20 m) were established at an interval of 100 m at five transect lines (Figure 1) resulting in 25 plots covering a total area of 1-ha . This elevation was selected as there is access to the area via abandoned logging roads. All trees 10 cm ≥ dbh were tagged, measured and identified.

Figure 1. The location of the study plots

The stand data was analysed for species composition and diversity. Species composition was calculated based on the percentage of the individual species over the total species recorded. Importance Value (IV) index for each species was calculated by adding the relative frequency (RF), relative density (RD), and relative dominance (Rd) for that species. This value gives a reliable overall estimate on the importance of species in the community.

Stand species diversity analysis was based on Shannon-Wiener Diversity and Simpson's Diversity Indices. The Shannon-Wiener Diversity Index (H Index) assumes that individuals are randomly sampled from an indefinitely large population (Magurran, 1991). Simpson's Diversity Index (D Index) considers the number of species(s), the total number of individuals and also the proportion of the total that occurs in each species. It represents the probability that two randomly selected individuals in the habitat belong to the same species (Simpson, 1949). Jaccard Similarity Index (C_J) was based on presence or absence of species that are shared between study plots and species that are unique to each study plot (Magurran, 1991).

Analysis of Variance (ANOVA) was conducted to compare the means on number of species and diversity index values among transects. All significant differences means were grouped using Tukey's Range Test. Cluster analyses were conducted using SPSS on the species distribution among the study plots. The classification was based on Squared Euclidean Distance. Species-area curves were developed by plotting species number as a function of the sample plot size or area. This has been used in studies of community ecology which provides the fundamental component for conservation biology. This is also important in formulating recommendations on species preservation and extinction rates (Codit et al., 2002).

Results and discussion

The species composition of the 1-ha forest stand was represented by 40 families, 68 genera and 151 species. The list of species recorded in the study is as in Table 1. Fagaceae represented 26 % of the families recorded. The dominance of this family is expected as the distribution of this family is at 500-1,800 m (Soepadmo et al., 1995). In this study, *Castanopsis*, *Lithocarpus* and *Quercus* genera represented this family. *Castanopsis* was represented by eight species. This covers 38% of the total reported species for Sabah and Sarawak. Three species (*C. endertii*, *C. hypophoenicea* and *C. oviformis*) are endemic to Borneo and these represent 30 % of the total endemics species reported.

Castanopsis is distributed from sea level up to 2,500 m. The genus is important as Borneo has the largest number of species. *Lithocarpus* was represented by 10 species, representing 16 % total recorded for Sabah and Sarawak. It is distributed from sea level up to 3,000 m. Only two species (*L. bullantus* and *L. echinifer*) were reported and endemic to Borneo. *Quercus* was represented by two species (*Q. gemelliflora* and *Q. subsericea*) and these cover 12 % of the total recorded species. The low occurrence could be due to their common distribution being at 600-1,500 m (Soepadmo et al., 1995).

Myrtaceae represented by S*yzygium* and *Tristaniopsis* genera contributed about 16 % of the families recorded. They are found in every type of habitat in Borneo (Ashton, 2011). *Syzygium* was represented by six species with *Syzygium multibracteolatum* being endemic to Borneo. Their dominance on the montane forest is not unusual as they are more dominant than *Shorea* at this altitude (Ashton, 2011). It is also found to be abundant in kerangas, peat swamp and upper montane forests (Whitmore, 1984). *Tristaniopsis* was represented by five species which covers 45 % of the total species reported for Sabah and Sarawak. This genus is important in Borneo and New Caledonia as it is the centre of diversity for this genus (Ashton, 2011). Two species under this genus namely *T. beccarii* and *T. microcarpa* are endemic to Borneo and are recorded in this study.

Clusiaceae represented by *Garcinia* and *Calophyllum* genera comprised about 12 % of the families recorded. It is commonly found in all forests except mangroves but most abundant on acidic soils and kerangas forest at low and high altitudes (Ashton, 1988). Two species were recorded but only one was identified as *Calophyllum buxifolium* which is common on mountain ridges up to as high as 2,000 m. *Garcinia* was represented by four species in this study. This genus is found in most of the habitats including the montane area.

The dominance of Fagaceae, Myrtaceae, Clusiaceae, Lauraceae and Casuarinaceae in this study is expected as they are typical families of the montane forest. The main floristic zone in the lower montane forest is called oak-laurel forest and is dominated by Fagaceae and Lauraceae while the upper montane forest is represented by Myrtaceae (Cranbook 1988).The montane forest in Borneo was reported to be represented by the family Araucariaceae, Clethraceae, Ericaceae, Fagaceae, Lauraceae, Myrtaceae, Podocarpaceae, Symplocaceae, Theaceae (WWF, 2014), Elaeocarpaceae, Hamamelidaceae, Flacourtiaceae, Magnoliaceae and Moraceae (Ohsawa, 1991). In relation to this, Fagaceae, Myrtaceae, Clusiaceae, Euphorbiaceae are important families in Borneo being the centre of plant distribution and diversity in the world (Soepadmo, 1995). This finding reflects the importance of montane forest as seed and gene banks for various species. This information supports its potential as a site for developing a conservation area for highland species.

Importance Value Index (IV) analysis among the plots showed that *Lithocarpus urceolaris* (Fagaceae) represented 36 % of the 25 study plots, followed by *Gymnostoma sumatranum* (12 %) (Casuarinaceae) and *Tristaniopsis microcarpa* (12 %) (Myrtaceae). The ranking of IV among plots are shown in Table 2. Analysis based on 1-ha showed similar pattern where *L. urceolaris* are the most important species (IV=294 %). This is followed by *G. sumatranum* (IV=273 %), *T. microcarpa* (IV=194 %), *L. bennettii* (IV=174 %) and *Calophyllum* sp. (IV=117 %). As expected *L. urceolaris* also has the highest IV index in this study. *L. urceolaris* is reported to be widespread in Sabah and Sarawak (Soepadmo et al., 1995). Another dominant species in this study is *G. sumatranum* representing some 50 % of the recorded species in Sabah and Sarawak. This species is confined to hill, ridge and lower montane forests at altitude 600-1,800 m (Pungga, 1995) which can explain its dominance in the area. *T. microcarpa* is commonly found in mixed dipterocarp forests up to an altitude of 1000 m (Ashton, 2011). These represent the common species found in the lower montane forest such as *Lithocarpus* and *Castanopsis* and *Syzygium*, while *Tristaniopsis* and *Rhodamnia* in the upper montane forest. The dominance of these species is an indication of a lower montane forest. In the lower montane forest, oak (*Quercus* spp. and *Lithocarpus* spp.) and chestnut (*Castanopsis* spp.) forests are dominant (WWF, 2014).

Table 1 The list of species recorded in this study.

No	Scientific Name	No	Scientific Name	No	Scientific Name
1	*Acronychia* sp.	29	*Castanopsis* sp. (no. 2)[3]	57	*Elaeocarpus valentonii*
2	*Actinodaphne obovata*	30	*Cinnamomum* sp.	58	*Endiandra* sp.
3	*Actinodaphne* sp.	31	*Conocarpus* sp.	59	*Engelhardia serrata*[3]
4	*Adinandra dumosa*	32	*Cordia* sp.	60	*Engelhardia roxburghiana*[3]
5	*Adinandra* sp.	33	*Cotylelobium melanoxylum*[2]	61	*Euonymus* sp.
6	*Agathis* sp.	34	*Cratoxylum formosum*[2]	62	*Eurya acuminata*
7	*Alangium* sp.	35	*Cryptocarya ferrea*[3]	63	*Fagraea* sp.
8	*Alseodaphne bancana*	36	*Cryptocarya strictifolia*	64	*Ganua* sp.
9	*Alseodaphne* sp. (no. 1)	37	*Dacrycarpus elatus*	65	*Garcinia bancana*[2]
10	*Alseodaphne* sp. (no.2)	38	*Dacrycarpus imbricatus*[2, 3]	66	*Garcinia nitida*
11	*Ardisia* sp.	39	*Dacrydium elatum*[3]	67	*Garcinia parvifolia*[2, 3]
12	*Austrobuxus nitidus*[2, 3]	40	*Dacrydium gracilis*[2]	68	*Garcinia* sp.
13	*Beilschmiedia dictyoneura*	41	*Dehaasia firma*[3]	69	*Glochidion ellipticum*
14	*Beilschmiedia kunstleri*	42	*Dehaasia* sp.	70	*Glochidion littorale*
15	*Beilschmiedia madang*	43	*Diospyros elliptifolia*	71	*Glochidion sericeum*
16	*Beilschmiedia* sp.	44	*Diospyros* sp.	72	*Glochidion* sp.
17	*Bhesa paniculata*[2, 3]	45	*Diospyros subrhomboidea*[2]	73	*Gomphia serrata*
18	*Calophyllum buxifolium*	46	*Elaeocarpus angustifolius*[3]	74	*Gonystylus augescens*
19	*Calophyllum* sp.	47	*Elaeocarpus floribundus*[2]	75	*Gonystylus borneensis*
20	*Campnosperma squamatum*[2]	48	*Elaeocarpus glaber*	76	*Gordonia* sp.
21	*Carallia brachiata*[2, 3]	49	*Elaeocarpus mastersii*[2]	77	*Gymnacranthera* sp.
22	*Castanopsis acuminatissima*[3]	50	*Elaeocarpus pedunculatus*[2]	78	*Gymnostoma sumatranum*[1, 3]
23	*Castanopsis endertii*[1, 3]	51	*Elaeocarpus serratus*	79	*Horsfieldia carnosa*[1, 2]
24	*Castanopsis evansii*	52	*Elaeocarpus* sp. (no. 1)	80	*Horsfieldia laticostata*[1, 2]
25	*Castanopsis hypophoenicea*[1]	53	*Elaeocarpus* sp. (no. 2)	81	*Knema latifolia*
26	*Castanopsis oviformis*[1, 2]	54	*Elaeocarpus* sp. (no. 3)	82	*Knema* sp. (no. 1)
27	*Castanopsis psilophylla*[3]	55	*Elaeocarpus stipularis*[3]	83	*Knema* sp. (no. 2)
28	*Castanopsis* sp. (no. 1)	56	*Elaeocarpus submonoceras*	84	*Kokoona littoralis*[2,3]

Table 1 Continue

85	*Kokoona ochracea*	115	*Phobe opaca*	145	*Tristaniopsis microcarpa*[1,3]
86	*Kokoona* sp.[3]	116	*Phoebe* sp.	146	*Tristaniopsis* sp.[2, 3]
87	*Lithocarpus bennettii*[2, 3]	117	*Phyllocladus hypoplyllus*[2]	147	*Tristaniopsis whiteana*[2,3]
88	*Lithocarpus blumeanus*[3]	118	*Podocarpus imbricatus*	148	Unknown (no. 1)
89	*Lithocarpus bullantus*[1, 3]	119	*Podocarpus neriifolius*[2, 3]	149	Unknown (no. 2)
90	*Lithocarpus echinifer*[1, 3]	120	*Polyosma latifolia*[2]	150	*Vernonia arborea*[2]
91	*Lithocarpus elegans*[3]	121	*Quercus gemelliflora*[3]	151	*Xanthophyllum* sp.
92	*Lithocarpus garcilis*[3]	122	*Quercus subsericea*[3]		
93	*Lithocarpus lampadarius*[3]	123	*Saurauia amoena*[3]		
94	*Lithocarpus lucidus*[3]	124	*Saurauia glabra*[2]		
95	*Lithocarpus* sp.	125	*Saurauia* sp.		
96	*Lithocarpus sundaicus*[2, 3]	126	*Stemonurus umbellatus*[2, 3]		
97	*Lithocarpus urceolaris*[2, 3]	127	*Symplocos odoratissima*		
98	*Litsea accedens*[2, 3]	128	*Syzygium multibracteolatum*[1,2]		
99	*Litsea castanea*[2, 3]	129	*Syzygium scortechinii*[3]		
100	*Litsea elliptica*[2]	130	*Syzygium* sp. (no. 1)		
101	*Litsea ferruginea*	131	*Syzygium* sp. (no. 2)		
102	*Litseama chilifolia*[2]	132	*Syzygium* sp. (no. 3)		
103	*Litsea* sp. (no. 1)	133	*Syzygium* sp. (no. 4)		
104	*Litsea* sp. (no. 2)	134	*Talauma* sp.		
105	*Macaranga pachyphylla*	135	*Teijsmanniodendron* sp.		
106	*Macaranga* sp.	136	*Terminalia* sp.		
107	*Mangifera griffithii*	137	*Ternstroemia coriacea*		
108	*Memecylon* sp. (no. 1)	138	*Ternstroemia hosei*		
109	*Memecylon* sp. (no.2)	139	*Ternstroemia sp.* (no 1)		
110	*Palaquium oxleyanum*	140	*Ternstroemia* sp. (no. 2)		
111	*Palaquium* sp. (no. 1)	141	*Tetramerista glabra*[1]		
112	*Palaquium* sp. (no.2)	142	*Timonius flavescens*		
113	*Parastemon* sp.	143	*Tristaniopsis beccarii*[1,2,3]		
114	*Parkia* sp.	144	*Tristaniopsis merguensis*[2,3]		

Note: 1 indicates endemic to Borneo, 2 indicates species found in kerangas forest, 3 indicates species found in montane forest

Table 2 Species composition and diversity among transects in the study area

	Transect								
	1	2		3		4		5	
No of tree	36-53	18-42		29-39		25-39		26-53	
No of species	13-23	10-16		16-21		13-25		6-25	
Shannon-Wiener Diversity Index	1.91-2.64	1.79-2.36		2.05-2.85		2.37-3.01		1.05-3.07	
Simpson's Diversity Index	0.79-0.93	0.76-0.93		0.84-0.96		0.93-0.97		0.50-0.97	
	IV (%)		IV (%)		IV (%)		IV (%)		IV (%)
Tristaniopsis microcarpa	480	*Lithocarpus urceolaris*	307	*Dacrydium elatum*	300	*Calophyllum* sp.	123	*G. sumatranum*	188
Garcinia sp.	114	*Engelhardtia roxburghiana*	67	*Lithocarpus urceolaris*	288	*Lithocarpus bennettii*	94	*Agathis* sp.	125
Gonystylus sp.	83	*Tristaniopsis microcarpa*	37	*Calophyllum buxifolium*	199	*Lithocarpus echinifer*	93	*Dacrydium elatum*	100
Calophyllum buxifolium	65	*Knema* sp. (no 2)	37	*Lithocarpus* sp. (no. 1)	194	*Talauma* sp.	68	*Quercus gemelliflora*	68
Stremonurus umbellatus	63	*Alseodaphne* sp. (no 1)	36	*Garcinia* sp. (n.o 1)	113	*Kokoona ochracea*	64	*Adinandra dumosa*	62

Table 2 continue

L. bennettii	525	*T. microcarpa*	143	*L. urceolaris*	173	*Calophyllum* sp.	149	*G. sumatranum*	612
Endiandra sp. (no. 1).	151	*Calophyllum buxifolium*	115	*L. lampadarius*	157	*G. sumatranum*	132	*T. merguensis*	101
Syzygium sp. (no. 1)	149	*Ternstroemia hosei*	98	*Tristaniopsis microcarpa*	120	*Syzygium* sp. (no. 2)	129	*Calophyllum* sp.	63
Glochidion sp. (no. 1)	85	*Syzygium* sp. (no. 3)	94	*Calophyllum buxifolium*	76	*Macaranga* sp.	90	*Garcinia* sp.	38
Adinandra dumosa	85	*Lithocarpus* sp.	78	*Garcinia bancana*	60	*Ternstroemia hosei*	62	*Dacrydium elatum*	33
L. sundaicus	400	*T. microcarpa*	283	*L. lampadarius*	150	*Palaquim oxleyanum*	150	*Palaqium oxleyanum*	119
L. bennettii	275	*L. urceolaris*	129	*Calophyllum* sp.	133	*Calophyllum* sp.	108	*Syzygium* sp. (no. 4)	93
Castanopsis sp. (no. 1)	75	*Adinandra* sp.	94	*T. merguensis*	66	*Syzygium* sp. (no. 4)	105	*Beilschmiedia madang*	63
Garcinia bancana	50	*C. buxifolium*	92	*Litsea castanea*	60	*L. lampadaius*	59	*Castanopsis endertii*	53
Ternstroemia sp. (no. 1)	50	*Syzygium* sp (no. 2).	58	*Syzygium* sp. (no. 2)	66	*Macaranga* sp.	59	*Agathis* sp.	41

Table 2 continue

L. urceolaris	511	*L. urceolaris*	376	*Adinandra* sp.	344	*Lithocarpus bullantus*	205	*G. sumatranum*	855
Syzygium sp. (no. 2)	145	*T. microcarpa*	160	*L. urceolaris*	181	*L. lampadarius*	144	*Podocarpus neriifolius*	240
Castanopsis sp. (no. 1)	118	*C. buxifolium*	115	*C. buxifolium*	66	*Elaeocarpus mastersii*	87	*T. merguensis*	89
Elaeocarpus angustifolius	114	*Syzygium* sp. (no. 2)	87	*Elaeocarpus angustifolius*	61	*Calaphyllum* sp.	71	*Calophyllum* sp.	31
L. bennettii	59	*Cordia* sp.	64	*Syzygium* sp. (no. 1)	60	*Podocarpus imbricatus*	67	*Lithocarpus garcilis*	30
Adinandra dumosa	186	*Alseodaphne* sp. (no. 1)	272	*Syzygium* sp.	186	*L. blumeanus*	221	*Dacrydium elatum*	141
E. serratus	148	*Gymnostoma sumatranum*	163	*Alseodaphne* sp. (no. 1)	176	*Syzygium* sp. (no. 4)	99	*Syzygium* sp. (no. 4)	119
E. angustifolius	121	*Garcinia bancana*	126	*L. urceolaris*	152	*Elaeocarpus* sp.	67	*L. blumeanus*	88
L. urceolaris	94	*T. microcarpa*	96	*E. angustifolius*	91	*L. lucidulus*	63	*Calophyllum* sp.	62
Saurairia sp.	91	*Dacrydium elatum*	65	*L. lampadarius*	89	*P. oxleyanum*	63	*Garcinia* sp.	61

Table 3 Species composition of selected forest types

No.	Forest type	Altitude (m)	Plot size (ha)	Min dbh (cm)	Species (no.)	Genus (no.)	Family (no.)	References
1	Tropical forest	n.a.	n.a.	n.a.	52-141	n.a.	n.a.	Swaine et al. (1987)
2	Danum Valley Conservation Area, Sabah, Malaysia	n.a.	1.00	10.0	114	n.a.	n.a.	Jumaat and Kamarudin (1992)
3	23-year old lowland secondary forest, Bintulu, Malaysia	50	0.04	10.0	120	80	38	Kueh et al. (2013)
4	Lowland primary forest, Pasoh Forest Reserve, Negeri Sembilan, Malaysia	80	50.00	1.0	822	298	77	Okuda et al. (2003)
5	Lowland regenerating forest, Pasoh Forest Reserve, Negeri Sembilan, Malaysia	80	36.00	1.0	672	254	76	Okuda et al. (2003)
6	Lowland secondary forest Ayer Hitam Forest Reserve, Selangor, Malaysia	500	1.00	10	146	82	39	Kueh (2000)
7	Lambir Hills National Park, Miri, Malaysia	465	52.00	1.0	1173	286	81	Lee et al. (2002)
8	Gunung Silam, Sabah, Malaysia	700-870	0.04-0.24	19-91				Proctor et al. (1988)

Table 3 Continue

9	Ba Vi National Park, Vietnam	>1,000	0.20	10.0	45			Van Do et al. (2015)
10	Payeh Maga Highland, Lawas, Malaysia	1,600	1.00	10.0	151 (12-25)	68	40	This study
11	Gunung Kinabalu, Sabah, Malaysia	1,700	0.20-0.50	10.0	32-84	29-51	22-31	Aiba and Kitayama (1999)
12	Gunung Kinabalu, Sabah, Malaysia	2,700	0.2-0.25	10.0	15	13-14	11-13	Aiba and Kitayama (1999)
13	Gunung Kinabalu, Sabah, Malaysia	3,000	0.06-0.20	10.0	4-17	4-14	3-10	Aiba and Kitayama (1999)
14	Middle montane forest zone, Yunnan, China	1,650-1,780	0.25	5.0	62-70	n.a.	n.a.	Zhu et al. (2015)

Note: The number of species per plot (0.04ha) in hypen; n.a. denotes not available

Table 4 Species diversity of selected forest types

No.	Forest types	Shannon-Wiener Diversity Index	Simpson's Diversity Index	References
1	55 year-old secondary forest, Central Kalimantan	3.40	n.a.	Brearley et al. (2004)
2	Primary forest, Central Kalimantan	4.17	n.a.	Brearley et al. (2004)
3	23 year old secondary forest, Bintulu, Malaysia	4.23	0.98	Kueh et al. (2012)
4	Coastal forest/Pasir Tengkorak Forest Reserve, Langkawi (130m)	5.607	0.962	Abdul Hayat et al. (2010)
5	Payeh Maga Highland, Lawas, Malaysia	4.16 (1.05-3.08)	0.97 (0.5-0.97)	This study
6	Lower montane forest zone, Yunnan, China	3.55-3.56	0.95-0.96	Zhu et al. (2015)
7	Ba Vi National Park, Vietnam	3.51	0.92	Van Do et al. (2015)
8	Gunung Kinabalu (1,700m)	2.81-3.93	n.a.	Aiba & Kitayama (1999)
9	Gunung Kinabalu (2,700m)	2.02-2.21	n.a.	Aiba & Kitayama (1999)
10	Gunung Kinabalu (3,100m)	0.39-2.3	n.a.	Aiba &Kitayama (1999)

Note: n.a. denotes not available

The mean number of species among transects showed no significant differences despite Transects 4 and 5 being at a higher altitude compared to Transects 1 and 3 (Figure 2). In the case of this study, there were 151 species per hectare which is comparable to what was reported by other researchers in the range of 114-146 species per hectare (Jumaat & Kamarudin 1992; Kueh 2000). This forest is also comparable to those reported for montane forest which range from 4-87 species. The number of species found in the tropical forest can range from 52 to 1173 as reported by various researchers (Table 2). This forest is considered to be as comparatively as rich as those reported for lowland forests in the region, such as by Swaine et al. (1997), Jumaat & Kamarudin (1992) and Okuda et al. (2003). Species diversity analysis using the Shannon-Wiener Index (H index) recorded a range of 1.05 to 3.08. H Index is generally more sensitive to species evenness compared to richness (Colwell 2008). This is reflected in Plot 24 (Transect 5) where 15 species were recorded but with lower H=1.67 as it has lower evenness compared to other plots (Plot 2 and 4) of similar number of species. The highest H index was recorded in Plot 16 (Transect 4) which recorded high species richness but more evenness. The dominance of *Calophyllum* sp. was 11 % of the total species. The lowest H index was recorded in Plot 22 (Transect 5) with low richness and evenness. The low evenness was due to the prominent of *G. sumatranum* which covered 70 % of the total species. The reduction in the number of species with higher altitude remains unclear. The altitude above 1,690 m the H index was lower except for Plot 18 at 1,715 m. The other exception was the low H index for Plot 6 (Transect 2) due to the fact that *L. urceolaris* was only distributed half of the study plots. This could explain the low evenness this transect.

In the case for Simpson's Diversity Index (D Index), it recorded a range of 0.50-0.97 for species diversity. D index is more sensitive to richness in comparison to H index (Colwell 2008). These are reflected in the study plots where the lowest species richness corresponds with the lower D index. The lowest species richness was in Plot 22 (Transect 5) with D=0.50 while the highest in Plot 16 (Transect 4) and 25 (Transect 5) with D=0.97. The low D index is due to the dominance of *G. sumatranum* in the study plots. D index also did not indicate that the species diversity is decreasing due to change in altitude and this pattern remains unclear. This is true in the case for forests in Sabah and Sarawak. This is contrast to the traditional altitudinal sequence as found in Peninsular Malaysia is unrecognizable. The main contributing factors to the floristic communities are usually correlated to the soil types as reported by Ashton (1995) that a combination of sharply defined topography, diverse rock substrate and shallow low nutrient soils create the diversity of the forest covers.

Despite this, analysis of variance showed that there is no significant differences for both diversity indices among those transects (Figure 2), when analysed as 1-ha size, the H= 4.16 while D= 0.97. The diversity index in this study is comparable to those reported in the lowland forest with a range of H= 3.40-4.23. This shows a similar pattern with the species richness as discussed earlier. In relation, the study plots also show that it has similar species diversity to other montane forests in the region (such as by Aiba & Kitayama 1999; Van Do et al., 2015) (Table 3). The diversification promotes the uniqueness of the highlands in Sarawak especially in Payeh Maga Highland forest. The high species diversity and richness means that this montane forest has a wealth of forest products which can be beneficial to mankind, wildlife and the environment.

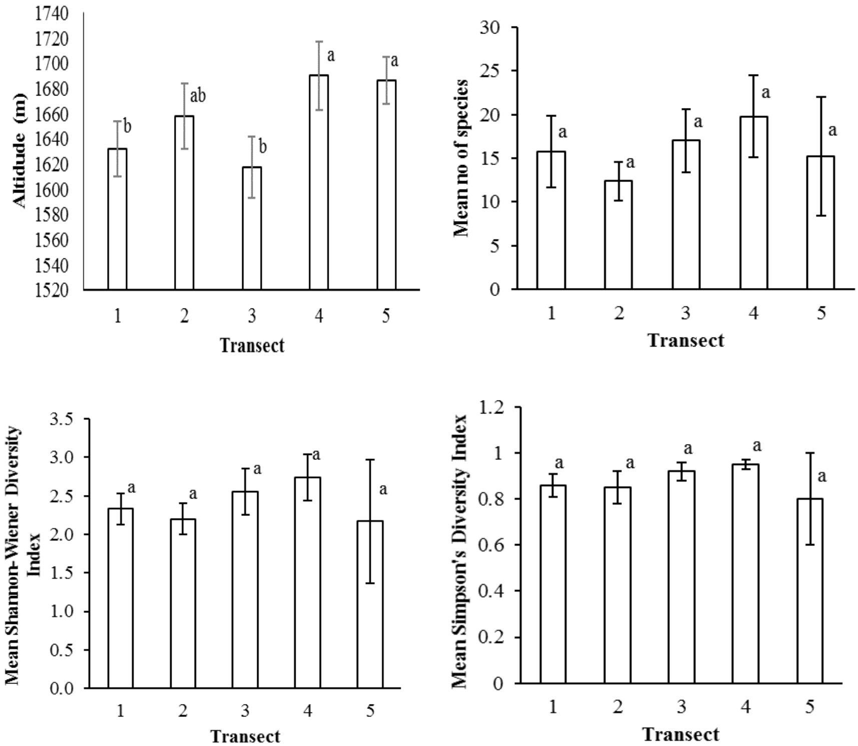
Cluster analysis in Transect 1 shows the prominent species community is *Lithocarpus bennettii* while another prominent species community is *L. urceolaris-Tristaniopsis microcarpa-L. sundaicus* (Figure 3). *L. bennettii* is dominant as the species that occurred in three plots with IV=59-525 %. *L.*

urceolaris with IV=510 % clustered with *T. microcarpa* (IV=480 %) and *L. sundaicus* (IV=400 %) and other species. The Fagaceae and Myrtaceae contributed 68 % of the total individuals in this transect. In the case of Transect 2, the main species community is *L. urecolaris* with another prominent species community *Tristaniopsis microcarpa-Alseodaphnae* sp. (no. 1). *L. urceolaris* is dominant as it occurred in three plots with high IV=129-306 %. *T. microcarpa* is present in all plots (IV=96-283 %) and clustered with *Alseodaphne* sp. (no. 1) (IV=271 %). Fagaceae contributed 21 % of the total individual while *Lauraceae* and *Myrtaceae* contributed 35 % of the total individuals in this transect. In Transect 3, the prominent species community is *Adinandra* sp. While another prominent species community *L. urceolaris-L. lampadarius-Alseodaphne* sp. (no. 1). *Adinandra* sp. (no. 1) is a prominent species in this transect as it has the highest IV=344 %, despite only being distributed in two plots. In comparison, *L. urceolaris* occured in four plots (IV=152-288 %) while *L. lampadarius* occurred in three plots (IV=89-157 %) and *Alseodaphne* sp. (no. 1) (IV=176%) in one plot. *Fagaceae* contributed 25 % of the total individuals while *Lauraceae* contributed 9 % of the total individuals in this transect.

In Transect 4, the prominent species community is *Lithocarpus blumeanus*. *L. blumeanus* is the most important species with highest IV=221 %. The *Calophyllum* sp. is clustered with *L. lampadarius-L. bullantus* and *Palaquium oxleyanum-Syzygium* sp. (no. 4). The other group is *Calophyllum* sp. which occurs in three plots (IV=107-123 %) while *L. lampadarius* occurs in three plots (IV=30-144 %) and *L. bullantus* occurs in one plot but has the highest IV=205 % in that particular plot. Another subgroup under this cluster is *P. oxleyanum* which has the highest IV=150 % in plot 17 while *Syzygium* sp. (no. 4) with IV=67-105 % which occurred in two plots. *Fagaceae* and *Clusiaceae* dominated this transect with a contribution of 35 % of the total individual. As for Transect 5, the prominent species community is *G. sumatranum-Podocarpus neriifolius*. *G. sumatranum* occurs in three plots with IV=188-855 % with *P. neriifolius* (IV=34-240 %). *Casuarinaceae* and *Podocarpaceae* contributed 47 % of the total individuals in this transect.

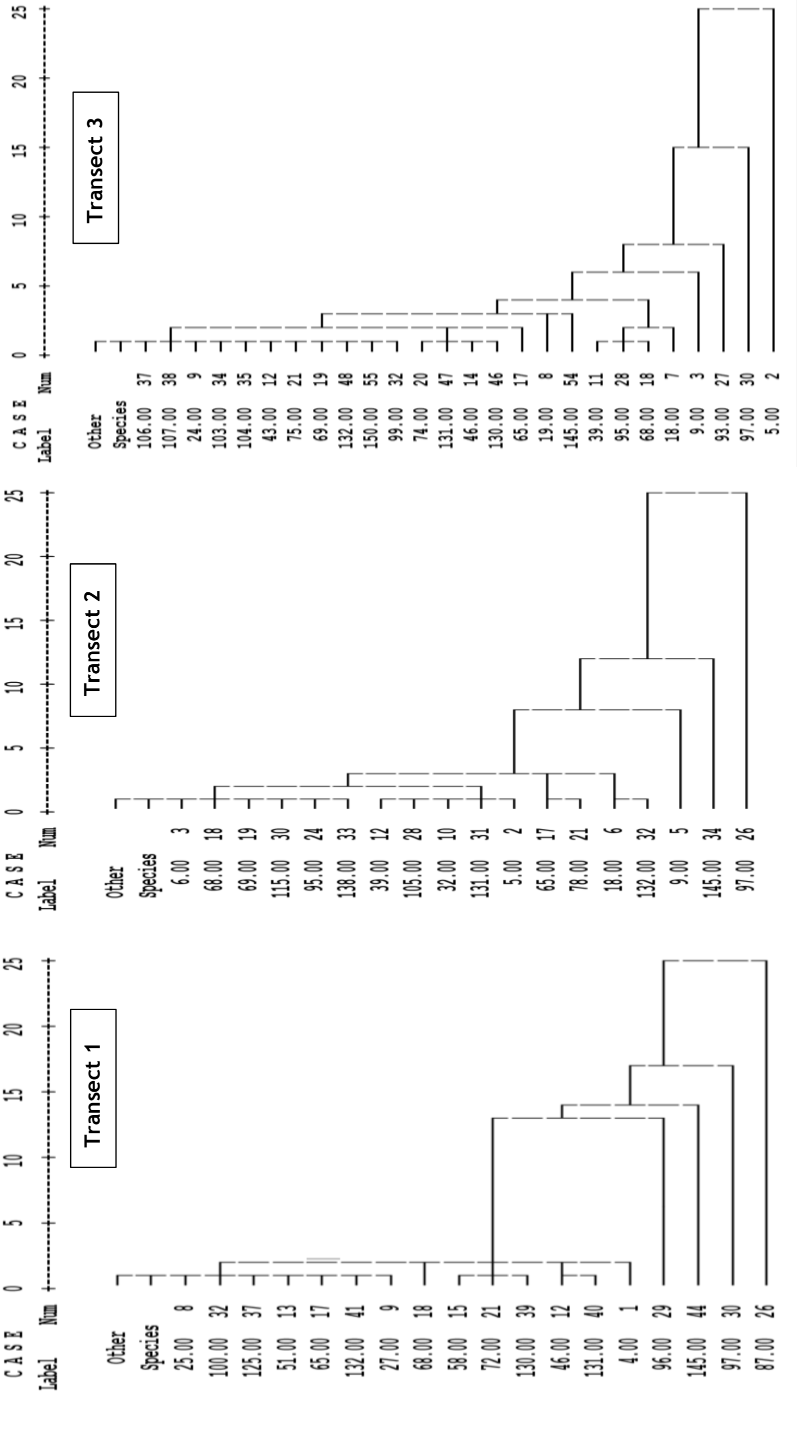
The analysis suggests that the species community is complex in the lower transect (1 to 3). Less complex species community is reflected in Transect 5. However, the less complex species community in relation to altitude remains unclear warranting study plots to be established also at higher elevation to validate this theory. Based on the cluster analysis for 1 ha, the prominent species is the *G. sumatranum* forest. This forest dominated 60 % of the plots in

Transect 5 with IV index of 188-855 %. The second forest community is the *L. urcelaris* which dominated 20-40 % is Transect 1, 2 and 3, while the third forest community is the *L. benentii* which is found in all the plots in Transect 1. The fourth forest community is *T. microcarpa* which is 20-40 % in Transect 1 and 2. Based on the IV index, the top 4 species are *G. sumatranum* (IV=611.7-855.0 %) are the dominant species with *L. bennettii* (IV=525.0 %), *L. urceolaris* (IV=510.7 %) and *Tristaniopsis microcarpa* (IV=480.4 %). With this information, the forest can be named as *Gymnostoma-Lithocarpus-Tristaniopsis* (Rhu-Mempening-Selunsur) montane forest.



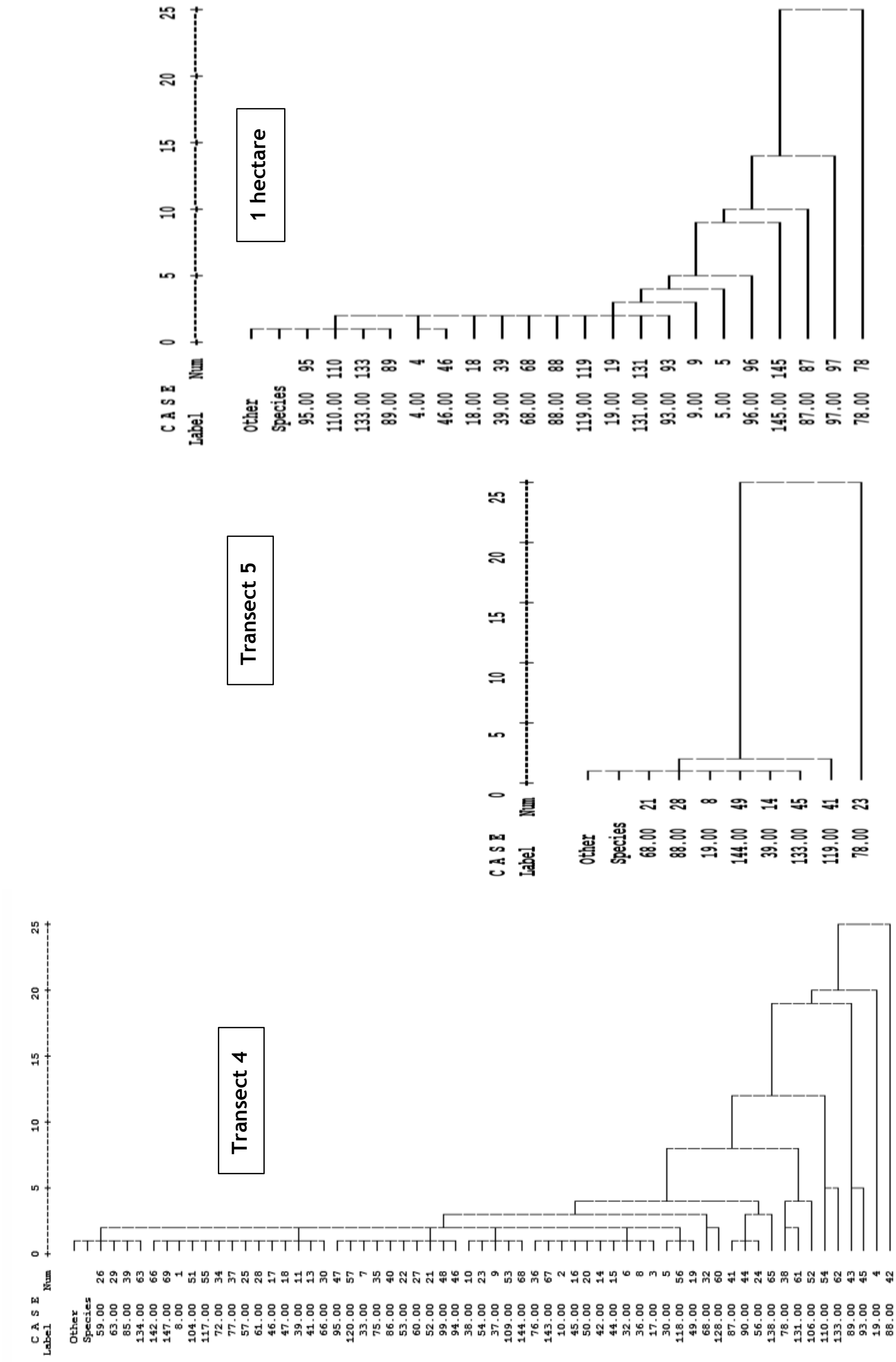
Note: Means with different alphabets indicate significant differences between transects by Tukey Range Test at p≤ 0.05

Figure 2. The mean distribution of altitude (m), number of species, Shannon-Wiener Diversity and Simpson's Diversity Indices among the transects



Note: The number in this analysis corresponds with the species number in Table 1

Figure 3. The cluster analyses for species community



Note: The number in this analysis corresponds with the species number in Table 1

Figure 4. The cluster analyses for species community

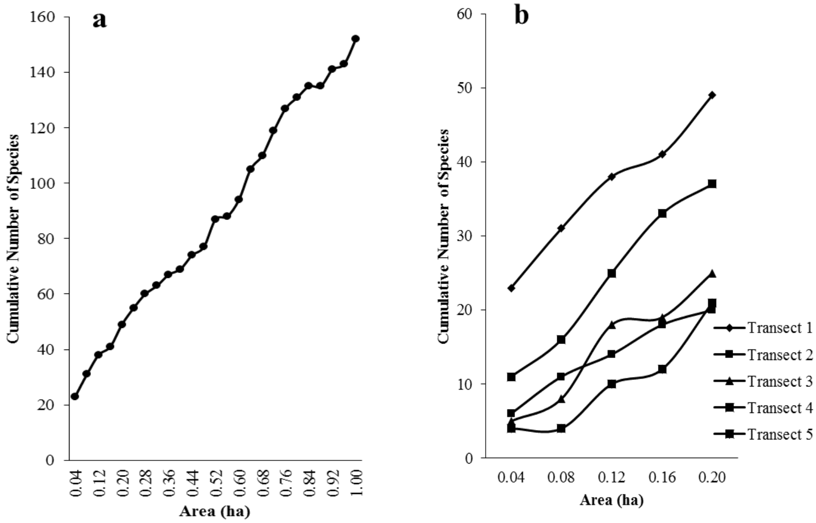


Figure 5. Species area curve (a) over 1 ha, (b) among transects

The cumulative species curve as in Figure 5 shows that the species-area curve is normally more steep in the early part of tree sampling. This is due to the fact that common species in the area are detected relatively quickly. Generally, the curve continues to rise as more tree species are sampled. Hence, the slope becomes more gentle progressively and eventually flattens when when the sampling area is homogenous where are all species are sampled (Gotelli & Choa, 2013). In this study, the plots are rather heterogeneous as Jaccard Similarity Index (C_J) showed about 38 % or less similarity (Table 5). The curve has yet to show any point of levelling off (Figure 5). This can be an indication that there are high chances that rare tree species can be detected if large sampling plots are considered.

In this case, if the species area curve is considered separately, Transect 2 species-area curve begins to flatten after 0.16 ha. This could be explained by the higher similarity among the study plots in Transect 2 where Jaccard Similarity Index (C_J) showed 20-38 % similarity. This is considered high when compared to other transects with only 35 % similarity to as low as null. Lower number of species (n=10-16 species) while smaller range of diversity indices were recorded (H=1.91-2.53; S=0.79-0.93) among the plots in Transect 2. This is in contrast with Transect 1 with H=1.79-2.36 and S=0.76-0.88 (n=13-23 species), Transect 3 with H=2.05-2.82, S=0.84-0.96 (n=12-21 species), Transect 4 with H=2.37-3.09, S=0.93-0.97 (n=13-23 species) and Transect 5 with H=1.05-3.07, S=0.50-0.97 (n=6-25 species).

The asymptotes were not expected in the other transects probably to the fact that in the tropical forest, expectation of the asymptote in species-area curve is unclear. Species-area curve reported for 50 ha plots in 3 different old forests namely Pasoh Forest Reserve (Malaysia), Barro Colorado Island (Panama Canal) and Mudumalai Game Reserve (Tamil Nadu) showed that species continues to accumulate beyond 50 ha (Condit et al., 2002). There are similar findings in Sungai Menyala and Bukit Lagong, Malaysia which may imply all inland tropical rainforests have a similar pattern. The expectation of an asymptote only comes from delimited communities defined by edaphic and climatic regimes (Cranbook, 1988).

The heterogeneity in the species is due to rare species where the species is represented by a single individual. This study recorded 44 % rare species. Similar patterns have been recorded in all transects (Figure 6). Hence, this contributes to the high degree of endemism (Cranbook, 1988). At 1,600 m, the climatic regimes could have limited the species distribution. The continued

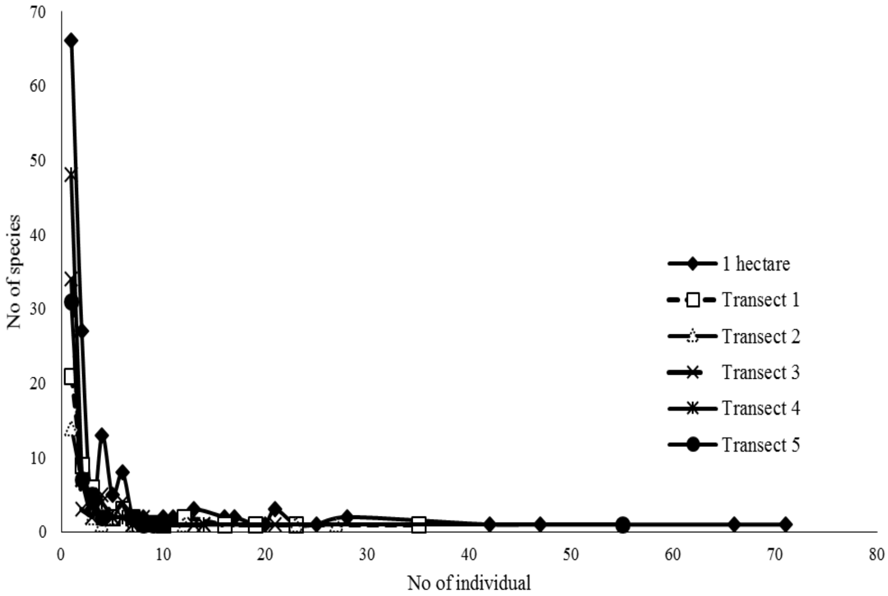


Figure 6. The species abundance in the study area

accumulation of species is an indication that this highland could support and provide habitat for larger tree species communities. With the theory of rare species, there are high possibilities that high endemism of species could be found in this area. This study recorded 8% of the total species which are endemic to Borneo.

The presence of white sand in the study sites with black water streams are main characteristics for a kerangas forest (Whitmore, 1984). 23 % species recorded in this study are found to be distributed in kerangas forest. The dominance of *Clusiaceae* and *Myrtaceae* in this study area can be attributed to these found abundantly on acid soils and in kerangas forest (Ashton, 1988; 2011). In montane forest, families such as Myrtaceae, Theaceae, Podocarpaceae, Ericaceae, Clusiaceae and Ebenaceae are also present in kerangas forest (Ashton, 1995). At this altitude, trees are covered with bryophytes which are termed as mossy forest. Therefore, the study forest area could be named as Rhu-Mempening-Selunsur kerangas-mossy montane forest.

Overall, the tree diversity in Payeh Maga Highland forest is rich when compared to lowland and montane forests such as reported by Aiba & Kitayama (1999), Brearley et al. (2004) and Zhu et al., (2015). This makes the area important as a source of seeds as well as a gene bank. This would facilitate in the securing planting materials to initiate any forest rehabilitation activities. The uniqueness of the area is reflected by the occurrence of rare and endemic species. The priority to conserve this area should be the interest of forest managers and policy makers.

Conclusions

The Payeh Maga Highland has a forest which is high in tree number and diversity. The assessment of the floristic composition provides base line information to manage conservation initiatives in the area. With such information, it would facilitate local authorities and policy makers to extend more conservation efforts in protecting the fragile and sensitive the highland ecosystems. This would ensure the sustainability of these highlands ecosystems to provide ecological products and services to mankind, wildlife and the environment. Long term monitoring is still required to understand the forest dynamics especially in relation to the climate change and other environmental issues.

Acknowledgments

This project was conducted under research permit NCCD.907.4.4 (Jld.12)-45. The project was funded under the Ministry of Natural Resources and Environment Malaysia (NRE) (Project code: P23099000070O2). We would like to acknowledge the financial assistance, support and cooperation from State Government of Sarawak, Director of Forests (Forest Department Sarawak), management of Universiti Putra Malaysia Bintulu Sarawak Campus (UPMKB) and the community in Long Tuyo, Lawas for assistance in this study.

References

Abdul Hayat MS, Kudus KA, Faridah-Hanum I, Awang Noor AG, Nazre M. 2010. Assessment of plant species diversity at Pasir Tengkorak Forest Reserve, Langkawi Island, Malaysia. *Journal of Agricultural Science* **2(1):** 31-38

Aiba S-I, Kitayama K. 1999. Structure, composition and species diversity in an altitude-substrate matrix of rain forest tree communities on Mount Kinabalu, Borneo. *Plant Ecology* **140:** 139-157

Ampeng A, Mee K, Sapuan A, Hamdan M, Madeline GP. 2013. *The Heart of Borneo Series: Paya Maga Sarawak's pristine highland forest*. Kuching: Sarawak Forest Department and UNIMAS.

Ashton PS. 1988. *Manual of The Non-Dipterocarp Trees of Sarawak*.(2nd ed). Selangor Darul Ehsan: Dewan Bahasa dan Pustaka.

Ashton PS. 1995. Biogeography and ecology. In: Soepadmo E, Wong KM. (ed.). *Tree Flora of Sabah and Sarawak*. (1st ed.). Kuala Lumpur: Ampang Press Sdn. Bhd.

Ashton PS. 2011. Myrtaceae. In: Soepadmo E, Saw LG, Chung RCK, Kiew R. (eds.). *Tree Flora of Sabah and Sarawak*. (7th ed). Selangor Darul Ehsan: Straits Digital Sdn. Bhd.

Brearley FQ, Prajadinataa S, Kidda PS, Proctor J, Suriantata. 2004. Structure and floristics of an old secondary rain forest in Central Kalimantan, Indonesia, and a comparison with adjacent primary forest. *Forest Ecology and Management* **195:** 385–397

Bruijnzeel LA, Scatena FN, Hamilton LS. 2011. *Tropical montane cloud forests: science for conservation and management*. Cambridge: Cambridge University Press.

Colwell RK. 2008. Biodiversity: concepts, patterns, and measurement. In: Levin SA, Carpenter SR, Godfray HCJ, Kinzig AP, Loreau M, Losos JL, Walker B, Wilcove DS. (eds.). *The Princeton guide to ecology*. New Jersey: Princeton University Press

Condit R, Hubbell SP, Lafrankie JV, Sukumar R, Manokaran N, Foster RB, Ashton PS. 1996. Species-area and species-individual relationships for tropical trees: a comparison of three 50-ha Plots. *Journal of Ecology* **84(4):** 549-562

Cranbook E. 1988. *Key environments: Malaysia*. Oxford: Pergamon Press.

Forest Department Sarawak (FDS). 2014. Heart of Borneo Initiative. Available at: <http://www.forestry.sarawak.gov.my/modules/web/page.php?id=993&menu_id=0&sub_id=146> [accessed on 22.02.16].

Jumaat A, Kamarudin I. 1992. An enumeration of one hectare of lowland dipterocarp forest at Danum Valley Field Centre, Lahad Datu, Sabah, Malaysia. In: Nik Majid MNA, Adenan IAM, Hamzah MZ, Jusoff K. (eds.). *Proceedings International Symposium on Rehabilitation of Tropical Rainforest Ecosystem: Research and Development Priorities. 2nd - 4th September, 1991, Kuching, Sarawak, Malaysia*. Serdang: Universiti Pertanian Malaysia Press.

Kueh RJH, Ab. Majid NM, Gandaseca S, Ahmed OH, Jemat S, Ku, MKK. 2013. Assessment of floristic composition in a rehabilitated forest, Sarawak, Malaysia. Borneo *Journal of Resource Science and Technology* 2(2): 60-66.

Kueh RJH. 2000. *An estimate of primary productivity in Ayer Hitam Forest Reserve*. Master of Science Thesis, Universiti Putra Malaysia.

Lee HS, Davies SJ, LaFrankie JV, Tan S, Yamakura T, Itoh A, Ohkubo T, Ashton PS. 2002. Floristics and structural diversity of mixed dipterocarp forest in Lambir Hills National Park, Sarawak, Malaysia. *Journal of Tropical Forest Science* **14(3):** 379-400

Magurran AE. 1991. *Ecological diversity and its measurement*. New York: Chapman and Hall.

Malaysian Nature Society (MNS). 1998. *Malaysian Nature Society 1998 Expedition to the proposed Pulong Tau National Park Sarawak, Malaysia*. Miri: Malaysian Nature Society Miri Branch.

Ohsawa M. 1991. Structural comparison of tropical montane rain forests along latitudinal and altitudinal gradients in South and East Asia. *Vegetatio* **97:** 1-10

Okuda T, Suzuki M, Adachi N, Eng SQ, Hussein NA, Manokaran N. 2003. Effect of selective logging on canopy and stand structure and tree species composition in a lowland dipterocarp forest in Peninsular Malaysia. *Forest Ecology and Management* **175:** 297-320

Pearce KG. 2006. *The flora of Pulong Tau National Park*. ITTO Project PD 224/03 Rev. 1(F) Transboundary Biodiversity Conservation-The Pulong Tau National Park, Sarawak, Malaysia. Kuching: International Tropical Timber Organization and Sarawak Forest Department.

Proctor J, Lee YF, Langley AM, Munro WRC, Nelson T. 1988. Ecological studies on Gunung Silam: A small ultrabasic mountain in Sabah, Malaysia: I. Environment, forest structure and floristics. *Journal of Ecology* **76(2):** 320-340

Pungga RS. 1996. Casuarinaceae. In: Soepadmo E, Wong KM, Saw LG. (eds.). *Tree Flora of Sabah and Sarawak*, (2nd ed). Kuala Lumpur: Ampang Press Sdn Bhd.

Simpson EH. 1949. Measurement of diversity. *Nature* **163:** 688

Soepadmo E. 1995. Background to the tree flora of Sabah and Sarawak project. In: Soepadmo E, Wong KM (eds.). *Tree flora of Sabah and Sarawak*. (1st ed.). Kuala Lumpur: Ampang Press Sdn. Bhd.

Soepadmo E, Julia S, Go R. 1995. Fagaceae. In: Soepadmo E, Saw LG (eds.). *Tree flora of Sabah and Sarawak*. (3rd ed.). Kuala Lumpur: Ampang Press Sdn. Bhd.

Spracklen DV, Righelato R. 2014. Tropical montane forests are a larger than expected global carbon store. *Biogeosciences* **11:** 2741–2754

Suratman MZ, Abd. Hamid NH, Md. Sabri MD, Yamani SAK. 2015. Changes in tree species distribution along altitudinal gradient of Montane Forests in Malaysia. In: Ozturk M, Hakeem KR, Faridah-Hanum I, Efe R. (eds.). *Climate change impacts on high altitude ecosystems*. Switzerland: Springer International Publishing.

Swaine MD, Lieberman D, Putz FE. 1987. The dynamics of tree populations in tropical forest: a review. *Journal of Tropical Ecology* **3:** 359-366

Symington CF. 1943. *Foresters' Manual of Dipterocarps*. Malayan Forest Record No. 16. Kuala Lumpur: Forest Department Peninsular Malaysia.

Van Do T, Kozanand O, Tuan TM. 2015. Altitudinal changes in species diversity and stand structure of tropical forest, Vietnam. *Annual Review and Research in Biology* **6(3):** 156-165

Whitmore TC. 1984. *Tropical Rain Forests of the Far East*. Oxford: Clarendon Press.

Whitmore TC. 1998. *An Introduction to Tropical Rain Forests*. New York: Oxford University Press.

World Wide Fund for Nature (WWF). 2014. *The Environmental Status of the Heart of Borneo*. WWF Report on HoB.

Zhu H, Yong C, Zhou S, Wang H, Yan L. 2015. Vegetation, floristic composition and species diversity in a tropical mountain nature reserve in southern Yunnan, SW China, with implications for conservation. *Tropical Conservation Science* **8 (2):** 528-546

Instructions for Authors

Managing Editors: Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, MALAYSIA.
Tel: +60-88-320000 ext. 2414; Fax:+60-88-320291.
E-mail: jtbc@ums.edu.my

Manuscripts submitted to ***Journal of Tropical Biology and Conservation*** should comprise original, unpublished material and should not currently be under consideration for publication elsewhere.

General

The ***Journal of Tropical Biology and Conservation*** is an international reviewed journal published **once a year (15 October)** by the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah. This journal is devoted to the publication of research papers, short notes or communications, reports and reviews in all fields that are of general relevance to tropical biology and conservation including investigations on biodiversity, systematics and taxonomy, experimental biology, applied ecology, wildlife management and control, ethnobotany and ethnozoology, natural product chemistry and ecotourism. The editors encourage contributions of papers from Southeast Asian region.

Preparation of manuscripts

The text of the manuscript should be a Word. In general, the manuscript should be organised as follows: **Title,** followed by the full name(s) of author(s) and address(es), **Abstract (should be less than 250 words), Keywords** (not more than six (6) words) and **Running Heading** (not more than 50 characters), **Introduction, Materials and Methods, Results, Discussion (Results** and **Discussion** may be combined), **Conclusions** (if appropriate) and **References. Acknowledgements** (if any) may be included at the end of the text preceding the references cited. Tables and figures legends should be at the end of the manuscript. Each heading in the main text may be divided into sections and sub-sections (where appropriate). The placing of each table and figure should be indicated in the text. Each table and figure should be numbered according to the order of appearance in the text. The legends should be understandable to someone who has not read the text. Citations of references in the text are by author(s) and year of publication, e.g.:

one author: Smith (1998) or (Smith, 1998)
two authors: Smith & Gomez (1999) or (Smith & Gomez, 1999)
three authors: Smith et al. (1999) or (Smith et al., 1999) – "et al." - not italic
multiple references when within parentheses (Smith, 1990, 1998; Liu, 1999a, b; 2000; Kon, 2004)

References should be arranged alphabetically according to authors' names and then by date. Journal names should be given in full. Use the following format in the reference section:
For Books, e.g.:
Begon M, Mortimer M. 1986. *Population ecology: A unified study of animals and plants.* (2nd ed.). Oxford: Blackwell Scientific Publications
For chapters in a book, e.g.:
Esau K. 1964. Structure and development of the bark in dicotyledons. In: Zimmermann MH. (ed.). *The Formation of Wood in Forest Trees.* New York: Academic Press
For paper in journals, e.g.:
Slater EE, Mackenzie NA, Nightingale N, Aken KM, Chai PPK. 1985. Habitat use, ranging behaviour and food habits of the proboscis monkey, *Nasalis larvatus* (Van Wrumb) in Sarawak. *Primates* **26:**436-451

Submission of manuscripts

For initial submission of manuscript, upload a Word (.doc) file containing the complete paper. The front page should only contain the title, name of authors, affiliation, addresses, contact details, running heading, key words and corresponding author. Later, when submitting a revised article, upload a text file (Word) containing the revised text, references, tables and figure captions. This file should not include graphics. Figures need to be submitted in a separate file in JPG (.jpg) or TIFF (.tif) format. Filenames should clearly corresponds to the number (and part) of figure(s) enclosed in each file. Manuscripts should be submitted via email attachments to the Managing Editor. Alternatively, hardcopy of the manuscript in triplicates should be sent to the Managing Editor. All manuscripts are subjected to peer review.

Copyright and Reprints

Authors who wish to republish an article or a significant part of it must obtain written permission to reprint the material from the original publisher.
http://jurcon.ums.edu.my/ojums/index.php/jtbc