UNIVERSITI PUTRA MALAYSIA

LITTERFALL, NUTRIENTS AND FISHERY PRODUCTION IN KUALA SIBUTI MANGROVE, MALAYSIA

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FSPM 2015 11

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By

MOHAMMED MUZAMMEL HOQUE

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2015

DEDICATION

To

My Father who passed away during my PhD study period,

My most beloved Mom, who is fighting against cancer,

My wife Nahid Sultana for years of love and care,

and

My sweet daughters Bushra and Rahma

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

LITTERFALL, NUTRIENTS AND FISHERY PRODUCTION IN KUALA SIBUTI MANGROVE, MALAYSIA

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August 2015

Chairman : Abu Hena Mustafa Kamal, PhD
Faculty : Agriculture and Food Sciences (Bintulu)

Research on ecological productivity of pristine mangroves in Sarawak is scanty. This study was carried out to determine some of the important attributes of ecological productivity, especiallly litterfall, nutrients release through decomposition, sediment productivity, nutrient inputs from different sources, fisheries diversity and production of undisturbed Kuala Sibuti mangrove, Sarawak, Malaysia from January 2013 to March 2014. Three sampling plots, each 100 m × 100 m (river mouth, middle and last part of the forest) were established considering the structure, density and topography of the mangrove to represent the whole forest for collection of data and information related to this study.

Annually 1640.82 g/m^2 dry weight of litterfall was estimated, of which *Rhizophora apiculata* contributed 92.94%, followed by *Xylocarpus granatum* (4.01%) and other species (3.05%). Total litterfall of both the species did not vary seasonally and the litterfall production of this forest was higher compared to other *R. apiculata* dominated tropical mangroves of the world. Monthly total litter standing crop correlated negatively (r=-0.58, p<0.05) with number of high tide that flooded, suggesting that tidal frequency determines the amount of litter remains on the forest floor. The decay constants (k) of almost all the litter components of the two species varied among the components and between the species. The half-life ($T_{50\%}$) and 95% lifespan ($T_{95\%}$) of non-leafy components such as flower, propagule, stipule and twig of both the species were remarkably high compared to the leaf. The slow decay rates of maximum litter components of the species positively correlated with the higher content of lignin, suggesting significant influence of lignin on the rate of litter decomposition. The order of nutrients release from the various litter components of the species was leaf > flower > propagule > stipule > twig.

The annual rate of tidal sediment accumulation in the mangrove was 0.93 g/cm^2. The monthly accumulation of sediments correlated positively (r=0.69) with the rate of monthly rainfall. The tidal sediments were relatively rich in texture, organic matter, organic carbon, cation exchange capacity and nutrients. The nutrient contents were also higher in the tidal borne sediments compared to the surface (0-5 cm) and deeper (30-50 cm) soils of the study area. In general, highly significant positive correlation between the sediment nutrients and corresponding nutrient contents in the components (leaf, stipule, flower, propagule, stem, bark and root) of *R. apiculata* and *X. granatum* trees,

saplings and seedlings indicates the nutritive roles of tidal borne sediments in the productivity of this mangrove ecosystem.

Nutrients of surface soil, especially C, N, P, K, Na and S correlated positively with the nutrients of deeper soil. Pore and river water nutrients (NH_4^+, NO_3^-, $PO_4^=$, K, Ca, Mg and Na) of this forest were higher in the dry season and NH_4^+, Ca, Mg and Na of pore water correlated positively with the nutrients of river water. Although the overall nutrient contents were higher in the surface soil, most of the nutrients, especially P, S, Mg and Na of deeper soil correlated positively with the corresponding nutrient contents of plant components of the two species, suggesting the plants uptake more nutrients from the root zone of the deeper soil. The lower C/N ratio is related to higher nutrition. Relatively lower C/N ratio was found in all the components of *R. apiculata* trees (47-104), saplings (42-81) and seedlings (41-60) than that of *X. granatum* trees (47-146), saplings (44-95) and seedlings (30-60) components. This suggests that the dominant species *R. apiculata* plays the important roles in the nutrient dynamics of Kuala Sibuti mangrove forest.

Kuala Sibuti mangrove estuary is relatively species rich in terms of fishery production and diversity, comprising 60 species from 32 families. Among all the species, *Coilia dussumieri* was the most dominant species (22.63%) followed by *Nemapteryx caelata* (11.85%), *Otolithes ruber* (7.85%) and *Ilisha elongata* (5.80%). The diverse species composition of fishery resources in this estuary could be due to favorable hydro-biological factors as well as enormous detritus and nutrients supplied from the mangrove forest. The findings of this study acknowledge that ecologically Kuala Sibuti mangrove is a highly productive ecosystem. The dominant species *R. apiculata* plays the key roles behind its productivity. The outcomes of this study would be useful for the scientific community to conduct further in depth research in various dimensions as well as to realize the importance of pristine mangrove forests.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

GUGURAN SISA, NUTRIEN DAN PRODUK PERIKANAN DI PAYA BAKAU KUALA SIBUTI, MALAYSIA

Oleh

MOHAMMED MUZAMMEL HOQUE

Ogos 2015

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Kajian mengenai produktiviti ekologikal paya bakau asli di Sarawak adalah kurang. Kajian ini telah dijalankan bagi menentukan sebahagian daripada kepentingan produktiviti ekologikal, terutamanya guguran daun, pelepasan nutrien melalui penguraian, produktiviti mendapan, input nutrien daripada sumber berbeza, kepelbagaian perikanan dan pengeluaran di paya bakau asli Kuala Sibuti, Sarawak dari Januari 2013 hingga Mac 2014. Tiga kawasan persampelan, setiap satu 100 m × 100 m (muara sungai, tengah dan hulu bahagian hutan) telah dilakukan dengan mengambilkira struktur, kepadatan dan topografi bakau mewakili keseluruhan hutan bagi pengumpulan data dan maklumat berkaitan dengan kajian ini.

Secara tahunan, 1640.82 g/m^2 berat kering guguran daun telah dianggarkan, yang mana *Rhizophora apiculata* menyumbangkan 92.94%, diikuti oleh *Xylocarpus granatum* (4.01%) dan spesis-spesis lain (3.05%). Jumlah guguran sisa bagi kedua-dua spesis tidak berbeza dari segi musim dan pengeluaran sisa bagi hutan ini adalah tinggi berbanding bakau tropika dunia yang dipenuhi oleh *R. apiculata*. Jumlah sisa dirian pokok pada setiap bulan adalah berhubungkait secara negatif (r=-0.58, p<0.05) dengan jumlah air pasang yang membanjiri, di mana kekerapan pasang surut air menentukan jumlah sisa tertinggal di atas permukaan lantai hutan. Pemalar bagi penguraian (k) bagi hampir semua komponen sisa bagi kedua-dua spesis adalah berbeza di antara setiap komponen. Separuh hayat ($T_{50\%}$) dan 95% jangka hayat ($T_{95\%}$) bagi komponen bukan daun seperti bunga, propagul, stipul dan ranting bagi kedua-dua spesis adalah berbeza sepenuhnya berbanding daun. Penguraian perlahan bagi komponen sisa yang maksima berhubungkait secara positif dengan kandungan lignin yang tinggi, menunjukkan pengaruh penting lignin terhadap kadar pereputan sisa. Turutan pelepasan sisa daripada berbagai komponen sisa dari spesis adalah daun > bunga > propagul > stipul > ranting.

Kadar tahunan pengumpulan mendapan pasang surut di paya bakau adalah 0.93 g/cm^2. Pengumpulan bulanan mendapan berhubungkait secara positif (r=0.69) dengan kadar hujan bulanan. Mendapan pasang surut secara relatif kaya dengan tekstur, bahan organik, organik karbon, keupayaan penukaran kation dan nutrien. Kandungan nutrien adalah tinggi pada mendapan pasang surut berbanding dengan permukaan (0-5 cm) dan kedalaman (30-50 cm) tanah di tempat kajian. Secara amnya, hubungkait positif yang signifikan adalah tinggi di antara mendapan nutrien dan kandungan nutrien dalam komponen (daun, stipul, bunga, propagul, batang, kulit kayu dan akar) pokok, pokok

muda dan anak pokok *R. apiculata* and *X. granatum* menunjukkan fungsi mendapan pasang surut dalam pengeluaran ekosistem paya bakau ini.

Nutrien pada permukaan tanah, terutamanya C, N, P, K, Na dan S berhubungkait secara positif dengan nutrien pada kedalaman tanah. Nutrien dan liang air sungai (NH_4^+, NO_3^-, $PO_4^=$, K, Ca, Mg and Na) hutan ini adalah tinggi pada musim kering dan NH_4^+, Ca, Mg and Na pada liang air berhubungkait secara positif dengan nutrien air sungai. Walaupun seluruh kandungan nutrien adalah tinggi pada permukaan tanah, kebanyakan nutrien terutamanya P, S, Mg dan Na pada tanah dalam berhubungkait secara positif dengan kandungan nutrien pada komponen pokok bagi kedua spesis, mencadangkan pengambilan nutrien tanaman adalah lebih pada kedalaman tanah melalui zon akar. Kadar C/N adalah berkaitan dengan tinggi nutrisi. Rendah kadar C/N didapati dalam semua komponen pokok *R. apiculata* (47-104), pokok muda (42-81) dan anak pokok (41-60) berbanding komponen pokok *X. granatum* (47-146), pokok muda (44-95) dan anak pokok (30-60). Ini menunjukkan penguasaan spesis *R. apiculata* yang memainkan peranan penting dalam dinamik nutrien hutan paya bakau di Kuala Sibuti.

Paya bakau di kawasan muara Kuala Sibuti secara dasarnya adalah pelbagai dan kaya dari segi pengeluaran sepsis perikanan yang terdiri daripada 60 spesis daripada 32 famili. Di antara semua spesis *Coilia dussumieri* adalah paling dominan (22.63%) diikuti oleh *Nemapteryx caelata* (11.85%), *Otolithes ruber* (7.85%) dan *Ilisha elongata* (5.80%). Komposisi pelbagai spesis bagi sumber perikanan di muara ini kemungkinan disebabkan faktor hidro-biologikal yang sesuai dan juga detritus dan nurtien yang dibekalkan oleh hutan paya bakau. Penemuan kajian ini mengakui paya bakau Kuala Sibuti adalah ekosistem yang produktif. Spesis yang dominan *R. apiculata* memainkan peranan penting di sebalik produktiviti ini. Hasil daripada kajian ini akan berguna kepada para saintis bagi menjalankan kajian lanjut~~an~~ dalam berbagai dimensi dan juga kesedaran tentang kepentingan hutan paya bakau asli.

ACKNOWLEDGEMENTS

All praise and admiration to the Almighty Allah (SWT), the most merciful and benevolent, who has given me the strength and ability to deal this challenge at this middle stage of life.

I would like to release my deep sense of gratitude to my supervisor Dr. Abu Hena Mustafa Kamal for his cordial assistance from the beginning and continuous guidance throughout the PhD endeavor. Special thanks are due to the committee members Dr. Mohd Hanafi Idris and Associate Prof. Dr. Osumanu Haruna Ahmed for their invaluable suggestions and professional guidance to accomplish this task.

I would also like to acknowledge the Dean, Associate Prof. Dr. Nur Ashikin Abdullah and all the faculty members of UPMKB for their cordial support and suggestions, whenever I needed. Special thank also goes to my friend Dr. A.T.M. Rafiqul Hoque, Post-Doctoral Fellow, JSHP and Dr. Tapan Kumar Nath, Associate Professor, Nottingham University, Malaysia for their cordial and critical suggestion related to my research.

My sincere appreciation goes to Dr. Huck, Latifah, Saifullah, Khursid, Ali, Kaleem, and Hasmidah for their cordial help, advice and suggestions. My heartfelt thanks and gratefulness to Md. Masum Billah, who really helped me during the analysis of data and interpretation. I am also thankful to lab assistants Ms. Elizabeth, Mr. Arni, Mr. Awang for their very cordial cooperation during lab works.

Field experiments and *in situ* data collection in the difficult working environment of pristine mangrove forest would not have been possible without the magnificent assistance of Mr. Rozi and his brother of Kuala Sibuti village.

It will be really ungratefulness, if I would not acknowledge our most respected Bhabi Mrs. Sadia Binte Hossain (wife of my supervisor) for her inherent role and encouragement during the course of study.

I am grateful to Ministry of Science, Technology and Innovation (MOSTI), Malaysia for providing necessary funding (E-Science; Project No. 04-01-04-SF1422) and also to UPM for providing Graduate Research Assistance (GRA) fellowship to make possible this study.

My father who was the main encourager to complete my PhD, and passed away in the middle of my study, is highly acknowledged. Finally, I would like to thank my mom, brothers, my wife, father/mother in laws, brother in law and his wife, for their love and encouragement which helped pursuing me passed through this long journey. I would also like to express my humbly apology to those persons, who helped me but could not remember to acknowledge in my narration here.

I certify that a thesis examination committee has met on 05/08/2015 to conduct the final examination of Mr. Mohammed Muzammel Hoque on his thesis titled ‘Litterfall, Nutrients and Fishery Production in Kuala Sibuti Mangrove, Malaysia’ in accordance with the Universities and University College act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 march 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophometer
AIL	Acid-insoluble Lignin
ASL	Acid-soluble Lignin
ANOVA	Analysis of Variance
˚C	Centigrade
CAP	Community Analysis Packages
CEC	Cation Exchange Capacity
cm	Centimeter
D	Margalef richness
DBH	Diameter at Breast Height
DOE	Department of Environment
FAO	Food and Agriculture Organization
FPOM	Fine Particulate Organic Matter
Govt.	Government
g/cm^2	Gram per centimeter square
H´	Shannon diversity
ha	Hectare
Int	Intermediate
J´	Peilou evenness
K. Sibuti	Kuala Sibuti
mg/g	Milligram per gram
Mg/L	Milligram per litre
mS/cm	Mili Siemens per centimetre
NTFP	Non Timber Forest Products
SOM	Soil Organic Matter
UNEP	United Nations Environmental Program
UPM	Universiti Putra Malaysia
UPMKB	Universiti Putra Malaysia Kampus Bintulu
US$	United States Dollar
t/ha	Tonnes per hectare

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Mangroves are the only woody halophytes and unique ecosystems that are generally found between the confluence of land and sea, especially in the tropical and sub-tropical regions (Kathiresan and Bingham, 2001; Alongi, 2002; Polidoro *et al*., 2010). They grow in such environment where other species generally do not grow and they have the tolerance capacity to cope with the harsh environments with high temperature, extreme tide, high salinity, strong winds, muddy and anaerobic soils (Kathiresan and Bingham, 2001). To survive in such harsh and extreme environments, they are enriched with special morphological and physiological adaptation characters such as aerial (prop, knee and plank) roots, pneumatophores, viviparous embryos, water-dispersed propagules, highly nutrient retention mechanism which are generally very rare in other plants (Kathiresan and Bingham, 2001; Saint-Paul and Schneider, 2010; Krauss *et al*., 2014).

Mangrove forests are considered as one of the most productive ecosystems in the tropic and have multiple roles and functions (Karami *et al*., 2009). They have various functions such as ecological, environmental, socioeconomic and physical which contribute to the stability of biodiversity, coastlines and communities live in the surrounding (Rambok *et al*., 2010; Saint-Paul and Schneider, 2010; Kathiresan, 2012). They protect and stabilize coastlines, and serve as natural barriers against strong winds including floods, sea level rise, coastal erosion, cyclone and tsunamis (Kathiresan, 2012; Krauss *et al*., 2014). They also play key roles for trapping of sediments and recycling of nutrients within and nearby aquatic ecosystem (Alongi, 2002; Kathiresan, 2012). Mangroves are the essential source of forest and non-timber forest products (NTFP) such as timber, charcoal, fuel wood, honey, wax, fodder, pulp, thatching materials and medicine (Field, 1995; Kathiresan, 2012). They also serve as nursery and breeding ground for commercial and artisanal fishery resources (Kathiresan and Bingham, 2001; Franco-Gordo *et al*., 2003; Akin *et al*., 2003; Huxham *et al*., 2004). Mangroves export detritus and nutrients into nearby systems that form the food base of numerous marine organisms which in turn support valuable near shore fishery resources (Sasekumar *et al*., 1992). It has been found that, around 80% of global fish are directly or indirectly reliant on mangroves (Sullivan, 2005; Ellison, 2008). They have the buffering capacity to stop storms, flooding, and provide enormous benefits and values to human beings and other marine organisms (Garcia *et al*., 2014). Moreover, mangroves are the potential sources of carbon (Golubic, 1973; Potts, 1979; Grimsditch, 2011), aquaculture and place for eco-tourism (Kathiresan and Bingham, 2001). The value of mangrove forest in regards to biomass production is also high as compared to other plant community (Rodriguez and Feller, 2004). The economic valuation of mangroves forests is estimated from 200,000 to 900,000 US$ km^2/year (UNEP-WCMC, 2006). The productivity of mangroves is 25 folds higher compared to paddy cultivation (Kathiresan, 2012).

There are about 15.2 million hectares of mangrove forests around the world (FAO, 2007). These forests are distributed in almost 124 countries, covering an area of about 1% of the world (Saenger, 2002). Out of total mangroves forests, 37% are in Asia, 27.2% in North, Central and South America, 21% in Africa and 12% in Australia, New Zealand, South Pacific Islands and Papua New Guinea (FAO, 2007; Sandilyan and Kathiresan, 2012). Around 60% of the world mangroves belong to ten countries including Malaysia (FAO, 2007). Malaysia contributes about 4% of the world mangroves and placed at the 6^{th} position in terms of area coverage (FAO, 2007). There are about 577, 500 ha of mangrove forests in Malaysia (Jusoff, 2013), which cover less than 2% of the total land area of the country (Shukor, 2004). The mangroves of Malaysia are under the jurisdiction of different states forest department and the major portions of mangroves are in Sabah (59%), Sarawak (23%) and Peninsular Malaysia (17%) (Jusoff, 2013). These mangroves are mostly distributed along the west coast of Peninsular Malaysia, at the estuaries of Sarawak, Rejang delta, Trusan-Lawas and along the east coast of Sabah (Chan, 1987; Latif and Faidah-Hanum, 2014).

Out of numerous attributes of mangroves ecological productivity, some of the most important attributes are litterfall and nutrients release through decomposition, nutritive roles of tidal borne sediments, nutrients inputs from different sources, nursery and breeding ground for fishery resources are remarkable. Litterfall is the function and indicator of primary productivity and important for within stand nutrient cycling, and exports of nutrients and organic detritus to the adjacent estuarine ecosystem (Gong and Ong, 1990; Ashton *et al*., 1999). It has significant importance on the detritus based food webs in the coastal environment as well as coastal fisheries (Odum and Heald, 1975; Lee, 1995). However, the amount of nutrients and organic matter that transport from the mangroves to adjoining aquatic ecosystem are associated with the rate of litter decomposition (Valiela *et al*., 1985; Twilley *et al*., 1986; Roberston, 1988; Chale, 1993; Kathiresan, 2012). Apart from this, nutrient cycling within mangrove ecosystem (Lu and Lin, 1990; Steinke *et al*., 1993), mangroves tree productivity and adjoining food chain (Ashton *et al*., 1999) are completely depends on the rate of nutrients and organic matter release during the process of decomposition. Therefore, decomposition process studies are necessary to estimate the contribution of mangroves in regards to nutrient recycling within as well as adjoining estuarine ecosystems.

Mangroves are frequently inundated by tidal action, while numerous materials are exchanged within mangroves and adjacent aquatic ecosystems (Ye *et al*., 2011). Mangroves forest floor are generally flooded by tidal water during high tide and these tidal water carry enormous sediments and nutrients to the mangroves in the form of dissolved and particulate matter. These tidal sediments are rich in nutrients and play significant roles in the productivity and nutrient dynamics of mangrove ecosystem (Mackey and Hodgkinson, 1995).

Nutrients in plants are interlinked with the soil and water characteristics which control the growth, composition and distribution of species (Alongi *et al*., 1993; Ukpong, 1994). Optimum amounts of nutrient availability are the most important factors that have noteworthy roles in regards to forest structure and productivity of mangroves (Reef *et al*., 2010). Plants uptake available form of nutrients from the soil and then translocate to different components. These nutrients are essential for different physiological function, normal growth and metabolism of plants or to complete life cycle (Jones *et al*., 1991; Marschner, 1995). Therefore, it is important to measure, compare and find out the relationship of soil, water parameters and nutrients in regards to forest health, productivity and nutrient dynamics of a particular mangrove ecosystem.

Besides, mangrove dominated estuary is a highly productive ecosystem as a nursery, breeding and feeding ground for fishery resources (Akin *et al*., 2003; Huxham *et al*., 2004). Most of the estuarine fishery resources are directly or indirectly dependent on the detritus and nutrients which are derived from the mangroves. Therefore, litterfall and nutrients release through decomposition, tidal sediment nutrients, nutrients of soil, water and plants are interlinked in a dynamic mangrove ecosystem and have significant roles and influence on the diversity and productivity of estuarine fishery resources.

1.2 Research Problem

In spite of versatile roles and functions, globally mangroves are under heavy pressure. Despite the increasing recognition of the need to conserve mangroves, losses are continuing. Around 35% of the world mangroves were lost in last two decades mainly in 1980s and 1990s, of which 26% losses were due to firewood and timber production (Valiela *et al*., 2001). Moreover, worldwide, 38% of mangroves were lost due to the conversion of mangroves to shrimp culture along with other aquaculture activities that account for another 14% mangroves loss (Ellison, 2008). Currently, mangroves are disappearing at the rate of 1% per year worldwide (FAO, 2003; 2007); however, in another study it is estimated from 2-8% per year (Miththapala, 2008). As a result of human pressure and activities, many mangrove species are at the verge of extinction (Polidoro *et al*., 2010). In recent years, the human impact on mangroves has increased and 50-80% forests cover have been disappeared in many countries over the last 50 years (Macintosh *et al*., 2011). The present trend of mangroves deterioration is expected to continue or accelerate unless proper conservation efforts are undertaken considering the mangroves as valuable resource (Alongi, 2002). Moreover, mangroves might functionally disappear within 100 years, if the present trends continue (Duke *et al*., 2007). The increasing threats and human pressure on the mangrove resources make the situation complex; hence more research works are essential emphasizing the ecological significance and attributes of mangroves as a baseline and valuable information of an ecosystem.

Likewise other countries, the loss of mangroves in Malaysia are also not different especially from 1973 to 2000, while around 111,046 ha of mangroves had been disappeared and found to be a bit higher considering the average global loss of mangroves (Chong and Sasekumar, 2002). At that period, although the overall loss is about 16%, some of the states (Johor, Selangor, Negeri Sembilan and Terengganu) lost around 30-70% of their total mangroves areas (Chan *et al*., 1993; Alongi, 2002). The destruction of mangroves in Malaysia is mainly due to the construction of sea ports, airport, industrial estate as well as conversion to aquaculture and agricultural land (Ong, 1982). For converting mangroves forests into other land uses such as for aquaculture, housing estate, planting rice, palm oil and other development projects, Sarawak had lost around 24% of its pristine mangroves over the past 30 years (Anon, 2008). The conversion of peat swamp forests to other land uses affect the peat and impair its functions (Peter, 2003; Firdaus *et al*., 2010). The losses of mangroves result in serious ecological, environmental and economic constraints in the coastal regions of some estates. These losses lead to long term impacts on fishery resources, loss of detritus, flora and fauna and even in the acceleration of coastal erosion (Saenger *et al*., 1983; FAO, 1994). Because of the aforementioned losses, it is assumed that the losses may impart negative effect on the ecological process of mangroves ecosystem that may effect on the coastal productivity. Litter exchange and biogeochemistry of mangroves may also be hampered along with the nutrient exchange from the mangrove forests to nearby coastal ecosystems (Twilley and Chen, 1997).

Despite of versatile function, exceptional and unique characteristics and variations of these functions and characteristics in regards to geographical location and changing environment, knowledge on the ecological processes of mangroves are still inadequate worldwide (UNEP-WCMC, 2006). Moreover, in spite of versatile importance of mangroves in regards to ecological services, very scarce information are available in Malaysia, especially in Sarawak, where pristine and undisturbed mangroves are found along the coastlines (Kasawani *et al*., 2007; Latif and Faidah-Hanum, 2014; Wan Juliana *et al*., 2014). But no studies have yet been conducted on the ecological roles especially on primary productivity, sedimentation, nutrient dynamics and mangroves-fishery linkages of an undisturbed and matured forest of Sarawak, Malaysia. This leads to incomplete understanding of mangrove function in Sarawak, Malaysia.

Worldwide researches on mangroves are diverse (Krauss *et al*., 2014). For example, some of the researches are conducted on different aspects of mangroves such as soil and water physiological characteristics (Tam *et al*., 1995; Ashton and Macintosh, 2002), standing biomass (Komiyama *et al*., 2000), productivity (Day *et al*., 1996; Ye *et al*., 2011), litter production (Sharma *et al*., 2012; Ye *et al*., 2013; Abu Hena *et al*., 2015), litter decomposition (Hossain and Othman, 2005; Imgraben and Dittmann, 2008; Dewiyanti, 2010; Oliveira *et al*., 2013), nutrient dynamics (Sanchez-Andres *et al*., 2010; Hossain *et al*., 2014). Interestingly, almost all of the litter decomposition study of mangroves conducted worldwide was on leaf litter decomposition. Though leaf is the major components of litters and most of the cases it is around 40-70%, it does not cover the rate of total litter decomposition in a mangrove ecosystem. Because non-leafy components such as flowers, propagules, stipules and twigs are also part of litters and might have significant roles in the long term productivity and nutrient dynamics of mangrove ecosystems. Moreover, tidal borne sediments are an important source of nutrients to the mangrove ecosystem (Boto, 1982; Aksornkoae, 1993). However, almost all the studies related to sediments are on geochemistry, trace metals and pollution control, and research on productive roles of tidal borne sediments are less. On the other hand, considering the major ecological processes of an undisturbed mangrove is also found very few to understand the overall function of pristine mangroves.

Considering the global scenario, the progress of research, especially for some of the important states of Malaysia is also not adequate. Most of the researches in Malaysia are on the mangroves of Peninsular Malaysia, although Sarawak and Sabah are enriched with numerous pristine Mangroves (Saifullah *et al*., 2014). The researches are mostly on sustainably managed Matang mangroves such as standing biomass, productivity and litter dynamics (Gong *et al*., 1984, Ong *et al*., 1985; Putz and Chan, 1986), nutrient flux (Gong and Ong, 1990), litter decomposition (Japar Sidik, 1989, Hossain, 2004). Some partial researches were also conducted on the ecological processes of Sarawak mangroves such as carbon sequestration (Arianto, 2014), water characteristics (Rosli *et al*., 2010; Saifullah *et al*., 2014), Soil properties (Rambok *et al*., 2010), heavy metals in mangrove sediments (Billah *et al*., 2014), litterfall (Othman, 1989), species diversity and composition (Ashton and Macintosh, 2002; Kaleem *et al*., 2015). Therefore, research on ecological roles and productivity of Sarawak mangroves is few; however, for effective management, an understanding of ecological process is essential (Ashton and Macintosh, 2002; Latif, 2012; Latif and Faridah-Hanum, 2014).

1.3 Significance of the Study

Globally, the overall services of mangroves are well documented and these services vary due to geographical location, species composition, density, age of stand, climatic and edaphic factors, and also due to whether it is planted, undisturbed or pristine in nature (Duke *et al*., 1998; Alongi, 2002). Therefore, it is essential to determine the regional status or site specific services of mangroves to quantify and evaluate its status for the sustainable conservation and management in future. Although, economic and environmental services of mangroves are prioritized than that of ecological services, ecological services have numerous direct and indirect benefits. Besides, economic and environmental services are inter-linked with the ecological services of an ecosystem. Therefore, for a systematic study, at first, it is pre-requisite to determine the ecological services of an ecosystem that will be helpful to evaluate the economic and environmental services of that ecosystem, considering the ecological services as baseline and valuable information (Ashton and Macintosh, 2002). On the other hand, the productivity of mangrove forests depend on overall functions as well as inter-relations among the various components of ecological processes such as productivity of plant materials, soil-water and plants inter-relation, productive and nutritive roles of sediments, nutrient dynamics within and nearby aquatic ecosystems, production of fishery resources which are dependent on the mangrove based food detritus.

Kuala Sibuti mangrove, the study area is an undisturbed mangrove forest of Sarawak (Saifullah *et al*., 2014) dominated by *Rhizophora apiculata* (Gandaseca *et al*., 2011; Kaleem *et al*., 2015). Being an undisturbed and matured forest, it was hypothesized that the ecological roles of this forest could be different which need to be explored.

Therefore, considering the aforementioned research works, global and regional significance and recommendations of the various researchers, the most important ecological and productive roles of mangroves such as litterfall and nutrients release through decomposition, sediment productivity, nutrient inputs from different sources, fisheries diversity and production were emphasized for the purpose of the present study. Hence, the findings of this study would be helpful for the scientists especially ecologists, planners, decision makers, conservationists and the development practitioners to conduct further in depth research in other various dimensions as well as to formulate an effective conservation management plan (CMP) considering the ecological significance of the area.

1.4 Objectives of the Study

Considering the stated research problems, the overall goal of the present study was to explore the productive ecological roles of an undisturbed mangrove forest of Sarawak, Malaysia.

The specific objectives were:

1. To quantify the litterfall production and nutrients release through decomposition in Kuala Sibuti mangrove forest;

2. To determine the nutrition of tidal borne sediments in the study area;

3. To observe the seasonal pattern and productivity of nutrients in the study area; and

4. To assess the diversity and productivity of fishery resources in Kuala Sibuti mangrove estuary.

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