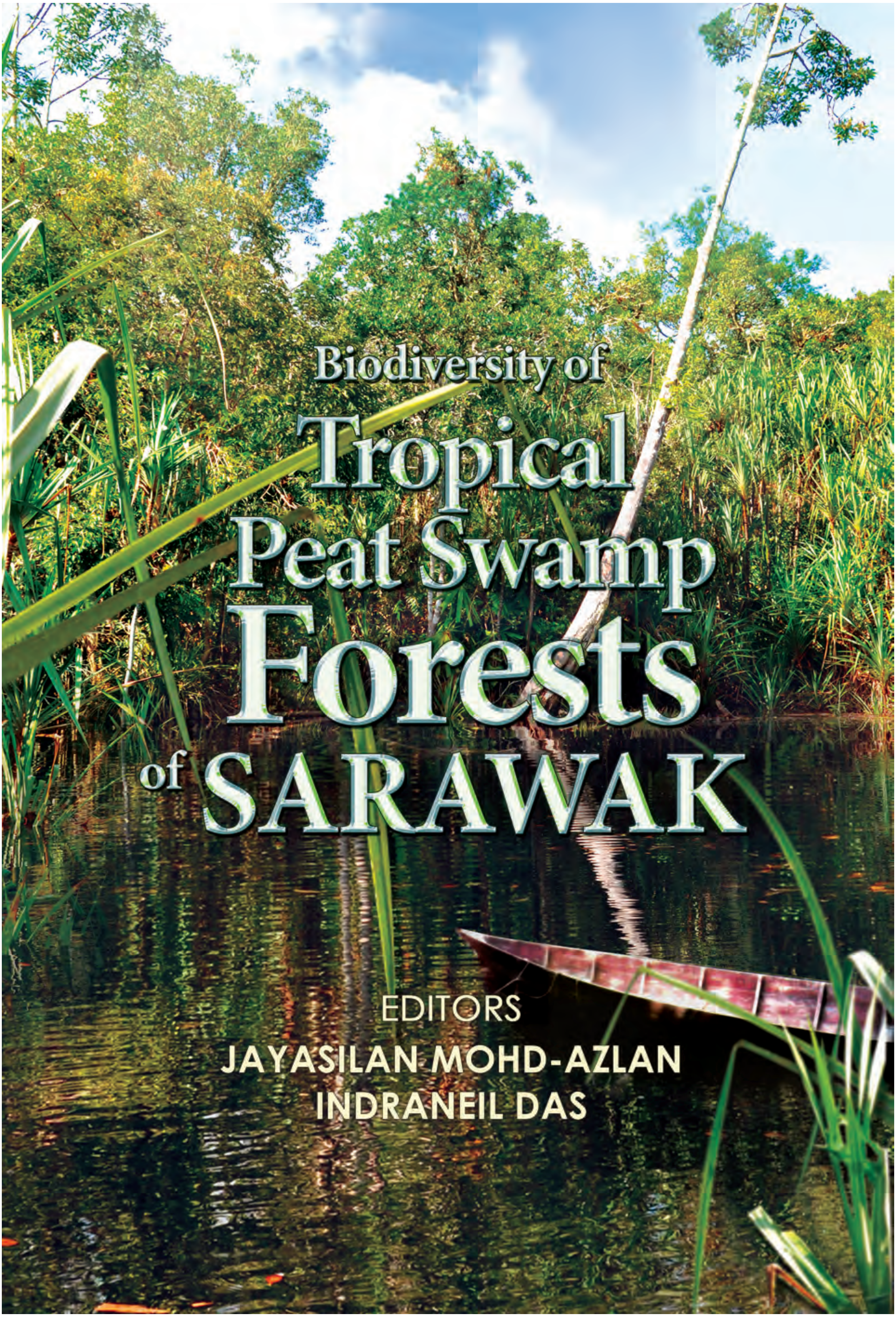

Biodiversity of Tropical Peat Swamp Forests of SARAWAK

EDITORS

JAYASILAN MOHD-AZLAN

INDRANEIL DAS

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Published in Malaysia by
UNIMAS Publisher,
Universiti Malaysia Sarawak,
94300 Kota Samarahan,
Sarawak, Malaysia.

Printed in Malaysia by
Malien Press Sendirian Berhad
Unit E1-9 G/FL, Sublot 9, Jalan Petanak,
93100 Kuching,
Sarawak, Malaysia.

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data

Mohd-Azlan Jayasilan, 1973-
Biodiversity of Tropical Peat Swamp Forest of SARAWAK /
JAYASILAN MOHD-AZLAN, INDRANEIL DAS.
Includes index
ISBN 978-967-5527-90-6
1. Peatland forestry--Sarawak. 2. Peatland ecology--Sarawak.
3. Swamp ecology--Sarawak. 4. Swamps--Sarawak.
5. Biodiversity--Sarawak.
I. Indraneil Das, 1964-. II. Title.
577.6870959522

PREFACE

With the largest proportion of Malaysian peat swamp forest located in Sarawak, and their continued exploitation for a variety of purposes the need for substantial research on these threatened habitats and ecosystems has never been more urgent. Many of us here in Universiti Malaysia Sarawak continue to stride into peat swamp forests, especially the one within our campus, in our attempt to increase knowledge on its natural history. The results of some of these efforts have been complied in the chapters of the volume that you hold in your hands.

As will be evident to the readership, a variety of approaches have been taken by the authors of the book. Jason Hon and J. Mohd-Azlan's essay extols the virtue of peat swamp forests, emphasizing their conservation importance. Siong Fong Sim presents results of her investigations of humic substances and the chemistry of humic substances of the tropical peat. Wong Sin Yeng provides a description of the Araceae portion of the peat swamp flora. Awang Ahmad Sallehin Awang Husaini, Mohd Hasnain Md Hussain and Hairul Azman Roslan propose the use of sago palm (*Metroxylon sagu*) as a starch, to bolster national food security. Within the zoological sciences, separate contributions include investigations on endohelminth parasites of frogs at a degraded forest, by Ramlah Zainudin, Farliana Zulkifli and Fatimah Abang; ichthyological communities and their relationship with water quality in blackwater environments by Lee Nyanti, Ella Michael Dosi, Jongkar Grinang, Ling Teck-Yee and Khalid Haron; description of the avifaunal diversity of such forests by Mohamad Fizl Sidq Ramji, Mustafa Abdul Rahman, Andrew Alek Tuen, Bettycopa Amit and Khalid Haron and finally, an essay on wildlife conservation, with emphasis of its megafauna, by the editors.

In producing this volume, we are grateful to the authors for their contribution and to the following reviewers: Datuk Seri Lim Chong Keat, Anthony Sebastian, Lim Chan Koon, Abdullah bin Samat, Khairul Adha Abd Rahim, Kopli Bujang, Murtedza Mohamed and Andrew Alek Tuen. Finally, we thank our colleague, Jongkar Grinang for the image used on the front cover of this work. This book greatly benefited from the Niche Research Grant Scheme awarded to Universiti Malaysia Sarawak (NRGS/1087/2013/(01)).

This modest volume commemorates the 23rd year of establishment of Sarawak's first university.

J. Mohd-Azlan and Indraneil Das
Kota Samarahan, 26 January 2016

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1

PEAT SWAMP FORESTS AND THEIR CONSERVATION IMPORTANCE

Jason Hon and J. Mohd-Azlan

INTRODUCTION

How well do we know about peat swamp forests? Arguably, the name combination itself has equated these forests to ‘wet’, ‘smelly’, ‘dirty’ and ‘mosquito-infested’ places that are unfit for humans. These are some of the common perceptions that are conceived by many, including researchers, and consequently, peat swamp forests are one of the least known of the lowland ecosystems in the tropics.

Globally, peatlands (areas with peat substance) cover an estimated 400 million hectares or three per cent of the earth’s land surface (Strack, 2008). About 11 per cent of tropical peatlands are found in Malaysia, which is second to Indonesia that had till the recent past, 80 per cent coverage of tropical peatlands (Rieley *et al.,* 1996; Page *et al.,* 2006). In Malaysia, peat swamp forests form the largest of all wetland areas, accounting for 75 per cent of the total areas (UNDP, 2006). Within Malaysia, Sarawak comes out top with the largest peat swamp forest coverage, accounting for about 64 per cent of the total 2.6 million hectares in Malaysia (Hon, 2011). The peat swamp forests of Sarawak are distributed widely in the deltaic plains, and stretches along the Samarahan-Sadong, Lupar-Saribas, Rajang, Baram and Limbang river systems (Sawal, 2004) and the lowland and coastal plains of Mukah. Collectively, these areas account for about 60 per cent of the total peatlands in Sarawak (Sime Darby Services, 1999).

A WORLD OF UNIQUE RICHNESS

Extensive studies on the peat swamp forests of Sarawak were conducted by the British botanist, J. A. R. Anderson in the early 1960s. He recorded six phasic plant communities in a mature peat swamp forest, which form concentric zones of plant communities that intergrade and then slowly replace each other from the perimeter to the centre of the swamp (Anderson, 1960). Peat swamp forests (Figure 1) contain over 240 plant species with endemics such as *Eugenia nemestrina* and *Garcinia eugenaefolia* (Rieley and Ahmad-Shah, 1996; Rieley, 1992).

Figure1. Peat swamp forest of Loagan Bunut NP with large stands of Alan *(Shorea albida)*

Some of the most unique and rare fauna species occur in peat swamp forests, such as the red-banded lred-banded langur (*Presbytis chryosomelas cruciger*), (Figure 2), of which about 300 remaining individuals are found in the Maludam National Park (Hon and Gumal, 2004; 2005). The park also contains populations of the Bornean endemic proboscis monkey (*Nasalis larvatus*).

Figure 2. The only viable population of red banded langur (*Presbytis chrysomelas cruciger*) is only found in Maludam NP in Sarawak

Figure 3. The Bornean endemic proboscis monkey (*Narsalis larvatus*)

The largest colonies of flying foxes (*Pteropus vampyrus*), numbering over 20,000 can be found in the peat swamp forests of Loagan Bunut National Park (Gumal *et al.,* 2008) and also Sedilu National Park. The peat swamp forests of Sedilu National Park and Ulu Sebuyau National Park harbour significant populations of the endangered orang-utan (*Pongo pygmaeus pygmaeus*). In Sarawak, the only sightings of Storm's stork (*Cicornia stormi*) Pongo pygmaeus pygmaeus and masked finfoot (*Heliopais personata*) were made in peat swamp forest (Hon, 2011) and the only known breeding colony of Oriental darter (*Anhinga melanogaster*) and little cormorant (*Phalacrocorax niger*) were recorded in Loagan Bunut, but both species have since disappeared from this area due to over-harvesting of eggs and chicks (Aonyx, 2012).

ECOLOGICAL IMPORTANCE OF PEAT SWAMP FOREST

The unique chemical, physical and biological attributes make peat swamp forests different from all other terrestrial and wetland areas. Briefly, peat swamp forests perform crucial functions in flood prevention, nutrient storage and carbon sink, to name a few.

Peat domes are higher than surrounding areas and are characterised by high soil absorbency and water-retention ability. Generally, peat acts like a sponge, absorbing most excess water during heavy rainfall events, thereby reducing flood peaks and mitigating floods. Absorbed water is released slowly during drier periods, thereby mitigating droughts in adjacent areas. Peat domes serve as reservoirs of water for many of Sarawak's coastal areas, which would otherwise suffer water shortages during droughts (Sawal, 2004). Clearing of peat swamp forests directly affect water catchments areas, and consequently, the livelihoods of people (Ong and Yogeswaran, 1992; Shakeran, 1999).

Peat swamp forests play important roles in maintaining carbon balance, at a capacity 10 times more efficient than other forest types (ASEAN Peatland Forests Project, 2010). Worldwide, peatlands store about 20 per cent of all the carbon in the soil, with 50 billion tonnes found in south-east Asia alone (Maltby, 1997). These figures show how important peatlands and peat swamp forests are, especially in Sarawak, which has extensive peat swamps.

THREATS

Peat swamp forests in Sarawak are imperiled, their loss driven by economic demands to open land for agricultural expansion. Many of the potential threats to peat swamp forest derive from agricultural conversion and conversion to other land uses.

The forest industry sector plays an important part in Sarawak's economy, as well as in that of Malaysia as whole. The rate of deforestation in Sarawak is higher than in Sabah and Peninsular Malaysia: a conservative estimation of timber exports reveals that Sarawak exports more logs than Peninsular Malaysia and Sabah put together (Mohd-Azlan and Lawes, 2011).

In Sarawak, selective logging system was introduced in the lowland peat swamp forest areas in the early 1950s and continued until the early 1970s (Sawal, 2004). In fact, commercial logging began in the peat swamp forests, where the high valued Alan, *Shorea albida,* were found in abundance in former times.

In more recent years, logged-over peat swamp forests in the coastal areas were and continue to be excised from state land and permanent forest estates to make way for oil palm plantations, forest plantation, pineapple, sago, paddy, field crops and other land development projects. Research and development carried out in recent years have made it possible to maximise economic returns utilizing land once considered marginal, such as peat swamp forests areas (Sawal, 2004).

Between 1959–2011, oil palm in Malaysia expanded from 51,053 hectares to 5,229,739 hectares (Department of Statistics Malaysia, 2010; MPOB, 2014). In Sarawak alone, the acceleration to plantation economy, particularly oil palm, was driven by the exhaustion of land bank in Peninsular Malaysia. Both Malaysia and Indonesia have been the world's major exporter of oil palm, accounting for more than 85% of global export (FAO, 2012).

To maintain its production and position as a major world exporter, the oil palm industry expanded to Sarawak, notably under the Third National Agriculture Policy (1998–2010) (MOA, 1998). Since then, oil palm planting has intensified in Sarawak, increasing at an average 10.5% from 2002–2011 (Hon and Shibata, 2013), the highest for all states in Malaysia. The development and intensification of the oil palm industry in Sarawak under the said policy targeted 1.12 million hectares of land, of which 27 per cent was situated within peat swamp forests (Drahman, 1999).

The conversion of peat swamp forest and peatlands into other land use, notably agriculture, is occurring at a fast pace. Since the 1980s, over a million hectares of peatlands in Malaysia have been converted for agricultural purposes (GEF, 2006). In Sarawak, the increase in planted area for oil palm was largely at the expanse of peat swamp forests that are situated in the low lying coastal plains (Hon, 2011).

Peat swamp forests are particularly vulnerable to fires, especially during the dry season. Drained peat swamp forests are highly flammable, and once burned, may take months or years before they are put out (Yule, 2010). Peat fires typically burn underground as well as above, not only eliminating the seedbank but also destroy the soil (Hogan and Caley, 2008). In 1997, the great peat swamp fires in Indonesia and Malaysia burnt for months and destroyed over 5 million hectares of forests (Butler, 2006).

Additionally degraded peat swamp forests are frequently invaded by pioneer secondary forest type plant species such as *Colocasia* sp., *Macaranga* sp., *Melicope* sp. and *Melastoma* sp., most of them non-merchantable timber species and rarely harvested or utilized by the local communities. The succession will not only permanently alter the species composition, structure, ecology and dynamics, but will render these economically useless.

Pollutants discharged from surrounding areas into peat swamp forests affect severely the forests' water quality, through acidification of local and downstream water-bodies with increased river water biological oxygen demand and turbidity (Sawal, 2004). Water-quality monitoring carried out by the Natural Resource and Environmental Board (NREB) of Sarawak, on activities prescribed under the Natural Resource and Environment Ordinance 1993 indicate that major agricultural, non-point source pollution is due to activities such as livestock farming, agro-chemical application, irrigation, planting and harvesting, as they emit or discharge sediments, nutrients, pathogens, pesticides and salts (Sawal and Mamit, 1998). Therefore, managing point of source of pollution from agricultural lands is important in order to minimize the impacts of the surrounding natural ecosystems. This is particularly crucial for long term conservation of peat swamp forests, largely because they are regarded as fragile ecosystems, and are likely to lie adjacent to large scale agricultural lands such as oil palm plantations. The Loagan Bunut National Park is a suitable example of peat swamp forest under threats from the surrounding anthropogenic activities, notably logging and oil palm planting in the upstream.

CONSERVING PEAT SWAMP FORESTS

In Sarawak, a protected area system is in place to safeguard some of the unique ecosystems and their wildlife. However, the total coverage is small, being slightly over 0.6 million hectare of land area, out of a total land area of over 12 million hectares, implying that about 4.9 per cent of its land is granted full protection. Of the 48 currently gazetted national parks, wildlife sanctuaries and nature reserves, only four are predominantly peat swamp forests-Loagan Bunut NP, Maludam NP, Sedilu NP and Ulu Sebuyau NP. These parks collectively account for about 13 per cent of the total protected land area.

The total area under peatlands in Sarawak, including peat swamp forests is about 1.7 million hectares (SPU, 2011). Taken into account the total coverage of 78,481 hectares, peatlands with protection status represent a conservative value of less than 5 per cent of the total peatlands in Sarawak. Thus, a huge proportion of peatlands and peat swamp forests in Sarawak are not protected, much of which are under threats from conversion for other land uses.

The future of protected peat swamp forests in Sarawak is not secured unless the surrounding areas are managed sustainably. The long-term existence of Loagan Bunut is at risk, whereby the lake inside the park predicted to dry up permanently in less than 60 years if upstream activities are not curbed. Additionally, logging and expansion of oil palm plantations surround the park (Sayok *et al.,* 2007) have deteriorated water quality, caused higher surface run-off and increase of suspended solids in the water (Lau *et al.,* 2006; Noweg *et al.,* 2006), which, in turn, deposit huge amount of silt into the park. The hydrological properties of Maludam is also at risk from land use change surrounding the park, whereby forests are being cleared and drained to make way for establishment of agricultural plots and human settlements. The hydrological properties of Maludam itself will be affected by the surrounding land development, which, in turn, may adversely affect its unique flora (remaining stands of Alan, *Shorea albida*) and fauna communities (population of red-banded langur). Insufficient enforcement personnel in many of these parks may leave these protected areas defenseless against human encroachment.

STRINGENT POLICY ON LAND USE

The Malaysian government, and the Sarawak State in particular, should emphasise the importance of conserving peat swamp forests, notably changing its agriculture policy and discouraging the large conversion exercise of remaining peat swamp forests. Sarawak, being home to extensive swathes of peat swamp forests, should take a bold move in intensifying research and increasing understanding of the unique plant and animal communities of these forests. Apart from the floral and faunal characteristics of peat swamp forests, the social aspects, notably the livelihoods of people living within and adjacent to peat swamp forests, should be given attention. Most peat swamp forests in Sarawak are closely associated with coastal belts, with large urban and sub-urban communities. There is an urgent need to protect more peat swamp forests in Sarawak, and to leave them in their natural state.

As required under Article 3 of the Natural Resources and Environment (Prescribed Activities) Order 1997, development of an oil palm plantation or forest harvesting exceeding 500 hectares falls within the order's prescribed activities, thereby warranting an environmental impact assessment approval before commencement of project implementation (Sawal, 2004). The prescribed activities include logging, industrial mining, establishment of commercial golf courses and housing estates.

There is an urgent need to set aside sufficient areas of peat swamps forests, pristine and otherwise, to ensure that the ecosystem, species and genetic diversity are preserved. Therefore, resources and attention should be focused on conserving peat swamp forest patches that are left, with similar effort expended on rehabilitation of degraded or logged over forests.

In areas that are already protected, the relevant agencies, such as the Sarawak Forestry Corporation and the Forest Department of Sarawak, as custodians to all protected areas in the State, must ensure permanent presence of enforcement and park management personnel to safeguard the areas against illegal activities. The government can and should support through increasing the operation budget for park management and to improve staff capacity to properly manage our protected areas.

Sarawak is the proud custodian of the largest peat swamp forests in Malaysia, which also contain unique as well as rare floral and faunal species on Borneo that are of great global importance. It is a legacy of our State, of which we can proudly proclaim that the flooded mosquito infested black water environment is, in fact, not a wasteland at all, but a forest that we should strive to protect.

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2

HUMIC SUBSTANCES AND THE CHEMISTRY OF TROPICAL PEAT

Siong Fong Sim

INTRODUCTION

The extent of peatland in Sarawak is 1.66 million ha (Wong, 1991), covering ca. 13% of the total state land area and occurring mainly in Kuching, Samarahan, Sri Aman, Sibu, Mukah, Sarikei, Bintulu, Miri and Limbang districts (Figure 1). It is home to a vast number of flora and fauna blanketed with peat soils that are typically acidic with high organic matter content. The organic constituents are primarily the decomposition products of plants and animal residues, scientifically termed as humic substances (HS) that refer to a complex mixture of compounds susceptible to chemical reactions, ultimately contribute to various beneficial and detrimental consequences.

Humic substances have been found to relate to human health. The Blackfoot disease and Kashin-Beck disease (a bone and joint disorder) endemically occur in Taiwan and China, respectively, are correlated to drinking water containing humic substances (Lu *et al.*, 1988; Yang *et*

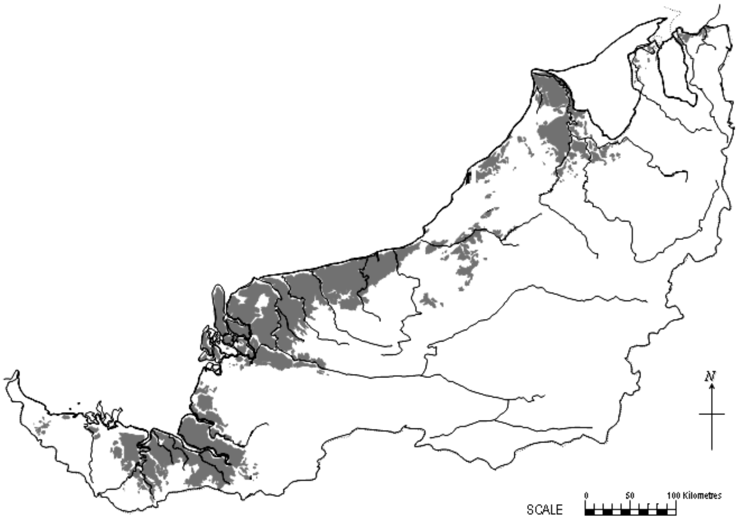

Figure 1: The distribution of peatland in Sarawak (Sim and Mohamed, 2007).

al., 2002; Peng *et al*., 1999). These natural organic compounds are in addition precursors of disinfection by-products. They are conventionally removed by coagulation and sedimentation nevertheless the residues remain after treatment can react with chlorine during disinfection process forming trihalomethanes (THMs) that are carcinogenic (cancer-causing). In Sarawak, water tainted by peat swamp leachate rich of humic matter is an important source of freshwater supply; an estimated 3,000 million litres of water are extracted annually from the affected streams throughout the state (McCartney and Acreman, 2009). The presence of humic substances causes a characteristic dark brown or black colour to the water therefore it is often called the tropical black water. Sim and Mohamed (2005) evaluated the level of THMs in drinking water produced from peat and non-peat source water in Sarawak revealed that treated water from peat swamp runoff contained elevated levels of THMs. Table 1 summarises the chloroform level found in treated water obtained from various treatment plants, as reported in Sim and Mohamed (2005).

Table 1: Level of chloroform in treated water obtained from various treatment plants.

Treatment plant	Chloroform, CH_3Cl (mg/L)
Batu Kitang (non-peat source)	17.40
Bau (non-peat source)	18.73
Bako (peat swamp runoff)	54.55
Asa Jaya (peat swamp runoff)	80.24

Despite the reported adverse health implications of HS, peat therapy has long been used to treat musculoskeletal disease, gynaecological disease, skin disease as well as osteoarthritis where humic substances are believed to be the key agent responsible for the therapeutic effects. They are also found to demonstrate antiviral, anti-inflammatory and estrogenic activities (Steinbüchel and Marchessault, 2005). In fact, many more studies have revealed the remarkable medicinal values of humic substances for treatment of ulcerous cornea infection, chronic ulcerous colon, acute upper gastroenterological bleeding, haemorrhoid as well as gastric and duodenal ulcers with encouraging results (Saroya, 2014). In environmental applications, humic substances possess the ability to complex with metals and organic compounds and eventually immobilize the pollutants. For example, humic acid was used to treat highly contaminated soil with polyaromatic hydrocarbon around a former chemical plant in northern

Italy (Conte *et al.*, 2005). This humic fraction was also employed for cadmium detoxification in aquaculture, reducing the metal toxicity in fish (Osman *et al*., 2009).

Extensive research has confirmed the metal-chelating attribute of humic substances, leading to development of a range of commercial HS products for pollutant remediation, soil conditioner and health supplements. The soil conditioner, as marketed as sodium/potassium humates, enhances nutrient availability increasing the germination rate, seedling growth and yield (Adani *et al.*, 1998; Patil *et al*., 2010; Patil, 2011). The growth stimulating ability of local humic matter has also been explored. Vegetables grown on low fertile soil amended with humic composites extracted from peat swamp runoff similarly illustrated improved plant development corroborating its beneficial effects (Mohd Razak, 2013).

BASIC CHEMISTRY OF HUMIC SUBSTANCES

Fundamentally humic substances are divided into three major fractions, namely humic acid, fulvic acid and humin, according to their solubility in acid and base. The insoluble fraction is called humin, the fraction that is soluble under all conditions is fulvic acid, while that insoluble at $pH < 2$ but alkali-soluble is humic acid. Each fraction is a mixture of compounds sharing average properties with molecular size of humin > humic acid > fulvic acid. Structurally, humic substances contain hydrophobic (weak affinity for water) and hydrophilic (strong affinity for water) moieties with diverse functional groups (carboxyl, alcoholic hydroxyl, phenolic hydroxyl, carbonyl, amine) serving as the active sites permitting adsorption and other possible chemical reactions to take place.

Humic substances have been a subject of research for over two centuries since it was first extracted in 1786 (Achard, 1786). However, their precise chemical structures are yet unknown although various model structures have been proposed. Figure 2 illustrates the structural model of fulvic acid according to Alvarez-Puebla *et al.* (2006).

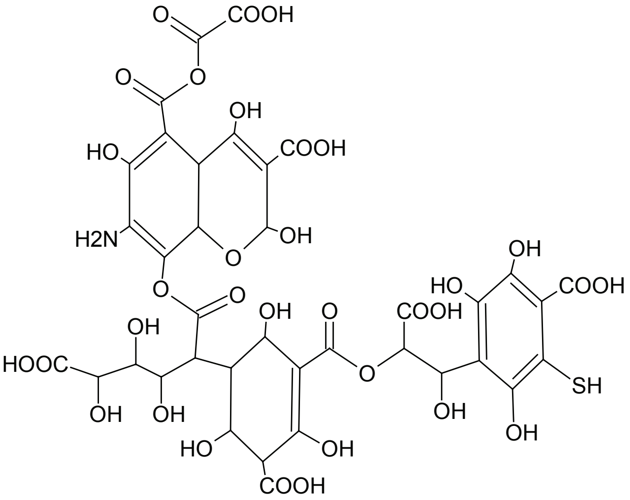

Figure 2: Model structure of fulvic acid according to Alvarez-Puebla *et al.* (2006).

HS are macromolecules undergoing decomposition as a result of cumulative influence of various factors, such as land use, topography, climate, microbial diversity and botanical composition that governs the resultant chemical properties determining their fate and potential in the environment. The extent of decomposition, known as the degree of humification, is used to describe the basic changes in the properties of humic matter.

DEGREE OF HUMIFICATION

Degree of humification based on von Post Scale

Degree of humification is measurable based on the von Post scale of H1 (least humified) to H10 (most humified) where samples are squeezed in hands to observe the amount of recognizable plant residues and the appearance of soil-water released (Wüst *et al*., 2003). For example, peat soil of H1 is undecomposed containing unaltered plant residues with clear water extruded. A study by Ong and Yogeswaran (1992) suggested that the humification degree of the peat soil in Sedi, Semah, Tambirat, Sai and Semup in Sarawak were between H2 and H8, while Aminur *et al*. (2011) assigned the peat soil in Matang area at depths between 0.40–0.80 m to H4–H10, with majority of the locations categorised under H4–H6. This is in agreement with the H4 level of decomposition reported by Kolay and Pui (2010) at the same area. The peat soil in Dalat Sago Plantation on the other hand was ranked between H3–H7 where the top soil (0–15 cm) was probably slightly less humified (H3–H5) than that of 15–30 cm (H4–H7) (Sim *et al*., 2005). Kawahigashi and Sumida (2006) concluded similar observation on the relative humification of surface and bottom soil in Mukah and Dalat. This however is in contrast to the findings of the study on peat soil in Johor by Katimon and Abd Wahab (2003) – which indicated that the surface soil was found to be more humified (H7–H9) than the deeper soil (H5–H6). In the northern region of Sarawak, the organic soil at Loagan Bunut National Park near Miri was anticipated to be one of the deepest in the world, with a depth of 20.7 m with the humification degree of H2–H4 (Sayok *et al*., 2008). This further added to the fact that peat soil in Sarawak is characterised by a considerable range of humification degree. Apparently the scale only describes the appearance of the peat providing limited information on the chemical characteristics that are crucial for understanding the role of humic substances in the environment however the method is useful in the field.

Degree of humification based on spectrophotometry

Alternatively, the degree of humification can be determined using the spectrophotometric technique – a rapid method not limiting to characterisation but also quantification of humic substances. Typically, the absorbance at 465 nm vs 665 nm, referred to as E_4/E_6, is used as an index of humification to suggest the aliphaticity/aromaticity of humic molecules (Kononova, 1968). Aliphaticity implies straight chain hydrocarbons whilst aromaticity refers to ring forming hydrocarbons therefore a high value of E_4/E_6 concludes the presence of relatively more aliphatic structures and a low ratio infers higher degree of aromatic constituents.

Mat Nuri *et al.* (2011) examined the peat soil of Batang Igan, Sibu reported the value of E_4/E_6 between 6 and 8; this is comparable to the value suggested in Mukah ranging between 6.46–7.24 (Rosliza *et al.,* 2009). Similarly, Sim and Mohamed (2007) examined the humification indices of different humic fractions isolated from peat soil and peat swamp runoff in Sarawak: The E_4/E_6 of aquatic fulvic acid (13–18) was found to be notably higher than humic acid (8.2–10) indicating that the latter possesses a relatively bigger molecular size. Nonetheless the E_4/E_6 value of terrestrial humic substances was found to be relatively lower, at an average of 7.8, corresponding well to other studies done locally. In comparison to the values reported elsewhere, summarised in Table 2, the E_4/E_6 of indigenous humic matter appears to fall in the higher range, especially the aquatic humic compounds, depicting possible smaller molecular size with richer aliphatic fractions.

Table 2: The reported E_4/E_6 values of humic fractions extracted from peat swamp forest.

Source	**E_4/E_6**
Peat soil, Sarawak	6-8
Peat swamp runoff, Sarawak	8-10 (HA) 13-18 (FA)
Peat, Poland (Szajdak and Szatylowicz, 2010)	5.6-7.0
Peat, Poland (Szajdak and Szczepanski, 2011)	6.0-7.1
Peat, Poland (Szajdak *et al.* 2007)	5.6-6.9
Peat, Spain (Gondar *et al.* 2005)	3.8-5.9 (HA) 6.8-11.9 (FA)
Peat, Latvia (Klavins and Sire, 2009)	2.8-3.8
Peat, Latvia (Klavins *et al.* 2008)	1.5-2.7
Peat, Indonesia (Garnier-Sillam *et al.* 1999)	3-8
Peat, Taiwan (Chen *et al.*, 2011)	5.63
Peat, Switzerland (Zaccone *et al.* 2007)	6-10
Peat, Brazilian Amazonian (Cunha *et al.* 2009)	4.2-6.0

HA: humic acid

FA: fulvic acid

Degree of humification based on carboxyl and phenolic OH contents

The E_4/E_6 is insufficient to provide a good indication on the potential reactivity of local humic compounds although their molecule monomer has been postulated as relatively smaller in size. Their reactivity is profoundly governed by the occurrence of active functional groups. The more reactive fulvic acid was characterised by richer oxygenated functional groups such as carboxyl (-COOH), hydroxyl (-OH) and carbonyl (C = O) than humic acid (Sim and Mohamed, 2007). The carboxyl and phenolic OH contents can be used to suggest the susceptibility/reactivity of humic matter and indicative of humification degree. Carboxyl groups, according to Schnitzer and Desjardins (1965) are the most reactive groups.

Unsal and Ok (2001) proposed that humic substances with high carboxyl and phenolic OH groups are less humified, i.e., at the early stage of humification. This is in contradiction to the statement by Tsutsuki and Kuwatsuka (1978) who instead implies that carboxyl and carbonyl groups increased whilst alcoholic and phenolic OH decreased during humification. Schnitzer and Desjardins (1965) agreed with the postulation of Tsutsuki and Kuwatsuka (1978) on the formation of carboxyl groups, but suggested that the prevalence of phenolic groups are unrelated to humification degree. Naturally, enhanced carboxyl and phenolic groups would render humic substances more vulnerable to reactions.

Ritchie and Purdue (2003) compared the carboxyl and phenolic content of commercial humic acid against humic materials derived from peat, leonardite and Summit Hill. The – COOH and phenolic OH content reported ranging between 3.2–4.8 meq/g and 4.8–6.6 meq/g, respectively. On the other hand, Unsal and OK (2001) revealed the humic materials from organic wastes with –COOH and phenolic OH varying between 0.51–2.23 meq/g and 11–20.7 meq/g correspondingly. In comparison with the study of humic substances elsewhere, the chemical characteristics of the indigenous humic matter are relatively scarce. The study by Sim and Mohamed (2007) speculated that the humic compounds from Sarawak were richer in carboxyl and phenolic OH (COOH: 3–9 meq/g and phenolic OH: 2–6 meq/g), attributable to accelerated oxidative degradation under warm and wet weather conditions, resulting in smaller molecular sizes.

CONCLUSIONS

Humic substances have been regarded as ‘*gold medicine*’ or ‘*black gold for agriculture*’, considering their miraculous biological effects (Lester, 2009; Klöcking and Helbig, 2005). Although the medicinal use of HS of the tropical peat of Sarawak are yet to be explored, the potential agricultural use as growth stimulant has been studied (Mohd Razak, 2013). Limited chemical studies suggest that humic substances in Sarawak may be smaller in their monomeric molecular size, containing more acidic functional groups as a result of accelerated degradation under hot and humid climate all year round. Couteaux *et al.* (1995) revealed that HS decomposition is climate-dependent. The decaying rate, based on the modelling simulation by Moorhead *et al*. (1999), was found to be more rapid under warm and moist environment. This was further supported by a field experimental work by Devi and Yadava (2010), who showed that the rate of decomposition was the highest during rainy summer months. Under the tropical climatic influence, the resulting oxygen-rich and smaller molecular size HS generated in the local peat may be more susceptible to chemical reactions, exhibiting stronger metal complexing capability and are more susceptible to formation of trihalomethanes.

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3

ARACEAE OF PEAT SWAMP FORESTS

Wong Sin Yeng

INTRODUCTION

Although regarded as ecologically significant, Bornean peat swamps are curiously depauperate of representatives of the Araceae, a family otherwise contributing a substantial percentage of the mesophytic flora of the low to mid-elevation forests of Borneo. Of an estimated total for Borneo of 600 species in 39 genera (Boyce *et al.,* 2010), the peat swamp forests of Sarawak claim only 19 species from 13 genera. Contextually this total is for species occurring in peat swamp alone, and explicitly excludes species from heteroecological habitats that occur within peat swamps, for example karst stacks emerging from oligotrophic water systems (such as occurs at Mulu and Merirai), which carry their own highly specific aroid floras.

Although aroids do not contribute a significant percentage of the floristic biome of peat swamp, a few species may be locally dominant. For example, *Homalomena rostrata* Griff. often forms extensive pure stands, outcompeting any but the most vigorous other species.

Species of *Cryptocoryne*, too, are often found in very large colonies, and furthermore are important indicators of forest quality as they are highly intolerant of suspended alluvium and steep increases in dissolved nutrients that accompany extensive habitat disturbances.

Peat swamp aroids fall into two broadly-defined ecological categories. A minority of species occur in permanently inundated situations. Of these a few occur in open areas and are always helophytic (i.e., *Alocasia sarawakensis* M.Hotta, *Homalomena rostrata*, *Lasia spinosa* (L.) Thwaites). Others favour shaded situations, either occurring as lianes (*Rhaphidophora lobbii* Schott), mesophytes (*Podolasia stipitata* N.E.Br.), or aquatics (*Cryptocoryne*) in forest pools fed by slow-moving oligotrophic streams, or in the streams themselves. However, most aroid species in peat swamp occur on podzols that are at least seasonally drier.

Aroids occurring in Sarawak peat swamp forest are: *Aglaonema nebulosum* N.E.Br., *A. nitidum* (Jack) Kunth, *Alocasia longiloba* Miq., *A. minuscula* A.Hay, *A. sarawakensis*, *Amydrium medium* (Zoll. & Moritzi) Nicolson, *Cryptocoryne cordata* Griff. *sensu lat.*, *C. longicauda* Becc. ex Engl., *C. pallidinervia* Engl., *Cyrtosperma ferox*, *Hestia longifolia* (Ridl.) S.Y.Wong & P.C.Boyce, *Homalomena rostrata*, *Lasia spinosa*, *Podolasia stipitata*, *Pothos scandens* L., *Rhaphidophora lobbii* Schott, *Scindapsus coriaceus* Schott *sensu lat., S. pictus* Hassk., and *S. treubii* Engl.

Alocasia minuscula, all the *Cryptocoryne*¸ *Homalomena rostrata* and *Podolasia stipitata* are restricted to peat swamp forest.

Alocasia minuscula, *A. sarawakensis*, *Cyrtosperma ferox*, and *Scindapsus coriaceus* are endemic on Borneo.

The definitive floristic account of Bornean peat swamp remains that of Anderson (1963). Of the aroids Anderson lists nine species in nine genera, all from Phase Communities 1 & 2 (Anderson, 1963, 1964). Since these publications there have been nomenclatural and taxonomic changes affecting Anderson's listing. These are tabulated in Table 1.

Table 1: Comparison of Araceae listed in Anderson's "The flora of the peat swamp forests of Sarawak and Brunei. Including a catalogue of all recorded species of flowering plants, ferns and fern allies" [Gardens' Bulletin Singapore 20(2):131–228 (1963)], with current taxonomic application.

Anderson, 1963	Current identification	Comments
Aglaonema pictum (Roxb.) Kunth	*Aglaonema nebulosum* N.E.Br.	Misidentified in Anderson (1963). *Aglaonema pictum* is restricted to upper hillforest on Sumatera. Clarified by Nicolson (1969).
Alocasia longiloba Miq.	*Alocasia longiloba* Miq.	-

Alocasia beccarii Engl.	*Alocasia minuscula* A.Hay	*Alocasia beccarii* sensu Engler & Krause (1920) is a species' complex of several ecology-obligated taxa. See Hay (1998).
Cryptocoryne pallidinervia Engl.	*Cryptocoryne pallidinervia* Engl.	-
Cyrtosperma lasioides Griff.	*Cyrtosperma ferox* N.E.Br.	Hay (1988) showed *C. lasioides* to be synonymous with *C. merkusii* Griff., and in this also included *C. ferox*. See notes under *C. ferox*.
Epipremnopsis media Engl.	*Amydrium medium* (Zoll. & Moritzi) Nicolson	Nicolson (1968) showed *Epipremnopsis* Engl. and *Amydrium* Schott to be synonymous.
Homalomena rostrata Griff.	*Homalomena rostrata* Griff.	-
Podolasia stipitata N.E.Br.	*Podolasia stipitata* N.E.Br.	-
Rhaphidophora lobbii Schott	*Rhaphidophora lobbii* Schott	-

KEY TO ARACEAE OF PEAT SWAMP IN SARAWAK

1a. Lianes 2

1b. Plants not climbing 7

2a. Leaves perforated or pandurately lobed; infructescence comprised of separate berries ripening white . . . . . . *Amydrium medium*

2b. Leaves entire; infructescence a monsterocarp with sloughing stylar plates or, if individual berries, then these ripening red . . 3

3a. Leaves resembling those of *Citrus*, with the petiole expanded and blade-like; leaf blade with the primary lateral veins on each side of the midrib traversed by one or more intramarginal veins . . . . *Pothos scandens*

3b. Petiole not blade-like; primary lateral veins not traversed by intramarginal veins 4

4a. Leaf blade cordiform; blade epidermis scintillating, almost always with jagged silver blotches; stems markedly scabrid . . . . *Scindapsus pictus*

4b. Leaf blade widely to very narrowly elliptic; blade epidermis not scintillating and never with jagged silver blotches, although occasionally with grey banding; stems smooth or weakly scabrid 5

5a. Leaf blade very strongly unequal; petiole less than 1/5 as long as the blade; petiolar sheath persistent; juvenile plants often with the leaf blades grey-banded. . . . . *Scindapsus treubii*

5b. Leaf blade not unequal; petiole more than 1/3 as long as the blade; petiolar sheath marcescent; juvenile plants uniformly coloured leaf blades 6

6a. Leaf blades stiffly coriaceous; abaxial surface with primary lateral veins not differentiated from the interprimaries; stems terete, smooth . . . . *Scindapsus coriaceus*

6b. Leaf blades softly coriaceous; abaxial surface with primary lateral veins well differentiated from the interprimaries; stems sulcate, weakly scabrid . . . . *Rhaphidophora lobbii*

7a. Plants prickly; spadix with bisexual, tepalate flowers 8

7b. Plants not prickly; spadix with unisexual, atepalate flowers . . 10

8a. Stems suffruticose, erect to decumbent, usually with prickly conspicuous internodes; leaves hastate to pinnatifid; spathe very long and narrow, spiral, opening only slightly at the base, dull yellow to brown; fruit spinulous . . . . *Lasia spinosa*

8b. Stem a condensed rhizome, rarely with distinct internodes, and these then unarmed; leaves entire, sagittate to hastate; spathe not very long, opening flat; fruit smooth 9

9a. Spathe interior white, infructescence nodding, fruits barely emerging from between the tepals, ripening dull purple; plant with spines mixed straight and up-turned . . . *Cyrtosperma ferox*

9b. Spathe interior red-purple, infructescence erect, fruits emerging fully from between the tepals, ripening bright red. Plant with spines mixed straight and down-turned . . . *Podolasia stipitata*

10a. Plants fully aquatic 11

10b. Plants mesophytic or helophytic. 13

11a. Terminal part of spathe limb reflexed, not drawn out into a greatly extended tail 12

11b. Terminal part of spathe limb hooded, drawn out into a greatly extended tail; dark purple . . . . *Cryptocoryne longicauda*

12a. Limb of spathe rough, usually yellow . . . *Cryptocoryne cordata sens. lat.*

12b. Limb of spathe red with numerous protuberances . . . . *Cryptocoryne pallidinervia*

13a. Colonial helophytes with strongly aromatic vegetative tissues; leaf blades very variable, ranging from linear-lanceolate to broadly sagittate; spathe with a marked constriction between the lower part and the limb; entire limb persistent into ripe fruit; mature fruits small, yellow-green . . . . *Homalomena rostrata*

13b. Solitary to clumping mesophytes or helophytes, vegetative tissues odourless; leaf blades of any one species not variable in shape; spathe with or without a strong constriction; spathe falling prior to fruiting, or the lower part persistent and the limb falling . . 14

14a. Plants suffruticose 15

14b. Plants clumping. 16

15a. Large plants (to ca. 1 m tall); leaf blades oblong with the mid-rib impressed; all veins obscure; spathe ellipsoid, persisting until after anthesis; spadix cylindrical. . . . . *Aglaonema nitidum*

15b. Small plants (to ca. 25 cm tall); leaf blades elliptic, with the mid-rib raised; primary lateral veins impressed; spathe globose, falling during anthesis; spadix clavate . . . . . *Aglaonema nebulosum*

16a. Leaf blades sagittate to hastate-sagittate 17

16b. Leaf blades oblong or peltate-elliptic 18

17a. Massive helophytes; leaf blades very large (ca. 1.5 m long), abaxially pubescent with conspicuously raised interprimary veins; petioles green with scattered dark red glands; inflorescences many together; infructescences with a large (ca. 4 cm long) ellipsoid white persistent lower spathe . . . . *Alocasia sarawakensis*

17b. Moderate mesophytes; leaf blades medium large (up to ca. 50 cm long), abaxially glabrous with interprimary veins flush or only slightly raised; petioles with conspicuous snakeskin patterning;

inflorescences solitary or three together; infructescences with a small (ca. 2 cm long) globose green persistent lower spathe . . . . *Alocasia longiloba*

18a. Leaf blades oblong, base cuneate; inflorescences many together on a very thin, nodding peduncle; infructescences with persistent lower spathe disintegrating to reveal very small (ca. 3 mm) pale green berries . . . .*Hestia longifolia*

18a. Leaf blades peltate elliptic; inflorescences solitary on a relatively stout, erect peduncle; Infructescence with persistent lower spathe splitting to reveal large (ca. 5 mm) bright red berries . . . . *Alocasia minuscula*

SPECIES DESCRIPTIONS

1. *Aglaonema nebulosum* N.E.Br., Ill. Hort. 34: 67, t.24. 1887; Nicolson, Smithsonian Contr. Bot. 1: 30–32, Fig.11. 1969. — *Aglaonema minus* Hook.f., Fl. Brit. India 6: 530. 1893. — *A. nanum* Hook.f., Fl. Brit. India 6: 530. 1893. — *A. scortechinii* Hook.f., Fl. Brit. India 6: 530. 1893. — *A. minus* var. *nanum* (Hook.f.) Ridl., Mat. Fl. Malay. Penins. 1907. — *A. minus* var. *scortechinii* (Hook.f.) Ridl., Mat. Fl. Malay. Penins. 1907. — *A. obovatum* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 322. 1922. — *A. pictum* var. *nanum* (Hook.f.) Ridl., Fl. Malay Penins. 5: 102. 1925. — *A. pictum* var. *scortechinii* (Hook.f.) Ridl., Fl. Malay Penins. 5: 102. 1925. — *A. nebulosum* f. *nanum* (Hook.f.) Nicolson, Smithsonian Contr. Bot. 1: 31. 1969.

Small, rather slender weakly suffruticose to decumbent, evergreen herb to 30 cm tall, but usually much less. *Stem* erect, 10-60 cm tall, 0.5-1.0 cm thick. *Leaves* few together, clustered at the tips of the stems; *petioles* 2-5 cm long, (0.1) 0.2-0.4 times as long as the leaf blade; *petiolar sheath* membranous, ca. over one-third as long as the petiole, 0.5-1.5 (2) cm long; *leaf blade* oblanceolate to narrowly elliptic-oblong, rarely obovate to elliptic, (6.5) 9-18 (20) cm long, (2.5) 3-5.5 (7) cm wide; base obtuse to cuneate; apex often apiculate, acuminate to abruptly acuminate; dull above, either plain or variegated in ashy or silvery irregular blotches, rarely nearly entirely ashy grey with a narrow green margin; *primary lateral veins* usually strongly differentiated into 5-10 or more pairs and adaxially with the midrib strongly blunt-raised. *Inflorescence* solitary, rarely 2 together; *peduncle* 2-4.5 cm long, equalling the petioles; *spathe* globose, apiculate, very light green to white at anthesis, 1.7-2.7 cm long, decurrent for 0.2-0.5 cm, caducous during anthesis; *spadix* clavate, exserted from spathe for 0.5 cm at anthesis, 1.2-2.0 cm long; *stipe* 0.3-1.0 cm long; *pistillate zone* 0.3-0.6 cm long, ca. 0.6 cm thick, *staminate zone* 0.9-1.5 cm long, 0.3-0.4 cm thick at base, × ca. 0.8 cm wide at or above middle, white. *Fruits* ellipsoid, ripening from dark green to dark red. **Figure 1**.

Distribution. — Peninsular Malaysia, Singapore, islands off the east coast of Sumatra, Borneo.

Habitat. — Peat and freshwater forests, on raised podzols.

Notes. — *Aglaonema nebulosum* originally was described from vegetative material cultivated by Linden in Belgium, and reported to have originated on Jawa. All available evidence is against this source, with three other cultivated specimens sent earlier to Brown by Linden and Bull were noted as having originated from Borneo; the species is not known to reach Java. Hooker (1893) did not include *A. nebulosum,* but had three non-variegated collections of material assignable to this species, each of which he recognized as the type of a new species: *A. minus, A. nanum,* and *A. scortechinii*. Ridley (1907) reduced *A. nanum* and *A. scortechinii* to varieties of *A. minus.* Engler (1915), not cite Ridley's work and recognized all the four species: *A. nebulosum, A. minus, A. nanum,* and *A. scortechinii,* noting that *A. nebulosum* and *A. scortechinii* were "Species imperfecte cognita." Ridley (1925) added a new element of confusion when he reduced *A. minus* to synonymy with *A. pictum* and recognized *A. nanum* and *A. scortechinii* as varieties of *A. pictum*. *Aglaonema pictum* is, to be sure, closely related to *A. nebulosum* but distinct. In *A. pictum* the petiolar sheath is consistently well over half the petiole length while in *A. nebulosum* the sheath is rarely over one-third as long as the petiole. Apparently Ridley confused the species because variegation patterns in the two species are almost identical.

Figure 1: *Aglaonema nebulosum* N.E.Br. A-D In various leaf forms, either plain or variegated in ashy or silvery irregular blotches, rarely nearly entirely ashy grey with a narrow green margin. E. At female anthesis. F. Spathe artificially removed to reveal the spadix.

2. *Aglaonema nitidum* (Jack) Kunth, Enum. Pl. 3: 56. 1841; Nicolson, Smithsonian Contr. Bot. 1: 33–37, Fig.7 & 13. 1969. — *Calla nitida* Jack, Malayan Misc. 1(1): 24. 1820. — *Arum integrifolium* Link, Enum. Pl. 2: 394. 1822. — *Aglaonema oblongifolium* Schott, Wiener Z. Kunst 1829: 829. 1829. — *A. integrifolium* (Link) Schott in Schott & Endl., Melet.

Bot.: 20. 1832. — *A. princeps* Kunth, Enum. Pl. 3: 55. 1841. — *A. helferi* Hook.f., Fl. Brit. India 6: 529. 1893. — *A. oblongifolium* var. *curtisii* N.E.Br., Gard. Chron., III, 21: 70. 1897. — *A. oblanceolatum* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 322. 1922. — *A. oblanceolatum* f. *maximum* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 323 1922. — *A. nitidum* f. *curtisii* (N.E.Br.) Nicolson, Baileya 15: 126. 1968. — *A. nitidum* var. *helferi* (Hook.f.) Nicolson, Smithsonian Contr. Bot. 1: 37. 1969. — *A. nitidum* f. *cinereum* Jervis, Aglaonema: 31. 1980.

Medium to large, somewhat robust, pachycaul or decumbent, evergreen herb, to 2 m tall. *Stem* erect or with lower part reclining on ground in larger plants, 0.5–5 cm thick. *Leaves* several to rather many together, usually restricted to the terminal portion of stems in larger plants; *petioles* deeply channelled, (8–)11–26(–29) cm long; *petiolar sheath* extending to the petiole tip, margins scarious; *leaf blade* narrowly elliptic to narrowly oblong or oblanceolate, 11–50 × 4–20 cm, base cuneate to attenuate, rarely broadly acute, apex acuminate to broadly acute or shortly acuminate, apiculate, coriaceous, usually plain green, sometimes with grey variegation either in bars following the venation or in rather irregularly scattered blotches; *venation* barely or not differentiated in fresh and dry material but sometimes *primary veins* weakly differentiated into 5–9 or more primary lateral veins. *Inflorescences* 2–5 together; *peduncle* 5–21 cm long, equalling or surpassing the subtending petiole; *spathe* oblong, 3–8.5 cm, decurrent for 4–20 mm, white at anthesis, becoming green during fruiting, persistent until fruit full-sized but still green, then marcescent; *spadix* cylindrical, equalling or slightly exceeding spathe, 1.3–7 cm, stipitate; *stipe* 0.2–0.9 cm long; *pistillate zone* (0.2–)0.5–1.0 cm long with 16–37 flowers; *staminate zone* 1.1–6.0 × ca.1.5 cm, white. *Fruits* ellipsoid, green, changing to white then pink and finally red. **Figure 2**.

Distribution. — Thailand, Peninsular Malaysia south to Sumatera, and Jawa, and west to Borneo.

Ecology. — Lowland to upper hill evergreen gallery forest wet or dry evergreen forest, and peat-swamp forest.

Vernacular. — Not recorded.

Notes. — A distinctive species immediately identifiable in the field by the large smooth leaves with the primary lateral veins very obscure. There has been considerable confusion in herbaria between *A. nitidum* and *A. simplex*, although the latter is readily identifiable by the thinly textured leaves with strongly differentiated primary lateral veins, and a spathe limb caducous at the onset of staminate anthesis.

Populations of *A. nitidum* in peat swamp forest are almost always silver-grey variegated adjacent to the primary veins. These plants equate to *A. nitidum* f. *curtisii*.

See Nicolson (1969) for the complex typification details.

Figure 2: *Aglaonema nitidum* (Jack) Kunth. A. Evergreen forest population B. At female anthesis. C. The fruits mature from green through white to pink and finally scarlet.

3. *Alocasia longiloba* Miq., Fl. Ned. Ind. 3: 207. 1856; Hay, Gard. Bull. Singapore 50: 299. 1998. — *Alocasia cuspidata* Engl., Bot. Jahrb. Syst. 25: 25. 1898. — *Alocasia amabilis* W.Bull, Cat. 143: 9. 1878. — *Alocasia cochinchensis* Pierre ex Engl. & K.Krause in Engl., Pflanzenr. IV, 23E (Heft 71): 103. 1920. — *Caladium veitchii* Lindl., Gard. Chron. 1859: 740. 1859. — *Alocasia veitchii* (Lindl.) Schott, Ann. Mus. Bot. Lugduno–Batavi 1: 125. 1863. — *Alocasia lowii* var. *veitchii* (Lindl.) Engl. in A.DC.

& C.DC., Monogr. Phan. 2: 508. 1879. — *Alocasia amabilis* W. Bull, Retail List 143: 9. 1878.

Small to moderately robust, evergreen to sometimes seasonally dormant, terrestrial (occasionally lithophytic) herbs to 150 cm tall. *Stem* usually rhizomatous, erect to decumbent, often completely exposed, ca. 8–60 × 2–8 cm, bearing remains of old leaf bases and cataphylls. *Leaves* often solitary, occasionally up to 3 together, each subtended by conspicuous lanceolate papery-membranaceous often purplish-tessellate cataphylls degrading to papery fibres; *petioles* terete, ca. 30–120 cm long, sheathing in the lower ca. ¼ or less, glabrous, purple-brown to pink to green, strikingly obliquely mottled chocolate brown (snakeskin pattern); *leaf blade* pendent, hastate-sagittate, rather narrowly triangular, 27–85 × 14–40 cm, dark to very dark green, usually with the major venation grey-green adaxially, and abaxial surface either green or flushed purple, posterior lobes peltate for (5–)10–30% of their length, acute; anterior costa with 4–8 *primary lateral veins* on each side, the proximal ones diverging at ca. 60–100°; *axillary glands* conspicuous; *secondary venation* initially widely spreading, then deflected towards the margin; *interprimary collective* veins weakly formed and zig-zagging at widely obtuse angles. *Inflorescences* solitary to paired, up to 4 pairs in succession without interspersed foliage leaves; *peduncle* 8–18 cm long, resembling petioles, erect at first, then declinate; *spathe* 7–17 cm long, abruptly constricted ca. 1.5–3.5 cm from the base; lower spathe ovoid to subcylindrical, green; *spathe limb* lanceolate, canoe-shaped and longitudinally incurved, 5.5–7.5 cm, eventually reflexing after staminate anthesis, membranous, pale green; *spadix* somewhat shorter than to subequalling the spathe, ca. 6–13 cm long, stipitate, *stipe* conical, to 5 mm long, whitish; *pistillate zone* 1–1.5 cm; *interstice* 7–10 mm, narrower than the fertile zones, corresponding with the spathe constriction; *staminate zone* subcylindrical, somewhat tapered at the base, 1.2–2.5 × 4.5–8 mm, ivory white; *synandria* 4–6–merous, more or less hexagonal, ca. 2 mm diam.; *appendix* 3.5–9 cm long, about the same thickness as the staminate zone, demarcated from it by a faint constriction, subcylindrical, distally gradually tapering to a point, very pale orange to bright yellow; *fruits* globose-ellipsoid, ca. 1.5 × 0.75 cm, green, ripening orange-red. **Figure 3**.

Distribution. — Cambodia, Laos, S Vietnam north to S.W. China, south to Peninsular Malaysia, Sumatera, Jawa and Borneo.

Ecology. — Rainforest and regrowth understory, in swampy areas and well drained slopes, occasionally on rocks. 0–500 m asl.

Notes. — The leaf blades of *Alocasia longiloba* are highly variable. There exist numerous local populations, of which some have been described as separate species, often from cultivated plants. However, peat swamp populations in Sarawak seem remarkably uniform.

For discussion of the extensive and complex synonymy see Hay (1998).

Figure 3: *Alocasia longiloba* Miq. A & B. Leaf blade pendent, hastate-sagittate, rather narrowly triangular, dark green. C. Petiole snakeskin-like. D. Synflorescence. E. Inflorescence at female anthesis. F. Infructestence brightly orange, bird dispersed.

4. *Alocasia minuscula* A.Hay, Gard. Bull. Singapore 50(2): 320. 1998.

Diminutive herb 10–20 cm tall. *Stem* suberect, ca. 1 cm diam., condensed, rooting along its length and clothed in old leaf bases and marcescent cataphylls. *Leaves* several to 9 together, interspersed with papery-membranous cataphylls to ca. 5.5 m long (these occasionally bearing redued petiole and blade); *petiole* 5–10 cm long, sheating in the lower ca. $^1/_7$; *leaf blade* narrowly ovate to oblanceolate, 8 × 2-13 × 3 m, peltate, coariaceous, pale abaxially, anterior lobe 7-10.5 cm long, the tip acuminate for ca. 1 cm; anterior costa with *primary lateral veins* 8-10 on each side, diverging at 60-45° then somewhat up-curved and joining a marginal vein, posterior lobe almost completely united save for a ca. 2 mm incision at the extrema base of the leaf, combined posterior lobes attenuate, 1–2 cm long. *Inflorescence* solitary; peduncle about the same length as the petioles at anthesis, later extending somewhat; *spathe* 3.5-4 cm long; *spadix* shorter than the spathe, ca. 2 cm long, *stipe* ca. 3 mm, the fertile zones entirely within the lower spathe; *pistillate zone* 3 mm long; *interstice* ca. 2 mm long; *staminate zone* 5 mm long; *appendix* ca. 6 mm long, cylindric. *Fruiting spathe* ca. 1.5 m diam., berries red-orange.

Distribution. — Endemic to Borneo; Sarawak.

Ecology. — In lowland peat swamp forest.

Notes. — *Alocasia minuscula* can be readily distinguished from *A. beccarii* and *A. peltata*, which it closely resembles, in its narrow peltate leaf shape and reduced posterior lobes, in its diminutive stature, by the distinctive pattern of leaf venation. The primary veins are much more numerous, and characteristically some appear, in the dried state, not to reach the midrib. *Alocasia minuscula* appears restricted to peat swamp forest, while *A. beccarii* and *A. peltata* are hill forest species.

5. *Alocasia sarawakensis* M.Hotta, Acta Phytotax. Geobot. 22: 159. 1967; Hay, Gard. Bull. Singapore 50(2): 247–249. 1998.

Massive arborescent herb. *Stem* more or less erect, to c. 15 cm diam., to 70 cm tall. *Leaves* several together with the blades erect to oblique; *petiole* to 130 cm long, sheathing in the lower $^{1}/_{3}$-$^{2}/_{5}$, pale dull green, very slightly rough, with numerous glands mainly in the sheathing portion; *leaf blade* somewhat glossy mid-green above, paler below, glabrous in adult plants, abaxially hairy in juveniles, cordato-sagittate, c. 90 cm × 80 cm; anterior lobe c. 60 cm long, with the margins slightly undulate; posterior lobes c. 35 cm long, rounded, held somewhat above the plane of the anterior lobe; posterior costae diverging at c. 80-90°, naked in the sinus for c. 2 cm; *primary lateral veins* 10-12 on each side of the anterior costa diverging at c. 45°; secondary veins forming very well-defined interprimary collective veins; glands conspicuous in axils of primary veins and very large at junction of petiole with costae, yellowish green. *Inflorescence* very numerous, to c. 40 crowded in the centre of the leaf crown from within the cataphylls, with a few scattered glands, pale dull green, c. 2 cm diam; *spathe* c. 19 cm long; lower spathe 7 cm × 2.5 cm and somewhat flattened, white with a basal ring of confluent glands, these at first shiny white, becoming purple, the remainder of the lower spathe with scattered ellipsoid glands aligned transverse to the long axis of the spathe and somewhat clustered at about 2/3 of the way up the lower spathe; spathe limb white, to 12 cm long, erect at pistillate anthesis, then sharply reflexed and rolled back at staminate anthesis, broadly lanceolate, to 5 m wide, horizontally wrinkled abaxially; *spadix* to c. 16 cm long, stipitate for c. 5 mm, *stipe* white; *pistillate zone* 2.5 m long c. 1.5 cm wide at base, distally somewhat tapering; *staminate* zone 3 cm × 1 cm, partly within the lower spathe chamber; synandria ± hexagonal, opening by apical pores not overtopped by synconnective, 6-8-merous, ivory; *appendix* apricot coloured, 9 cm long, 1.5 cm diam., tapering to a point, the surface covered with horizontally elongate, sinuous staminodes. *Fruiting* spathe white, dehiscing longitudinally; fruits red. **Figure 4**.

Distribution. — Endemic to Borneo; in Sabah and Sarawak.

Ecology. — Common in open swampy places; often seen in roadside ditches; encountered in swampy places in forest as a hairy juvenile; from sea level to c. 1200 m altitude.

Notes. — This species is easily distinguished from *A. robusta* and *A. macrorrhizos*, which sometimes all occur together and resemble each other in the very large broad leaves and preference for open habitats, by the very prominent venation on the abaxial side of the leaf blade, forming well defined interprimary collective veins. It can be distinguished further from *A. robusta* by having the posterior costae naked in the sinus and the abaxial side of the lamina not glaucous (Hay, 1998).

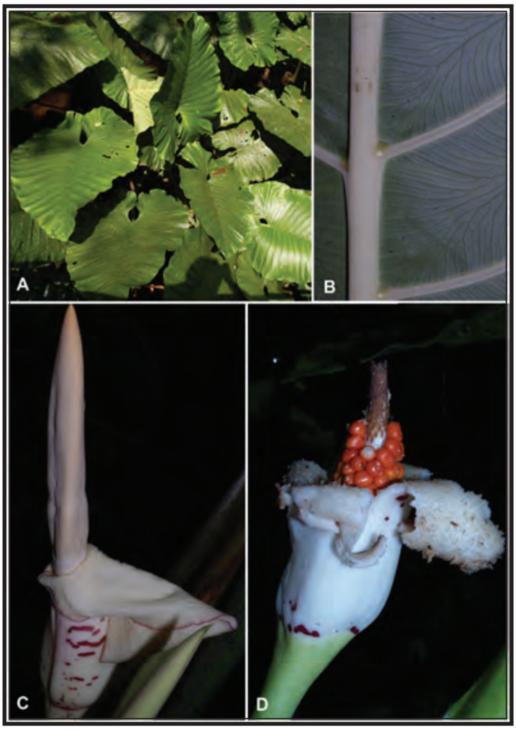

Figure 4: Alocasia sarawakensis M.Hotta. A. Massive arborescent herb. B. Leaf blade abaxially pubescent with numerous glands. C. Inflorescence with reflexed spathe limb. D. Infructescence revealing orange fruits.

6. ***Amydrium medium*** (Zoll. & Moritzi) Nicolson, Blumea 16: 124. 1968. — *Scindapsus medius* Zoll. & Moritzi in H.Zollinger, Syst. Verz.: 82. 1854. — *Anadendrum medium* (Zoll. & Moritzi) Schott, Bonplandia 5(3): 45. 1857. — *Rhaphidophora huegelii* Schott, Prodr. Syst. Aroid.: 384. 1860. — *Scindapsus huegelii* (Schott) Ender, Index Aroid.: 74. 1864. — *Epipremnum medium* (Zoll. & Moritzi) Engl. in A.DC. & C.DC., Monogr. Phan. 2: 250. 1879. — *Rhaphidophora korthalsiana* Engl. in

A.DC. & C.DC., Monogr. Phan. 2: 250. 1879. — *Epipremnopsis media* (Zoll. & Moritzi) Engl. in Engl., Pflanzenr. IV. 23B (Heft 21): 1. 1908. — *E. huegelii* (Schott) Engl. in Engl., Pflanzenr. IV, 23B (Heft 21): 138. 1908. — *Epipremnum truncatum* Engl. & K.Krause in .Engl., Pflanzenr. IV, 23B (Heft 21): 63. 1908. — *Epipremnopsis subcordata* M.Hotta, Acta Phytotax. Geobot. 22: 2. 1966.

Evergreen, medium-sized, somewhat robust, hemiepiphytic lianes to 10 m. *Stem* (adult) root-climbing, producing long flagelliform shoots with reduced cataphylls and scattered foliage leaves. *Leaves* remote from one another, the nodes between foliage leaves bearing papery cataphylls, although foliage leaves a few together at the tips of stems; *petiole* 15–35 cm, pulvinate apically and basally; *petiolar sheath* very short, barely exceeding the basal pulvinus; *leaf blade* (adult) ovate-cordate or pandurate–trilobed, 12–45 × 9–25 cm, largest leaves with several to many round to oval perforations near midrib, (juvenile) entire to once or twice perforated, rarely pinnatisect; deep glossy green to markedly greyish or strkingly bluish; *primary lateral veins* pinnate, running into marginal vein; *higher order venation* wholly reticulate. *Inflorescence* 1–several in each floral sympodium; *peduncle* erect, much shorter than petiole, 4–10 cm, subtended by several membranous, later papery cataphylls; *spathe* conchiform to ovate, apiculate, reflexed at anthesis and then caducous, very occasionally marcescent, ca. 9 × 7 cm, white; *spadix* stipitate, ca. 4–6 × 1 cm, white to cream, stipe obliquely inserted onto spadix, 0.5 cm, green; *pistillate zone* obpyramidal or obconoid, tetragonal; *stylar region* broader than ovary, ca. 3.5 × 2 mm, slightly prominent centrally below stigma, otherwise ± truncate; *stigma* small, hemispherical to transverse-linear. *Infructescence* comprising individual subglobose *berries*, these ca. 1 cm diam., domed at apex, ripening white. **Figure 5**.

Distribution. — S Burma and S Thailand through Peninsular Malaysia and Sumatera to Jawa, Borneo, and the Philippines.

Ecology. — Perhumid to wet primary to disturbed evergreen and peat swamp forest on a wide variety of substrates. 0–450 m asl.

Notes. — The ovate-cordate leaves with pandurate lobing and large perforations are immediately diagnostic. The pendent infructescences comprised of large discrete berries ripening white are unmistakable.

Figure 5: *Amydrium medium* (Zoll. & Moritzj) Nicolson. *Amydrium medium* is unusual among hemi epiphytic monsteroids in remaining small, usually climbing less than 4 m, and thus flowering low on the tree trunk. Adult plants have the leaves both perforated and pinnately divided (A). Juvenile plants have less elaborately divided leaves (B). As in most Monstereae the spathe is shed during anthesis (C), but unlike most the fruits are indehiscent berries (D).

7. *Cryptocoryne cordata* Griff., Not. Pl. Asiat., 3: 138. 1851 & Icon. Pl. Asiat., 3: tab. 172. 1851; Ridley, Fl. Malay Pen. 5: 86. 1925. — *C. kerrii* Gagnep., Notul. Syst. 9,3: 132. 1941. — *C. siamensis* var. *kerrii* (Gagnep.) Rataj, Revision of the Genus *Cryptocoryne* Fischer, Stud. Ceskoslov. Akad. Ved., č. 3, 93. 1975. — *C. stonei* Rataj, Revision of the Genus *Cryptocoryne* Fischer, Stud. Ceskoslov. Akad. Ved., č. 3, 95. 1975.

Rhizome somewhat rugged and slender. *Runners* slender. *Cataphylls* sometimes present in non-flowering specimens. *Leaves* variable, smooth to somewhat bullate, upper surface dark green with markings to purplish or purple, lower surface paler with reddish veins or shades to dark red; *leaf blade* narrowly ovate to cordate, (3–) 5–15 (–20) × 2–12 cm; *petiole* 5–50 cm long, longest in continuously submerged specimens from slow-running water. *Spathe* 7–35 (–50) cm long, white on the outside, sometimes brownish/greenish towards the apex; *peduncle* 2–5 cm; *kettle* white inside, 1–3 cm long; *tube* 4–40 cm long, white inside; *limb* more or less flat, 2–5 cm long, more or less backwards twisted, ovate with a shorter or longer point, surface more or less smooth, yellow to red-brownish shaded, if shaded, then more intensively so towards the margins and the apex; *collar* broad, yellow, gradually merging into the white tube; *pistillate flowers* 5–8 whitish; *stigma* rounded, ovate to emarginate, occasionally three-partite, and more or less upright; *olfactory bodies* round to irregular, somewhat rugose on the upper surface, yellowish; *staminate flowers* 30–60 (–80). *Infructescence* more or less purplish, ovoid, broad and shortly pointed, 1.5–2 cm long, surface smooth or with rounded protuberances. *Seeds* brownish, rugose, 5–10 mm long; endosperm present, embryo conical with an undifferentiated plumula.

Distribution (*C. cordata* sensu lat.). — Peninsular Thailand, Peninsular Malaysia, Sumatera, Borneo

Ecology. — Small or large streams with slow or more quickly running water under acid conditions in lowland peat swamp forests, where it usually occurs submerged.

Notes. — The identity and circumscription of *C. cordata* has been a matter of discussion for a number of years. Recently *C. grabowskii* Engl. (Borneo), *C. zonata* De Wit (Borneo), and *C. diderici* De Wit (Sumatra), all with a *chromosome number* of 2n = 68, have been referred to *C. cordata* at the variety level (Jacobsen, 2002).

8. *Cryptocoryne longicauda* Becc. ex Engl., Bull. Soc. Tosc. Ort. 4: 302. 1879. — C. *johorensis* Engl., Pflanzenreich IV**,** 23, F: 244. 1920.

Rhizome rather slender; plants from deep water with long internodes. *Runners* long and slender. *Cataphylls* only present in flowering specimens. *Leaves* green, occasionally evenly purple; *leaf blade* ovate, with a cordate base, 3-15 cm long, 3-10 cm broad, surface smooth to rough to strongly bullate, margin entire to finely undulate; *petiole* 5-30 cm long (largest specimens in deep, slow running water; smaller specimens more or less emerged in forest pools). *Spathe* 20-50 cm long, sometimes long pedicellate; *kettle* 1-2 cm long, white; *tube* 8-20 cm long, the upper part more or less purple on the outside; *limb* 15-30 cm long, caudate; collar present, dark red to black purple, sometimes yellowish; limb dark red to black purple, rugose, the tail sometimes whitish; *pistillate flowers* 5-7, *stigmas* ovate to elliptic, the upper part more or less emarginated; *staminate flowers* 30-50, smooth, olfactory bodies whitish, rounded. *Infructescence* ovoid, seeds brownish, more or less smooth; endosperm present, embryo in the fully developed seed with several plumulary processes. **Figure 6**.

Distribution. — Peninsular Malaysia (Johor), Sumatera, Borneo.

Ecology. — Forming large stands in more or less slow running rivers, or in lowland forest pools, mostly in deep mud. In small forest streams, the plants can form luxurious growths that cover the whole bottom and sides while, in forest pools, the specimens are smaller and more scattered (Jacobsen, 1985).

Figure 6: *Cryptocoryne longicauda* Becc. ex Engl. A. In its natural habitat at Mulu National Park. B. Spathe long pedicellate C. Spathe artificially removed to reveal the spadix.

9. *Cryptocoryne pallidivenia* Engl., Bull. Soc. Tosc. Ort. 4: 301. 1879. — C. *venemae* De Wit, Belmontia 13: 279. 1970. — *C. pallidivervia* Engl. ssp. *venemae* (De Wit) De Wit, Aquarium planten 219. 1983.

Rhizome rather slender. *Runners* slender. *Cataphylls* only present in flowering specimens. *Leaves* green, ovate with a cordate base; *leaf blade* 3-7 cm long, 24 cm broad, surface smooth to strongly bullate, margin some- times finely undulate, appearing denticulate; *petiole* 5-10 cm long. *Spathe* 6-10 cm long; *kettle* ca. 1 cm long, black purple inside; *tube* 3-8 cm long, brownish, white outside; *limb* ca. 1 cm long, ovate, more or less re- curved, surface with red protuberances; collar zone present, yellowish with small red spots that become smaller towards the throat; *pistillate flowers* 4-7, stigmas ovate to somewhat emarginated, olfactory bodies yellowish, rounded; *staminate flowers* 30-50, smooth, situated on a short sterile spadix immediately above the olfactory bodies. *Infructescence* unknown.

Distribution. — Endemic to Borneo.

Ecology. — A plant of lowland forests where it grows in slow running rivers and streams, and in seasonally inundated forest pools.

Notes. — *Cryptocoryne pallidinervia* is characterized by the cordate, more or less bullate leaves. The spathe has a long tube, the limb is red with protuberances, and the collar zone is yellowish with red spots. The spadix has the staminate and pistillate flowers situated adjacent to each other.

10. *Cyrtosperma ferox* N.E.Br. & L. Ill. Hort. 39: 59, t.153. 1892.

Large to massive rhizomatous herbs. 1 m or more tall, usually solitary, sometimes clump-forming, rhizome thick, condensed, creeping. *Leaves* several, held spreading; *petiole* sometimes very long, mottled and usually heavily armed, spines mixed straight and up-turned, sheath short. *Leaf blade* deeply sagittate, hastate-sagittate; veins sometimes aculeate on lower surface; basal ribs very well-developed, *primary lateral veins* pinnate, running into marginal vein, higher order venation reticulate. *Inflorescence* solitary, appearing with the leaves; *peduncle* long, similar to petioles; *spathe* marcescent, erect, blackish purple, interior white, convolute in lower part, upper part rarely somewhat fornicate, long-acuminate and twisted; *spadix* stipitate; *flowers* bisexual, perigoniate; tepals 4–6, somewhat thickened at apex, fornicate; *pistillate flowers* 1-locular, ovules 1–many, stylar region short or inconspicuous, stigma subhemispheric, exuding droplet at anthesis; *staminate flowers* 4–6, free, filaments free, flat and broad, connective slender, thecae oblong-ovate, dehiscing by apical slit. *Infructescence* nodding, fruits barely emerging from between tepals, ripening dull purple. **Figure 7**.

Distribution. — Endemic to Borneo.

Habitat. — Lowland freshwater swamp forest margins, sometimes persisting in flooded pas ture, or in swampy areas of lowland perhumid broadleaf evergreen tropical forest, sometimes on kerangas.

Notes. — The majority of *Cyrtosperma* occur in Papuasia, with only one or two species in Borneo. The most commonly met with is C. *merkusii* (Hassk.) Schott, a large plant (2 m or more tall) plant almost always found in open swampy places in association with habitation, has leaves held erect and petioles normally only lightly armed.

Occasionally, much more heavily armed smaller plants with spreading leaves are encountered in wet areas in forest, often along water courses, and these equate to C. *ferox* N.E.Br. The most recent revision (Hay, 1988) merges C. *ferox* and C. *merkusii,* although in Sarawak at least they are consistently distinct in terms of morphology and ecology (Boyce *et al.,* 2010).

Figure 7: *Cyrtosperma ferox* N.E.Br. A. Young plant showing the distinctive leaves. B. Detail of the petiole bases with their distinctive ascending prickles. C. Inflorescence at pistillate anthesis. Note the conspicuous stigma droplets. D. Mature infructescence. The nodding posture, marcescent-persistent spathe, and fruits barely emerging from the surrounding tepals are diagnostic in Borneo.

11. *Hestia longifolia* (Ridl.) S.Y.Wong & P.C.Boyce., Bot. Studies. 51: 252. 2010. —*Schismatoglottis longifolia* Ridl. J. Bot. 40: 37. 1902.

Herbaceous mesophyte. *Stem* pleionanthic, epigeal, erect to decumbent. *Leaves* few to many, often clustering terminally; petiole usually glabrous, sometimes minutely puberulent, leaf sheath fully attached, tapering, persistent to slowly degrading in the marginal distal part; *leaf blade* oblonceolate to ovato-sagittate, sometimes variegated, glabrous adaxially and abaxially, basal cuneate to saggitate, apex acute to long acuminate; *primary and secondary venation* bipinnate, tertiary venation obscure. *Inflorescence* solitary or synflorescence, up to 5 together; spathe long, up to 20 cm; lower spathe, ovoid, differentiated from the spathe limb with gradual or abrupt constriction; spathe limb oblong-lanceolate, upper spathe persistent until well after anthesis, then delisquescing, opening only slightly, the distal portion remaining convolute, with only the ventral part of the staminate zone exposed; *spadix* equaling or less than spathe; *pistillate zone*, more or less cylindric, obliquely inserted to adnate for up to $^1/_3$ of its length; *interstice* prominent, mostly naked with a few groups of small more or less sessile staminodes; *staminate zone* cylindrical to slightly tapering, the lower part corresponding with the spathe constriction; *appendix* present. *Fruiting spathe* urceolate. **Figure 8**.

Distribution. — Disjunct between the Malay Peninsular, where it is known to only from Perak, and Borneo, where it is known from numerous but widely scattered localities in Sarawak and Brunei.

Ecology. — In kerangas formations in lowland rain forest and lowland hill forest, and regrowth, always occurring on raised podsols in swampy areas, sometimes near streams to c. 250 m alt.

Notes. — This is a very distinctive genus easily recognised by the rather numerous nodding inflorescences on relatively very long slender wiry peduncles. There is only a weak constriction present between the lower spathe and upper spathe and the orifice of the lower spathe is open during fruiting. The entire non-pistillate portion of the spadix often dries and adheres to the spathe limb with the whole combined unit shedding.

Hestia longifolia has vegetative modules that readily disarticulate from the deep-seated rhizome. The function of the disarticulation in this podsol-obligated species is not clear, but it is speculated that it may be an adaption to fire resistance in a highly fire-prone habitat. Perhaps enabling the shoot unit to be destroyed in some way prevents damage to the main perennating system (Wong and Boyce, 2010).

Figure 8: *Hestia longifolia* (Ridl.) S.Y.Wong & P.C.Boyce. A. Plant in habitat on podsol. B. Nodding inflorescences, the inflorescence to the left at pistillate anthesis; upper right at staminate anthesis, lower right post-anthesis with spathe beginning to degrade prior to being shed. C. Spadix with the spathe removed artificially to reveal the pistillate and staminate flower zones. D. Spathe slightly gaping at pistillate anthesis. E. Inflorescence post-anthesis with spathe limb rotting at junction of lower spathe, later to be shed together with spent part of spadix. F. Infructescences with the distinctive narrowly campanulate lower spathe. G. Fruits.

12. *Homalomena rostrata* Griff., Not. Pl. Asiat. 3: 154. 1851 (‘*roshalum*’); Wong *et al., Gard. Bull. Singapore* 62 (2): 106–112, Fig.3. 2011. — *Cyrtocladon sanguinolentum* Griff., Not. Pl. Asiat. 3: 147. 1851. — *Chamaecladon sanguinolentum* (Griff.) Schott, Prodr. Syst. Aroid.: 316. 1860. — *Homalomena sagittifolia* Jungh. ex Schott, Prodr. Syst. Aroid.: 311. 1860. — *H. miqueliana* Schott, Ann. Mus. Bot. Lugduno–Batavi 1: 126. 1863. — *H. propinqua* Schott, Ann. Mus. Bot. Lugduno–Batavi 1: 280. 1864. — *H. beccariana* Engl., Bull. R. Soc. Tosc. Ortic. 4: 296. 1879. — *H. paludosa* Hook.f., Fl. Brit. India 6: 53. 1893. — *H. sagittifolia* var. *pontederiifolia* Ridl., J. Straits Branch Roy. Asiat. Soc. 44: 172. 1905. — *H. ridleyana* Engl., Bot. Jahrb. Syst. 37: 123. 1907. — *H. teysmannii* Engl.in Engl., Pflanzenr. IV, 23Da (Heft 55): 68, Fig.43. 1912. — *H. raapii* Engl. in Engl., Pflanzenr. IV, 23Da (Heft 55): 73, Fig.69. 1912. — *H. triangularis* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 181. 1922. — *H. sagittifolia* var. *Sumaterana* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 192. 1922. — *H. ensiformis* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 335. 1922. — *H. miqueliana* var. *truella* Alderw., Bull. Jard. Bot. Buitenzorg, III, 4: 336. 1922. — *H. sagittifolia* var. *angustifolia* Furtado, Gard. Bull. Straits Settlem. 10: 228. 1939.

Medium to large, usually robust, colony-forming, strongly aromatic (pinene) helophyte to 1 m tall, but usually less. *Stem* hypogeal, stoloniferous, 1–3 cm thick. *Leaves* few together; *petioles* 10–25 cm, rather spongy, deep green; *petiolar sheath* 3–4 cm, margins membranous; *leaf blade* very variable, ranging from linear-lanceolate through ovate-lanceolate to strongly hastate, 6–35 × 3–20 cm, base cuneate to truncate to cordate or strongly hastate, apex blunt to long acuminate, with a 2–5 mm tubular mucro, rubbery–coriaceous, deep green; *primary lateral veins* 4–11 per side; *interprimary veins* much finer, striate; *secondary venation* almost invisible. *Inflorescences* 1–2 together; *peduncle* 15–25 cm, green to purple-brown; *spathe* with a moderate constriction between the lower part and the spathe limb, 8–14 cm long; *lower part* ovoid-ellipsoid, 2–4 × 1–1.5 cm; *spathe limb* lanceolate to lanceolate-elliptic, 6–9 × 2–3.5 cm, spreading at anthesis, then closing again; *spadix* tapering-cylindrical, 6–10 cm, subequalling spathe, stipitate; stipe ca. 1 cm long; *pistillate flower zone* 1.5–3 × 1 cm; *ovary* depressed ovoid-globose, ca. 1 mm diam., with an associated clavate staminode ca. equalling the height of the ovary; *stigma* sessile, capitate, ovary pale green, staminode white; *sterile interstice* ca. 1 cm long, with a few scattered staminodes, these ovoid, compressed, white, axis of interstice pale green; *staminate flower zone* 4.5–5.5 cm × 3 mm; *staminate flowers* rhombohexagonal in plan view, ca. 1–2 mm diam., each with two stamens overtopped by a large connective, white. *Fruits* ripening dull yellow. **Figure 9**.

Distribution. — Peninsular Thailand, Peninsular Malaysia, Sumatera, N.W. Borneo.

Ecology. — Lowland freshwater swamp forest and peat swamp forest.

Notes. — *Homalomena rostrata* is highly polymorphic in terms of leaf lamina shape, and overall plant size, even within a single population, and has attracted a considerable synonymy as a result. Flowering size plants range in height from barely 20 cm to over 1 m, with the largest plants generally occurring in areas of abundant nutrient availability, for example along the margins of freshwater swamp forest, while smaller plants are generally confined to nutrient-poor soils, especially on white sand and peat kerangas, or along oligotrophic stream systems. Smaller plants tend to have sagittate leaves. For a detailed discussion of typifications of *H. rostrata* see (Wong *et al.,* 2011).

Figure 9: *Homalomena rostrata* Griff. A - C Plants in habitat showing variation in leaf lamina shape. D. Inflorescence at pistillate anthesis with the presence of two individuals of *Parastasia* sp. E. Mature inflorescence with spathe artificially removed. F. Pistillate zone.

13. *Lasia spinosa* (L.) Thwaites, Enum. Pl. Zeyl.: 336. 1864; Hay, Blumea 33: 458–462, Fig.15 & 16 (1988). — *Dracontium spinosum* L., Sp. Pl.: 967. 1753. — *Lasia aculeata* Lour., Fl. Cochinch.: 81. 1790. — *Pothos heterophyllus* Roxb., Fl. Ind. 1: 457. 1820. — *Pothos lasia* Roxb., Fl. Ind. 1: 458. 1820. — *Pothos spinosus* (L.) Buch.–Ham. ex Wall., Numer.

List: 4447 C. 1831. — *Lasia heterophylla* (Roxb.) Schott in Schott & Endl., Melet. Bot.: 21. 1832. — *Lasia loureirii* Schott in Schott & Endl., Melet. Bot.: 21. 1832, *nom. illeg.* — *Lasia roxburghii* Griff., Not. Pl. Asiat. 3: 155. 1851. — *Lasia hermannii* Schott, Bonplandia (Hannover) 5(8): 125. 1857. — *Lasia jenkinsii* Schott, Bonplandia (Hannover) 5(8): 125. 1857. — *Lasia zollingeri* Schott, Bonplandia (Hannover) 5(8): 125. 1857. — *Lasia desciscens* Schott, Ann. Mus. Bot. Lugduno–Batavi 1: 127. 1863. — *Lasia spinosa* var. *hermannii* (Schott) Engl. in A.DC. & C.DC., Monogr. Phan. 2: 274. 1879. — *Lasia crassifolia* f. *angustisecta* Engl., Exsicc. (Arac.): 194. 1883. — *Lasia crassifolia* f. *latisecta* Engl., Exsicc. (Arac.): 194. 1883. — *Lasia crassifolia* Engl., Bot. Jahrb. Syst. 25: 15. 1898.

Robust, colony-forming, stoloniferous, evergreen helophytes to 1.5 m. *Stem* thick, prickly, rarely unarmed, erect to decumbent, epigeal or submersed, green. *Leaves* several together; *petiole* to 100 cm long, aculeate, weakly pulvinate apically, sheath relatively short; *leaf blade* (juvenile) sagittate to hastate-sagittate, (adult) deeply pinnatifid in anterior division, with posterior divisions pedatifid, sometimes simple, 18–75 × 6–35 cm; major veins aculeate on lower surface; *primary lateral veins* pinnate in anterior division, pedate in posterior divisions; *higher order venation* reticulate. *Inflorescence* solitary; *peduncle* subequal to petiole, to 45 cm tall, aculeate; *spathe* linear, 25–55 × 2–4 cm, very long and narrow, thick and spongy, spirally twisted, marcescent, basal part enclosing spadix, gaping at anthesis, yellow to purple or brownish; *spadix* shortly cylindrical, 4–5 × 1 cm, obtuse, sessile; *gynoecium* ovoid to ellipsoid, ca. 2 mm diam. *Infructescence* stoutly cylindrical, to 7 × 2 cm; *fruits* quadrangular, apically densely muricate to spinose, ca. 1.5 cm diam., green when ripe. **Figure 10**.

Distribution. — Widespread throughout tropical Asia from southern India and Sri Lanka eastwards as far as New Guinea and north to southern China.

Ecology. — Open wet areas in deciduous and evergreen forest, along rivers and in ditches; frequently remaining after land clearance; on a variety of substrates but not recorded from limestone.

Uses. — The emerging leaves and inflorescences are used locally as a green vegetable (recorded by several collectors).

Notes. — For discussion of typifications see Hay, *Blumea* 33: 427–469. 1988.

Figure 10: *Lasia spinosa* (L.) Thwaites. A. Flowering plant. B. The greatly attenuated spathe limb opening only at the base. C. Young emerging leaf lamina. D. Inflorescence. E. Ripe infructescence. Note the spinulose berries.

14. *Podolasia stipitata* N.E.Br., Gard. Chron., ser.2, 18: 70. 1882; Hay, Blumea 33: 463–465, Fig.17(1988).

Small clumps, rhizomatous herbs. *Stem* erect to decumbent, internodes distinct, unarmed. *Leaves* several; *petiole* long, geniculate apically, aculeate, spines straight and/or pointing downwards, sheath short; *leaf blade* unarmed, sagittate to hastate, coriaceous, posterior divisions ± equalling anterior, sometimes longer; basal ribs well-developed; *primary lateral veins* mostly arising near petiole insertion, long-arcuate towards division apex and running into margin, higher order venation reticulate. *Inflorescence* solitary; *peduncle* subequal to petiole and similar in appearance; *spathe* ovate lanceolate, fully expanded, persistent, red brown, interior red-purple; *spadix* shorter or equalling spathe, cylindric, stipitate, *stipe* basally adnate to spathe, flowering sequence basipetal; *flowers* bisexual, perigoniate; tepals 4–6, fornicate; *pistillate flowers* cylindric to obovoid, ovary 1-locular, ovule 1, anatropous, placenta parietal to subbasal, stigma discoidhemispheric; *staminate flowers* 4–6, free, filaments oblong, flattened, connective slender, thecae ellipsoid, dehiscing by longitudinal slit. *Infructescence* erect; *fruits* emerging fully from between the tepals, ripening bright red. **Figure 11**.

Distribution. — One species occurring disjunctly in Sumatera, Peninsular Malaysia, and Borneo.

Ecology. — Lowland peat swamp forest, usually on slightly raised peat deposits (podzols) but still subject to seasonal inundation.

Notes. — *Podolasia stipitata* is very sporadic in distribution throughout its range, although it is frequently locally abundant (as at Batang Ai)

Figure 11: ***Podolasia stipitata*** **N.E.Br.** A. Flowering and fruiting plant in habitat. B. Inflorescence at staminate anthesis. Note the terminal portion of the spadix is differently coloured, this zone comprises flowers that are post anthesis and will proceed down the spadix until post anthesis the entire spadix is purple. C. Detail of the spadix base near to completion of anthesis. Note that only a small area of white spadix remains. D. Infructescence nearing maturity. Note that the fruits are almost wholly exserted from between the tepals. When ripe the berries are scarlet.

15. *Pothos scandens* L., Sp. Pl.: 698. 1753; Boyce & Hay, Telopea 9: 461. 2001. — *Batis hermaphrodita* Blanco, Fl. Filip. ed. 1: 791. 1837. — *Pothos hermaphroditus* (Blanco) Merr., Sp. Blancoanae: 90. 1918. — *P. angustifolius* C.Presl, Epimel. Bot.: 243. 1849. — *P. chapelieri* Schott, Aroideae: 22, t. 35. 1856–1857. — *P. exiguiflorus* Schott, Aroideae: 21, t. 41. 1856–1857. — *P. cognatus* Schott, Aroideae: 22, t. 42. 1856–1857. — *P. scandens* L. var. *cognatus* (Schott) Engl. in A.DC. & C.DC., Monogr. Phan. 2: 84. 1879. — *P. zollingerianus* Schott, Oesterr. Bot. Wochenbl. 5: 19. 1855. — *P. horsfieldii* Miq., Fl. Ned. Ind. 3: 178. 1856. — *P. decipiens* Schott, Bonplandia (Hannover) 7(11): 165. 1859. — *P. fallax* Schott, Prodr. Syst. Aroid.: 560. 1860.

Moderate to rather large, slender to moderately robust, homeophyllous, root-climbing secondary hemiepiphyte to 6 m. *Stem* 10 mm diam., weakly four-angled or slightly compressed-terete in cross-section. *Leaves* dense; *petiole* 2–14 cm × 5–20 mm, broadly winged, obovate-oblong to linear-oblong, with 2–3 secondary veins and numerous veinlets per side, base decurrent, apex truncate, rounded or auriculate; *leaf blade* 2–10 × 1–4 cm, ovate to elliptic or lanceolate with 2 intramarginal veins per side, base rounded to acute, apex attenuate-mucronate, leathery. *Flowering shoot* much abbreviated, arising from most of the mid- to distal leaf axils of fertile shoots, bearing a minute prophyll and a few 3–10 mm, sequentially longer, cataphylls. *Inflorescence* solitary; peduncle slender, 3–15 × 0.5–2 mm, erect to spreading, green to purple-tinged; *spathe* 4–8 × 4–7 mm, ovate, concave, margins variously in-rolled, base short or somewhat long-clawed, apex rounded to acute with a tiny rather stout mucro, greenish to maroon; *spadix* stipitate; *stipe* terete in cross-section, 5–10 × ca. 1 mm, erect, the distal part erect to bent through 270°, greenish to maroon; *fertile portion* globose or ovoid to subclavate, 4–10 × 3.5–10 mm, yellow green to off-white; *flowers* ca. 12 mm diam.

Infructescence with 1–5 berries; *fruit* obclavate, 1–1.75 × 1–1.5 cm, mid-green ripening to deep scarlet. **Figure 12**.

Distribution. — Madagascar to India and Sri Lanka, through Bangladesh and Burma, Thailand and Indo-China to SW China, south through Indonesia (Sumatera, Jawa to Bali) through Peninsular Malaysia to Borneo, and the Philippines.

Ecology. — On trees and rocks in primary and secondary wet to dry lowland to hill evergreen tropical to subtropical forest, rare in peat swamp forest, occasionally on sea cliffs, on a variety of substrates including clay, limestone or granite. 0–2100 m asl.

Notes. — *Pothos scandens* is unmistakable in its typical aspect, carrying numerous rather small inflorescences on diagnostically bent peduncles.

Figure 12: ***Pothos scandens*** **L.** A. Root-climbing plant with its leathery leaf blades. B. Petiole broadly winged. C. Several small inflorescences.

16. ***Rhaphidophora lobbii*** Schott, Bonplandia (Hannover) 5(3):45. 1857; Boyce, Gard. Bull. Singapore 51: 223–226, Fig.10. 1999. — *Scindapsus lobbii* (Schott) Ender, Index Aroid. 74. 1864.

Small to moderate, somewhat slender, leptocaul, homeophyllous secondary hemiepiphyte to 5 m. *Stems* puberulent-scabrid to asperous, especially on older growth, climbing stems weakly rectangular to ± terete in cross-section, free stems ± terete in cross-section, often branching extensively and growing to moderate lengths, hanging under their own weight, dull brown, without prophyll, cataphyll and *petiolar sheath* fibre. *Leaves* weakly spiralled and often sparsely arranged on adherent and proximal portions of free shoots, densely spirally–distichous distally on flowering shoots; *petiole* grooved adaxially, 4–9.5 × 0.2–0.3 cm, smooth, with moderate apical and prominent basal pulvini; *petiolar sheath* slightly prominent, extending beyond the apical pulvinus by two ligules, very soon drying and falling in strips to leave a continuous scar from the petiole base, around the top of the apical pulvinus and back to the base; *leaf blade* entire, narrowly elliptic to elliptic-lanceolate to oblong or oblanceolate, 6–24 × 2–10 cm, very softly coriaceous, upper surfaces slightly glossy, lower surfaces pale satin-matte, drying markedly discolorous, dark brown above, pale brown below, base cuneate to acute or sub-ovate, briefly decurrent, apex acute to ovate-acuminate, with a prominent apiculate tubule; *midrib* slightly raised abaxially, slightly sunken adaxially; *primary venation* pinnate, slightly raised abaxially, prominent (dark veins against pale lamina) in dried material. *Inflorescence* solitary, subtended by a fully developed foliage leaf and a very quickly falling cataphyll; *peduncle* compressed-cylindrical, 1.5–5 × 0.15–0.4 cm; *spathe* ovate-elliptic, stoutly long-beaked, 3–5 × 0.4–1 cm, thickly fleshy, exterior minutely puberulent, dull yellowish at anthesis, soon falling to leave a substantial, slightly oblique scar; *spadix* slender cylindrical, sessile, inserted level on peduncle, 3–3.5 × 0.4–0.5 cm, dull yellow-white; *anthers* barely exserted at anthesis. *Infructescence* oblong-cylindrical, 2.5–4 × 1–1.2 cm, ripening dirty white, stylar plates sloughing away to reveal amber coloured pulp and pale grey seeds. **Figure 13**.

Distribution. — S Peninsular Thailand, Peninsular Malaysia, Singapore, Sumatera, throughout Borneo extending to the Philippines (Palawan), and Sulawesi.

Ecology. — Lowland to hill dipterocarp forest on wet to inundated soils, peat swamp and freshwater swampforest. 10–200 m asl.

Notes. — A distinctive climber by the combination of the slender, asperous stems and softly leathery leaves, and minutely pubescent spathe exterior. Dry material is remarkable by the strongly discolorous leaves, and primary veins prominently darker than the abaxial leaf surface.

Figure 13: *Rhaphidophora lobbii* Schott. A. Adult plant. B. Solitary inflorescence, subtended by a fully developed foliage leaf, spathe ovate-elliptic, stoutly long-beaked, and thickly fleshy. C. Cylindrical spadix. D. Infructescence ripening dirty white, stylar plates sloughing away to reveal amber coloured pulp and pale grey seeds.

17. *Scindapsus coriaceus* Engl., Bull. Soc. Tosc. Ortic. 4: 271. 1879.

Medium sized scandent or climbing herbs. *Stem* terete, smooth. *Leaves* often forming tufts of foliage at the tips of active shoots with the preceding leaves scattered; *petiole* 5-10 cm long, pulvinate apically; *petiolar sheath* extending the to petiole tip, marcescent, degrading to fibres; *leaf blade* narrowly elliptic, oblique, oblong-lanceolate, stiffly coriaceous; *primary lateral veins* hardly differentiated from the interprimaries, pinnate, running into marginal vein, all other venation obscure *Inflorescence* always solitary; *peduncle* shorter than petiole; *spathe* boat-shaped, white to yellow, gaping at anthesis; *spadix* cylindric, a little shorter than spathe; *flowers* bisexual, perigone absent; pistillate flowers, ovary short, compressed; *staminate flowers* 4, free. *Fruits* berry.

Distribution. — Endemic on Borneo.

Ecology. — Raised podzols in peat swamp forest, kerangas.

Notes. — *Scindapsus* has not been revised in its entirety since 1908 (Engler and Krause, 1908), and not treated for Malaysia since Ridley's accounts for the flora (Ridley, 1907, 1925), when he recognized 5 species: *Scindapsus beccarii* Engl., *S. hederaceus* Miq., *S. perakensis* Hook.f., *S. pictus* Hassk., and *S. scortechinii* Hook.f. Since Ridley, fieldwork has revealed two further species: *S. treubii* Engl., a widespread species from Sumatera to Borneo, and *S. lucens* Bogner and P.C.Boyce, described in 1994. *Scindapsus coriaceous* is a species complex.

18. *Scindapsus pictus* Hassk., Tijdschr. Natuurl. Gesch. Physiol. 9: 164. 1842. — *Pothos argenteus* W.Bull., Cat. 1887: 11. 1887. — *Pothos argyraeus* Engl., in A.DC. & C.DC., Monogr. Phan. 2: 255. 1879. —

Scindapsus argyraceus Engl., in A.DC. & C.DC., Monogr. Phan. 2: 255. 1879. — *Scindapsus pictus var. argyraeus* (Engl.) Engl., Bot. Jahrb. Syst. 25: 13. 1898. — *Scindapsus pictus var. oblongifolius* Engl., Bot. Jahrb. Syst. 25: 13. 1898. — *Scindapsus pothoides* Schott, Prodr. Syst. Aroid.: 394. 1860.

Small to large, moderately robust lianes. *Juvenile and pre-adult stems* with the leaves arranged in an overlapping (or nearly so) shingle pattern; adult stems with leaves distichously arranged. *Stem* long, at most scabrid, older portions with conspicuous orange-brown brittle epidermis. *Leaves* many; *petiole* ca. 2 cm long; *petiolar sheath* narrow; *leaf blade* 8–12 cm × 2–2.5 cm, ovate-cordiform (juvenile and pre-adult) to falcate (adult), adaxially matte to somewhat scintillating, medium green, usually with silvery jagged spots or with these coalescing into larger areas; *primary lateral veins* hardly differentiated, pinnate, running into marginal vein; higher order venation obscure. *Inflorescence* solitary; *peduncle* shorter than petiole, 0.5 to 1 cm long; *spathe* 4–8 cm long, ovate-cuspidate, thickly leathery, white; *spadix* stout ca. 2 cm long, white; *flowers* bisexual, perigone absent; pistillate flowers, ovary sometimes short, compressed ± cylindric; stamens flowers 4, free, filaments oblong, flattened, broadish, connective slender, thecae oblong-ellipsoid, dehiscing by apical slit. *Infructescence* a monsterocarp ca. 7 cm long × 2.45 cm wide, pale grey-green, glaucous, stylar plates sloughing at maturity to reveal the orange pulp cavity. **Figure 14**.

Distribution. — Peninsular Malaysia, Sumatera, Jawa, Borneo, Philippines, and Sulawesi.

Ecology. — In a variety of habitats in the lowlands to mid-elevation. Not rare, but almost always encountered as a juvenile shingling climber. The rarely encountered adult plants form extensive curtains of much-branched stems pendent from the tops of tall forest trees, with the inflorescences born on the tips of the stems.

Figure 14: A. ***Scindapsus treubii* Engl.** Note the subsucculent, strongly oblique leaf blade, and smooth stem. B-E. ***Scindapsus pictus* Hassk.** B. Primary axis showing the diagnostic and older portions with conspicuous orange, brittle scabrid epidermis. C-E. A selection of leaf markings typical of *S. pictus*. Notes the somewhat scintillating quality particularly in C & E.

19. *Scindapsus treubii* Engl., Bot. Jahrb. Syst. 25: 13. 1898. — *Pothos enderianus* N.E.Br. Gard. Chron., n.s., 1884(1): 711, 1884.

Small to large, moderately robust lianes. *Juvenile and pre-adult stems* with the leaves arranged in an almost overlapping pattern; adult stems with leaves distichously arranged; *Stem* smooth, terete. *Leaves* many; *petiole* short, petiolar sheath persistent; *leaf blade* narrowly elliptic to very narrowly falcate oblanceolate (juvenile and pre-adult), to oblique-elliptic (adult), concolorous deep green, although juvenile plants often with the leaf blades grey-banded; *primary lateral veins* hardly differentiated, pinnate, running into marginal vein. *Inflorescence* solitary; *peduncle* shorter than petiole, ca. 2–3 cm long; *spathe* boat-shaped, 3.5 – 6 cm long, rather thickly (2–3 mm) leathery, gaping slightly, yellow; *spadix* cylindric, narrowly ellipsoid, shorter than spathe, 3–4.5 cm long, ca. 7 mm diam., white; *flowers* bisexual, perigone absent; pistillate flowers, ovary short, compressed; stamens 4, free. *Infructescence* a monsterocarp ca. 10 cm long × 2.5 cm wide, pale grey-green, somewhat glaucous, stylar plates sloughing at maturity to reveal the pale yellow pulp cavity. **Figure 14**.

Distribution. — Peninsular Malaysia, Sumatera, Jawa and Borneo.

Ecology. — Usually in well drained subtropical and tropical perhumid to everwet broadleaf subtropical and tropical forest at low to mid elevations.

Acknowledgements

This is part of on-going research funded by the Ministry of Education Malaysia through Vote No. ERGS/01(02)/808/2011(03), FRGS/STWN10(01)985/2013 (26) and NRGS/1089/2013-(03). The collaboration and support of the Sarawak Forestry Department is gratefully acknowledged. Most recent fieldwork and research was under Research Permit No. NCCD.907.4.4(Jld.9)-69 and Park Permit No. 140/ 2013.

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4

SAGO PALM (*METROXYLON SAGU* ROTTB.) – A POTENTIAL SOURCE OF STARCH FOR FOOD SECURITY

Awang Ahmad Sallehin Awang Husaini,

Mohd Hasnain Md Hussain and Hairul Azman Roslan

INTRODUCTION

Sago palm (*Metroxylon sagu* Rottb.) is a well-known plantation crop used as a source of starch in the South-east Asian region. Generally it grows in areas of the developing world thus viewed as a 'poor man's crop (Flach, 1997). The palm can mainly be found in the Southern regions such as Indonesia, Malaysia, Thailand and Papua New Guinea (Flach, 1977; Nakamura *et al.,* 2004). Interest in sago palm started to increase in the last 25 years thus reveal many uses of starch (Flach, 1997). It is a valuable crop because of its economic value, reasonably sustainable, environmentally friendly, grows vigorous, unique multipurpose uses, and promotes socially stable systems in Agroforestry (Stanton, cited in Flach, 1997). In addition, this plant is able to live in harsh conditions such as peat soil, submerged soil, acid soil, and saline soil (Nozaki *et al.,* 2004). Due to these values, sago palm is considered as an important crop in the industrial sector, as a source of starch.

Briefly, every part of this plant has its own applications to human, for example, the leaf and the rachis can be used for building homes; the pith contains the starch meanwhile the dried pith can either be used as feed for animal or processed to produce fertilizer (Flach, 1983). Furthermore, sago palm has been well established to contribute economically to countries such as Malaysia, Indonesia, Japan, Korea and the Middle East (Flach, 1997). For example, the imported tonnage of starch from Malaysia, Thailand and Indonesia to Japan in 1987 was 80,000 tons and the value had increased in 1988 to 120,000 tons (Sudwikatmono, 1991). Besides that sagu was ranked as the fifth highest agricultural earner in Malaysia, behind pepper, rubber, palm oil, and cocoa in 1988 (Nasir and Eng-Tian, 1991).

The development of sagu industry in Sarawak started with the participation of small holdings and private plantation. The widest area of sagu cultivation can be located in Mukah district. Department of Statistics Sarawak reported that the cultivation area of sago palm in Sarawak fluctuates throughout the years in between 51,763 hectares to 63,053 hectares (Figure 1). In 2007, the acreage has been reported to be 56,916 hectares. Nevertheless, the incomes from sagu have been increased throughout the years.

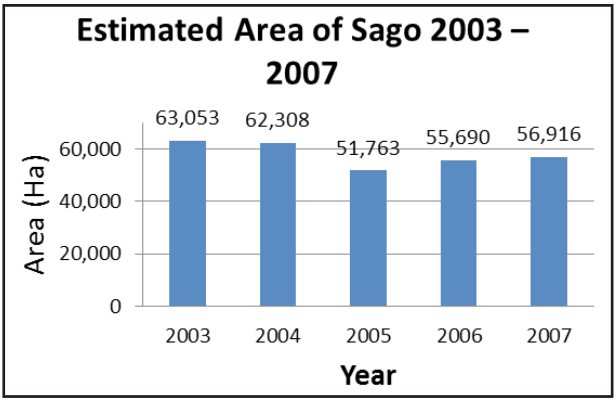


Figure 1: The estimated area of sagu in Sarawak in 2003 to 2007 (Courtesy of the Department of Statistics Sarawak, http://www.doa.sarawak.gov.my/statistik07.htm).

However, the contribution of sagu industry in the agricultural sector in Malaysia is small compared to other industries such as palm oil, rubber and pepper. Figure 2 shows a chart of the export value of agricultural products of Malaysia in 2007 and the sagu industry contributed only 1% (RM 51, 407,000.00) compared to other exports. The income for palm oil, rubber and pepper are 81% (RM 4,183,515, 000.00), 6% (RM 299,152, 000.00) and 3% (RM 177,466, 000.00), respectively.

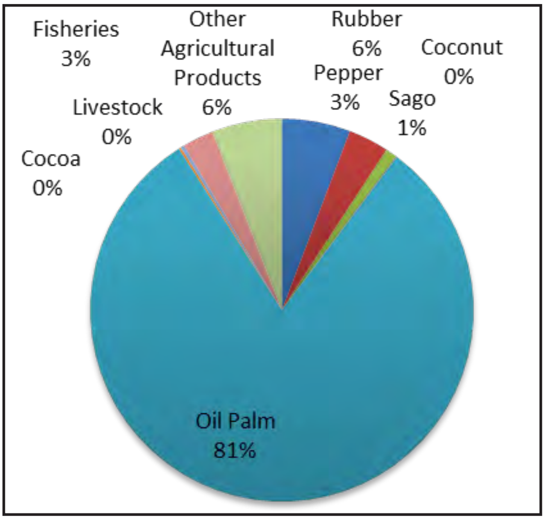


Figure 2: The export of agricultural products by Malaysia in year 2007 (*http://www.doa.sarawak.gov.my*).

SAGO PALM (*Metroxylon sagu* Rottb.)

The name sago palm *Metroxylon sagu* Rottboel, is derived from '*metra*' which refers to pith or *parenchyma* and '*xylon*' which refers to *xylem* (Flach, 1997). It was commonly known as 'Balau' among the Melanau tribe in Sarawak, and 'rumbia' in Peninsular Malaysia. Sago palm mainly propagates via vegetative suckers but also able to propagate using both pollinated and non-pollinated fruit (Flach, 1997). The vegetative phase in sago palm can grow to 7–15 years (Pei-Lang *et al.,* 2005), where large quantities of starch accumulate in the trunk (Nakamura *et al.,* 2004). According to McClatchey *et al.* (2004), *M. sagu* have four stages of life cycle, which include the rosette stage, bole formation stage, inflorescence stage and fruit ripening stage. According to previous research on sago palm in Sarawak, the Plawei stage is the stage where the palms were at its maximum growth and the inflorescence starts to emerge at the Plawei manit stage. The starch usually will be harvested from *Metroxylon sagu* at the inflorescence stage. This plant can grow to reach fifteen meter high and 35–60 cm bole diameter (McClatchey *et al.,* 2004) (Figure 3).

Figure 3: Picture of *Metroyxlon sagu* Rottb. at Plawei stage recorded at Bau (Singai area) district, Sarawak, Malaysia.

This plant is morphologically varied by its trunk's maturity, the diameter, the presence and length of spines, the morphology of leaves, and the quantity of starch (Kjaer *et al.,* 2004). Sago palms are found growing in different types of soil, but mostly it grew or cultivated in swampy areas. *M. sagu* can be found growing in other peat swampy areas of southern Thailand, Peninsular Malaysia, Indonesia, and the Philippines (McClatchey *et al.,* 2004). Furthermore, this plant is also found in high volcanic land islands such as Micronesia and Polynesia (McClatchey *et al.,* 2006).

In Malaysia, the cultivation of sago palm is located mostly in Sarawak and cultivated as a smallholder's crop. The developmental growth can be divided into 12 stages; Sulur, Angkat Punggung, Awal Bibang, Bibang, akhir Bibang, Plawei, Plawei Manit (inflorescence emerging), Bubul, Angau Muda, Angau, Angau Tua and Mugun (end cycle) (Lim, 1991; Jong, 1995; Pei-Lang *et al.,* 2005). Table 1 below shows the estimated year of planting for 5 growth stages of *M. sagu*.

Table 1: The physiological growth stage of sago palm.

Growth stage	Estimated age of planting (year)	Description of palm
Plawei	10	75% of the trunk had developed 6-8 m in length and it's the maximum growth of its vegetative phase.
Plawei manit	11.5	Inflorescence stage emerged and trunk's growth stops. (7-14 mm in length)
Bubul	6.5	Development growth of inflorescence stage.
Angau muda	12.5-13	Palm start to flowering and starch synthesis reach its maximum yield per trunk.
Angau tua	14	Palm starts to fruiting. (Senescent stage)

* This naming was provided by the local people in Sarawak, specifically from the Melanau tribe. (Jong, 1995; Pei-Lang *et al.,* 2005; Karim *et al*, 2008).

Even though various efforts have been undertaken to maximize the production in sagu industry, the sagu starch return still has not reached its maximum production, which enables it to compete with other worldwide starchy crops. Therefore, serious efforts have to be taken into consideration in order to boost the sagu industry, thus enabling it to compete with other industrial crops.

The uses of biotechnology have been applied to various important crops such as maize, paddy and sorghum. These crops have been abundantly modified by biotechnology to reach its maximum productions. Therefore, application of biotechnology in sago palm is needed to understand the full benefits. To achieve this, researches on the molecular and proteomic levels are required. Understanding the starch biosynthesis in sagu could help in boosting the palm's starch production.

Many starch biosynthesis research have been performed to study the pathway of starch synthesis in higher plants. Enzymatic studies done previously in the starch biosynthesis include the amyloplast-specific ADP-glucose pyrophosphorylase (AGPase), involved in the initial biosynthesis of starch; starch synthase (SS), involved in the formation and elongation of granule; and starch branching enzyme (SBE), involved in the formation of granule and branching (Martin and Smith, 1995; Tetlow *et al.,* 2004; Jeon *et al.,* 2010).

Researchers in the field of Biotechnology have performed various kinds of studies on these enzymes, aimed to understand its pathway and metabolism. Moreover, the studies were not only focused on those enzymes, but also its isoforms. For example, the starch synthase have been found consisted of five subfamilies. Starch synthase is one of the main components in the starch biosynthesis of higher plants. It can be found in many isoforms which was generally divided into two types that are granule-bound starch synthase (GBSS) and soluble starch synthase (SS) (Baguma, 2004). Specifically starch synthase isoforms are granule-bound starch synthase (GBSS), starch synthase I, II, III, and IV (SS I, SS II, S III, S IV) (Dian *et al.,* 2005).

The GBSS is currently well understood. It is a 60 kDa protein and highly conserved class (Martin and Smith, 1995). Several studies have revealed that GBSS contributed to the synthesis of amylose and soluble starch synthase is involved in amylopectin synthesis (Denyer *et al.,* 1995; Dian *et al.,* 2003; Baguma, 2004). These studies also propose that the role of GBSS is not only for the production of amylose but indirectly for amylopectin production as well. However the soluble starch synthase (SS) was reported to only involve in the production of amylopectin (Nakamura, 2002). Hence the GBSS provided interesting and vast information regarding the biosynthesis of starch. GBSS has been partially purified from a number of plant sources such as normal maize kernels (Macdonald and Preiss, 1983), wheat endosperm (Denyer *et al.,* 1995), potato tubers (Lloyd *et al.,* 1999) and cassava (Baguma, 2004). Furthermore, several isoforms were reported to be involved in the synthesis of amylose such as GBSSII from waxy wheat (Nakamura *et al.,* 1998) and GBSSIb from pea leaves (Edwards *et al.,* 2002).

STARCH STRUCTURE AND COMPOSITION

Starch is composed of two types of polysaccharides called amylose and amylopectin, as shown in Figure 4. Amylase is a linear polymer in structure and its glucose units are linked by α-1, 4- glucosidic bonds.

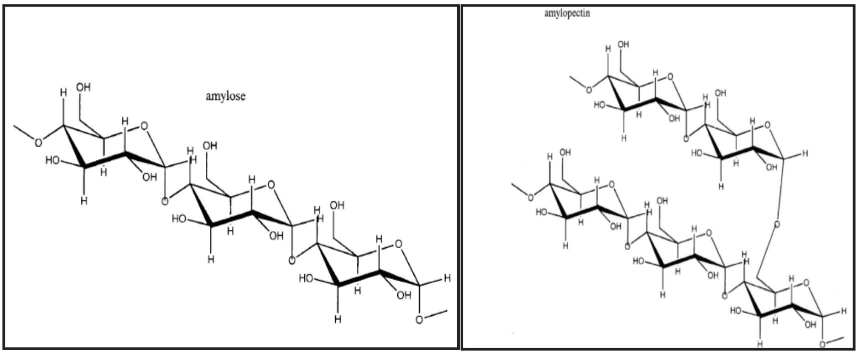


Figure 4: The molecular structure of amylose and amylopectin (Shaw, 1999).

Meanwhile, amylopectin is a highly branched glucose polymer where the branches are linked through the α-1, 6- glucosidic bonds. Martin and Smith (1995) stated that amylose and amylopectin makes up 30% and 70% of the starch structure, respectively. These polysaccharides are joined together through the glucosidic bonds to form an organized structure. The granule can be found in clear and colourless under the observation of light microscope, as described by Shaw (1999). Starch is generally divided into two types that are transitory starch and reserve starch (Messerli, 2007). Transitory starch is biomolecule that responsible in plant's daily carbohydrate metabolism. Meanwhile reserve starch is produced for plants long term storage and it is orderly accumulates in plants organs.

Research on the structure of the starch granules of sago palm has been done by previous researchers. Wong *et al.* (2007) reported the effect of pullulanase enzyme on the structure of starch granules in sago palm by scanning electron microscope (SEM) and obtained the ratio of amylose to 24.9% (Figure 5). Native sagu starch contains 20% amylose (Wong *et al.,* 2007), therefore the wider the range of amylose is obtained, it will enable further modification to enhance the quality of the starch itself such as in terms of starch's viscosity, shear resistance, solubility, gelatinization temperature, gel stability and texture (Yong *et al.,* 1998; Wong *et al.,* 2007). This finding is another attempt to enhance the quality of sagu starch at downstream level. Nevertheless, research at the upstream level, which aims to increase starch production in sago palm, would be an added advantage to Wong *et al.*'s (2007) finding.

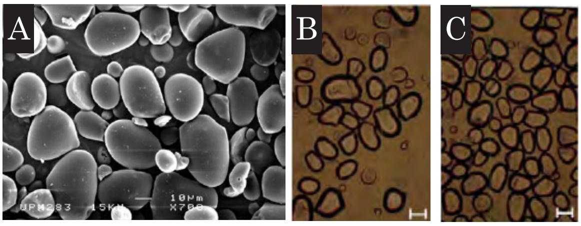


Figure 5: Closed views of starch granules of sago palm. (A) The SEM micrograph of starch granules in native sago palm, 700x (Wong *et al.,* 2007). (B) & (C) Optical microscope view of starch granule cultivated in mineral soil (Nozaki *et al.,* 2004).

STARCH BIOSYNTHESIS

Studies on starch biosynthesis in higher plant have revealed a basic pathway of how starch is produced. The pathway consists of three critical steps involving the enzymes; AGPase, SS, and SBE (Figure 6). The first step is the synthesis of ADP Glucose (ADPG) through AGPase from Glucose-1-phosphate and Adenosine Triphosphate (ATP) (Baguma, 2004). This is followed with the addition of ADPG units to the non-reducing end of α–1,4 glucan chain. This step is catalysed by starch synthase to produce a linear α–1,4 glucan chain. Following this, a third step is then activated where starch branching enzyme cuts the linear α–1,4 glucan chain to form α–1,6 glucan called amylopectin. In addition, another enzyme, the starch debranching enzyme (SDBE) trims on the glucan polymers produced by the basic pathway (Baguma, 2004), and in constructing a fine structure of amylopectin (Nakamura, 1996).

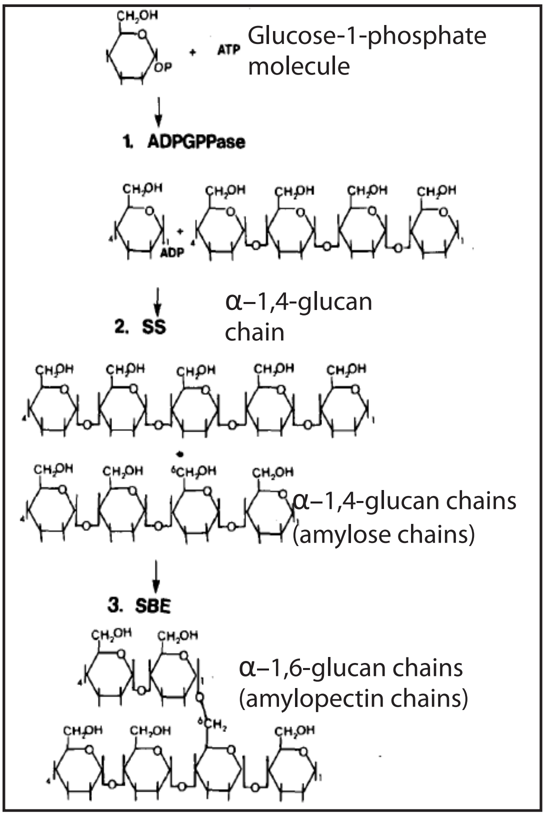


Figure 6: The three steps of starch biosynthesis in higher plants (Martin and Smith, 1995).

Specifically, AGPase can be found in the starch or glycogen pathway of plant and bacteria. In plants, it is comprised of two catalytic subunits that are smaller subunits (SSs) and large subunits (LSs) (Hwang *et al.,* 2007). Meanwhile the enzyme in bacteria (*Escherichia coli*) found to be a single subunit that forms a tetramer (Obana *et al.,* 2006). The activation of AGPase in bacteria is triggered by fructose-1, 6- diphosphate and inhibited by adenosine monophosphate (AMP), whereas the activation of plant's AGPase is triggered by 3-phosphoglycerate (3-PGA) and inhibited by inorganic phosphate (Pi) (Sivak and Preiss, 1998; Obana *et al.,* 2006; Hwang *et al.,* 2007). This enzyme has been identified as a key enzyme to boost the starch production in plants, since its function is to generate glucosyl precursor (Glucose-1-phosphate-ATP complex) for starch production.

On the other hand, SBE is divided into two classes or families that are class A (or SBE II) and class B (or SBE I) (Burton *et al.,* 1995; Martin and Smith, 1995; Andersson *et al.,* 2002a; Han *et al*., 2007). These enzymes are categorised in the amylase family (glycoside hydrolase family 13; GH13) (Ito *et al*., 2004). Members of these families display different enzymatic properties such as substrate preferences as observed in SBE of potato (Rydberg *et al.,* 2001). The rate of amylose branching by potato SBE I is higher and lower in amylopectin production when compared to the potato SBE II. Furthermore, the affinity to amylose by class A of maize SBEs is lower than class B isoform (Slattery *et al.,* 2000). Common methods to study the activity of SBE and their effect on starch structure are through the iodine staining, phosphorylase stimulation assay, and spectroscopic method (Boyer and Preiss, 1978; Takeda *et al.,* 1993; Andersson *et al.,* 2002b).

Furthermore, the starch debranching enzyme (SDBE) can be divided into two types of enzyme, direct debranching enzyme and indirect debranching enzymes (Shaw, 1999). The direct debranching enzyme type is found in plants and bacteria. Meanwhile, the indirect debranching enzyme type is found in animals and yeasts. The direct debranching enzyme has been subdivided into two classes that are the "isoamylase-type" debranching enzymes (DBE) and "pullulanase-type" DBEs as described by Beatty *et al*. (1999) and Shaw (1999). Application of debranching enzyme in the food industry has rapidly increased in recent years. Enzymes such as pullulanase and isoamylase, has been applied to develop three types of nutritious starch called Rapidly Digestible Starch (RDS), Slowly Digestible Starch (SDS) and Resistant Starch (RS) (Pongjanta *et al.,* 2009; Cai *et al.,* 2010). Resistant Starch has been shown to benefit as it can work as a dietary fiber, that can reduce the chances of colon cancer and ulcerative colitis (Walter *et al.,* 2005; Pongjanta *et al.,* 2009).

RATIONALE IN RESEARCH ON MOLECULAR BIOLOGY AND PROTEOMICS OF SAGU

Multiple isoforms have been identified to exist for each biosynthesis enzyme in plants, nevertheless the function of each isoform were generally not been fully understood. Regarding the role of GBSS that has been widely explored in starchy plants, the study of SS also has to be extensive as it involved essentially in addition ratios of amylopectin in starch formation.

High ratios of amylopectin over amylose reflected the importance of SS in starch elongation. Indeed, it was a major constituent of starch in plant tissues. Meanwhile not many studies have been conducted and published on the starch synthase in sago palm, except for the AGPase (Hwang *et al.,* 2005).

The research studies were very much needed and performed due to the lack of definitive experiments supporting the fundamental and understanding of starch biosynthesis in plants. It is a necessity because the palm is widely cultivated in Sarawak and has been recognized as a main producer for starch in Sarawak (Nasir and Eng-Tian, 1991).

Studies in previous years of starchy plants have been widely focused on the starch storage organs such as seeds, fruits, tubers, storage roots, and other storage organs. Therefore, this study is focused on starch biosynthesis at storage organ of the sago palm, the trunk. For this study, one developmental stage was selected, plawei stage, because theoretically the starch production at this stage is at its maximum. This is a stage where the plant prepares to enter inflorescence stage, where the trunk's growth will stop and increase in starch production. Thus the starch synthase enzymatic activity is presumed to be at its optimum and highest level. This project emphasized on the distribution and levels of starch synthase to further understand the biosynthesis of starch in sago palm.

OMICS APPROACH FOR STUDYING TRUNKING OF SAGO PALM

Sago palm grows through a series of developmental stages that takes up to 14 years for harvest. The pith inside a mature sagu trunk or bole can produce average yield of up to 160–180 kg of starch per palm (dry weight basis) (Yamamoto *et al.,* 2003). There have been instances of sago palms failed to form trunks during growth, which may be partly due to lack in proper plantation management. In addition, environmental factors such as lack of plant spacing or nutrients, or presence of stress factors have been also reported to play a part in the failure to form trunk, but further research involving omics approach has been conducted to understand the mechanism or pathway involved. In this omics approach, leaf tissue samples were obtained from both normal sago palms and non-trunking sago palms. The leaf tissue samples were compared for differences in the genetic expression using GeneFishing and Representative Differential Analysis

(RDA). In addition, metabolomics and proteomics comparison were also conducted. Differences in the expression pattern will lead to the determination of the genes, protein and metabolites involved for the growth and determination of the trunking process in sago palm.

TRANSCRIPTOMICS

The transcriptomics analysis was based on GeneFishing (SeeGene, Korea) and RDA technology. It is to produce transcripts representing the genes being expressed in the selected sago palms. The leaf samples from a normal (trunking) sago palm and non-trunking sago palm were used in the analysis and compared for differences in the transcript pattern. Samples were amplified and run on agarose gels to determine transcripts that are differentially expressed.

PROTEOMICS

For proteomics work, analysis included one and two-dimensional electrophoresis (SDS-PAGE and 2D-PAGE), MALDI-TOF and RP-HPLC. Following extraction of protein from trunking and non-trunking samples using phenol extraction/methanol-ammonium acetate precipitation, 2D gel electrophoresis (2D PAGE) were done to detect differentially expressed protein spots. Protein spots showing significant differences ($p < 0.05$) were selected, excised for tryptic digestion and extracted according to standard techniques (Bringans *et al.,* 2008). Peptides were characterised by MALDI-TOF mass spectrometer using a 5800 Proteomics Analyzer (Applied Biosystems).

METABOLOMICS

In metabolomics approach, water soluble-based extraction method described by Sobolev *et al*. (2005), acetone and methanol were used. In addition, organic solvent extraction method (Bligh and Dyer, 1959) with some adaptation, n-hexane, petroleum ether, dichloromethane (DCM), tetrahydrofuran (THF), ethyl acetate were employed. The adaptation involved treatment of leaf tissue with 0.15M acetic acid to deactivate the enzymes that are involved in lipid catalytic and degradation. Both extracted samples were analyzed using one dimensional proton NMR spectroscopy analysis for initial comparison.

MOLECULAR BIOLOGY AND OMICS APPROACH TO ABIOTIC AND BIOTIC STRESSES

Plants encountered various environmental stresses such as low temperature, dehydration, phytohormone, abscisic acid and anaerobic stress, during their growth and development. Anaerobic stress refers to the shortage of the oxygen in the root of the plants that occurs with several environmental stresses such as flooding, waterlogged soil and heat. In tropical regions, severe crop losses are caused by prolonged seasonal rainfall where excess water produces anoxic soil conditions (Gambrell and Patrick, 1978; Liao and Lin, 2001). According to Lee *et al.* (2010), salinity in agricultural fields is a major environmental stress that is a severe constraint on crop growth and productivity in many regions and the situation had become a global concern. There are several ways for plant to adapt with these conditions such as altering the plant structural morphology and adopting alternate metabolic pathways that can adapt to the environmental stresses (Daugherty *et al.,* 1994). Environmental stresses had dramatically changed the pattern of gene expression in many plants and facilitate series of adaptive physiological and biochemical changes which improved their ability to survive in such condition.

A CASE OF ALCOHOL DEHYDROGENASE

Plants respond to various stresses by altering the pattern of protein synthesis. The proteins which are synthesized due to such specific response are called the Anaerobic polypeptides (ANPs) (Liao and Lin, 2001). ANPs that are induced in turn increases the mRNA levels indicating the increased activity of specific genes related to the response (Dennis *et al.,* 1984; Rowland and Strommer, 1986). Among the ANPs, alcohol dehydrogenase is predominant and has been extensively studied. Alcohol dehydrogenase plays a key enzymatic function in the response to anaerobic conditions in plants and has been observed in various higher plants such as maize, pea, rice, wheat, palms, tomato and Arabidopsis (Sachs, 1996; Miyashita, 2001).

In hypoxic or anoxic conditions, alcohol dehydrogenase (ADH; alcohol:NAD+ oxidoreductase, EC 1.1.1.1) catalyzes the reversible conversion of aldehydes to alcohols. Alcohol dehydrogenase is an enzyme that converts pyruvate into ethanol in the fermentation pathway in organisms ranging from bacteria to animals and plants. The enzyme is presumably required by plants for reduction of acetaldehyde to ethanol during NADH metabolism, in response to periods of anaerobic stress. In periods of environmental stresses, ADH has been shown to be activated and to allow glycolysis to proceed to a normal level of ATP to be maintained in plant cells exposed to low oxygen condition. High levels of ADH activity are found in dry seeds and in anaerobically treated seeds, roots and shoots (Chang and Meyerowitz, 1986).

A preliminary work on ADH expression had been conducted to determine the level of ADH being expressed in several tissues of sago palm (Roslan and Sundaraj, 2007). Several tissues such as the young leaf and roots (upper, middle and lower) were subjected to protein expression and subsequently resolved on polyacrylamide gel electrophoresis analysis (PAGE) and agarose gel electrophoresis. Isozyme stainings specific to ADH activity showed ADH expression being detected highest in young leaf (Figure 7). The different tissues samples also show the varied expression of ADH at different level of the root reflecting the relative amount of each subunit present. ADH intensity in submerged roots particularly in the middle and bottom parts are shown to be higher compared to dry roots at the same parts (middle and bottom). Anaerobic conditions have been shown to significantly induce the ADH gene in root tissues.

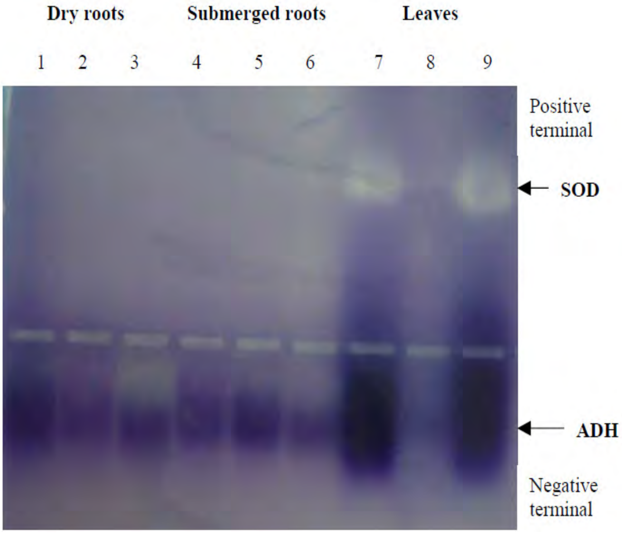
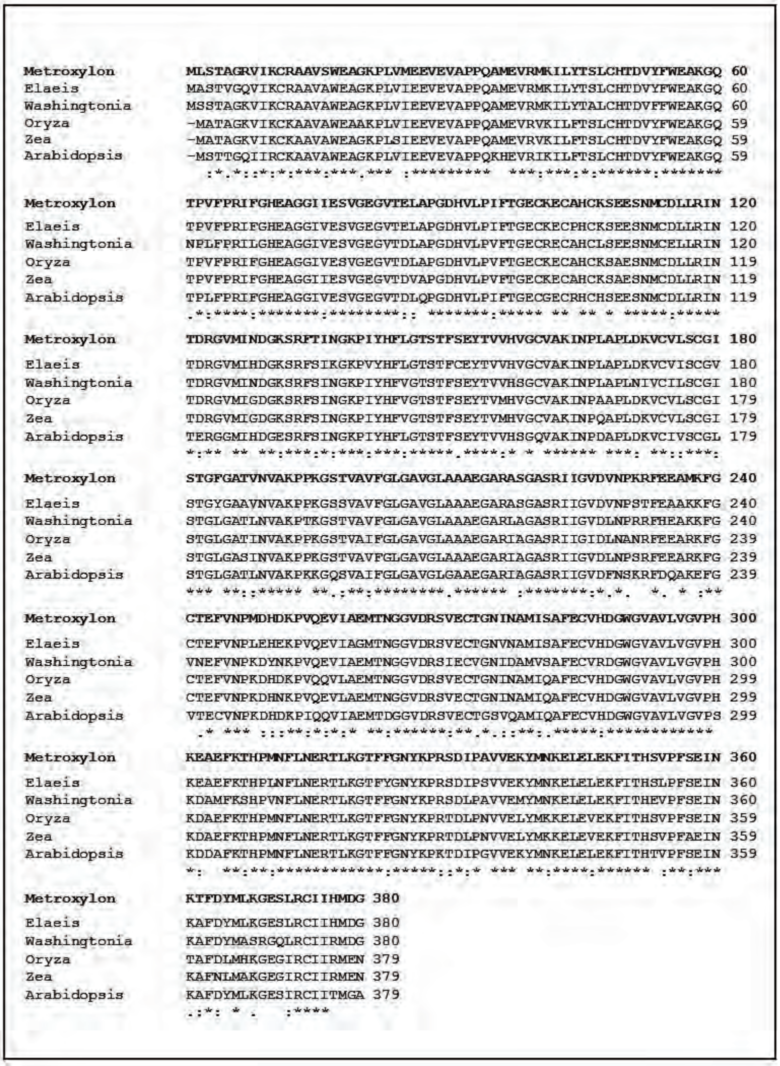


Figure 7: Alcohol dehydrogenase and superoxide dismutase staining of sago palm leaf and root samples. Lanes 1–3 represents proteins from dry roots (upper, middle and bottom parts respectively). Lanes 4–6 are submerged root samples (upper, middle and bottom parts respectively), lanes 7 and 9 are young sagu shoots whereas lane 8 is a mature leaf (Roslan *et al.,* 2008).

Based on the protein results, the ADH gene was subsequently isolated via the techniques of reverse transcriptase-polymerase chain reaction and genome walking (Wee and Roslan, 2012b). The ADH was isolated using mRNA derived from young leaf of sago palm. The complete cDNA was isolated and sequence was analysed. The msAdh1 cDNA sequence was determined to contain 1143 bp ADH open reading frame, encoding for 380 amino acids with a predicted molecular mass of 41.8 kDa. Amino acid sequence alignment of ADH of *Metroxylon sagu* and selected plant species is shown in Figure 8.



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Metroxylon      MLSTAGRVIKCRAAVSWEAGKPLVMEEVEVAPPQAMEVRMKILYTSLCHTDVYFWEAKGQ 60
Elaeis          MASTVGQVIKCRAAVAWEAGKPLVIEEVEVAPPQAMEVRMKILYTSLCHTDVYFWEAKGQ 60
Washingtonia    MSSTAGKVIKCRAAVAWEAGKPLVIEEVEVAPPQAMEVRMKILYTALCHTDVFFWEAKGQ 60
Oryza           -MATAGKVIKCKAAVAWEAAKPLVIEEVEVAPPQAMEVRVKILFTSLCHTDVYFWEAKGQ 59
Zea             -MATAGKVIKCKAAVAWEAGKPLSIEEVEVAPPQAMEVRVKILFTSLCHTDVYFWEAKGQ 59
Arabidopsis     -MSTTGQIIRCKAAVAWEAGKPLVIEEVEVAPPQKHEVRIKILFTSLCHTDVYFWEAKGQ 59
                  :*.*::*:*:***:***.*** :*********  ***:***:*:******:*******

Metroxylon      TPVFPRIFGHEAGGIIESVGEGVTELAPGDHVLPIFTGECKECAHCKSEESNMCDLLRIN 120
Elaeis          TPVFPRIFGHEAGGIVESVGEGVTELAPGDHVLPIFTGECKECPHCKSEESNMCDLLRIN 120
Washingtonia    NPLFPRILGHEAGGIVESVGEGVTDLAPGDHVLPVFTGECRECAHCLSEESNMCELLRIN 120
Oryza           TPVFPRIFGHEAGGIVESVGEGVTDLAPGDHVLPVFTGECKECAHCKSAESNMCDLLRIN 119
Zea             TPVFPRIFGHEAGGIIESVGEGVTDVAPGDHVLPVFTGECKECAHCKSAESNMCDLLRIN 119
Arabidopsis     TPLFPRIFGHEAGGIVESVGEGVTDLQPGDHVLPIFTGECGECRHCHSEESNMCDLLRIN 119
                .*:****:*******:********:: *******:***** ** ** * *****:*****

Metroxylon      TDRGVMINDGKSRFTINGKPIYHFLGTSTFSEYTVVHVGCVAKINPLAPLDKVCVLSCGI 180
Elaeis          TDRGVMIHDGKSRFSIKGKPVYHFLGTSTFCEYTVVHVGCVAKINPLAPLDKVCVISCGV 180
Washingtonia    TDRGVMINDGKSRFSINGKPIYHFVGTSTFSEYTVVHSGCVAKINPLAPLNIVCILSCGI 180
Oryza           TDRGVMIGDGKSRFSINGKPIYHFVGTSTFSEYTVMHVGCVAKINPAAPLDKVCVLSCGI 179
Zea             TDRGVMIGDGKSRFSINGKPIYHFVGTSTFSEYTVMHVGCVAKINPQAPLDKVCVLSCGI 179
Arabidopsis     TERGGMIHDGESRFSINGKPIYHFLGTSTFSEYTVVHSGQVAKINPDAPLDKVCIVSCGL 179
                *:** ** **:***:*:***:***:*****.****:* * ****** ***: **::***:

Metroxylon      STGFGATVNVAKPPKGSTVAVFGLGAVGLAAAEGARASGASRIIGVDVNPKRFEEAMKFG 240
Elaeis          STGYGAAVNVAKPPKGSSVAVFGLGAVGLAAAEGARASGASRIIGVDVNPSTFEAAKKFG 240
Washingtonia    STGLGATLNVAKPTKGSTVAVFGLGAVGLAAAEGARLAGASRIIGVDLNPRRFHEAKKFG 240
Oryza           STGLGATINVAKPPKGSTVAIFGLGAVGLAAAEGARIAGASRIIGIDLNANRFEEARKFG 239
Zea             STGLGASINVAKPPKGSTVAVFGLGAVGLAAAEGARIAGASRIIGVDLNPSRFEEARKFG 239
Arabidopsis     STGLGATLNVAKPKKGQSVAIFGLGAVGLGAAEGARIAGASRIIGVDFNSKRFDQAKEFG 239
                *** **::***** **.:**:********.****** :*******:*.*.  *. * :**

Metroxylon      CTEFVNPMDHDKPVQEVIAEMTNGGVDRSVECTGNINAMISAFECVHDGWGVAVLVGVPH 300
Elaeis          CTEFVNPLEHEKPVQEVIAGMTNGGVDRSVECTGNVNAMISAFECVHDGWGVAVLVGVPH 300
Washingtonia    VNEFVNPKDYNKPVQEVIAEMTNGGVDRSIECVGNIDAMVSAFECVRDGWGVAVLVGVPH 300
Oryza           CTEFVNPKDHDKPVQQVLAEMTNGGVDRSVECTGNINAMIQAFECVHDGWGVAVLVGVPH 299
Zea             CTEFVNPKDHNKPVQEVLAEMTNGGVDRSVECTGNINAMIQAFECVHDGWGVAVLVGVPH 299
Arabidopsis     VTECVNPKDHDKPIQQVIAEMTDGGVDRSVECTGSVQAMIQAFECVHDGWGVAVLVGVPS 299
                 .* *** :::**:*:*:* **:******:**.*.::**:.*****:************

Metroxylon      KEAEFKTHPMNFLNERTLKGTFFGNYKPRSDIPAVVEKYMNKELELEKFITHSVPFSEIN 360
Elaeis          KEAEFKTHPLNFLNERTLKGTFYGNYKPRSDIPSVVEKYMNKELELEKFITHSLPFSEIN 360
Washingtonia    KDAMFKSHPVNFLNERTLKGTFFGNYKPRSDLPAVVEMYMNKELELEKFITHEVPFSEIN 360
Oryza           KDAEFKTHPMNFLNERTLKGTFFGNYKPRTDLPNVVELYMKKELEVEKFITHSVPFSEIN 359
Zea             KDAEFKTHPMNFLNERTLKGTFFGNYKPRTDLPNVVELYMKKELEVEKFITHSVPFAEIN 359
Arabidopsis     KDDAFKTHPMNFLNERTLKGTFFGNYKPKTDIPGVVEKYMNKELELEKFITHTVPFSEIN 359
                *:  **:**:************:*****::*:* *** **:****:****** :**:***

Metroxylon      KTFDYMLKGESLRCIIHMDG 380
Elaeis          KAFDYMLKGESLRCIIHMDG 380
Washingtonia    KAFDYMASRGQLRCIIRMDG 380
Oryza           TAFDLMHKGEGIRCIIRMEN 379
Zea             KAFNLMAKGEGIRCIIRMEN 379
Arabidopsis     KAFDYMLKGESIRCIITMGA 379
                .:*: * .   :****
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Figure 8: Alignment of the deduced amino acid sequences of ADH1 proteins between *Metroxylon sagu* and selected plant species. The asterisk (*) below denotes identical amino acids, while "." denotes that semi-conserved substitutions are observed and ":" denotes that conserved substitutions have been observed (Wee and Roslan, 2012b)

EXPRESSED SEQUENCE TAGS ANALYSIS

To better understand the molecular mechanism and gene expression during sago palm development and its ability to withstand the various stresses, an Omics approach to the study was conducted. cDNA library of young leaf was created, that contained the gene expression information. The Expressed Sequence Tags (EST) technique generated from specific tissues represents the presence of active mRNAs in the selected tissue and sampling conditions. The creation of an EST database is an approach that could accelerate the researches of non-model and emerging species, such as *Metroxylon sagu*. As for the palm family, extensive EST database have only been established for oil palm (*Elaeis guineensis*) (Jouannic *et al.,* 2005; Ho *et al.,* 2007; Low *et al.,* 2008). In addition, EST is an approach to investigate transcriptomes and identify genes regulated by development, biotic and abiotic stresses (Lindqvist *et al.,* 2006; Wang *et al.,* 2007; Thanh *et al.,* 2011).

For sago palm, we have reported (Wee and Roslan, 2012a) a total of 412 clones were analyzed yielding 372 tentative unique genes (TUGs) sequences that consist of 32 contigs and 340 singletons (Table 1). Apart from that, sequence annotation analysis assigned a total of 1,710 gene ontology (GO) terms and distributed in three main GO categories: biological process (2,156) (Figure 9), molecular function (960) (Figure 10) and cellular component (2,384) (Figure 11). The EST results in Table 2 showed that in sago palm young leaf, various genes are activated that is involved in specific tissue expression.

Table 2: Summary of total EST sequencing (Wee and Roslan, 2012a)

EST	**No.**	**%**
Clean ESTs for assembly	412	
No. of consensi	32	
No. ESTs within consensus	72	17
No. of singletons	340	83
Unique sequences	372	90

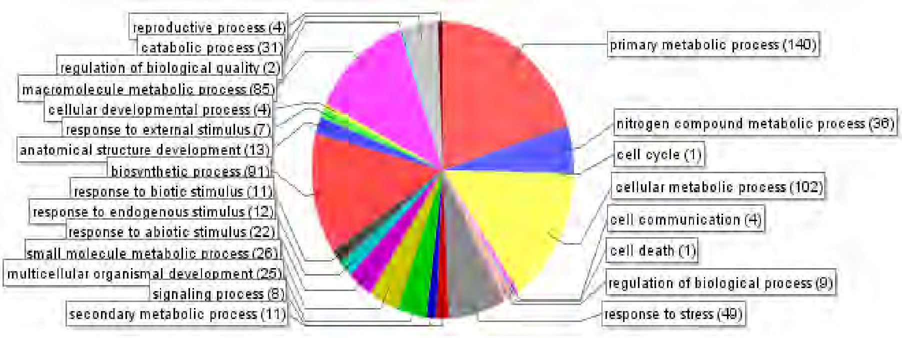

Figure 9: GO-annotation classification of *Metroxylon sagu* ESTs by putative biological processes (Wee and Roslan, 2012a)

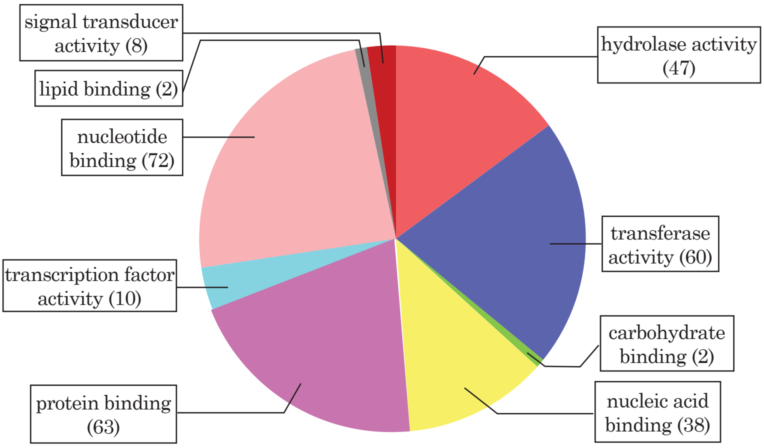

Figure 10: GO-annotation classification of *Metroxylon sagu* ESTs by putative molecular function (Wee and Roslan, 2012a)

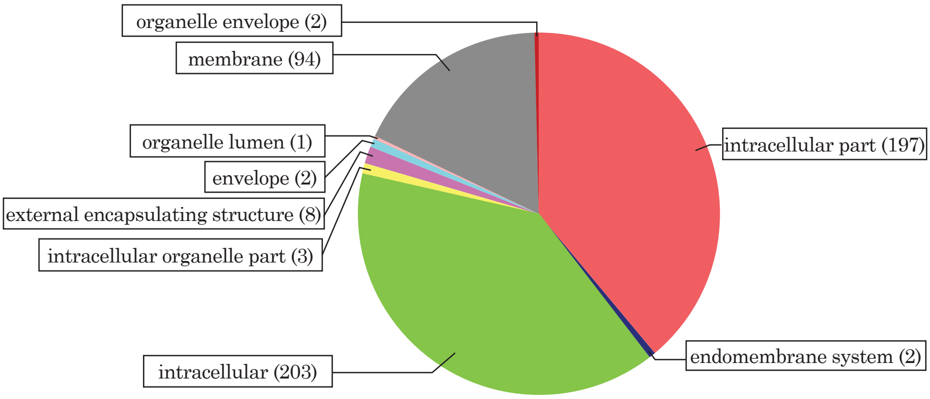

Figure 11: GO-annotation classification of *Metroxylon sagu* ESTs by putative cellular component (Wee and Roslan, 2012a)

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5

ENDOHELMINTH PARASITES OF FROGS AT A DEGRADED PEAT SWAMP FOREST

Ramlah Zainudin, Farliana Zulkifli and Fatimah Abang

INTRODUCTION

At least nine species of anuran amphibians occur commensally with humans, while the remaining Bornean frog species are either inhabitants of forest edges or the interiors (Inger and Stuebing, 2005). Several frogs that occur commensally with man are hunted for food resources by the native people. Yet, parasites that inhabit frogs and their effect on humans are unknown. Understanding the factors that drive emergence of infectious disease in amphibians are central to understanding contagion in human and wildlife populations for several reasons. The sensitivity of frogs to subtle changes in their environment and the origins of most new frog and toad pathogens have been linked to human-induced environmental change (Kiesecker *et al.,* 2002). The conditions that cause outbreaks among amphibians could have similar effects on other organisms. Thus, studies are needed to explore occurrences of endoparasites that inhibit internals organ of frogs. An endoparasite is defined as an organism that lives inside the organs or tissues or body cavities or body fluids of a specific host, and is metabolically dependent on hosts (Dusen *et al.,* 2010; Bhatia *et al.,* 2006). Helminth parasites specifically are metazoans (multicellular) parasites, and little is known of endoparasites that inhabit Bornean frogs due to current perception of lower importance of frogs as being a major host of zoonotic parasites.

Page (1997) noted that peat swamp forest is one the major forest formations of Borneo, which are richly endowed with biodiversity. Currently, 13 species of frogs have been reported from Sarawak's peat swamp forests (Zainudin, 2002; 2006; Inger and Stuebing, 2005; Inger *et al*. 2005). Due to uncontrolled logging practices in the last few decades, Sarawak has lost much of its major peat swamp forests. Recent sampling (Zainudin, 2009) in Sadong Jaya (oil palm plantation) managed to document only two species of frogs, *Hylarana baramica* and *Hylarana erythraea* (the latter species a commensal of humans), indicating reduction of species assemblages at degraded peat swamp forests.

There are limited studies of parasites of Malaysian frogs (Thanaletchumy, 1976; Miyata and Yong 1990). Rahman *et al.* (2008) recorded seven parasites species inhabiting *Fejervarya limnocharis* and *Duttaphrynus melanostictus*. Other studies have shown the presence of various species of helminths in frogs of the British Isles (Baylis, 1998), blood parasites of frogs in Canada (Fantham *et al.,* 1942, John and Sherwin, 1984) and in Japan (Miyata *et al.,* 1978), while parasites from various species of European and American frogs have also been extensively investigated (Mapletone, 1969; Prudhoe and Bary, 1982; Vojtkova, 1990; Vojtkova and Roca, 1993; Naciye and Ismail, 2000). It is noted that global declines in amphibian populations have coincided with a sharp rise in new and resurgent human infectious diseases (Kiesecker *et al.,* 2002). Schmidt and Roberts (2000) reviewed the pathogenic effects of trematodes, cestodes and nematodes on frog species. The prevalence of the parasites may be due to host-specificity of the parasites or biological aspects of the host (Al-Attar, 2010). However the prevalence of the parasites in Bornean frogs is unknown except the occurrence of frog-biting midges from Brunei Darussalam (Grafe *et al.,* 2008). This study aims to investigate the diversity of endohelminth parasites found in frogs, as well as to determine their attachment guilds, either being host-specialists or host-generalists at a degraded peat swamp forest in the campus of Universiti Malaysia Sarawak, Sarawak, East Malaysia.

MATERIALS AND METHODS

The campus of Universiti Malaysia Sarawak (UNIMAS) is located at Kota Samarahan, *ca*. 32 km from Kuching city, in Sarawak, Malaysian Borneo. Kota Samarahan serves as a key growth centre for coastal and riverine settlements along the Batang Samarahan. Most of the vegetation here consists of degraded peat swamp forest, which has been logged over 50 years ago. Specimens were collected between 29 July to 21 September 2010, from the area within the campus vicinity (Table 1, Figure 1).

Table 1: Study sites, Global Positioning System (GPS) reading and sampling methods.

No	Study Sites	GPS Reading	Sampling Methods
1	External Laboratory road to Bus Depo	- N 1°28.25′; E 110°26.870′ - N 1°27.858′; E 110°27.159′	Road transect
2	Peat swamp forest near Bunga Raya College	- N 1°27.863′; E 110°27.230′	Forest transect
3	ROTU forest, marching field, Seroja college, FEB, FSS, and ASASI area	- N 1°27.551′; E 110°27.337′	Forest and road transect

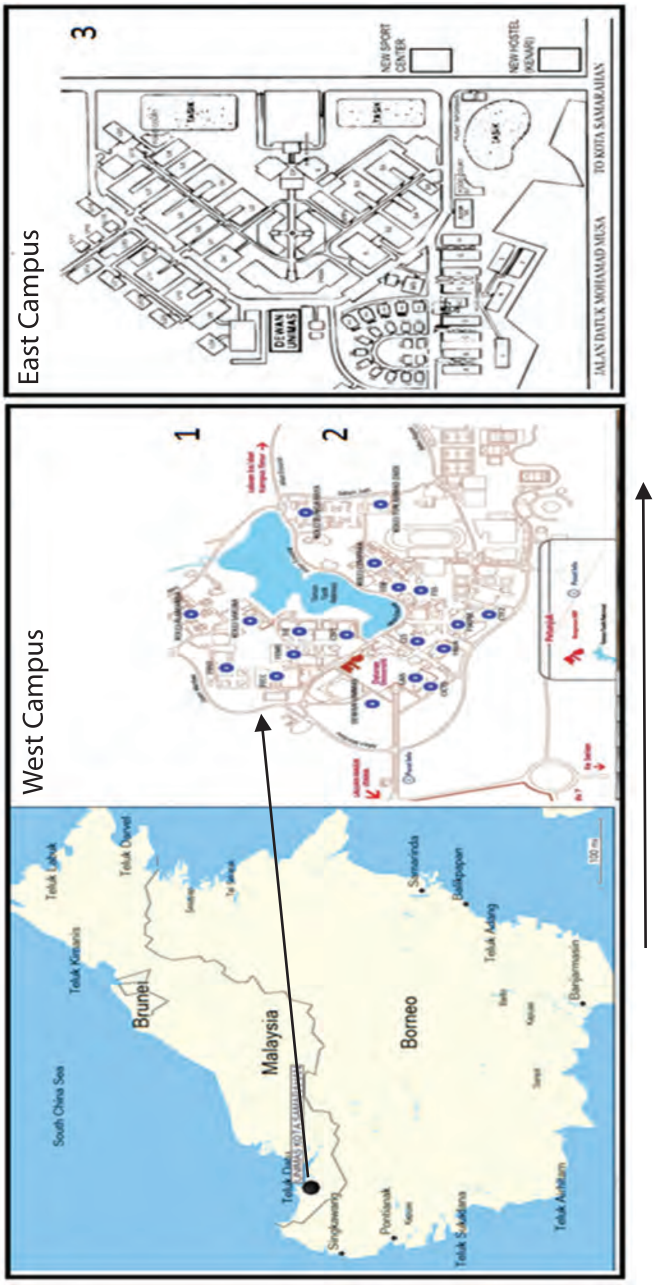

Figure 1: Map of Sarawak, Malaysian Borneo showing location of study sites (**1-3**) at UNIMAS campus.

Frogs and toads were captured for two to three hours per night along line transects in the forested region and open areas (road). For each transect, time started and completed, ecological data (vegetation type, microhabitats (horizontal, vertical position and substrate) and species captured, were noted. Captured frogs were killed with a chlorobutanol solution and fixed in 4% formaldehyde and stored in 70% of ethanol as vouchers in the UNIMAS Museum. Frogs were identified with the help of Inger and Stuebing (2005).

Captured frogs were dissected by longitudinal incision from throat to vent. The digestive tract was excised by cutting across the esophagus and rectum. The organs such as lungs, liver and heart were mixed separately with 5% formaldehyde solution in a cryovial tube. The alimentary canals were excised and the large intestines were taken as gastrointestinal representative sample. Any parasites (endohelminths) that were encountered outside and near to any particular organ during dissection were placed in vials of 5% formaldehyde for further examination. Each specimen was labelled according to their field number, species name, locality, collection date, specimen part and solution used. The specimens were stored in 4^{o}C for subsequent examination. Preparation and isolation of the specimen were based on Bhatia *et al.,* 2006). Slide preparation, staining and dehydrating procedures of cestodes and trematodes were modified from Culling (1974) and Lemke *et al*. (2008). The isolate endohelminths were first examined under 20x and 40x magnificent of stereomicroscope (Zeiss with Pixelink) for species identification. Further species identification via compound microscope (Leica DME) were based on Bhatia *et al*. (2006), Bowman *et al.* (2003), Fox *et al.* (1993), Garcia *et al*. (1993), Hendrix *et al.* (2007) and Taylor *et al.* (2007). Upon completion the inventory number, order, family, genus and species of endohelminths were tag on the right side of the slides following Garcia *et al*. (1993).

Shannon index, H, was used to measure species diversity of endohelminth parasites in frog community via Multivariate Statistical Package MVSP 3.1 ver. Software (Kovach, 2002). Modified Morisita's Index of Similarity on the occurrence of the endohelminth parasites among Bornean frogs was calculated using Multivariate Statistical Package MVSP 3.1 ver. Software (Kovach, 2002). Species utilizing the same resources will tend to cluster together compared to species with different resource requirements (the ecological guild concept), in which `a species' is a set of organisms adapted to a particular set of resources, called niche. The guild concept was also applied to the organ attachment of the endohelminths to frog hosts. The Non-metric Multidimensional Scaling (NMDS) via proximity scaling (Proxscal) in SPSS 16.0 (SPSS Inc., 2007) were used to described specificity and guilds of the endohelminth parasites that attached to the frog organs. The preferences organ attachment by the endohelminths species were interpreted in the guild pattern produced by NMDS configuration.

RESULTS

A total of 11 species, represented by 355 individuals of frogs, were collected, comprising five species that are commensals of man *Duttaphrynus melanostictus* (Asian black-spined Toad), *Fejervarya limnocharis* (Grass Frog), *Hylarana baramica* (Brown Marsh Frog), *Hylarana erythraea* (Green Paddy Frog), and *Polypedates leucomystax* (Four -lined Tree Frog). Two hundred cryovial tubes consisting of organ sample (intestine, lung, liver, heart) from

50 individuals (each species 10 individuals) were subjected for endohelminth diagnostic. The endohelminth that infected frogs at UNIMAS campus were *Heterakis*, *Hymenolepis* and *Raillietina* (Table 2). The infection were dominated by *Heterakis gallinarum* (49.3%) with 360 individual, followed by *Hymenolepis* spp. (44.5%) with 325 individual, *Heterakis isolonche (*3.3%) with 24 individual, and *Raillietina* spp. (2.9%) with 21 individual parasites in organs where most of the infections were in the intestines (Table 3). This is consistent with previous studies that showed the nematodes usually attached at the caecae of the hosts (Bhatia *et al.,* 2006; Taylor *et al.,* 2007). Interestingly Hyman (1951) stated that species belonging to the Family Heterakidae also infecting many groups of birds, while several species only found infecting mammals.

The four species of endohelminths recorded were abundant in their preferred hosts (Table 2), as well at their preferred organ attachment sites (Table 3). The result showed that the highest preference organ attachment is the intestine, while the heart is the lowest preference organ attachment by endohelminth parasites in the frog community at the current study area (Table 3). Hearts seem to be harder to invade than the intestine, as shown by the smaller number of endohelminths. This may be because infection occurs through ingestion of intermediate hosts containing the endohelminth eggs. When larvae hatch, they burrow through the intestine. The heart also serves as a migration pathway for endohelminths. The larvae that emerge from ingested eggs in the jejunum penetrate the intestinal wall and migrate by way of the hepatic venules to the right side of the heart and the pulmonary circulation (Schmidt and Roberts, 2000; Taylor *et al.,* 2007). The infection site and prevalence intensity of the endohelminth parasites show highest intensity in *Duttaphrynus melanostictus* (Table 4), an introduced toad species that is highly dependent on humans.

Table 2: Host preferences of the parasitic endohelminths at UNIMAS peat swamp forest.

Parasites Class	**Endohelminth Species**	**Frog species (endohelminth host)**				
		D. melanostictus	*F. limnocharis*	*H. baramica*	*H. erythraea*	*P. leucomystax*
Nematodes	*Heterakis gallinarum*	78	78	49	23	132
	Heterakis isolonche	0	0	18	6	0
Cestodes	*Hymenolepis* spp.	129	116	34	32	3
	Raillietina spp.	6	2	11	2	0
Total of individual parasites, Σ		213	196	112	63	146

Table 3: The preferences organ attachment by endohelminths species.

Endohelmith Species	Attachment Guild				Total	Relative Abundance (%)
	Intestine	**Lung**	**Liver**	**Heart**		
Heterakis gallinarum	167	80	80	33	360	49.3
Heterakis isolonche	-	9	-	15	24	3.3
Hymenolepis spp.	321	3	-	1	325	44.5
Railletina spp.	21	-	-	-	21	2.9
Total Individual	509	92	80	49	730	100
Total Species	3	3	1	3	4	

(The occurrence of parasites are based on their total individual in each of organ sample of frog host)

Table 4: Infection site, prevalence and number of infection for endohelminths parasite from frog host.

Frog Host (n = 10)	**Infection Site**	**Helminths**	**No. of helminths**	**Prevalence (intensity 100%)**
D. melanostictus	Intestine	*Heterakis gallinarum, Hymenolepis* spp., *Raillietina* spp.	213	213/10 (21.3)
F. limnocharis	Intestine, lung, liver, heart	*Heterakis gallinarum, Hymenolepis* spp., *Raillietina* spp.	196	196/10 (19.6)
H. baramica	Intestine, lung, Heart	*Heterakis gallinarum, Heterakis isolonche, Hymenolepis* spp., *Raillietina* spp.	112	11.2/10 (11.2)
H. erythraea	Intestine, lung, liver	*Heterakis gallinarum, Heterakis isolonche, Hymenolepis* spp., *Raillietina* spp.	63	63/10 (6.3)
P.leucomystax	Intestine, lung, liver	*Heterakis gallinarum, Hymenolepis* spp.	146	146/10 (14.6)

However, local people do not eat this toad due to its physical appearance, including bumpy and rough skin, indicative of presence of skin toxins. The parasites seem to be host specific as they infected the toad intestine only. This showed that the parasites might have entered their bodies through openings such as the mouth or anus, perhaps through ingestion of intermediate hosts containing endohelminth eggs. Different results were obtained from the other species of frogs as they were mostly infected at various organs. The endohelminth larvaes in *Fejervarya limnocharis*, *Hylarana baramica*, *Hylarana erythraea* and *Polypedates leucomystax* were able to penetrate the intestinal wall and emigrate straight to the right side of the heart and the pulmonary circulation.

Morphological characteristic of the endohelminth showed profound differences. *Heterakis gallinarum* has non-equal length of the spicules, large circular pre-cloacal sucker (male sexual organ) and prominent caudal alae supported by 12 pairs of caudal papillae (Figure 2). In contrast, morphological characteristic of *Heterakis isolonche* consist of asymetrical spicules and the presence of a large circular pre-cloacal sucker in the male and prominent caudal alae supported by large caudal papillae (Figure 3).

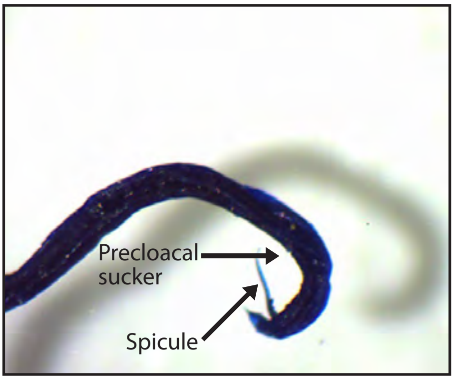

Figure 2: The spicules and precoacal sucker which are distinctive features of *H. gallinarum*. Identification was based on Bhatia *et al.* (2006), Garcia & Bruckner (1993) and Taylor *et al.* (2007).

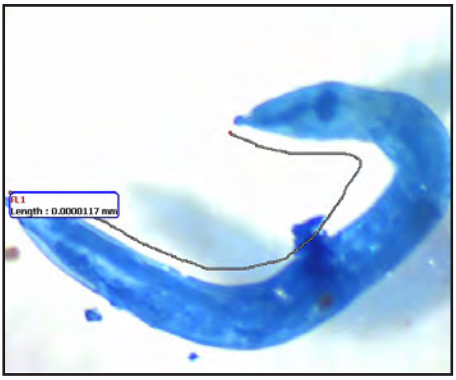

Figure 3: The body part of *Heterakis isolonche.*

Identification of the cestoda via morphological characteristics were not possible due to dislodged scolex during the process of separation of the endohelminths from the hosts. Soulsby (1968) stated that the identification of this species is more easily be performed in the presence of scolex. Thus the cestods can only be identified to the generic level. Species in the genus *Hymenolepis* (Figure 4) require intermediate hosts such as beettles to continue its life. The highest number of individual of *Hymenolepis* spp. were recorded in *D. melanostictus,* with 129 individuals while the lowest in *P. leucomystax* with three individuals. Since bettles and fleas are ground dweller, the chances of being eaten by the ground dweller frog such as *D. melanostictus* will be high and leads to the highest infection of *Hymenolepis* spp., as compared to the four-lined tree frog, *Polypedates leucomystax*. This is consistent with previous study that revealed that the parasites were also found in mammals that eat insects and rodents (Hyman, 1951). The other cestode found in this study was *Raillietina* spp. (Figure 5). They were recorded in all frog hosts (*D. melanostictus*, *F. limnocharis*, *H. baramica*, *H. erythraea)* except *P. leucomystax,* with the highest infection in *F. limnocharis* with 20 individual parasites. At least 200 species of *Raillietina* have been found infecting birds and mammals (Hyman, 1951). The accidental ingestion of arthropods especially beetles by *F. limnocharis* lead to the highest prevalence of *Raillietina* spp. found in this frog.

Shannon Diversity Index, *H'*, showed significant difference of endohelminth diversity among frog hosts (H = 4, df = 4, p = 0.40), with the highest in *H. baramica* (*H'* = 1.78) while *P. leucomystax* was the lowest, *H'* = 0.46 (Table 5). *H. baramica* show evenly distributed numbers of four endohelminths species - *Heterakis gallinarum*, *Heterakis isolonche*, *Hymenolepis* spp. and *Raillietina* spp. compared to *P. leucomystax* which mainly have two species of endohelminths- *Heterakis gallinarum* and *Hymenolepis* spp.

Figure 4: Endohelmith species of genus *Hymenolepis* (Bhatia *et al.*, 2006; Garcia & Bruckner, 1993; Taylor *et al.*, 2007).

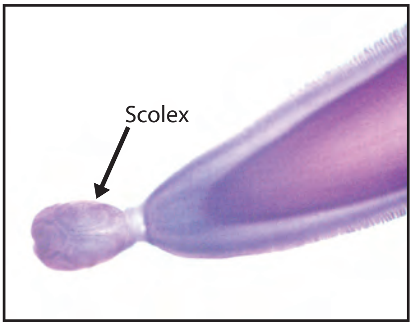

Figure 5: The endohelminth of genus *Raillietina.* (Bhatia *et al.*, 2006; Garcia & Bruckner, 1993; Taylor *et al.*, 2007).

Table 5: Shannon's diversity indices, *H′* of endohelminth in each frog species.

Frog Species	*D. melanostictus*	*F. limnocharis*	*H. baramica*	*H. erythraea*	*P. leucomystax*	Kruskal Walis test p-value
Shannon Diversity Index, H′	H′= 1.11	H′= 1.04	H′= 1.80	H′= 1.51	H′ = 0.15	0.40*
The number of endohelminth species, S	3	3	4	4	2	0.41*
The total number of all individuals, N	213	196	112	63	146	0.41*

*exact significant at $p < 0.5$

Organ attachment by the endohelminth species according to frog hosts show two apparent cluster of similarities- Clade A consists of endohelminth attachment at liver and lung, with high similarity of 95.2% and Clade B, heart and intestine attachment by endohelminths with similarity of 50.7%. This showed that the rare endohelminths such as *H. gallinarum* were mostly attach to the lung and liver. The common endohelminths species (including *Heterakis gallinarum*, *Heterakis isolonche*, *Hymenolepis* spp. and *Raillietina* spp.), on the other hand, mostly infected intestine and heart. These results suggest that different mode for transmission of rare endohelminths (HG) and common endohelminth (HG, HI, Hsp, Rsp) to hosts, and similar observations have been made by Bhatia *et al*. (2006); Garcia and Bruckner (1993); Schmidt and Roberts (2000) and Taylor *et al.* (2007).

The NMDS configuration of the attachment guild of each endohelminths species present in the frog hosts at UNIMAS campus showed good representation of actual data. The NMDS configuration of the attachment guild of each endohelminths species present in the frog hosts at UNIMAS campus showed good representation of actual data with low stresses (Stress-I = 0.03215, Stress-II = 04664, S-Stress = 0.00289) and high value of Tucker's Coefficient of Congruence with 0.99948 (Table 6).

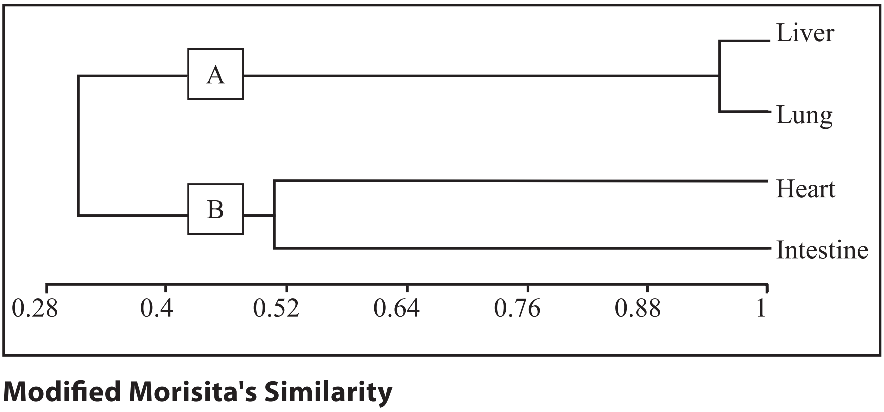

Figure 6: UPGMA dendrogram of Morisita Similarity Index of organ attachment by endohelmiths based on frog hosts.

Table 6: Stress and fit measures of NMDS configuration of the attachment guild of each endohelminths species in frog host at UNIMAS.

Normalized Raw Stress	0.00103
Stress-I	0.03215(a)
Stress-II	0.04664(a)
S-Stress	0.00289(b)
Dispersion Accounted For (D.A.F.)	0.99897
Tucker’s Coefficient of Congruence	0.99948

PROXSCAL minimizes Normalized Raw Stress.
a Optimal scaling factor = 1.001.
b Optimal scaling factor = .998.

Of 20 variables, only two were meaningful to describe the attachment guild of endohelminths species in frog hosts namely, intestine of *Duttaphrynus melanostictus* and *Fejervarya limnocharis* as shown in Figure 7(a) and Figure 7(b). From all meaningful variables, attachment organ were apparent along Dimension 1 and Dimension 2 (Figure 7(a) & Figure 7(b)). Six variables were apparent in Dimension 1 with three positive loading namely, *Duttaphrynus melanostictus*: Intestine (DMI), *Fejervarya limnocharis*: Intestine (FLI), and *Hylarana baramica*: Intestine (HBI), while three negative loading were produced which are in *Hylarana baramica*: Heart (HBH), *Hylarana erythraea*: Lung (HELu), and *Hylarana baramica*: Lung (HBLu). The dominant characteristic in dimension 1 is *Duttaphrynus melanostictus*: Intestine (DMI = 1.986) and in *Fejervarya limnocharis*: Intestine (0.971).

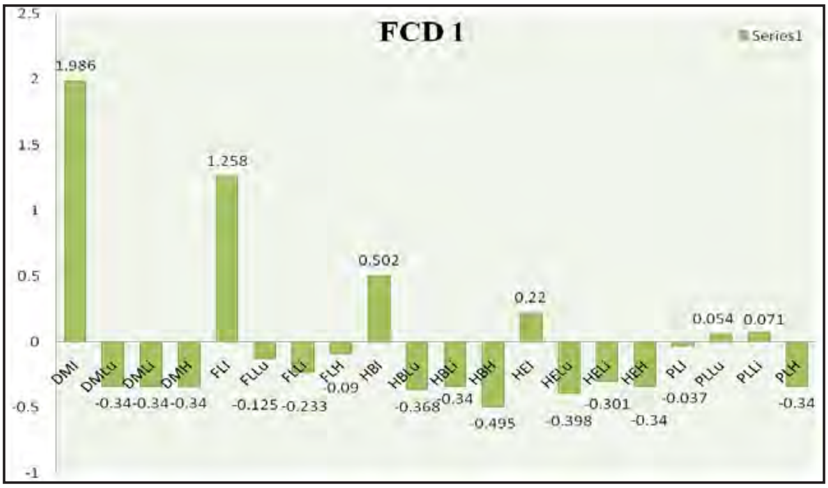

Figure 7: (a) Final Coordinate Dimension 1 represents the attachment guild of each endohelminth species in frog host at UNIMAS.

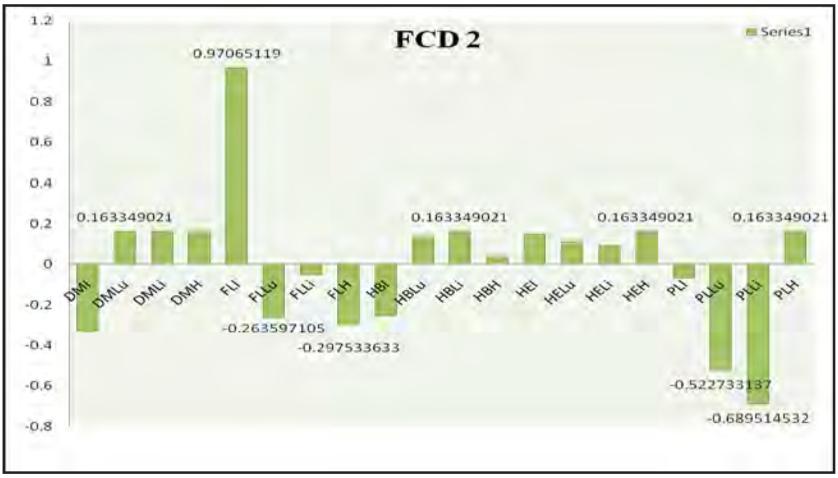

Figure 7: (b) Final Coordinate Dimension 2 represents the attachment guild of each endohelminths species in frog host at UNIMAS.

This shows that endohelminths of frogs in the peat swamp forest of UNIMAS prefer to occupy intestines of *Duttaphrynus melanostictus* (DMI = 1.986) and *Fejervarya limnocharis* (FLI = 1.258 Dimension 1) and *Hylarana baramica* (HBI = 0.502), while showing appearance avoidance occupying the heart of *Hylarana baramica* (HBH = -0.495) and lung of *Hylarana erythraea* (HELu = -0.398). The result indicates that most of the endohelminths preferred intestine of *Duttaphrynus melanostictus* and *Fejervarya limnocharis* organ since both frogs usually lives on the ground (Zainudin, 2006) that were exposed to parasites eggs while both *Hylarana baramica* and *Hylarana erythraea* are non-ground dweller, living on tree branches (*H. baramica*) or ponds (*H. erythraea*). In addition, *D. melanostictus* and *F. limnochoris* are larger than *H. baramica* and *H. erythraea* (Inger and Stuebing, 2005), providing more attachment space for parasites in the intestine rather than have to move up to the hearts and lungs.

Based on scatter plot obtained from NMDS configuration, three attachment guilds of the endohelmiths were apparent in five species of hosts, according to the organ attachment and the microhabitat of the hosts (Figure 8). The attachment guilds were summarized in Table 7.

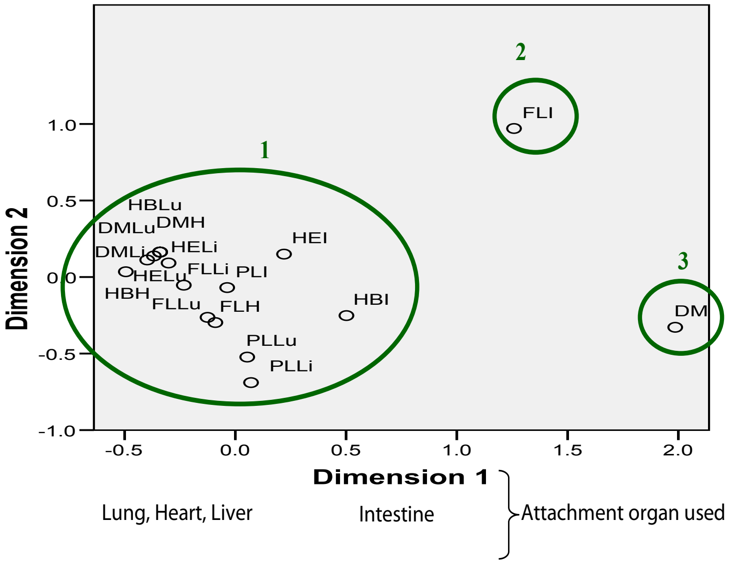

Figure 8 : Scatterplot of NMDS configuration showing the attachment guild of each endohelminth species in frog host at UNIMAS.

Table 7: Attachment guild of each endohelminths species in frog host at UNIMAS.

No.	Attachment Guild	Endohelminth Species
1	**General host with general attachment (intestine, liver, lung and heart)**: Intestine of *H. baramica*, liver and lung of *P. leucomystax*, intestine of *Hylarana erythraea,* heart of *F. limnocharis*, intestine of *P. leucomystax*, lung of *F. limnocharis,* liver of *F. limnocharis*, heart of *H. baramica*, lung and liver of *H. erythraea* and heart of *F. limnocharis* and *Hylarana baramica*	**Rare endohelminth**: *Heterakis gallinarum*, *Hymenolepis* spp., *Heterakis isolonche* and *Raillietina* spp.
2	**Specific host (*F. limnocharis*) with specific attachment (intestine)**	**Common endohelminth:** *Hymenolepis* spp. and *Raillietina* spp.
3	**Specific host (*D. melanostictus*) with specific attachment (intestine)**	**Common endohelminth:** *Hymenolepis* spp., *Heterakis gallinarum* and *Raillietina* spp.

The first guild comprised of (i) general host with general attachment (intestine, liver, lung and heart) in rare endohelminth (*H. gallinarum*, *Hymenolepis* spp., *H. isolonche*, and *Raillietina* spp. The endohelminths occupied various locations, such as at the intestine of *H. baramica*, liver and lung of *P. leucomystax*, intestine of *Hylarana erythraea,* heart of *F. limnocharis*, intestine of *P. leucomystax*, lung of *F. limnocharis,* liver of *F. limnocharis*, heart of *H. baramica*, lung and liver of *H. erythraea*, and heart of *F. limnocharis* and *H. baramica.* These results conclude that the first guild comprised of rare endohelminths which is referring as the low number of individual recorded in the hosts. The modes of infection are from accidental ingestion of insects and through ingestion of the embryonated infective stage by the host. (ii) Second guild reflects host specificity where specific host (*F. limnocharis*) had attached to the specific organ (intestine) in common endohelminth (*Hymenolepis* spp. and *Raillietina* spp.). Both types of cestodes had infected the host from accidental ingestion of insects that acts as an intermediate host. Besides, *F. limnocharis* lives in disturbed habitat or commensally with man, thus there are increased chances of endohelminths infections (Schmidt and Roberts, 2000). (iii) The third guild also reflects host specificity where specific host (*D. melanostictus*) with specific attachment (intestine) in common endohelminth (*Hymenolepis* spp., *Heterakis gallinarum*, and *Raillietina* spp.). Moreover, *D. melanostictus* is human-commensal, where the higher risk of endohelminths infection was occurred.

DISCUSSION

The lifestyle of frogs suggests a particular vulnerability to microbial and specific infection (Marcogliese *et al.,* 2008). The damp habitat preferred by most frogs favour survival of the infective stages of the pathogens. The frogs of UNIMAS utilize a variety of microhabitats, such as horizontal, vertical and substrate positions. Species commensally with man, *D. melanostictus, F. limnocharis,* and *H. erythraea* showed strong tendencies towards grass, muddy area and drainage. This probably reflects high prevalence of the parasites in those species while, *P. leucomystax* are confined to tree and also found at bank mud and on leaf. Inger and Stuebing (2005), stated that *P. leucomystax* is a common frog species of disturbed habitats, found almost everywhere, including inside the houses, though rarely entering forest. *Hylarana baramica* are most commonly found from leaf litter up to 2 metres up on tree.

The different helminth groups present different transmission patterns, ecological requirements and dispersal strategies (Fabio, 2000; Hickman *et al.,* 2006; Holmes *et al.,* 2007). Their dependence on abiotic and biotic factors is related to their free-living stages, and their environment–host population interactions. Among the numerous environmental modifications that give rise to changes in helminth infections, as noticed, the ecological and habitat preference variable appear to have a considerable influence to helminth infections. Significantly, it shows in the highly helminth species diversity and parasites burden in *H. baramica* (Brown Marsh Frog) from the family Ranidae with the highest Shannon Diversity Index, *H'* with 1.797 while *P. leucomystax* have the lowest diversity with Shannon Diversity Index, *H'* = 0.456. *H. baramica* have the evenly distributed numbers of endohelminths species which are *Heterakis gallinarum*, *Heterakis isolonche*, *Hymenolepis* spp. and *Raillietina* spp. However, *P. leucomystax* (Four-lined Tree Frog) from the family Rhacophoridae mainly have the intestine-specific attachment of endohelminths which are *Heterakis gallinarum* and *Hymenolepis* spp. The outcome possibly related to the ecology and environmental conditions of host-parasite interactions. *H. baramica* is known from a variety of lowland floodplain situations, including peat swamp forest and swampy flatland primary forest at low elevations, usually in swampy areas while *P. leucomystax* is a frog of disturbed habitat, but rarely entering primary forest (Inger and Stuebing, 2005).

These host-parasites interactions can be thought of as ecological associations that sometimes result in changes to the environment, such as pathology, or changes in the environment leading to effects on parasite survival, such as an immune reaction of frog host (Schmidt and Roberts, 2000). *H. baramica* has a diverse helminth fauna. This frog is a small to medium-sized, able to leave the water to occupy aquatic and terrestrial habitats, and able to feed on a variety of aerial, terrestrial, and aquatic organisms; therefore, this diversity likely derives from transmission of helminths through various intermediate hosts. The development of helminth communities in UNIMAS campus area is the result of several factors such as ectothermy, host alimentary canal being gape limited and the presence of a small number of helminth species with direct life cycles (Bolek, 2010; Janovy, 2002).

Furthermore, the foraging behaviour and feeding habits considerably influenced the endohelminths infection. Adults of *H. baramica* and *P. leucomystax* eat a variety of insects and other invertebrates (Inger and Stuebing, 2005). The generalist feeding habit led to higher transmission of endohelminths throughout the body of *H. baramica* (Bhatia *et al.,* 2006; Garcia and Bruckner, 1993). The microhabitat utilization of *H. baramica* is a semi-arboreal true frog while *P. leucomystax* is an arboreal frog. Besides, *H. baramica* breeds in water, hence, the mode of reproduction involving dense congregations in water that creates optimal conditions for endohelminth transmissions (Garcia and Bruckner, 1993).

We conclude that high prevalence of common endohelminths occur in the ground dweller frogs, *F. limnocharis* and *D. melanostictus,* as seen in number of endohelminths recorded, compared to arboreal and pond-dweller frogs.

ACKNOWLEDGMENTS

The authors would like to thank everyone who was directly and indirectly involved in this project. Our gratitude also goes to the Department of Zoology, Faculty of Resource Science and Technology, UNIMAS.

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6

FISH FAUNA AND WATER QUALITY OF BLACKWATER HABITATS IN MALUDAM NATIONAL PARK

Lee Nyanti, Ella Michael Dosi, Jongkar Grinang,

Ling Teck-Yee and Khalid Haron

INTRODUCTION

Sarawak has the largest peat land in Malaysia, occupying an area of approximately 1.66 million hectares or equivalent to 13% of the total area of the State (Wong, 1991). The largest peat land area is found in Sibu Division, followed by Sri Aman, Miri, Kota Samarahan, Sarikei and Bintulu.

Peat swamps are considered as one of the most extreme freshwater habitats for many aquatic organisms. The nutrient impoverished blackwater swamps are generally described as low in biodiversity and productivity (Johnston, 1968) and low in fish biomass and species number (Henderson and Crampton, 1997). It is often regarded as an inhospitable habitat for aquatic life due to the water that are highly acidic with pH ranging from 3.6 – 5.9, low organic ion and oxygen level, tea coloured when seen against transmitted light, and black when *en masse* via reflected light thus the name “blackwater” (Johnson, 1967; 1968). In spite of the extreme characteristics, rivers and streams in peat swamp areas support a unique community of fish fauna. Species of fish that lives in peat land are those able to adapt to relatively low pH and low dissolved oxygen, and therefore tend to have narrow niches and restricted distribution range.

In Sarawak, blackwater habitat is one of the most threatened ecosystems, as large areas of peat land have been licensed for timber harvesting (Lee, 1981) or being developed for other agricultural purposes. Unfortunately, blackwater peat swamp is also one of the least studied and poorly understood ecosystems. The earliest explorations of fishes in blackwater habitats of south-east Asia were carried out mostly in Peninsular Malaysia by Tweedei (1952), Johnson (1967; 1968), Mizuno and Furtado (1982) and Davies and Abdullah (1989). Later, boosted by the early work of Ng *et al.* (1992), follow-up investigations were carried out in Peninsular Malaysia (Zakaria *et al*., 1999; Beamish *et al*., 2003; Rezawaty, 2004; Shah *et al*., 2006), Brunei (Parenti and Meisner, 2003) and Sarawak (Murtedza *et al.,* 2000; Khairul and Yuzine, 2006; Nyanti *et al*., 2006; Khairul *et al*., 2009).

At Maludam National Park, the first survey of fish fauna was carried out by Nyanti and Bali (2004), and 28 species, representing 11 families were reported. However, all mentioned studies had focused on documenting the presence of fish diversity in the particular habitats, whereas knowledge on the biological aspects of the fish are lacking (Mazlan *et al*., 2012; Zakeyudin *et al.,* 2012). For instance, length-weight relationship is important for evaluating growth, condition, biomass and life history, and subsequently can be used for species conservation and fishery management (Sparre and Venema, 1998; Kumolu-Johnson and Ndimele, 2010). Therefore, the objectives of the present study were to update the information on fish fauna, determine their length-weight relationship and the water quality in the Maludam River.

STUDY AREA

The Maludam peat swamp forest covers the largest peat dome in northern part of Borneo (Whitmore, 1990). The gazettment of the area as a National Park by the Sarawak State Government in 2000 is to conserve the population of protected species including Proboscis monkey (*Nasalis larvatus*), langurs (*Presbytis melalophos cruciger* and *P. cristata*), hornbills (*Anthracoceros albirostris, A. malayanus and Buceros rhinoceros*) and Ramin tree (*Gonystylus bancanus*), while at the same time safeguarding the continuality of hydrological functions and carbon balance of the ecosystem (Sabki, 2005).

The Park is located about 5.1 km from Maludam town. The 43,147 hectare Park is divided by the 28 km Maludam River, which runs through the middle of the Park in the southeasterly-north-westerly direction (Figure 1). The waters of Maludam River are clear and black in appearance. It is slow moving in the upstream whereas the flow downstream is influenced by tide. The dominant vegetation found along the riverbanks comprises *Pandanus andersonni* (Muding), several species of *Syzygium* spp. (Jambu), herb *Hanguana malayana* (Bakong), and the fan palm *Licuala petiolulata* (Palas/Palah).

MATERIALS AND METHODS

Fish Sampling

Sampling of fish fauna were carried out in October 2010, January 2011, April 2011, July 2011, October 2011 and January 2012 at three sampling stations namely, Station A (N01°37.043′; E111°03.746′), B (N01°35.799′; E111° 04.415′) and C (N01°34.894′; E111°05.086′) (Figure 1). In addition, fish sampling were also carried out at the floodplain of the river bank near each station (A and C) and at Bakong River (B), a tributary of Maludam River during high water level.

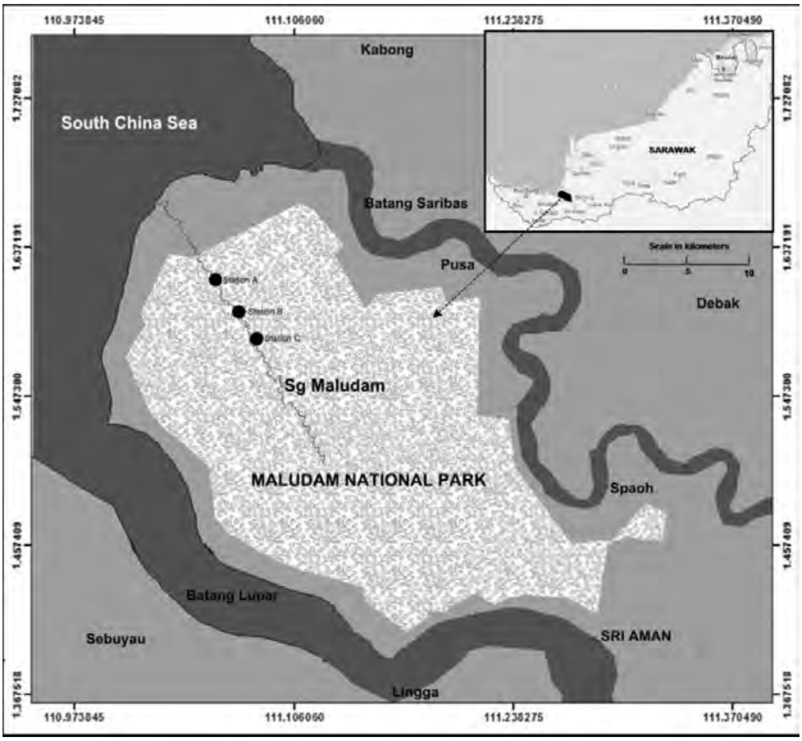

Figure 1: Fish fauna and water quality sampling stations (A, B and C) in Maludam National Park.

In every sampling occasion and each sampling station, fishing gears used were gill nets of three different mesh sizes (2.54 cm, 6.35 cm and 15.24 cm), 3-layer net, hooks and lines and bamboo traps. During the low water level in July 2012, electroshocker and scoop net were employed. A homemade electroshocking device use consisted of two copper electrodes on PVC fiber handles powered by a 1,000-watt portable AC generator. Multi-pass electroshocking technique was carried out for a distance of 30 m at shallow habitats, where one person operates the device and three persons collect the stunned fishes with scoop net. However, this method was not efficient in blackwater habitat due to low ion contents for electrical flow. In addition, black water limited the process of collecting stunned fishes in the water. Therefore, the method was not used in the subsequent sampling occasions.

Fish species were identified either *in situ* or in the laboratory. Specimens were preserved in 10% formalin and later transferred to 70% ethanol in the laboratory. Fish identification followed those of Kottelat and Widjanarti (2005), Inger and Chin (2002), Martin-Smith and Tan (1998), Kottelat *et al*. (1993), Roberts (1989) and Mohsin and Ambak (1983). Standard length and total length of every individual fish caught was measured with a ruler (to the nearest 0.1 cm) and their weight determined using a portable electronic balance Shimadzu ELB-600 (to the nearest 0.1 g).

The values of diversity, richness and similarity indices were calculated for each station. Although any base may be used, the indices were calculated using natural logarithm (Gorelick, 2006; Legendre and Legendre, 1998) according to formula [1] to [3]. Significant difference in Shannon index between stations was tested using modified *t* test (Zar, 1999), with the assumption of equal sampling condition across stations (Hammer *et al.*, 2001). Shannon and Weaver (1963) diversity index is expressed as formula [1],

$$H = \frac{n\log_e n - \sum f_i \log_e f_i}{n} H = \frac{n\log_e n - \sum f_i \log_e f_i}{n} \qquad [1]$$

where n is the total number of individuals caught and f_i is the number of individuals in species i, and i is $1, 2, 3, \ldots, S$. Margalef Richness Index (D) (Margalef, 1968) is expressed as formula [2],

$$D = \frac{S-1}{\log_e n} D = \frac{S-1}{\log_e n} \qquad [2]$$

where S is the total number of species and n is the total number of individuals caught; and Pielou Similarity Index (J) (Pielou, 1966) is expressed as formula [3],

$$J = \frac{H}{\log_e S} J = \frac{H}{\log_e S} \qquad [3]$$

Analysis of Growth and Condition

Eight species namely, *Channa bankanensis*, *C. lucius*, *Hemibagrus nemurus*, *Luciocephalus pulcher*, *Puntius johorensis*, *Rasbora cephalotaenia*, *R. pauciperforata* and *Wallago leerii* were analyzed for growth and condition by using length-weight relationships (LWRs) method. The analyses were not conducted for the other 20 species because the sample size of the fishes was inadequate for regression analysis. Length-weight relationship of the fish was estimated using the formula, $W = aL^b$, where W and L are the weight (in g) and total length (in cm), respectively. The formula was logarithmic transformed to obtain a linear expression, ln $W = L = \ln a + b \ln L$, where a and b are the intercept and slope of the straight line, respectively. The least squares regression of LWRs was run in GraphPad Prism version 6. The b value indicates the type of growth of fish, $b = 3.0$ (isometric or normal growth rate), $b > 3.0$ (positive allometric or over growth rate) and $b < 3.0$ (negative allometric or poor growth rate). Fulton's condition factor (K) was determined with the formula, $K = 100W/L^3$, a metric used for evaluating the degree of well being of the fish (Froese, 2006). The metric indicates that the higher the K value the better the condition of fish.

Water quality

Water quality data were recorded right before fish sampling and at the same stations where fish sampling were carried out. Temperature, dissolved oxygen, pH and turbidity were measured at each sampling station in October 2010, December 2010, February 2011, April 2011, June 2011, August 2011, October 2011, December 2011 and February 2012 using YSI Multiparameter Water Quality Sonde 6600 V2 during the survey. The values recorded for each sampling month were analyzed using one-way ANOVA. If there was significant difference among the means of the stations, Tukey's pairwise comparisons were conducted. All analyses were conducted using SPSS 21.0. Station C was not accessible due to low water level as a result of dry season in August 2011 and therefore statistical analysis was not conducted for that sampling month.

RESULTS AND DISCUSSION

Fish fauna composition

A total of 28 species representing 9 families were caught at Maludam National Park. Eighteen species were caught from station A, 23 species from station B and 14 species from station C (Table 1). The total number of species recorded in this study is similar to that reported by Nyanti and Bali (2004). However, one family of eel (Moringuidae) that was reported to be present earlier was not caught in this study. Species accumulation curves have not reached asymptote, which show that additional species may be expected from the study area (Figure 2).

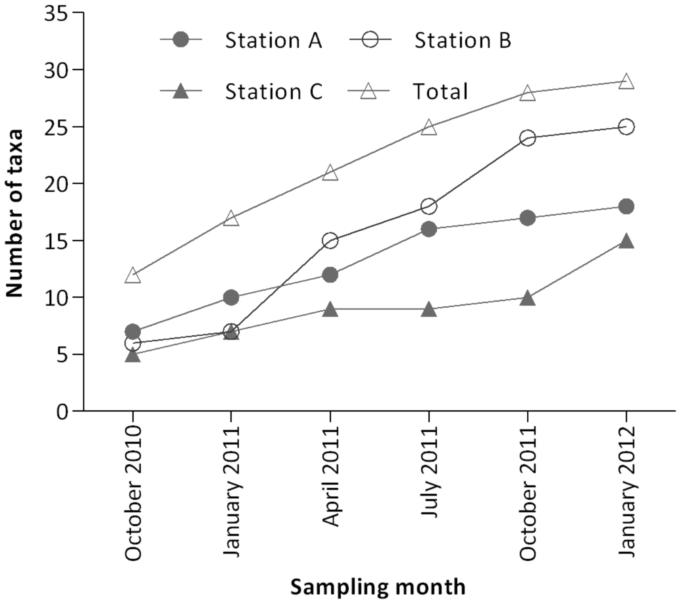

Figure 2: Accumulation curves for the number of species caught from the study area.

Table 1: Fish species caught from each of the stations in Maludam National Park. “x” indicates presence; “–“ absence. N is the total number of individuals caught in the study area.

Family	Species	St A	St B	St C	N
Anabantidae	*Anabas testudineus*	-	x	-	4
Bagridae	*Hemibagrus gulio*	x	-	-	1
	Hemibagrus nemurus	x	x	x	44
	Hemibagrus sabanus	x	-	-	2
	Hemibagrus sp.	x	-	-	1
	Leiocassis armatus	x	x	-	15
	Leocasis micropogon	x	-	-	1
Channidae	*Channa bankanensis*	x	x	x	19
	Channa lucius	x	x	x	87
Clariidae	*Clarias batrachus*	-	x	-	1
	Clarias leiacanthus	-	x	x	2
	Clarias nieuhofii	-	-	x	1
	Clarias sp.	x	x	-	4
Cyprinidae	*Rasbora einthovenii*	-	x	x	3
	Puntius johorensis	x	x	x	227
	Rasbora pauciperforata	-	x	x	55
	Puntius pentazona	x	x	-	13
	Puntius sp.	x	x	-	2
	Rasbora cephalotaenia	x	x	x	142
	Rasbora kalochroma	x	x	-	42
Helostomatidae	*Helostoma temminckii*	-	x	x	9
Nandidae	*Nandus nebulosus*	x	x	-	2
Osphronemidae	*Betta dimidiata*	-	x	x	5
	Betta akarensis	x	x	-	5
	Luciocephalus pulcher	x	x	x	67
Siluridae	*Silurichthys hasselti*	-	x	-	2
	Kryptopterus macrocephalus	-	x	x	12
	Wallago leerii	x	x	x	30
Total	**28**	**18**	**23**	**14**	**798**

In terms of the number of individuals caught in station A, the four dominant families are Cyprinidae representing 49% of all individuals caught, followed by Channidae (19%), Osphronemidae (17.5%) and 11.5% from the family Bagridae (Figure 3). In station B, 67.5% are from family Cyprinidae, 12% from Channidae, 8.5% Bagridae and 5% from Osphronemidae. In station C, 70% are from family Cyprinidae, 17.5% from Siluridae, 4% from Channidae and 3.5 % from Helostomatidae. In terms of the number of individuals caught in the study area, the four dominant families are Cyprinidae comprising about 60.7%, followed by Channidae (13.3%), Osphronemidae (9.9%) and Bagridae (8%).

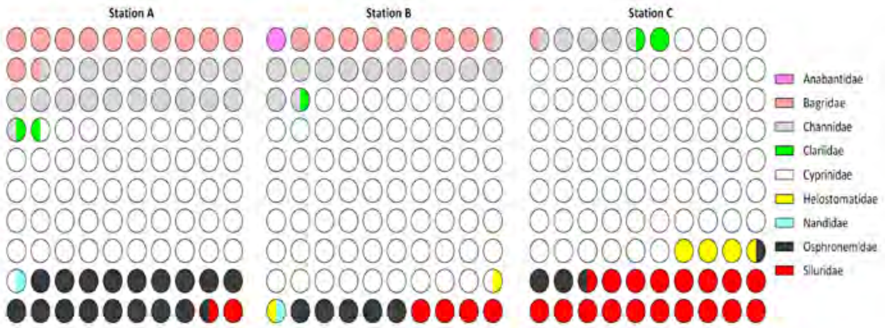

Figure 3: Dominant fish families caught (in percentage) in Station A, B and C.

Cyrpinidae was dominant in the study area, as is typical of freshwater rivers in south-east Asia (Lowe-McConnell, 1975), including Sabah (Nyanti, 1995) and Sarawak (Leh, 2000; Nyanti *et al.*, 2006). Parenti and Meisner (2003) reported that cyprinids were dominant in the peat swamps of Belait River, Brunei. The wide range of familial life histories and reproductive strategies of this family are probably the reasons for their success (Balon, 1975; Mills, 1991).

The dominant fish species caught in each of the three stations are shown in Figure 4. The four dominant species in station A are *Rasbora cephalotaenia* comprising 22.5% of the total number of individuals caught, *Puntius johorensis* (18.5%), *Luciocephalus pulcher* (17%) and *Channa lucius* (17%). In station B, the dominant species are *Puntius johorensis* (35.5%), *Rasbora cephalotaenia* (21%), *Channa lucius* (8.5%) and *Hemibagrus nemurus* (6%). In station C, the dominant species are *Rasbora pauciperforata* (35.5%), *Puntius johorensis* (32.5%), *Wallago leerii* (10%) and *Kryptopterus macrocephalu*s (7.5%). In terms of the number of individuals caught in the study area, the four dominant species are *Puntius johorensis* comprising about 28.4%, followed by *Rasbora cephalotaenia* (17.8%), *Channa lucius* (10.9%) and *Luciocephalus pulcher* (8.4%). As all four species are either stenotopic to acid water or stenotopic to acid blackwater (Ng *et al.*, 1994), the pH of Maludam River that ranged from 3.35–4.18 (Figure 5) appears suitable for these species. Additionally, species such as *Channa lucius* has the ability to breathe atmospheric air using its accessory respiratory organ (Kottelat *et al.*, 1993). Thus, it is advantageous for this species to live in the study area, as blackwaters can have extremely low dissolved oxygen during certain times of the year (Figure 6).

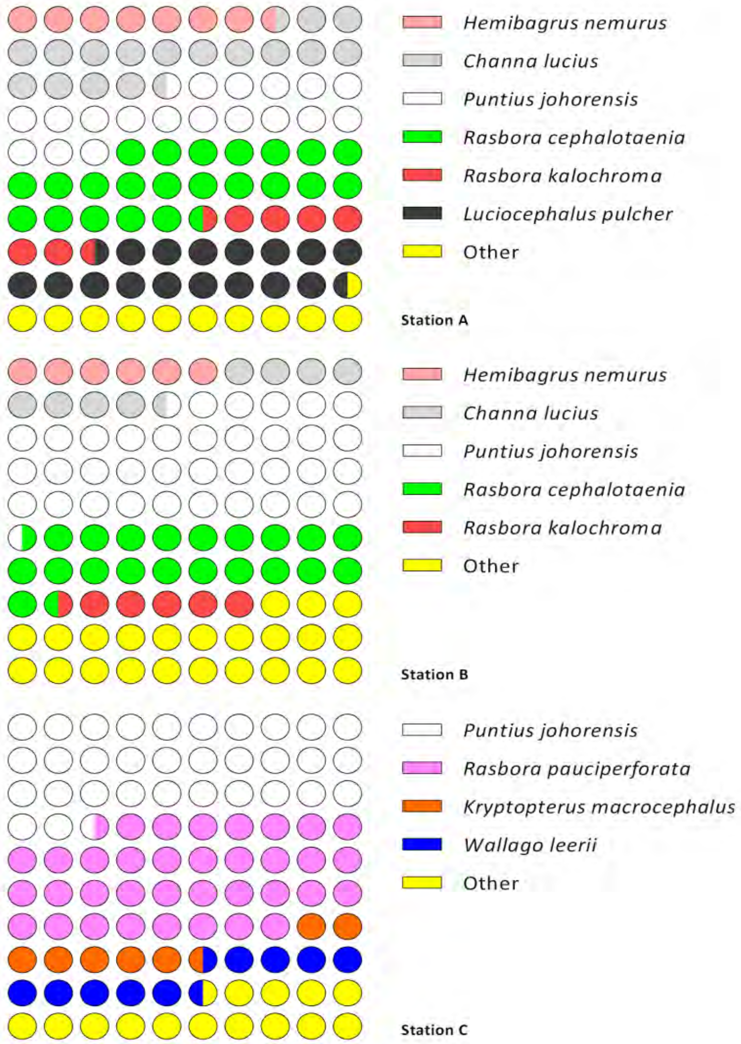

Figure 4: Dominant fish species caught (in percentage) in Station A, B and C.

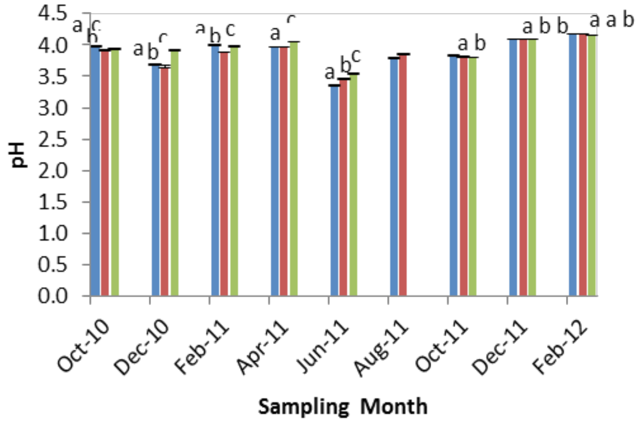

Figure 5: pH of the water at the three sampling stations from October 2010 to February 2012. Means in the same sampling month with the same letters are not significantly different at 5% level.

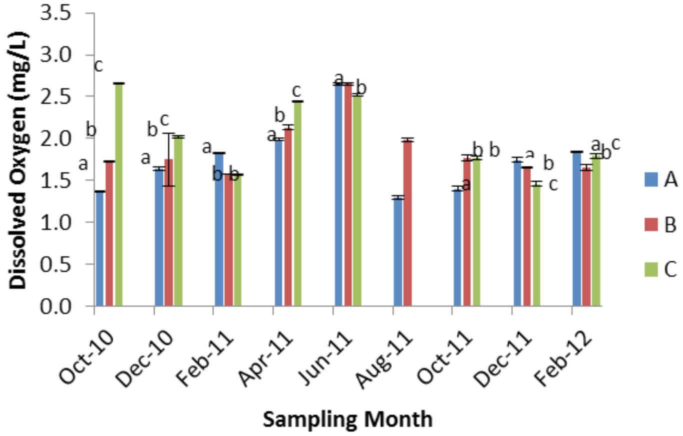

Figure 6: Dissolved oxygen of the water at the three sampling stations from October 2010 to February 2012. Same letter indicates mean values are not significantly different at 5% level. Means in the same sampling month with the same letters are not significantly different at 5% level.

One exotic species, *Helostoma temminckii*, that was introduced into Sarawak in 1956 through aquaculture activity (Hazebroek and Morshidi, 2000), was first reported from the Park in 2004 and accounted for 0.9% of the total number of individuals caught (Nyanti and Bali, 2004). In the present study, it accounts for 1.1% of the total number of individuals caught. Although this species have been reported abundant in some other peat swamp habitats in Sarawak (Murtedza *et. al*., 2000; Nyanti et. al., 2006; Khairul *et al*., 2009), their population in the Maludam National Park appears not to have increased significantly in the past seven years.

Fish species diversity

Shannon index has been widely used for species diversity measurement because it is a single value (which incorporate the species richness and evenness), where calculation and interpretation of the index is more straightforward (Ludwig and Reynolds, 1988). Our results showed Shannon index ranging between 1.75 and 2.15 (Table 2), which is still within the expected range of 1.5–3.5 (Legendre and Legendre, 1998). The index was significantly different among stations, and this result is attributable to the species caught not reaching asymptote of accumulation curves (Figure 2). As shown by the Margalef and Pielou indices, it is clear that high number of species was caught from each sampling trip, but the number of individuals in each species was uneven. This may be associated with the movement of certain species of fish following changes in water level and subsequently resulted in less successful sampling at that particular time (Goulding, 1980).

Table 2: Diversity, richness and evenness indice values at the three stations.

Index	St A	St B	St C
Shannon diversity index	2.10^{a}	2.15^{b}	1.75^{ab}
Margalef richness index	2.96	3.79	2.59
Pielou evenness index	0.45	0.37	0.41

Shannon diversity index in the same row with the same letter were not significantly different at $p < 0.0001$.

Analysis of growth and condition

Length-weight relationships analysis for eight fish species was significant at $p < 0.0001$, with variable R^2 values between 0.62 and 0.99 (Table 3). *Hemibagrus nemurus, Puntius johorensis* and *Rasbora pauciperforata* showed relatively low R^2 values. Low R^2 value of the species was possibly due to samples caught not representing the whole size range of the fishes as indicated by the exponential growth in Figure 7. The estimated parameter b for the eight species varies between 1.66 and 3.37. Five species, namely *Channa bankanensis, C. lucius, Luciocephalus pulcher, Rasbora cephalotaenia* and *Wallago leerii* showed positive allometric growth. This indicates that the weight of the fish increased faster than the length. Ecologically this implies that the fishes were in a good condition as a result of healthy environment and abundant food supply. *Hemibagrus nemurus, Puntius johorensis* and *Rasbora pauciperforata* showed a negative allometric growth. Condition factor for the fishes ranged from 0.53 (*Rasbora pauciperforata*) to 1.08 (*Puntius johorensis*). In the case of *Puntius johorensis*, it may probably be due to the abundant population that has resulted in heavy competition for food within this species, resulting in less amount of food available to the individuals. Other than habitat condition, food availability and water quality (Zakeyudin *et al*., 2012), as well as the technical differences during the data collection (Simon and Mazlan, 2008) could also affect the length-weight relationship.

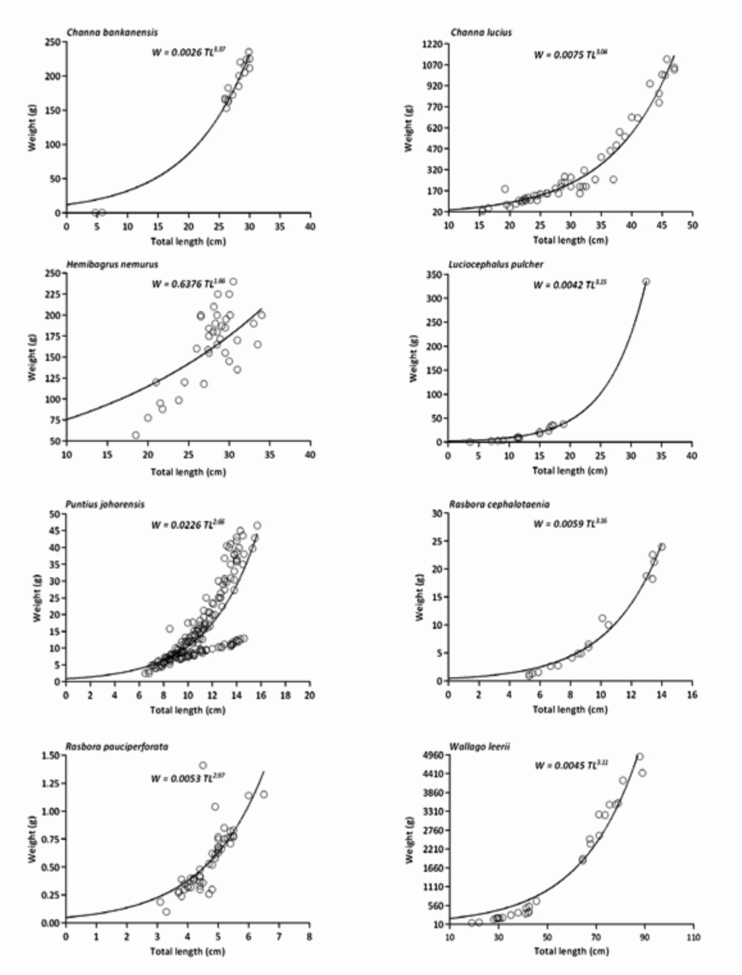

Figure 7: Exponential growth of eight fish species caught from Maludam National Park peat swamp forest.

Table 3: Descriptive statistics, estimated length-weight relationship and condition factor (*K*) for eight fish species. Regression analysis significant at $p < 0.0001$.

Species	**N**	**Total length (cm)** Range Mean (±SE)	**Weight (g)** Range Mean (±SE)	**LWR** R^2 Ln a (±SE) b (±SE) K (±SE)
Channa bankanensis	18	4.70 – 30.00 25.46 ± 1.77	0.57 – 235.00 171.59 ± 15.82	0.97 -5.97 ± 0.15 3.37 ± 0.05 0.83 ± 0.03
Channa lucius	54	15.50 – 47.00 30.25 ± 1.20	23.90 – 1110.00 325.90 ± 42.80	0.92 -4.89 ± 0.41 3.04 ± 0.12 0.91 ± 0.04
Hemibagrus nemurus	41	18.50 – 34.00 28.05 ± 0.62	56.91 – 240.00 163.36 ± 6.66	0.62 -0.45 ± 0.68 1.66 ± 0.20 0.76 ± 0.03
Luciocephalus pulcher	18	3.60 – 32.50 13.51 ± 1.57	0.26 – 335.00 33.94 ± 17.37	0.99 -5.48 ± 0.17 3.15 ± 0.07 0.61 ± 0.03
Puntius johorensis	200	6.50 – 15.70 10.73 ± 0.15	2.47 – 46.58 14.72 ± 0.76	0.72 -3.79 ± 0.28 2.66 ± 0.12 1.08 ± 0.02
Rasbora cephalotaenia	19	5.30 – 14.00 3.17 ± 0.70	0.90 – 23.39 8.72 ± 1.85	0.99 -5.14 ± 0.17 3.16 ± 0.08 0.83 ± 0.02
Rasbora pauciperforata	54	3.10 – 6.50 4.64 ± 0.09	0.10 – 1.41 0.55 ± 0.04	0.74 -5.24 ± 0.38 2.97 ± 0.25 0.53 ± 0.02
Wallago leerii	30	19.00 – 89.00 51.66 ± 3.99	50.00 – 4910.00 1553.20 ± 292.63	0.99 -5.41 ± 0.23 3.11 ± 0.06 0.69 ± 0.02

Water quality

Low pH of the water indicates the high acidity of Maludam River, as shown in Figure 6. The values ranged from 3.35 in June 2011 at station A to 4.18 in February 2011 at station B. These pH values were much lower compared to the rainwater of 6.2 as reported by Ling *et al.* (2009). The pH observed was also much lower than 6.41 of the Kebhor River that flows into Bakun Dam (Nyanti *et al*., 2012). pH values of the blackwater observed in the present study concur with those reported in literature of other similar blackwater in tropical region, with mean pH value of 3.80 (Gasim *et al.*, 2007), pH range of 3.50–4.21 (Shuhaimi-Othman *et al*., 2009) of the Bebar River in a forest reserve in Pahang, and mean value of 3.6 at the surface water of Sebangau River, Central Kalimantan, Indonesia (Page *et al*., 1999). The low pH of the water is due to the organic and inorganic acids produced in the process of decomposition of peat which accumulated in the ecosystem (Andriesse, 1988).

Dissolved oxygen at the study area was low throughout the sampling period with mean ranging from 1.29 mg/L at station A in August 2011 to 2.66 mg/L at station C in October 2011 (Figure 7). The lowest value occurred during the peak of the dry season, which started in April 2011 till August 2011. The highest dissolved oxygen was observed in the beginning of rainy season in October 2011. During each sampling month, dissolved oxygen was significantly different among all pairs of stations except in February 2011, June 2011 and October 2011. The low dissolved oxygen level is lower than the values reported at non peat swamp rivers; 9.34 mg/L at the Kebhor River in Sarawak (Nyanti *et al*., 2012) and 3.40–5.89 mg/L at the Serin River in Sarawak (Ling *et al*., 2006; 2010). This observation of low dissolved oxygen is similar to that reported in other peat swamp waters. In Bebar River in Pahang, it was reported that dissolved oxygen ranged from 0.54–1.76 mg/L (Gasim *et al.*, 2007) and 0.54–2.72 mg/L with 10 out of 11 stations showing values less than or equals to 1.11 mg/L (Shuhaimi-Othman *et al.*, 2009). As peat is partly decomposed vegetation, oxygen is being consumed in the continuing decomposition process (Andriesse, 1988) resulting in low dissolved oxygen.

Water temperature was the highest in August 2011 followed by June 2011 and October 2010 (Figure 8). February of both 2011 and 2012 showed the lowest mean temperatures. The highest temperature of 28.21°C at station B in August 2011 was 3°C higher than the lowest temperature (25.26°C), which was observed in station C in February 2012. Pairwise comparisons show that for each sampling trip, there was significant difference in temperature among the stations. For each trip, except Aug 2011, station A showed the highest temperature followed by station B and then station C. Temperature at each of the station depends on exposure and season of the year. Since this area is relatively pristine, season of the year is the major factor causing variation in temperature. In August 2011, it coincided with the dry season and therefore the temperature of the water was the highest. Conversely, temperatures were low in February due to wet season. However, the peat swamp water appears to have higher temperature than the other rivers as even the lowest temperature over the sampling period (25.26°C), which occurred in February, was higher than the river that flows into Bakun Reservoir, namely Kebhor River, which was 22.94°C in January 2012 (Nyanti *et al.*, 2012). The range of temperature observed in the present study is comparable to the range of 26.15–28.90°C at Bebar River, a forest reserve peat swamp river in Pahang of West Malaysia (Gasim *et al.*, 2007) and 26.08–29.22°C in the same river (Shuhaimi-Othman *et al.*, 2009). However, Rosli *et al.* (2010) reported a higher range of 26.85–32.90°C in an oil palm plantation of a peat swamp area at Igan River, which is likely due to the non-pristine nature of the vegetation resulting in more exposure to solar radiation.

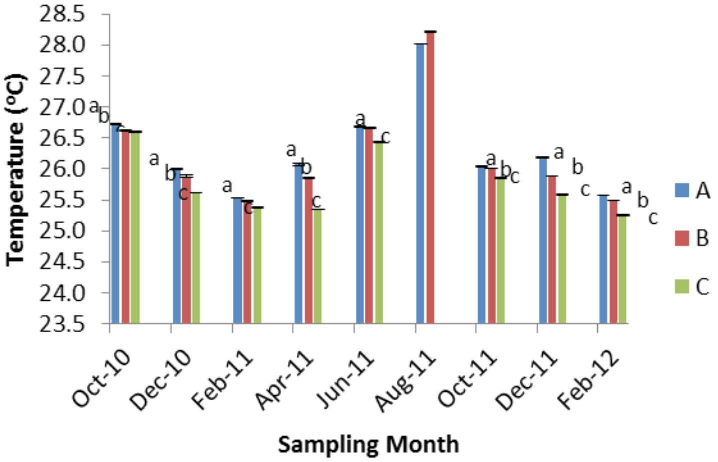

Figure 8: Temperature of the water at the three sampling stations from October 2010 to February 2012. Means in the same sampling month with the same letters are not significantly different at 5% level.

Turbidity values ranged from 3.40 NTU in December 2011 at station B to 4.17 NTU in August of 2011 at stations A and B. The values among the stations during each trip did not vary much as shown by frequent insignificant difference (P > 0.05) among stations (Figure 9). The range of turbidity observed in the present study is smaller compared to the range of 1.5–17.15 NTU recorded at Bebar River in a peat swamp forest reserve in West Malaysia (Gasim *et al*., 2007) and 0.30–14.80 NTU at the irrigation canals in oil palm plantation and tributaries of the Igan River (Rosli *et al*., 2010).

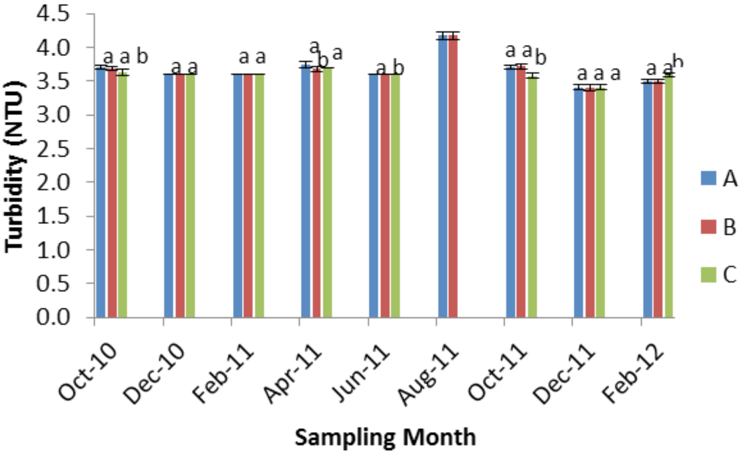

Figure 9: Turbidity of the water at the three sampling stations from October 2010 to February 2012. Means in the same sampling month with the same letters are not significantly different at 5% level.

ACKNOWLEDGEMENTS

The authors appreciate the assistance of Mr Roystone Stephen and Mr Paul Miki during the field samplings. The financial support through grant L1840I0100 MPOB Betong is gratefully acknowledged.

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7

DIVERSITY OF AVIFAUNA IN PEAT SWAMP FORESTS

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Andrew Alek Tuen, Bettycopa Amit and Khalid Haron

INTRODUCTION

Peat swamp formations in Sarawak, which are estimated to be about 1.14 million hectares (ha), are regarded as the largest tropical peatlands in Malaysia (Weatlands International, 2010). Based on the United Nations Development Programme (UNDP) report, the country’s current peat swamp remnant is estimated at 1.54 million hectares, with 70% occurring in Sarawak, about 20% in Peninsular Malaysia and elsewhere in the Klias Peninsular, Sabah (UNDP, 2006). Taking into account the extensive peatlands in the southern region of Central Kalimantan (ca. 6 million ha), the island of Borneo has the largest peatland area in South-east Asia (Wosten, 2008). In Sarawak, the distribution of large peatlands is over recent sediments of coastal Sarawak, most primarily in the Rajang Delta and Baram River basins (Smythies and Davison, 1999; Rahman and Tuen, 2004). Table 1 shows that most of the peatland occur in Sibu, Sri Aman, Kota Samarahan and Miri Division of Sarawak (Wetland International, 2010).

Table 1: Estimated size of undisturbed and disturbed peat swamp forests in Sarawak (source: Wetlands International, 2010).

Division	Relatively undisturbed PSF (ha) cc > 70%	Moderately disturbed PSF (ha) cc 40-70%	Severely disturbed PSF (ha) cc < 40%	Total
Limbang	701	1,256	5,436	7,393
Miri	63,279	60,930	100,158	224,367
Bintulu	18,756	26,712	25,540	71,008
Sri Aman	29,522	126,910	66,613	223,045
Sarikei	33,671	45,607	58,043	137,323
Sibu	44,567	162,825	115,396	322,788
Samarahan	32,781	62,206	54,759	150,746
Kuching	0	913	981	1,894
Total	223,277 (19.6%)	488,359 (42.9%)	426,926 (37.5%)	1,138,562

Peatland can be described as an area with accumulation of natural layer of dead organic material at the surface (Joosten, 2008). In their natural state, peat swamp forests are an integral component for the survival of wetlands. They are essentially home to numerous waterbird species, and to some extent, are considered as an alternative habitat for surviving refuges from degraded forested areas (Minayeva, 2008). This include critically endangered bird species such as the Storm's stork *Ciconia stormi* and several species of hornbills (Rahman, 2004). Peat swamp forest also offer significant benefits to local community in terms of providing daily goods and services, such as food resources, fisheries products, flood mitigation and water supply (Mohd Azmi *et al*., 2009).

Global attention on the significance and conservation value of peat swamp forests in South-east Asia had emerged since the early 1990s. On a broader scale, several studies have been initiated in the form of biodiversity baseline and environmental impact assessments in selected peat swamp forest across the region. Some of this primary peatlands include Maludam National Park and Logan Bunut National Park in Sarawak (Rahman, 2004; Tuen *et al*., 2006), south-east Pahang, north Selangor and Johor peat swamp forest in Peninsular Malaysia (UNDP, 2006; Mohd Azmi, 2009), Berbak National Park and Merang peat swamp forest in Sumatera (Eijk and Leenman, 2004; Mirmanto, 2009). Despite the massive coverage of peat swamp forests in Borneo, not much ornithological studies have focused solely on this habitat (Smythies and Davison, 1999; Birdlife International, 2003). This is due to the common view of peatlands being overlooked and synonymous with low species diversity (Joosten, 2008).

However, some exemplary survey outputs showed high bird diversity can potentially exist in harsh environment and nutrient-poor soils (Schrevel, 2008). In Berbak National Park, 224 bird species were recorded, while both Maludam National Park and south-east Pahang peat swamp forest have 192 bird species, respectively (Rahman, 2004; Schrevel, 2008; Mohd Azmi *et al*., 2009). In this chapter, we present the diversity of birds in several peat swamp forests in Sarawak by compiling multiple bird inventory studies conducted from 1996-2011. Comparison on the overall findings between sampling areas is discussed with regards to potential factors influencing bird composition and significance value of peat swamp conservation.

MATERIALS AND METHODS

Study area and sources of data

The study areas comprised of five selected peat swamp forests; (1) UNIMAS/Kota Samarahan peat swamp forest in south-western Sarawak, (2a) Maludam National Park (MNP), (2b) Tanjung Baru Forest (TBF) and (2c) Cermat Ceria Forest (CCF) in Betong Division and (3) Logan Bunut National Park (LBNP), located between the Tinjar and Teru rivers of the Baram River basin in north-eastern Sarawak (Figure 1). In Kota Samarahan, large portion of peat swamp forests had been gradually converted over the last 20 years into new residential areas leaving small fragmented forest patches. Some of these remaining areas include the 20 ha of peat swamp forest inside UNIMAS campus (N01°27.48′, E111°27.03′). Data from this area were derived from annual bird surveys and mist-netting activities that were documented in unpublished B.Sc. theses (e.g., Darub, 1997; Bakar, 1999; Ahmad, 2006; Ghani, 2008; Abdillah, 2011).

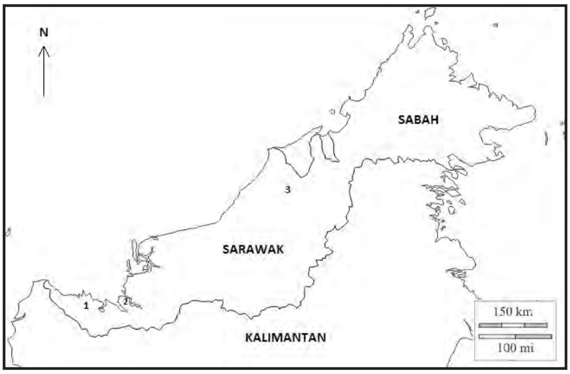

Figure 1: Map showing main sampling areas in Sarawak. Peat swamp forests are marked as 1 =UNIMAS/Kota Samarahan Forest, 2 = Maludam National Park/Cermat Ceria Forest/Tanjung Baru Forest and 3 = Loagan Bunut National Park.

For the second site, bird data were pooled from two main sources. Amit *et al.* (2012) conducted a comparative assessment on the bird diversity between MNP (N01°36.058′, E111°04.065′) and two adjacent sampling areas categorised as disturbed peat swamp forest. These include the TBF which is located just outside the national park borders (N01°38.733′, E111°02.669′), while CCF is situated farther away between two oil palm estates (N01°23′57.5′, E111°24′26.4′). In addition, another large portion of the database was accumulated from series of bird surveys and mist-netting activities reported by the Sarawak Forest Department from within and around Maludam National Park in 1998, 2001, 2002 and 2003 (Rahman, 2004). Another peat swamp forest surveyed is the LBNP. This wetland holds the largest natural freshwater lake in Sarawak with an estimated of 7,943 ha of peat swamp forest (LBNP, 2007). Data were obtained from study conducted by Laman *et al*. (2006) in three distinctive forest types which includes peat swamp forest (Site 1), fruit orchard (Site 2) and mix-dipterocarp forest (Site 3). Only data from Site 1 were chosen for this purpose.

Mist-netting and bird surveys

Birds were caught using conventional four-shelved mist-nets measuring 9 m/12 m x 2.5 cm and mesh size of 3 x 3 cm. Bird identification is based on Smythies (1999), Myers (2009) and Phillipps and Phillipps (2009). Duration and numbers of mist nets used varied between each study, implying different degree of total efforts. In general, bird trappings in UNIMAS campus were normally conducted for 12 hours period (0600–1800 hr) within three to five months. For sampling areas in Maludam, Amit *et al*. (2012) carried out 2160 net-hours of bird trapping using 15 mist-nets for three days during October 2010, April, July and October 2011. Comparatively, Laman *et al.* (2006) spent 10 sampling days of mist-netting in LBNP. Both studies by Rahman (2004) and Laman *et al.* (2006) conducted mist-netting together with bird observation using binoculars and listening to their vocalisations.

RESULTS AND DISCUSSIONS

A total of 227 species from 48 families were compiled from the seven studies conducted in peat swamp forest across Sarawak from 1996–2011 (Table 2). This comprised of 1125 individuals representing 93 species from 28 families. The birds were caught using mist nets while the additional 134 species was recorded via visual observation and vocalisation. The numbers generated through bird trapping proved to be significantly less due to the common drawback of using mist-nets that primarily focused on understorey birds compared to middle and high canopy flyers (Rahman and Tuen, 2004) (see Table 2 for identification technique of bird species). Essentially, the cumulative number of species/families and total numbers of species recorded from the three main sampling areas are shown in Figure 2. The total number showed significantly high species diversity in the Maludam areas compared to the peat swamp forest within UNIMAS. The highest total number of species and families were recorded within the Maludam Peninsular with 202 and 44, respectively.

Table 2: Compiled checklist of bird species recorded in main peat swamp areas in Sarawak from 1996–2011.

Family/Species	**S**	**I**	II	**III**	IV	V	**VI**	VII	Total
Ardeidae									
Little egret *Egretta garzetta**	M	-	✓	-	✓	✓	-	✓	-
Intermediate egret *Egretta intermedia**	M	-	✓	-	-	✓	-	-	-
Cattle egret *Bubulcus ibis***	M	-	✓	-	✓	✓	-	-	-
Chinese egret *Egretta eupholetes**	M	-	✓	-	-	-	-	-	-
Pacific reef egret *Egretta sacra***	R	-	✓	-	-	-	-	-	-
Great egret *Egretta alba**	M	-	✓	-	-	-	-	-	-
Chinese pond heron *Ardeola bacchus**	M	-	✓	-	-	-	-	-	-
Black-crowned night heron *Nycticorax nycticorax**	R	-	✓	-	-	-	-	-	-
Striated heron *Butorides striatus**	M	-	✓	-	-	-	-	-	-
Yellow bittern *Ixobrychus sinensis* *	M	-	✓	-	-	-	-	-	-
Cinnamon bittern *Ixobrychus cinnamomens* *	M	-	✓	-	-	-	-	-	-
Ciconiidae									
Storm's stork *Ciconia stormi***	R	-	✓	-	-	-	-	-	-
Lesser Adjutant *Leptoptilos javanicus***	R	-	✓	-	-	-	-	-	-
Rallidae									
White-breasted waterhen *Amaurornis phoenicurus*	R	-	✓	-	✓	✓	-	✓	-
Slaty-breasted rail *Gallirallus striatus*	R	-	✓	-	-	-	-	-	-
Heliornithidae									
Masked finfoot *Heliopais personata*	V	-	✓	-	-	-	-	-	-

(Table 2: continued)

Charadriidae									
Pacific golden plover *Pluvialis fulva*	M	-	✓	-	✓	-	-	-	-
Grey plover *Pluvialis squatarola*	M	-	✓	-	-	-	-	-	-
Lesser sand plover *Charadrius mongolus*	M	-	✓	-	-	-	-	-	-
Scolopacidae									
Common sandpiper *Actitis hypoleucos**	M	-	✓	-	✓	-	-	✓	-
Eurasian curlew *Numenius arquata* *	M	-	✓	-	-	-	-	-	-
Far eastern curlew *Numenius madagascariensis**	M	-	✓	-	-	-	-	-	-
Whimbrel *Numenius phaeopus**	M	-	✓	-	-	-	-	-	-
Common redshank *Tringa totanus**	M	-	✓	-	-	✓	-	-	-
Spotted redshank *Tringa erythropus**	M	-	✓	-	-	-	-	-	-
Common greenshank *Tringa nebularia**	M	-	✓	-	✓	-	-	-	-
Terek sandpiper *Xenus cinereus* *	M	-	✓	-	-	-	-	-	-
Red-necked stint *Calidris ruficollis**	M	-	✓	-	-	-	-	-	-
Acciptridae									
Crested goshawk *Accipiter trivirgatus*	R	2	✓	-	-	-	1	-	3
Oriental honey buzzard *Pernis ptilorhynchus orientalis*	M	-	✓	-	-	-	-	-	-
Japanese sparrow-hawk *Accipiter gularis*	M	-	✓	-	-	-	-	-	-
Jerdon's Baza *Avecida jerdoni*	R	-	✓	-	-	-	-	-	-
Brahmini kite *Haliastur indus*	R	-	✓	-	✓	-	-	-	-
Crested serpent eagle *Spilornis cheela*	R	-	✓	-	-	-	-	-	-
White-bellied fish-eagle *Haliaeetus leucogaster***	R	-	✓	-	-	-	-	-	-
Lesser fish-eagle *Ichtyophaga humilis*	R	-	✓	-	✓	-	-	-	-

(Table 2: continued)

Falconidae									
Black-thighed falconet *Microhierax fringilarius**	R	-	✓	-	-	-	-	-	-
Sternidae									
Black-naped tern *Sterna sumatrana***	R	-	✓	-	-	-	-	-	-
Great-crested tern *Sterna bergii*	M	-	✓	-	-	-	-	-	-
Caspian tern *Sterna caspia*	M	-	✓	-	-	-	-	-	-
Gull-billed tern *Sterna nilotica*	M	-	✓	-	-	-	-	-	-
Little tern *Sterna albifrons*	M	-	✓	-	-	-	-	-	-
White-winged black tern *Chlidonias leucoptera*	M	-	✓	-	-	-	-	-	-
Whiskered tern *Chlidonias hybrida*	M	-	✓	-	-	-	-	-	-
Columbidae									
Emerald dove *Chalcophaps indica*	R	1	-	-	✓	-	-	4	5
Pink-necked pigeon *Treron vernans*	R	-	✓	-	✓	✓	-	✓	-
Cinnamon headed-pigeon *Treron fulvicollis*	R	-	✓	-	✓	✓	-	-	-
Spotted dove *Streptopelia chinensis*	R	-	✓	-	✓	✓	-	✓	-
Thick-billed green pigeon *Treron curvirostra*	R	-	✓	-	✓	-	-	-	-
Little green pigeon *Treron olax*	R	-	✓	-	-	-	-	-	-
Green imperial pigeon *Ducula aenea***	R	-	✓	-	-	-	-	-	-
Rock pigeon *Columbia livia*	R	-	✓	-	-	-	-	-	-
Psittacidae									
Long-tailed parakeet *Psittacula longicauda**	R	-	✓	-	-	-	-	-	-
Blue-crowned hanging parrot *Loriculus galgulus**	R	-	✓	-	-	-	-	-	-

(Table 2: continued)

Cuculidae									
Banded bay cuckoo *Cacomantis sonneratii*	R	1	-	-	✓	✓	-	-	1
Rusty-breasted cuckoo *Cacomantis sepulcralis*	R	-	-	-	-	-	-	2	2
Chestnut-winged cuckoo *Clamator coromandus*	R	-	✓	-	-	-	-	1	1
Plaintive cuckoo *Cacomantis merulinus*	R	-	✓	-	✓	✓	-	✓	-
Indian cuckoo *Cuculus micropterus*	R	-	-	-	✓	✓	-	✓	-
Violet cuckoo *Chrysococcyx xanthorhynchus*	R	-	✓	-	-	-	-	-	-
Drongo cuckoo *Surniculus lugubris*	R	-	✓	-	-	-	-	-	-
Asian koel *Eudynamys scolopacea*	R	-	✓	-	-	-	-	-	-
Short-toed coucal *Centropus rectunguis*	R	-	✓	-	-	-	-	-	-
Lesser coucal *Centropus bengalensis*	R	-	✓	-	-	-	-	-	-
Greater coucal *Centropus sirensis*	R	-	✓	-	✓	✓	-	✓	-
Raffles's Malkoha *Phaenicophaeus chlorophaeus*	R	-	✓	-	✓	✓	-	✓	-
Black-bellied malkoha *Phaenicophaeus diardi*	R	-	✓	-	-	-	-	-	-
Chestnut-bellied malkoha *Phaenicophaeus sumatranus*	R	-	✓	-	-	-	-	-	-
Chestnut-breasted malkoha *Phaenicophaeus curvirostris*	R	-	✓	-	-	-	-	-	-
Strigidae									
Reddish scops-owl *Otus rufescens**	R	3	-	-	-	-	2	4	9
Brown hawk-owl *Ninox scutulata**	R	-	-	-	-	-	1	-	1
Oriental bay owl *Phodilus badius**	R	-	-	-	-	-	1	-	1
Buffy fish-owl *Ketupa ketupu**	R	-	✓	-	-	-	-	-	-
Collared scops-owl *Otus bakkamoena**	R	-	✓	-	-	-	-	-	-

(Table 2: continued)

Batrachostomidae									
Gould's frogmouth *Batrachostomus stellatus*	R	1	-	-	-	-	-	-	1
Sunda frogmouth *Batrachostomus cornutus*	R	-	✓	-	-	-	-	-	
Caprimulgidae									
Malaysian eared nightjar *Eurostopodus temminckii*	R	-	✓	✓	-	-	-	-	-
Large-tailed nightjar *Caprimulgus macrurus*	R	-	✓	-	-	-	-	-	-
Apodidae									
Black-nest swiftlet *Aerodramus maximus**	R	-	✓	-	-	-	-	-	-
Silver-rumped spinetail *Raphidura leucopygialis*	R	-	✓	-	-	-	-	-	-
Asian palm swift *Cypsiurus balasiensis*	R	-	✓	-	-	-	-	-	-
House swift *Apus affinis*	R	-	✓	-	-	-	-	-	-
Hemiprocnidae									
Grey-rumped treeswift *Hemiprocne longipennis*	R	-	✓	-	-	-	-	-	-
Trogonidae									
Scarlet-rumped trogon *Harpactes duvaucelii*	R	2	✓	-	-	-	3	-	5
Orange-breasted trogon *Harpactes oreskios*	R	1	-	-	-	-	-	-	1
Diard's trogon *Harpactes diardi*	R	1	-	-	-	-	-	-	1
Red-naped trogon *Harpactes kasumba*	R	-	✓	-	-	-	-	-	-

(Table 2: continued)

Alcedinidae									
Blue-eared kingfisher *Alcedo meninting**	R	2	✓	-	✓	✓	8	3/✓	13
Black-backed kingfisher *Ceyx erithacus**	R	1	✓	-2/✓	-	-	-	-	1
Rufous-backed kingfisher *Ceyx rufidorsus**	R	58	✓	✓	✓	-	8	14	82
Stork-billed kingfisher *Pelargopsis capensis**	R	1	✓	-	✓	✓	1	✓	2
Ruddy-kingfisher *Halcyon coromanda**	R	15	✓	-	✓	-	2	4	21
Banded kingfisher *Lacedo pulchella**	R	-	-	✓	-	-	1	-	1
Collared kingfisher *Halcyon chloris**	R	-	✓	-	-	✓	-	✓	-
Common kingfisher *Alcedo atthis**	M	-	✓		✓	✓	-	-	-
Meropidae									
Blue-tailed bee-eater *Merops phillipinus*	R	-	✓	-	-	-	-	-	-
Blue-throated bee-eater *Merops viridis*	R	-	✓	-	-	-	-	-	-
Coraciidae									
Dollarbird *Eurystomus orientalis*	R	-	✓	-	-	-	-	-	-
Bucerotidae									
Bushy-crested hornbill *Anorrhinus galeritus***	R	-	✓	-	-	-	-	-	-
Asian black hornbill *Anthracoceros malayanus***	R	-	✓	-	-	-	-	-	-
Oriental pied hornbill *Anthracoceros albirostris***	R	-	✓	-	-	-	-	-	-
Rhinoceros hornbill *Buceros rhinoceros***	R	-	✓	-	-	-	-	-	-
Wrinkled hornbill *Aceros corrugates***	R	-	✓	-	-	-	-	-	-

(Table 2: continued)

Megalaimidae									
Red-crowned barbet *Megalaima rafflesii*	R	3	✓	✓	✓	-	-	-	3
Brown barbet *Calorhamphus fuliginosus*	R	-	✓	-	-	-	-	1	1
Red-throated barbet *Megalaima mystacophanos*	R	-	-	✓	✓	✓	-	✓	-
Blue-eared barbet *Megalaima australis*	R	-	✓	-	✓	-	-	-	-
Indicatoridae									
Malaysian honeyguide *Indicator archipelagicus*	R	-	✓	-	-	-	-	-	-
Picidae									
Maroon woodpecker *Blythipicus rubiginosus**	R	6	✓	-	✓	✓	2	-	8
Rufous woodpecker *Celeus brachyurus**	R	3	✓	-	-	-	-	-	3
Common flameback *Dinopium javanense**	R	1	✓	-	-	-	-	-	1
Buff-necked woodpecker (*Meiglyptes tukki**	R	9	✓	-	-	-	5	1	15
Banded woodpecker *Picus miniaceus**	R	4	✓	-	✓	-	-	-	4
Crimson-winged woodpecker *Picus punicens**	R	1	✓	-	✓	-	-	-	1
Buff-rumped woodpecker *Meiglyptes tristis**	R	-	✓	-	✓	✓	-	1/✓	1
Rufous piculet *Sasia abnormis**	R	16	✓	-	✓	-	1	-	17
White-bellied woodpecker *Dryocopus javensis**	R	-	✓	-	-	-	-	-	-
Brown-capped woodpecker *Dendrocopus moluccensis**	R	-	✓	-	-	-	-	-	-
Grey-capped woodpecker *Dendrocopus carnicapillus**	R	-	✓	-	-	-	-	-	-
Grey and buff woodpecker *Hemicircus concretus**	R	-	✓	-	-	-	-	-	-
Great slaty woodpecker *Mulleripicus pulverulentus**	R	-	✓	-	-	-	-	-	-

(Table 2: continued)

Eurylaimidae									
Black and red broadbill *Cymbirhynchus macrorhynchus*	R	18	✓	-	-	-	-	4	22
Black and yellow broadbill *Eurylaimus ochromalus*	R	-	✓	-	-	-	-	-	-
Green broadbill *Calyptomena viridis*	R	-	✓	-	-	-	-	-	-
Pittidae									
Blue-winged pitta *Pitta moluccensis***	R	3	✓	-	-	-	-	-	3
Hooded pitta *Pitta sordiala***	R	1	-	-	-	-	-	-	1
Aegithinidae									
Green iora *Aegithina viridissima*	R	1	✓	-	-	-	-	-	1
Common iora *Aegithina thipia*	R	-	✓	-	✓	-	-	1/✓	1
Lesser green leafbird *Chloropsis cyanopogon*	R	-	✓	-	-	-	-	-	-
Greater green leafbird *Chlorpsis sonnerati*	R	-	✓	-	-	-	-	-	-
Campephagidae									
Black-winged flycatcher shrike *Hemipus hirundinaecus*	R	1	✓	-	-	-	-	-	1
Bar-bellied cuckoo shrike *Cioracina striata*	R	-	✓	-	-	-	-	-	-
Lesser cuckoo shrike *Coracina fimbriata*	R	-	✓	-	-	-	-	-	-
Pied thriller *Lalage nigra*	R	-	✓	-	✓	-	-	-	-
Fiery minivet *Pericrocotus igneus*	R	-	✓	-	-	-	-	-	-
Sittidae									
Velvet-fronted nuthatch *Sitta frontalis*	R	-	✓	-	-	-	-	1	1
Irenidae									
Asian fairy bluebird *Irena puella*	R	1	✓	-	-	-	2	-	3

(Table 2: continued)

Dicruridae									
Greater-racquet-tailed drongo *Dicrurus paradiseus*	R	14	✓	1/✓	✓	✓	-	3/✓	18
Bronzed-drongo *Dicrurus aeneus*	R	1	✓	-	-	-	-	-	1
Crow-billed drongo *Dicrurus annectans*	R	-	-	-	✓	✓	-	1/✓	1
Oriolidae									
Black and crimson oriole *Oriolus cruentus*	R	-	-	-	✓	-	-	-	-
Corvidae									
Crested jay *Platylophus galericulatus*	R	3	-	-	-	-	-	-	3
Black magpie *Platysmurus leucopterus*	R	4	-	-	-	-	-	-	4
Slender billed crow *Corvus enca*	R	-	✓	-	✓	-	-	-	-
Pityriaseidae									
Bornean bristlehead *Pityriasis gymnocephala***	E	-	✓	✓	-	-	-	-	-
Artamidae									
White-breasted woodswallow *Artamus leucorhynchus*	R	-	✓	-	-	✓	-	✓	-
Hirundinidae									
Pacific swallow *Hirundo tahitica*	R	-	✓	-	✓	✓	-	2/✓	2
Barn swallow *Hirundo rustica*	M	-	✓	-	-	-	-	-	-

(Table 2: continued)

Pycnonotidae									
Buff-vented bulbul *Hypsipetes charlottae*	R	1	✓	-	-	-	-	-	1
Red-eyed bulbul *Pycnonotus brunneus*	R	16	✓	-	✓	✓	4	-	20
Puff-backed bulbul *Pycnonotus eutilotus*	R	8	-	-	✓	-	-	-	8
Spectacled bulbul *Pycnonotus erythropthalamos*	R	5	-	-	✓	✓	2	-	7
Yellow-vented bulbul *Pycnonotus goiavier*	R	6	✓	-	✓	✓	3	✓	9
Olive-winged bulbul *Pycnonotus plumosus*	R	39	✓	-	✓	✓	27	9/✓	75
Hook-billed bulbul *Setornis criniger*	R	-	✓	1	-	-	24	-	25
Cream vented bulbul *Pycnonotus simplex*	R	-	✓	1	-	-	1	-	2
Black and white bulbul *Pycnonotus melanoleucos*	R	-	✓	-	-	-	-	-	-
Black headed bulbul *Pycnonotus atriceps*	R	-	✓	-	-	-	-	-	-
Sylviidae									
Eastern great reed warbler *Acrocephalus orientalis*	R	1	✓	-	-	-	-	-	1
Ashy tailorbird *Orthotomus ruficeps*	R	7	✓	-	✓	✓	1	✓	8
Rufous-tailed tailorbird *Orthotomus sericeus*	R	46	✓	✓	✓	✓	3	3	52
Arctic warbler *Phylloscopus borealis*	R	1	✓	-	-	✓	-	✓	1
Dark-necked tailorbird *Orthotomus atrogularis*	R	-	✓	-	-	-	-	-	-
Yellow-bellied prinia *Prinia flaviventris*	R	-	✓	-	-	✓	-	-	-
Pallas's warbler *Locustella certhiola*	R	-	✓	-	-	-	-	-	-
Clamorous reed warbler *Acrocephalus stentoreus*	R	-	✓	-	-	-	-	-	-
Motacillidae									
Grey wagtail *Motacilla cinerea*	M	-	-	-	-	✓	-	✓	-
White wagtail *Motacilla alba*	M	-	-	✓	-	-	-	-	-

(Table 2: continued)

Timaliidae									
Fluffy –backed tit babbler *Macronous ptilosus*	R	29	✓	-	✓	-	8	2	39
Striped-tit babbler *Macronous gularis*	R	47	-	3	✓	-	5	-	55
White-throated babbler *Malacopteron albogulare*	R	1	✓	5	-	-	3	-	9
Black-capped babbler *Pellorneum capsitratum*	R	15	✓	-	-	-	-	1	16
Chestnut-back schimitar babbler *Pomatorhinus montanus*	R	1	-	-	-	-	-	-	1
Chestnut-winged babbler *Stachyris erythropthera*	R	55	✓	-	✓	✓	23	18	96
Black-throated babbler *Stachyris nigricollis*	R	17	✓	2	-	-	14	-	33
Short-tailed babbler *Trichastoma malaccense*	R	25	✓	1/✓	✓	✓	10	2	38
White-chested babbler *Trichastoma rostratum*	R	4	✓	-	✓	✓	22	-	26
Chestnut-rumped babbler *Stachyris maculate*	R	-	✓	4	-	-	23	-	27
Temminck's babbler *Pellorneum pyrrogenys*	R	-	-	-	-	-	3	-	3
Rufous-crowned babbler *Malacopteron magnum*	R	-	✓	5	-	-	2	-	7
Scaly-crowned babbler *Malacopteron cinereum*	R	-	✓	3	-	-	2	-	5
Sooty-capped babbler *Malacopteron affine*	R	-	✓	-	-	-	-	-	-
Moustached babbler *Malacopteron magnirostre*	R	-	✓	-	-	-	-	-	-
Ferruginous babbler *Trichastoma bicolor*	R	-	✓	1	-	-	-	-	1
Abbott's babbler *Malacopteron magnum*	R	-	✓	-	-	-	-	-	-
Zosteropidae									
Oriental white-eye *Zosterops palpebrosus*	R	-	✓	-		-	-	-	-
Sturnidae									
Asian glossy starling *Aplonis panayensis*	R	1	✓	-	-	✓	-	✓	1
Common myna *Acridotheres tristis*	R	-	-	-	-	✓	-	✓	-
Hill myna *Gracula religiosa**	R	-	✓	✓	-	✓	-	✓	-

(Table 2: continued)

Turdidae									
White-rumped shama *Copsychus malabaricus**	R	1	-	2	✓	✓	-	✓	3
Rufous-tailed shama *Trichixos pyrropyga*	R	-	-	1	-	-	2	-	3
Magpie robin *Copsychus saularis*	R	1	✓	-	✓	✓	-	✓	1
White-crowned forktail *Enicurus leschenaulti*	R	1	-	-	-	-	-	-	1
Muscicapidae									
Mangrove blue flycatcher *Cyornis rufigastra*	R	15	-	-	-	-	-	3	18
White-throated jungle flycatcher *Rhinomyias umbratilis*	R	5	✓	1	-	-	-	-	6
Pied fantail *Rhipidura javanica*	R	19	✓	✓	✓	✓	18	5/✓	42
Bornean blue flycatcher *Cyornis superbus*	E	-	-	-	-	-	-	1	1
Large-billed blue flycatcher *Cyornis caerulatus*	R	-	-	-	-	-	-	1	1
Malaysian blue flycatcher *Cyornis turcosus*	R	-	✓	-	-	-	9	-	9
Hill-blue flycatcher *Cyornis banyumas*	R	-	-	-	-	-	1	-	1
Rufous-tailed jungle flycatcher *Rhinomyias ruficauda*	R	-	-	-	-	-	1	-	1
Black-naped monarch *Hypothemis azurea*	R	-	✓	2	-	-	5	-	7
Rufous-winged philentoma *Philentoma pyrhopterum*	R	-	✓	-	-	-	1	-	1
Brown-chested jungle flycatcher *Rhinomyias brunneata*	R	-	✓	-	-	-	-	-	-
Asian brown flycatcher *Muscicapa dauurica*	R	-	✓	-	-	-	-	-	-
Asian paradise flycatcher *Terpsiphone paradisi**	R	-	✓	✓	-	-	-	-	-

(Table 2: continued)

Dicaeidae								
Yellow-breasted flowerpecker *Prionochilus maculatus*	R	32	✓	✓	-	✓	5	8/✓	45
Orange-bellied flowerpecker *Dicaeum trigonostogma*	R	1	✓	✓	-	-	1	-	2
Scarlet-breasted flowerpecker *Prionochilus thoracius*	R	-	✓	-	-	-	-	-	-
Crimson-breasted flowerpecker *Prionochilus percussus*	R	-	✓	-	-	-	-	-	-
Yellow-rumped flowerpecker *Prionochilus xanthopygius*	E	-	✓	-	-	-	-	-	-
Scarlet-backed flowerpecker *Dicaeum cruentatum*	R	-	✓	-	-	-	-	-	-
Nectariniiidae									
Crimson sunbird *Aethopyga siparaja*	R	-	✓	-	-	✓	-	✓	-
Brown-throated sunbird *Anthreptes malacensis*	R	6	✓	-	-	-	-	2	8
Plain sunbird *Anthreptes simplex*	R	13	✓	-	-	-	-	-	13
Purple-naped sunbird *Hypogramma hypogrammicum*	R	18	✓	1	-	✓	5	4/✓	28
Ruby-cheeked sunbird *Anthreptes singalensis*	R	3	✓	-	-	-	2	3	8
Olive-backed sunbird *Nectarinia jugularis*	R	1	✓	-	-	✓	-	✓	1
Purple-throated sunbird *Nectarinia sperata*	R	-	✓	-	-	-	-	1	1
Temminck's sunbird *Aethopyga temminckii*	R	-	✓	-	-	-	-	-	-
Little spiderhunter *Arachnothera longirostra*	R	48	✓	1/✓	-	✓	22	13/✓	84
Spectacled spiderhunter *Arachnothera flavigaster*	R	-	✓	-	-	-	-	-	-
Estrildidae									
Dusky munia *Lonchura fuscans*	E	7	✓	-	-	✓	-	✓	7
Chestnut munia *Lonchura malacca*	R	-	✓	-	-	✓	-	✓	-

(Table 2: continued)

Passeridae									
Eurasian tree sparrow *Passer montanus*	R	-	✓	-	-	✓	-	✓	-
Total individuals		675	-	37	-	-	292	123	1125
Total species (mist-nets)		67	-	18	-	-	45	31	93
Total species (observation and vocalisation)		-	192	17	66	52	-	39	200
TOTAL		67	192	31	66	52	45	59	227

Note: Values indicate number of individuals caught using mist-nets while (✓) = species identified through visual observation and vocalisation. Distributional status of species (S) is denoted with resident (R), migrant (M), vagrant (V) and endemic (E). Data sources are represented as I (1996-1999) = Rahman and Tuen (2006), II (1998, 2001 and 2002) = Rahman (2004), III (2004) = Laman *et al.* (2006), IV (2005-2006) = Ahmad (2006), V (2008) = Ghani (2008), VI (2010-2011) = Amit *et al*. (2012), VII (2010) = Abdillah (2011). Totally protected** and protected species* are listed as in Schedule 1 of Wild Life Protection Ordinance (1998).

On the other hand, 111 species from 36 families were recorded in UNIMAS peat swamp forest. This was followed with 31 species and 14 families in LBNP. The sheer gap concerning the bird diversity and composition between Maludam and other sampling areas was evidently attributed by different sampling effort, study period and bird assessment technique.

However, another potential factor is probably the habitat condition or specifically the forest fragmentation-level factors. Here, the histogram for species/families are reaching plateau, therefore showing that smaller patches of peat swamp forest in UNIMAS campus may accommodate fewer bird species only (Figure 2). In contrast, MNP which hold significant continuous blocks of peat swamp forests (formerly loose-formation of Maludam Forest Reserve (16 593 ha), Triso Protected Forest (26,554 ha) and Saribas-Lupar Protected Forest) is able to support almost double number of species. Thus, species survival in fragmented patches is critically dependent on the landscape characteristics, overall size and quality of patches (e.g., area, plant composition, vegetation structure), as such proven by forest-interior species that can periodically withstand the habitat condition (Sodhi *et al*., 2008).

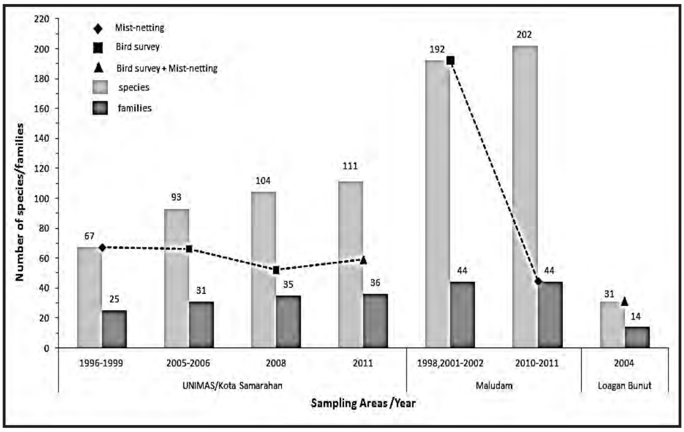

Figure 2: Comparative histogram indicating cumulative number of species/families with dashed-lines denoting total species recorded for each study and sampling year for respective peat swamp forests. Diamond, square and triangle markers indicate mist-netting, bird survey (observation and vocalisation) and combination of both techniques respectively.

Given the unequal sampling effort, methods chosen and varying degree of assessments, a direct comparison on the bird diversity should not be regarded absolute but in proximity of relative comparison. Hence, the species diversity in LBNP is most likely to be underestimated due to very short sampling duration (10 days) in a single trip. Furthermore, the overall 92 species from all three sites indicated higher species diversity (Laman *et al.*, 2006). This number is perhaps more reflective of the true diversity estimation. Considering the close proximity of respective sites, some important sightings, which include the Asian black hornbill *Anthracoceros malayanus*, Brahminy kite *Haliastur indus* and oriental darter *Anhinga melanogaster* are highly mobile and flexible in moving between different vegetation types. In relation to this, Smythies and Davison (1999) pointed out that peatland swamps with adjacent mixed dipterocarp forest may accommodate greater numbers of certain species, perhaps due to seasonal fruiting patterns.

As a whole, families with the most diverse species comprised of mainly forest-interior species such as Timaliidae- babblers (17 species), Cuculidae- cuckoos (15 species), Picidae- woodpeckers (13 species), Muscicapidae- flycatchers (13 species), Pycnonotidae- bulbuls (10 species) and Nectariniidae –sunbirds and spiderhunters (10 species). Of the species observed, 31 were migrants including most waterbirds (egrets, herons, bitterns, waders, plovers), wagtails, barn swallow *Hirundo rustica* and common kingfisher *Alcedo atthis* (see Table 2). The inclusion of high numbers of waterbirds and shorebirds species (Ardeidae- 11 species, Scolopacidae- 9 species and Charadriidae- 3 species) further designated peat swamp forest as permanent and alternative strong hold for thousands of migrating bird population (Minayeva, 2008). Two raptor species, the Oriental honey buzzard *Pernis ptilorhynchus orientalis* and Japanese sparrow-hawk *Accipiter gularis* are also common winter visitors to the coastal and lowland swamp forest from northeast Asian breeding grounds (Phillipps and Phillipps, 2009).

The selection of mist-netting method provided a good insight on the diversity and abundance of a understory bird population. The most abundant species is chestnut-winged babbler *Stachyris erythropthera* with 96 individuals followed by little spiderhunter *Arachnothera longirostra* (84 individuals), rufous-backed kingfisher, *Ceyx rufidorsus* (82 individuals), olive-winged bulbul *Pycnonotus plumosus* (75 individuals), stripe-tit babbler, *Macronous gularis* (55 individuals) and rufous-tailed tailorbird *Orthotomus sericeus*

(52 individuals). The high abundance strongly justified that most understory insectivores (*S. erythropthera, M. gularis* and *C. rufidorsus*) and small-bodied or poor flyers (*A. longirostra*) are dependent and highly adaptable in peat swamp ecosystems (Smythies, 1999). In another study conducted in Binyo peat swamp forest (near Bintulu), bird density in undisturbed peat swamp patches was estimated twice that of logged forest (Sheldon and Styring, 2011).

The significance of peat swamp forest can be highlighted by the presence of four Bornean endemics, most notably is the Bornean bristlehead *Pityriasis gymnocephala* and other common endemics such as Bornean blue flycatcher *Cyornis superbus*, Yellow-rumped flowerpecker *Prionochilus xanthopygius* and Dusky munia *Lonchura fuscans* (Table 2). Similarly, O'Brien and Fimbel (2001) also reported sightings on small flocks of Bornean bristleheads, Bornean blue flycatchers and yellow-rumped flowerpeckers in Malinau swamp forest, Kalimantan. In addition to this, 14 species were listed as totally protected species with 50 species categorised as protected species in Schedule 1 of Wild Life Protection Ordinance (1998) (Table 2). Among the list, the former includes the critically endangered Storm's stork *Ciconia stormi*, lesser adjutant *Leptoptilos javanicus*, white-bellied fish-eagle *Haliaeetus leucogaster*, Bornean bristlehead, black-naped tern *Sterna sumatrana*, cattle egret *Bubulcus ibis*, Pacific reef egret *Egretta sacra*, Blue-winged pitta *Pitta moluccensis*, hooded pitta *Pitta sordiala* and all five hornbill species. One vagrant species, the masked finfoot *Heliopais personata* which is currently absent from the Bornean bird list was only recorded in Maludam between January and April 2004 (Rahman, 2004; Hon, 2011).

Bird survival in peat swamp forest had continuously struggled with endless habitat pressures and degradation. For instance, peat swamps in Kota Samarahan had been dealing with land-clearing and draining for large scale urbanization since the 1990s (Rahman and Tuen, 2004). This was shown by the declining pattern of bird species observed since 2005 until recently (Figure 2). Likewise, the Maludam areas were pressurized by overexploitation of land conversions into oil palm estates (Schrevel, 2008). In LBNP, the major threats arise from extensive cultivation and wildlife hunting by the local community (Laman *et al.*, 2006). Elsewhere in Tanjung Puting National Park in Kalimantan, industrial-scale logging had been too massive and severe that the local and governing bodies are being kept powerless (Birdlife International, 2003).

CONCLUSIONS

On the basis of this review, we are able to summarize that peat swamp forests in Sarawak are high bird diversity areas, therefore should not be overlooked in terms of their role as important habitat for migrating waterbirds, critically endangered species and rare endemics. Comprehensive bird surveys should be updated annually to provide crucial data in monitoring possible changes in numbers of species and composition. In addition to this, future conservation efforts should also maintain and perhaps expand larger blocks of continuous peat swamp fragments available, as they are critical for bird survival.

ACKNOWLEDGEMENTS

We would like to thank the following contributors for providing important data from their respective works: Nurul Shuhada Abdillah, Muhd Ridzuan Ahmad, Shafini Ain Abdul Ghani, Baniazora, Angela and Charlie Laman.

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8

WILDLIFE CONSERVATION IN PEAT SWAMP FORESTS

J. Mohd-Azlan and Indraneil Das

> *"..if it is wet and hard to survey, it is a swamp..."*
>
> Magnussen (2012)

INTRODUCTION

Peat Swamp Forests (PSF) are important globally in terms of maintaining global carbon balance, providing reservoirs of fresh water, stabilizing water level, and buffering against saline intrusion. They are also reservoirs of biodiversity, and frequently support indigenous knowledge, and many have been declared as RAMSAR sites, especially for the conservation of waterfowl species (Sawal, 2003; Yule, 2010). Peat swamps have historically occupied vast tracks of Borneo (Anderson, 1964). Peat swamp forest in Sarawak faces the South China Sea to the west, with its inland boundaries formed by large and complex river systems. They can be classified into phasic communities, differentiating the forest patch based on species composition and vegetation structure (Anderson, 1961). For example peat swamps in the Ulu Baram region are considered to have six phasic vegetation communities, ranging from a structurally complex species-rich community around the edge of the peat dome to a species-poor ‘padang’ community on deep peat. However most peat swamps in Sarawak consist of Mixed Swamp Forest (MSF). Nearly all of the PSF in Sarawak have been extensively logged for their valuable timber (especially for high quality timber, such as ramin, (*Gonystylus bancanus*). Additionally, some of the Totally Protected Areas (TPA) are not free from illegal felling and hunting by local communities (Chai, 2005; Mohd-Azlan, 2004).

At present, only three blocks of Peat Swamp Forests remains, representing approximately 30% of the Totally Protected Areas system in Sarawak. The largest PSF block is in Maludam National Park (MNP). It was established in 2000 and is the most recently proclaimed totally protected peat swamp area in Malaysia. The other two PSF blocks are in Loagan Bunut National Park (LBNP) and in the Sungei Medalam basin. The PSF in LBNP covers about 7,000 hectares out of the total 10,736 hectares area of the Park. The PSF in the Medalam River basin has an area of 52,800 hectares and forms a small part of the Gunung Mulu National Park (Chai, 2005). These two National Parks are both located in the upper Baram basin in Miri Division. Established in 1991, LBNP is located between Sungei Tinjar and Sungei Teru, bordering the eastern and western side of the park, respectively. The lake can reach up to a maximum size of 650 hectares, and the water fluctuation observed throughout the year is in response to the change in water levels of the Tinjar and Baram rivers. The lake is almost dry during the month of June, which lasts up to five weeks. These three National Parks, including the 303,456 hectares declared as PFE, constitute approximately 60% of the protected

PSF in Sarawak (Chai, 2005). Together, these National Parks play an extremely important role in *in situ* conservation of the peat, at the state level, in fulfilling political, socio-economic and cultural targets and values, and in maintaining natural and ecological processes.

Peat Swamp Forest supports biological resources of global importance and harbour species from a variety of taxonomic lineages that have aesthetic or conservation values. Yet, much are being rapidly degraded and destroyed (Yule, 2010). Peat swamp forest is the main habitat for commercially important timber trees, such as *Gonystylus bancanus* (Ramin) and *Dactylocladus stenostachys* (Jongkong), Sepetir paya (*Copaifera palustris*), and four species of *Shorea,* including *Shorea albida*. In general, forest gaps are common in most areas, as a result of falling trees, clearing for trails, and over logging. At the lower canopy level, most peat swamp forests are dominated by *Pandanus andersonii*, several species of *Eugenia*, the herb *Hanguana malayana* (Bakong), and the fan palm *Licuala petiolulata* (Palas/Palah). Patches of elevated landscape is rather uncommon in lowland peat swamp forests. Exceptionally, the peat swamp of the Maludam Peninsular is of the raised bog type, and forms the single largest peat swamp dome in northern Borneo (Whitmore, 1984). The existing small hill forest such as Bukit Pelaku in MNP is rather unique and has logging history that resulted in disturbed forest with dense undergrowth, particularly in the south. Dense stands of invasive ferns such as *Dicranopteris* sp. and *Gleichenia* sp. are common in large forest gaps, especially near the summit. Dense undergrowth and shrubs with mosaics of pioneer tree species such as *Macaranga* are also observed in some parts of this forest. Emergent tree species are scattered along the ridge, but are not abundant. The middle and lower storey tree species are relatively denser in Bukit Pelaku, MNP. Other tree species noted on this hill are *Artocarpus anisophylus, Cratoxylum arborescens, Ilex cymosa, Durio* sp., *Eugenia* sp., *Gluta* sp., *Santiria* sp., *Brakenridgea* sp., *Ficus* sp., *Helicia* sp., *Palaquim* sp., *Blumeodendron* sp., and *Diospyros* sp., climbers such as *Connarus* sp., *Calamus* sp. and *Tetracera* sp. are also observed in this area.

This chapter highlights some terrestrial vertebrates (mammals, birds and herpetofauna) recognized as threatened and documented from peat swamp habitats, some of which can potentially be used as umbrella, keystone and/or flagship species for conservation.

MAMMALS OF CONSERVATION IMPORTANCE

Excluding members of the Chiroptera and Muridae, over 57 mammalian species have been recorded from the peat swamp forests in Malaysia (Sebastian, 2002). Compared to mixed dipterocarp forests, peat swamps appear not to support a great diversity of terrestrial mammals, especially representatives of frugivore guilds (or species dependent on fruits), presumably due to the low productivity in the forest type (Whitten *et al.,* 1984). The absence of megafaunal wildlife in this forest type is quite intriguing and warrants further research. Nevertheless, Bennett and Gombek (1991) recorded many endangered species of primates in the peat swamp forests of Sarawak, which include the orangutan (*Pongo pygmaeus*), proboscis monkey (*Nasalis larvatus*) and red-banded langur (*Presbytis melalophos*). MNP is the last stronghold for the red-banded langur, where they are known to subsist especially on fruits and leaves of peat swamp trees (Hon and Gumal, 2004).

Bornean orangutans are reported more abundant in low-lying forests (below 500 meters ASL) than in higher elevations. Water-logged forests and PSF produce more regularly larger fruits than dry dipterocarp forests and probably be a major factor for PSF to harbour the highest orangutan densities (Ancrenaz *et al.,* 2008). About 40 individuals of orangutan were reported in the Ulu Sebuyau area of MNP (Ancrenaz *et al.,* 2008).

In Sarawak, less than 1,000 individuals of proboscis monkey are thought to remain and their populations are distributed in patches (Meijaard *et al.,* 2008). Bennet and Sebastian (1998) suggested that proboscis monkeys are restricted to the coastal areas and areas near rivers because the interior areas have soils that are low in minerals and salts, which are important part of their diet. In MNP, the more uncommon primate species, including the red banded langur and the proboscis monkey are distributed in isolated pocket of peat swamp forests, compared to the more widespread *Macaca* species (e.g., long- and pig-tailed macaques; Hon and Gumal, 2004). Additionally, 60 species of mammals have been recorded in MNP, of which approximately 57% (n = 34) are small mammals. Surveys in Bukit Pelaku which is a small, elevated area in the MNP, have recorded approximately 25% of the total medium to large mammals found in Borneo. This indicates a low diversity of terrestrial large mammals in mixed dipterocarp forest surrounded by PSF. However, in dipterocarp forests adjacent to PSF, such as LBNP, large mammals appeared to be relatively common (compared to the isolated dipterocarp forest in MNP). Large mammals, such as the Bornean sun bear (*Helarctos malayanus euryspilus*), barking deer (*Muntiacus muntjak*) and sambar deer (*Rusa unicolor*) were recorded in habitats bordering the peat swamp of LBNP, especially the sambar which feeds on shrubs and grasses during the short dry period. Peat swamp forest appears to be an important habitat for the endangered flat-headed cat (*Prionailurus planiceps*) (Figure 1) (Wilting *et al.,* 2010; Cheyne and MacDonald, 2011). The cat's morphological features suggest its diet to be largely of fish, and thus its distribution being closely associated with wetland habitats (Medway, 1977; Payne *et al*. 1985). This species was recorded both in MNP and LBNP, where its habitat is protected (Gumal, 2010). The remaining populations of flat-headed cats are probably small, isolated, and probably increasingly utilizing polluted, turgid watercourses resulting from agricultural expansion. The flying fox (*Pteropus vampyrus natunae*) categorized as Near Threatened by the IUCN, 2011 (Bates *et al.,* 2008) forms large colonies mainly near lowland areas, including peat swamp forest (Mohd-Azlan *et al.,* 2001; Gumal, 2004). The flying foxes have been reported to utilize 20 families of trees (from 27 genera and 31 species) for roosting in the PSF (Gumal, 2004). Flying foxes are known to pollinate economically important trees and disperse large seeds over a long distance (Mickleburgh *et al.,* 1992). This keystone species was recommended for upgrade to inclusion in the protected species list in the Sarawak Wildlife Master Plan, 1996 and was later adopted in the 1998 Wildlife Protection Ordinance (WCS & SFD, 1996). Over-hunting for the wild meat and Chinese traditional medicine was suggested as the main reason for the rapid decline of flying foxes in Sarawak (Gumal *et al*. 1998). Three species of otters have been reported on Borneo. These otters are important indicator species of wetland environment. The hairy-nosed otter (*Lutra sumatrana*) is listed as endangered and is known to occur in a few localities of freshwater swamps in Borneo. The other two species, smooth-coated otter (*Lutrogale perspicillata*) and Asian small-clawed otter (*Aonyx cinereus*) are considered vulnerable and have wider distribution.

Figure 1: The flat-headed cat (*Prionailurus planiceps*) closely associated with aquatic habitat

BIRDS OF CONSERVATION IMPORTANCE

The bird fauna recorded in the PSF comprise approximately 38% of the overall Malaysian avifauna excluding seabirds. Over 200 species of birds have been recorded in the Peat Swamp Forests in Sarawak, which represents approximately 56% of the bird species reported on Borneo. Among the notable species observed in the PSF in Sarawak are the Chinese egret, *Egretta eulophotes* (VU), lesser adjutant stork, *Leptoptilos javanicus* (VU), Jerdon's baza, *Aviceda jerdoni* (LC), lesser fish-eagle, *Ichthyophaga humilis* (NT), short-toed coucal, *Centropus rectunguis* (VU), red-crowned barbet, *Megalaima rafflesii* (NT), hook-billed bulbul, *Setornis criniger* (VU), Bornean bristlehead, *Pityriasis gymnocephala* (NT), grey-headed babbler, *Stachyris poliocephala* (LC), ferruginous babbler, *Trichastoma bicolor* (LC), grey-breasted babbler, *Malacopteron albogulare* (NT), white-chested babbler, *Trichastoma rostratum* (NT), wrinkled hornbill, *Aceros corrugates* (NT), Asian black hornbill, *Anthracoceros malayanus* (VU), rhinoceros hornbill, *Buceros rhinoceros* (NT) and Malaysian blue flycatcher, *Cyornis turcosus* (NT). Species such as Storm's stork, *Ciconia stormi* and masked finfoot, *Heliopais personatus,* which are listed in the endangered category (Birdlife International, 2008) were also reported in the PSF in Sarawak. Many of these bird species are currently showing decreasing population trend primarily due to habitat destruction and anthropogenic pressures, including the conversion of forests to agriculture lands. The climate, topography and vegetation have attracted 18 Palaeartic migrants to the PSF in Sarawak, especially in the southern regions. Although PSF support lower understorey avifauna compared to lowland dipterocarp forest, they are important in supporting habitat-specific species and in providing feeding options for frugivores from surrounding matrices at sporadic intervals (Gaither, 1994), especially during periods when fruits are not abundant in adjacent forest habitats (Leighton and Leighton 1983).

REPTILES AND AMPHIBIANS OF CONSERVATION IMPORTANCE

The generalized amphibian fauna of peat swamps tend to be widespread across a swathe of habitats in the lowlands, and a majority (17 of 22; 77%) are in the Least Concern ('a taxon [that] does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa..') category. Two swamp frog species (*Limnonectes ingeri* and *L. malesianus*), both of which are large-growing and hunted for local consumption are in the Near Threatened ("A taxon [that] is close to qualifying for or is likely to qualify for a threatened category in the near future') category. A further amphibian species (*Pelophryne signata*) is listed in this category perhaps for its dependence on trees, and therefore, existence of some sort of forested habitat. The endotrophic tadpoles of this species develop in tree holes, and presumably require old growth or at least mature secondary forests. No threatened species of amphibians occur in the peat swamps of Borneo, and one, a caecilian, *Ichthyophis monochrous*, is classified as Data Deficient ("a taxon [for which there is] inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its range and/or population status") and is known from the peat swamps of Kota Samarahan on the basis of a single specimen collected.

Borneo's peatland reptiles, numbering 30 species, too show similar trends, with the predominance of widespread, lowland species. Excluding 12 species (43%) that are Not Evaluated ("a taxon [which has] not yet been evaluated against the criteria"), for lack of conservation assessment of most of the world's lizard species, seven of 28 species (25%) are in the Least Concern category. Nonetheless, significant populations of two threatened reptile species, the Malayan false gharial (*Tomistoma schlegelii*) and the Malayan black turtle (*Orlitia borneensis*), both classified as Endangered ("A taxon [for which] the best available evidence indicates ...[it to be] facing a very high risk of extinction in the wild") are found in such habitats (Stuebing *et al.,* 2006; Sharma and Tisen, 2000). An additional crocodilian species, *Crocodylus siamensis*, locally referred to as '*Buaya Badas hitam*' (= black peat swamp crocodile), is known from such habitats (see Cox *et al.,* 1993), and is placed in the Critically Endangered ("a taxon [for which] the best available evidence indicates [that it is] facing an extremely high risk of extinction in the wild") category in conservation assessments. Finally, two freshwater turtles, *Cuora amboinensis* and *Amyda cartilaginea*, classified as Vulnerable ("a taxon [for which] the best available evidence [suggests it] to be facing a high risk of extinction in the wild") are also known to occur in peat swamps. Both are harvested, the former as pets both in local longhouses and for sale in towns across Borneo and export to east Asian markets, the latter as a source of protein-rich food, chiefly for local consumption.

No amphibian or reptile species are known to be obligates of peat swamps on Borneo, but several (including the aquatic bufonid, *Pseudobufo subasper*; Lim and Ng, 1992 (Figure 2); Sukumaran *et al.,* 2006, and the crocodilian, *Tomistoma schlegelii*; Stuebing *et al.,* 2006) have important populations in such habitats. Plausibly some species of herpetofauna will be shown to be obligates of such habitats in the future, as the recent discovery of a widespread bufonid- *Ingerophrynus kumquat* (Das and Lim, 2001), close to the urban centre of Kuala Lumpur, suggests.

Figure 2: Aquatic bufonid (*Pseudobufo subasper*) considered a peat swamp specialist.

While *Tomistoma schlegelii* has been recorded from other habitats, such as lowland swamps, lakes and rivers (Figure 3) (Bezuijen *et al.,* 2010), many of the extant localities are within peat swamp regions (see Stuebing *et al.,* 2006). Nests of the species have been reported from mature peat swamp forests (Bezuijen *et al.,* 2001). A requirement of raised peat platforms was noted by Bezuijen *et al*. (2005), and with records of nesting presented by these authors from burnt swamp forest suggests some degree of tolerance for disturbed habitats.

Figure 3: The Malayan Gharial *(Tomistoma schlegelii),* a species restricted to Sundaland, that is largely restricted to peat swamp forests.

DISCUSSIONS

Peat swamp forests face the highest levels of deforestation with an average annual rate of 2.2% in south-east Asia, and representing approximately 5.0% of the annual forest loss in Sarawak (Miettinen *et al.,* 2011). Anthropogenic activities have reduced the extant and quality of peat swamps in the past three decades. Foremost is clear-felling for conversion of forest lands to oil palm plantation, a rather sensitive topic, vis-à-vis with current development planning policies. Fires are also prevalent in peat swamps, especially during the prolonged dry period of El Niño years, and many such events have been recorded in Borneo in the past decade. Their effects on the local wildlife species remain largely undocumented (except for individuals of turtles bearing fire-scars, see Jensen and Das, 2007).

Peat swamp forest adjacent to MDF provides habitat heterogeneity, additional protection as refugium and cover for various terrestrial mammals and potentially for many bird species from adjacent lowland forests, which are under great pressure from logging and development (Yule, 2010). It appears that the surrounding matrix habitats may have an effect on the composition of species in the PSF, this postulation, however, warrants further research. Peat swamp forest surrounded by several matrix types is likely to have different assemblage as structurally complex matrices may provide greater landscape connectivity. With increasing agricultural activities, such as expansion of oil palm plantations around protected areas, inclusion of adjacent mixed dipterocarp forests in the conservation plans for the PSF in Sarawak may be necessary to effectively maintain this habitat type and the diverse life forms it support. The continuing decline in the extent and quality of PSF in Sarawak will increasingly be a concern to the wildlife found in these areas. Consequently, loss of specialist species is likely to have major impacts on ecosystem function, particularly those species which have roles in seed dispersal and as top predators (Yule, 2010).

Our considered response to the peat swamp crisis can be summarized as follows: 1) initiate ecological studies to improve understanding of precise habitat requirements, tolerance of secondary habitats and response to fragmentation, 2) improvement of the management of protected areas that suffer encroachment, and 3) extend boundaries of protected areas with peat swamp forests to include adjacent non-peat habitat types and integrate them in management plans and strategies).

ACKNOWLEDGEMENTS

We are grateful to the Department of Zoology, Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, Sarawak Forestry Corporation and Sarawak Forest Department for supporting our research in Sarawak. MAJ was supported by research grant, FRGS-990/2013(31) & NRGS/1088/2013(02)). ID was supported by a research grant, UNIMAS 1/26/303/2002 (40). Our field assistants, Karen Jensen and Pui Yong Min, aided in data collection. Field work in Brunei was supported by the Brunei Museums Department and Universiti Brunei Darussalam, for which we remain grateful to Samhan bin Nyawa and Joseph K. Charles. Finally, we thank Antony Sebastian for sharing information and publications on his work in Kalimantan, and for commenting on the manuscript.

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Biodiversity of
Tropical Peat Swamp Forests of Sarawak

Peat swamps historically occupied vast areas of land and water in Sarawak State, East Malaysia. Yet, these environments remain poorly-known in terms of their biodiversity and potential for sustainable use. This volume is a compendium of papers on these topics, including the conservation importance of peat swamp forests; chemistry of humic substances of tropical peat, the Araceae of peat swamps; use of sago palm (*Metroxylon sagu*) to bolster national food security; assessment of infestation by endohelminth parasites of frogs at a degraded forest; the relationship between water quality and fish communities of blackwater environments; bird communities of peat swamp forests, and concludes a review of wildlife conservation, with emphasis of its megafauna, of this important habitat in Borneo.

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