DISSOLVED ORGANIC MATTER AND ITS RELATIONSHIP TO MACROPHYTES AND FISH ASSEMBLAGES IN THE LOWER KINABATANGAN RIVER CATCHMENT, SABAH, MALAYSIA

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DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries, and references, which have been duly acknowledged.

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ABSTRACT

Dissolved organic matter (DOM) is an important source of energy, which aquatic organisms rely heavily on for their survival. The significance of DOM toward the aquatic ecology and its influence on aquatic organism like macrophytes and fish assemblages has not been studied in Lower Kinabatangan River (LKR) Catchment, Sabah, Malaysia. This study was carried out from October 2015 till May 2016, at different types of land use; oil palm plantations (OP), secondary forest (SF) and mixed vegetation (MV). A total of 180 water samples were collected to characterize DOM. Spectroscopic analysis was applied to characterize the DOM and interpreted using discriminant analysis (DA). DA of DOM between land use indicates that pH was dominant at MV and dissolved organic carbon (DOC), dissolved nitrogen (DN), terrestrial-like and microbial processed of DOM (peak C & M) with low molecular DOM (ratio of Peak C/a340) were dominant in OP meanwhile absorbance coefficient (a_{340}) indicates allochthonous DOM was dominant in SF. Conversely, temperature, conductivity, DOC, absorption coefficients (a_{340}) and DN showed significant seasonal variation. DOM constituent at OP highly influence with microbial degraded DOM enhanced by DN during wet period while dry period (March 2016) the DOM highly influence with photodegradation enhanced by temperature as exposure of surface water to sunlight. A total of 777 individuals of fish (19 species from 11 families) caught using gill nets with mesh size of 50 mm, and macrophytes from 22 families with 25 species were recorded by using line transect and quadrat method in LKR. Subsequently, employment of canonical corresponded analysis (CCA) (Monte Carlo $p<0.05$) at LKR showed emergent macrophytes at SF significantly associates with humic substances and aromaticity of DOM, in contrast to OP, the free floating invasive species associates positively with high microbial metabolism and low DO concentration. The tolerable fish species able to adapt wider range of DOC concentration meanwhile the peak B and temperature show a negative correlation with *Labiobarbus sabanus* taxa. The findings suggest that changes in land use and seasonality affect the concentration of DOM in river environment, which in turn causes total alteration to the abundance and diversity of fishes compared to macrophytes.

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ABSTRAK

BAHAN ORGANIK TERLARUT DAN HUBUNGKAIT ANTARA TUMBUHAN AIR DAN IKAN DI SUNGAI KINABATANGAN, SABAH, MALAYSIA

Bahan organik terlarut (DOM) adalah sumber tenaga yang penting untuk kelangsungan hidup organisma akuatik. Kepentingan DOM terhadap ekologi akuatik dan pengaruhnya terhadap organisma akuatik tidak dikaji di kawasan Sungai Kinabatangan (LKR), Sabah, Malaysia. Kajian ini dijalankan dari bulan Oktober 2015 hingga Mei 2016, di pelbagai jenis penggunaan tanah; ladang kelapa sawit (OP), hutan sekunder (SF) dan tanaman bercampur (MV). Sejumlah 180 sampel air di ambil untuk menentukan kepekatan DOM. Spectroscopic analysis digunakan untuk mencirikan DOM dan ditafsirkan menggunakan Discriminant Analysis (DA). Perbandingan DOM antara penggunaan tanah menunjukkan bahawa pH dominan di MV dan karbon organik (DOC), nitrogen terlarut (DN), DOM daripada darat dan diproses oleh mikroba (Peak C & M) serta saiz DOM molecular terkecil dan terbaru (ratio of Peak C/a340) *dominan di OP, manakala pekali penyerapan (a_{340}) merupakan organic terlarut dalam air sungai dominan di SF. Sebaliknya, suhu, konduktiviti, DOC, pekali serapan (a340), DN menunjukkan variasi bulan persampelan. DOM daripada sumber darat di OP sangat berpengaruh dengan metabolism mikroba yang dipertingkatkan oleh DN semasa tempoh basah manakala pada tempoh kering (Mac 2016) DOM sangat berpengaruh dengan photodegradation dipertingkatkan oleh suhu hasil pendedahan permukaan air daripada cahaya matahari. Sejumlah 777 individu ikan (19 spesies dari 11 famili) ditangkap melalui pukat, bersaiz 50 mm, dan 22 famili dengan 25 spesies tumbuhan air dicatatkan mengunakan kaedah transek and quadrat di LKR. Canonical Corresponded Analysis (CCA) (Monte Carlo $p<0.05$) di LKR menunjukkan tumbuhan air di SF mempunyai korelasi dengan bahan humic dan aromacity DOM, berbeza dengan OP, spesies invasif terapung dikaitkan secara positif dengan metabolisme mikrob yang tinggi dan kepekatan DO rendah. Spesies ikan bertolenrasi boleh menyesuaikan kepekatan DOC yang lebih luas manakala Peak B dan suhu menunjukkan korelasi negatif dengan taxa Labiobarbus sabanus. Penemuan perubahan dalam penggunaan tanah dan musim mempengaruhi kepekatan DOM menyebabkan perubahan kepada kepelbagaian ikan berbanding dengan tumbuhan air.*

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LIST OF ABBREVIATIONS

a_{254}	-	Absorption coeffient at wavelength 254 nm
a_{340}	-	Absorption coeffient at wavelength 340 nm
β/a	-	Freshness index
C	-	Carbon
CCA	-	Canonical Correspondence Analysis
CDOM	-	Chromophoric/coloured DOM
CPOM	-	Coarse Particulate Organic Matter
DA	-	Discriminant Analysis
DOC	-	Dissolve Organic Carbon
DO	-	Dissolved Oxygen
DN	-	Dissolved Nitrogen
DOM	-	Dissolved Organic Matter
EEM	-	Excitation-Emission Matrix
EOC	-	Extracellular Organic Carbon
FI	-	Fluorescence Index
FPOM	-	Fine Particulate Organic Matter
GF/F	-	Glass microfiber filter
HDPE	-	High-density polyethylene
IPCC	-	Intergovernmental Panel on Climate Change
LDOM	-	Labile Dissolved Organic Matter
MV	-	Mixed Vegetation
OP	-	Oil Palm Plantation
OM	-	Organic Matter
Pg	-	Petagram (unit)
POC	-	Particulate Organic Carbon
RDOM	-	Refractory Dissolved Organic Matter
$S_{275-295}$	-	Spectral slope for interval of 275 to 295 nm
SF	-	Secondary Forest
SPSS	-	Statistical Package for Social Sciences.
SOM	-	Soil Organic Matter
$SUVA_{254}$	-	Specific UV-Visible absorption at 254 nm
QIIME	-	Quantitative Insights into Microbial Ecology
TDS	-	Total Dissolved Solids
TOC	-	Total Organic Carbon
TOM	-	Total Organic Matter
TSS	-	Total Suspended Solids
UV	-	Ultra-Violet
UV-Vis	-	Ultraviolet-visible absorbance spectroscopy

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Tropical wetlands and freshwaters perform about 40% for ecosystem functions and services. Owing to the fact that tropical wetlands usually receive high solar radiation and rainfall throughout the year, in which contributes to the flourishment of the diverse biological community (Zedler and Kercher 2005). However, throughout the twentieth century till present, tropical wetlands are rapidly shrinking as a result of conversion into the agricultural plantation and urban developments (Donald 2004; Koh and Wilcove 2008; Turner *et al.* 2008; Sayer *et al.* 2012; Savilaakso *et al.* 2014). In Malaysia, about 8% of the total wetland area has been converted into mono-cultured crop plantations such as oil palm and rubber plantations. The largest oil palm planting state in Malaysia is Sabah, contributing to economic profit as much as 27.4% compared to other states (MPOB, 2015). The plantations mainly expanded in floodplains areas at the eastern part of Sabah including 26% in the Lower Kinabatangan River catchment that has been converted into oil palm plantations (Josephine *et al.*, 2004). It has been estimated that the expansion will encroach up to 2.1 million hectares by 2025, compared to 1.43 million hectares (19.3%) in the year 2011 (Gunarso *et al.*, 2013; IDS, 2007).

As a consequence of the deforestation and conversion of wetlands, the hydrological cycle, nutrient fluxes, runoff characteristics, biotic environments, and microclimate of wetland are affected. The constant fluctuation of dissolved organic matter (DOM) characteristics in streams and rivers had increased the nutrient export to aquatic ecosystems (Bruijnzeel, 2004). Studies showed that most rainforest and wetlands that subjected to heavy logging and agricultural clearance incline in the production of autochthonous DOM. Likewise, anthropogenic activities as riparian clearing, fertilizer, and sewage inputs also contribute to high DOM concentration. Consequently, increase in DOM inputs able to attenuate the light availability to the river column and provide nutrients for the plant that enhance

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primary production (Walsh *et al.* 2005, Johnson *et al.* 2009, Yamashita *et al.* 2010). Meanwhile, other studies showed the continuous high load of DOM from the European and American region in the last decade (Hejzlar *et al.*, 2003; Evans *et al.*, 2005; Skjelkvåle *et al.*, 2005), postulate to low pH (Driscoll et al., 2003) and increase in temperature (Freeman et al., 2001). Importantly, the rapid load and transport of DOM affects the water quality of wetland by depleting the disolved oxygen concentration (Lu *et al.*, 2013) and eventually will be an effect to the aquatic biodiversity. Owe to the fact, incline of DOM load in the wetland leading to poor water quality condition.

Dissolved organic matter (DOM) is a mixture of soluble organic matter that plays a vital role in the aquatic ecosystem. Accordingly, DOM derived from various sources, including terrestrial, hydrology (*in-situ* production by aquatic biota) and anthropogenic activities (Fellman, 2010). When these soluble matters came in contact with water, it is altered by physicochemical processes and changes based on land use and temporal condition (Sachse *et al.*, 2005; Steinberg, 2004, Rosario-Ortiz *et al.*, 2007). Not to mention, DOM is known to have an essential role in the global biogeochemical cycle, and it is acknowledged to be the largest carbon pool storage in all aquatic systems (Jorgensen *et al.* 2011). It also provides energy and carbon sources to microbe community, nutrients to aquatic biota, influence the solubility and bioavailability of organic pollutants like heavy metals (Findlay and Sinsabaugh, 2003). The complex structure of DOM and functional role can be changed over time by undergoing photolysis, bacterial degradation and scavenging processes (Moran and Covert, 2000; Osburn *et al.*, 2001; Aufdenkampe *et al.*, 2001). The DOM quality and quantity are related to water system surrounded by land use type. The expansion of agriculture land use, the evaluation of water quality is important as aquatic system sustain a high aquatic biodiversity (He *et al.*, 2014).

Biological elements in aquatic ecosystems such as fish (Zaki *et al.*, 2014) and macrophytes are essential and relevant indicators for assessments of aquatic ecosystems health. Utilising of fish and macrophytes as biological indicators able to provide adequate information on the effects such as hydro-morphological

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degradation, eutrophication, organic pollutions from land use changes (Hering *et al.,* 2006). Hering *et al.,* (2006) stated fishes and macrophytes are suitable indicators as both responds to land use changes, eutrophication and organic pollutants. Besides, another study also supported the ability of macrophytes respond to environmental pollutions by showing changes in their growth and distribution (Steffen *et al.*, 2014). Other studies also indicates the monitoring for long-term ecological alteration in water quality (Lacoul and Freedman, 2006; Solimini *et al.*, 2006). A recent study, in Georgian Bay, Canada (Cvetkovic *et al.*, 2009) indicated that plants are consistently better indicators of the fish populations than water quality variables. Subsequently, Petry *et al.* (2003) suggested that the ubiquitous nature of several abundant fish species across habitat types implies a diversity of specialization among all species. However, although these three aquatic variables, water quality, fish and macrophytes have a positively intercorrelated association (Cvetkovic *et al.*, 2009), their nature of relationships with DOM still not been explored thoroughly. For example, increase in DOM concentration in the aquatic system can impact the aquatic organisms due to rapid oxidation of microbes on DOM lead to depletion of dissolved oxygen. Thus, the dynamic of DOM is still unclear in an aquatic ecosystem where the different fractions of the DOM pool need to be traced for better understanding (Stedmon *et al.*, 2003) and their relationship with aquatic biological indicator still scarcely explored especially in Lower Kinabatangan river catchment.

The development of spectroscopic technique such as UV-visible absorbance and fluorescence has been used vastly in the water science studies. Based on a conducted research, analysis using UV-visible absorbance demonstrated a positive correlation with dissolved organic carbon (DOC) concentration in which part of DOM fraction and aromaticity (Baker and Spencer, 2004; Leenheer and Croue, 2003). Meanwhile, absorption spectral slopes and slope ratios show useful indicators of molecular weight, source, and photo-bleaching of DOM (Helms *et al.*, 2008). Furthemore, using fluorescence spectroscopic, the excitation-emission matrix (EEMs) results indicates DOM constituents by peaks such as peak A and C have been shown in relation to humic substances (McKnight *et al.*, 2001) while peak T has been indicated to have significant correlation with biochemical oxygen demand (BOD) (Hudson *et al.*, 2007; Mandal *et al.*, 2010). The characterization of DOM

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based on spectroscopic measurement is more reliable, easy and require adequate amount of samples to explore DOM spatial and temporal variation. The ecological significance of the DOM and its relationship dynamics between macrophytes and fish assemblages based on land use type and seasonality has not been well studied and poorly understood. In this proposed study, the investigation between DOM and biological indicator (macrophytes and fish assemblages) based on the spectroscopic analysis will be explored. This study is one of the first as such to be conducted in tropical regions.

1.2 Relevance of the study

Lower Kinabatangan River tributaries (Sg. Pin, Sg. Takala, Sg. Resang and Sg. Menanggol) were selected as the study sites at Kinabatangan, Sabah, Malaysia. The total catchment of the river is 16,800 km^2 and 560 km in length. The Kinabatangan River covers approximately 23% of Sabah land and widely known as the largest river in Malaysia. In the early 1950s until 1987, the wetland in Lower Kinabatangan was converted to commercial logging activities (Boonratana, 2000). Then, in the 1980s, it was developed into permanent crops plantations like oil palm plantation till to date. The wetland also houses to the wildlife animals that have been stated in the IUCN Red List of Threatened Species (Ancrenaz *et al.*, 2013). The Lower Kinabatangan area was gazetted as a Ramsar site as Lower Kinabatangan-Segama Wetlands in the year 2008 where it covers approximately 78,800 ha including wetland and forest (Sabah Biodiversity Centre, 2011). Although the Lower Kinabatangan is one of the Ramsar sites, the problems still arise as the continuous development of oil palm plantations and oil palm mills, conversely impacts on water quality and biodiversity. The biological life status as well as incline in soil erosions, and habitat loss are now become questionable (Sabah Biodiversity Centre, 2011).

Based on the previous studies in Lower Kinabatangan River catchment had been carried out in Lower Kinabatangan River catchment were Harun (2006), Jawan (2008), Harun (2013), Harun *et al.*(2014), Harun *et al.* (2015); Harun *et al.*, (2016) mainly focus on the water quality, DOM evaluation and water quality relationship with aquatic insects and phytoplankton. There is a knowledge gap to be filled as there is no studies have been carried out regarding the effects of DOM on higher trophic aquatic organisms such as fish and macrophytes. In order to fill

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the gap, fish and macrophytes were chosen as they have a high potential as biological indicators due to their relationship with each other and they rely on water quality. On the other hand, the water quality evaluation in Malaysia commonly uses the Water Quality Index (WQI) to classify the river or wetland status and quality. In contra to WQI, in this study, we applied the DOM evaluation by using spectroscopic techniques. This technique was used widely in the northern region and proven to be a useful tool for wastewater treatment, drinking water treatment and water quality evaluation. Spectroscopic techniques are simple, cost-effective and easy to characterize DOM composition and sources. Besides, using this technique, we also can determine the biological activity involvement and photo-exposure involvement and their effect, cause and how to improve monitoring programme of water quality in Lower Kinabatangan river catchment. Hence, in this study, the investigation of DOM trend, macrophytes and fish assemblages in three types of land use were determined. Also, this study is interested in how these three elements are related to each other and their relationship based on land use type and seasonality to provide baseline data. This baseline data can be useful to enhance monitoring programme at Lower Kinabatangan River catchment in the future.

1.3 Objectives

The objectives of this study are:

1. To determine spatial variations of water quality, macrophytes and fish assemblages in different types of land use; mixed vegetation (MV), oil palm plantation (OP) and secondary forest (SF).

2. To determine temporal variations of water quality, macrophytes, and fish assemblages during the inter-monsoonal period, wet and dry seasons

3. To investigate the relationship between DOM, macrophytes and fish assemblages based on fluorescence and UV-Vis absorbance spectroscopy analysis.

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