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SEASONAL VARIATION AND HEAVY METAL CONTENT IN MANGROVE MACROALGAE FROM MIRI ESTUARY, SARAWAK

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By

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SEASONAL VARIATION AND HEAVY METAL CONTENT IN MANGROVE MACROALGAE FROM MIRI ESTUARY, SARAWAK

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May 2015

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Mangrove macroalgal assemblages can be used to assess the level of bioavailable metal for environmental monitoring. To date there have been very scarce information on influence of abiotic factors on the temporal variations in occurrences and biomass production of mangrove macroalgae and their use in environmental monitoring elsewhere. Consequently, present study examined influence of some abiotic factors on the temporal changes in occurrence and biomass production of macroalgae epiphytic on pneumatophores of *Avicennia marina* (Forsk.) Vierh., and accumulation of heavy metal (Cu, Zn, Fe and Mn) by some of these selected macroalgae in Miri estuary, Sarawak. Within a pneumatophore two vertical segments (apex and basal) were considered to estimate frequencies of occurrences and biomass of macroalgae considering 4 seasons of Malaysia namely southwest monsoon, northeast monsoon, and two inter-monsoon. Acid extracted metals (Cu, Zn, Fe and Mn) were measured using AAS (Atomic Absorption Spectrophorometry) in surface sediment, surface water and most dominant six macroalgal species.

Eleven species of mangrove macroalge were recorded, of which 6 species were common throughout the study period. From this study, macroalgal species such as *Caloglossa adhaerens*, , *C. stipitata*, *C. ogasawaraensis*, *Bostrychia kelanensis* and *B. anomala* were considered to be the new records in the Malaysian mangrove ecosystems. Significant differences (ANOSIM and nMDS) were observed in regards to biomass production between assemblages of two vertical segments (apex and basal) of pneumatophores. In general, marked seasonal variations were observed in the frequencies of occurrences and biomass for most of the dominant macroalgal species; presumably because of high temporal variations of hydrological and hydrochemical factors including turbidity and nutrients of the estuarine water. Canonical Correspondence Analysis (CCA) indicated that turbidity were the main variable influencing biomass production of mangrove macroalgae in Miri estuary.

The scheme of metal occurrences in estuarine surface water and sediment were Fe-Mn-Zn-Cu and Fe-Zn-Mn-Cu, respectively. Among the studied metals in algal thalli; irrespective of macroalgal species the concentrations of Fe was found to be the highest, but metal having the lowest concentration varied among the species. Significant positive correlations were found between Cu-Zn in all macroalgal species (except *Dictyota,* sp. and *C. ogasawaraensis*), indicating the common origin of these elements. Concentration of each of the studied metal in thallli varied among the species, probably because of variations of thalii structure, age and growth of thalli among the species. Bioconcentrations factors (BCFs) relative to water revealed that *C. leprieurii* was found to be the strongest bioaccumulator for Mn, C. *adhaerens* for Cu and Fe and *C. ogasawaraensis* for Zn.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PERBEZAAN MUSIM DAN KANDUNGAN LOGAM BERAT DALAM PAYA BAKAU MACROALGA DARI MUARA SUNGAI MIRI, SARAWAK

Oleh

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Himpunan macroalga bakau boleh digunakan untuk menilai tahap logam bio tersedia untuk pemantauan alam sekitar. Sehingga kini, maklumat berkenaan pengaruh faktor abiotik pada perubahan variasi yang berlaku dan pengeluaran biojisim makroalga paya bakau pemantauan alam sekitar mempunyai maklumat yang sangat terhad. Oleh yang demikian, kajian ini meneliti pengaruh beberapa faktor abiotik pada perubahan sementara yang berlaku dan pengeluaran biomass macroalga epibiont pada pneumatophores daripada *Avicennia marina* (Forsk.) Vierh., dan pengumpulan logam berat (Cu, Zn, Fe dan Mn) daripada beberapa macroalga terpilih di muara sungai Miri, Sarawak. Pada bahagian pneumataphore terdapat dua segmen menegak (atas dan bawah) telah digunakan untuk menganggarkan frekuensi yang wujud dan biojisim macroalga berdasarkan 4 musim di Malaysia iaitu monsun barat daya, monsun timur laut dan dua peralihan monsun. Asid logam (Cu, Zn, Fe dan Mn) diekstrak dan di analisis menggunakan AAS (*Atomic Absorption Spectrophorometry*) yang dikumul dari permukaan sedimen, air dipermukaan air dan enam spesies macroalga yang paling dominan.

Sebelas spesies makroalga paya bakau telah direkodkan, di mana 6 spesies adalah spesies yang ditemui sepanjang tempoh kajian. Dari kajian yang dijalankan spesies macroalga seperti *Caloglossa adhaerens, C. stipitata, C. ogasawaraensis, Bostrychia kelanensis, B. anomala* telah rekodkan sebagai rekod baharu dalam ekosistem paya bakau Malaysia. Perbezaan nilai (ANOSIM dan nMDS) diperhatikan dalam hal pengeluaran biojisim antara dua himpunan segmen menegak (atas dan bawah) dari pneumatophores. Secara am nilai variasi bermusim yang ketara dapat diperhatikan dalam frekuensi kehadiran dan biojisim bagi kebanyakan spesies makroalga dominan ini adalah disebabkan perubahan variasi yang tinggi dalam faktor hidrologi dan hidrokimia termasuk kekeruhan dan nutrien air muara sungai. "*Canonical Correspondence Analysis*" (CCA) menunjukkan

bahawa kekeruhan adalah pembolehubah utama yang mempengaruhi pengeluaran biojisim macroalga bakau di muara sungai Miri.

Susunan tahap logam di permukan air muara sungai dan sedimen adalah Fe-Mn-Zn-Cu dan Fe-Zn-Mn-Cu. Antara logam yang dikaji dalam tisu alga; tanpa mengira spesies macroalga, kepekatan Fe didapati paling tinggi tetapi logam mempunyai kepekatan terendah antara spesies macroalga. Korelasi positif yang signifikan didapati antara Cu-Zn dalam semua takson macroalga (kecuali *Dictyota* sp. dan *C. ogasawaraensis*) menunjukkan sumber elemen-elemen ini. Kepekatan setiap logam yang dikaji dalam thalli pelbagai kalangan spesies makroalgal, berkemungkinan kerana variasi struktur thalii, umur dan pertumbuhan thalli antara spesies makroalgal. Faktor kepekatan bio (BCFs) berhubung dengan air membuktikan bahawa *C. leprieurii* didapati pengumpulan bio paling kukuh untuk Mn, *C.adhaerens* untuk Cu dan Fe manakala *C.ogasawaraensis* menunjukkan kecekapan yang lebih tinggi dalam pengumpulan bio Zn.

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I certify that a Thesis Examination Committee has met on (13/05/2015) to conduct the final examination of Md. Masum Billah on his thesis entitled "Seasonal Variation and Heavy Metal Content in Mangrove Macroalgae from Miri estuary, Sarawak" in accordance with the Universities and University Colleges 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 Master Science.

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LIST OF ABBREVIATIONS

NPP	Net Primary Productivity
μg/l	Micro Gram Per Litter
μg/g	Micro Gram Per Gram
PSU	Practical Salinity Unit
CAP	Community Analysis Package
PCA	Principal Components Analysis
PAST	PAleontological Statistics (check spelling)
ANOSIM	Analysis of Similarity
SIMPER	Similarity Percentage Analysis
CCA	Canonical Correspondence Analysis
AAS	Atomic Absorption Spectrophotometer
Biom	Biomass
Freq	Frequency
BCFs	Bioconcentrations factors

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Coastal and estuarine ecosystems are thought to be one of the most important ecosystems on the earth both the economically and ecologically, as these ecosystems provide breeding, feeding and sheltering ground for commercially important fish and shellfish species (Little, 2000). These areas are among the most important place of human settlement, considered to be the receptacles of the organic and inorganic pollutants. Metals are, however, some of the major common pollutants in the coast and estuaries throughout the world (NSW EPA, 2000).

Heavy metal pollution is a common urban problem. These are persistent, non biodegradable, and are common in our surrounding environment (Claisse and Alzieu, 1993). They occur naturally in the environment and may mobilized by anthropogenic activities that consist of mining and discharging industrial effluents into natural ecosystems like forests, mangroves, estuaries and ocean (Larison *et al.,* 2000). Consequently, heavy metal poses potential threat to aquatic biota that can be shifted to higher trophic level by accumulation and magnification. Other detrimental effect of heavy metals includes degradation of habitat, alteration of food chain and probable poisoning of humans (Hsu *et al*., 2006).

Within an aquatic ecosystem any of three components (i.e., sediment, water, biota) can be taken to assess the level of contamination of that environment (Rainbow, 1995). Determination of the level of contamination by water has some limitations because sometimes they are bellow detection limit, and highly influenced by some physical factors like tidal currents (Villares *et al.,* 2001). However, analysis of sediments may overcome these limitations but metal accumulation in sediments is influenced by a number of specific physico-chemical parameters like pH, salinity, temperatures, organic content of the soil (Meyer, 2002). Consequently, water and sediment only cannot reflect the likely effect of contamination on the biota. Thus, biomonitor organisms are increasingly become use to quantify level of contamination within a given site. These organisms can accumulate contaminants up to bioavailable proportion (Phillips and Segar, 1986). For this purpose biota like molluscs and macroalgae are commonly used (Rainbow, 1995). Macroalgae, however can accumulates metal up to thousands times higher than that of surrounding water (Bryan and Langston, 1992). Macroalgae can sustain wide range of environmental variabilities from alkaline environments to acid mines (Jadeja and Batty, 2013), thus make it cosmopolitan biominitors.

Malaysia is now on her way towards being an industrialized country by the year 2020. The major industries of Malaysia include textile and leather, chemical products, fertilizers, pesticides, cement and cement products, medical equipment, oil refineries and welding fumes (Yap *et al*., 2002a). Sarawak, however, is one of the three major regions of the Malaysia (the rest two are peninsular Malaysia and Sabah) lies on the island of Borneo. Sarawak has substantial proportions of Mangrove (17300 ha; Anon, 1979). The main tree species of this mangrove forests include *Avicennia* sp., *Rhizophora* sp., *Sonneratia* sp., *Bruguiera* sp. and *Nypa* sp. (Bennett and Reynolds, 1993).

This region is renowned for its timber industry. The number of timber processing industries for example; sawn timber, plywood / venner mills, molding, laminated board, woodchip, particle board, fiberboard, charcoal briquette, klin drying plant and furniture industry are being increased rapidly in Sarawak (Leigh, 1998.). During timber processing CCA (Copper Chromated Arsenate) is used to preserve the timber that can consequently leacheate Arsencic (As), Cromium (Cr) and Copper (Cu) to the surrounding environment (Read, 2003). Besides, a number of heavy fleet and seagoing vessels are also associated with these industries. These may cause heavy metal contamination in the coastal ecosystems including mangroves.

Numbers of studies have been carried out to demonstrate the heavy metal quantities in sediment and water of the west coast of Malaysia (Shazili *et al.,* 2006). Since, biomonitor organisms can give more integrated long term or current metal pollution status of an aquatic ecosystems (Zhou *et al*., 2008), thus studies have also been reported some of the coastal organisms mainly molluscs as biomonitor for environmental assessment in the Western Malaysia e.g., shell of the green-lipped mussel *Perna viridis* (Yap *et al*., 2002b), byssus of *P. viridis* (Yap *et al*., 2003a), horn snail *Telescopium telescopium* (Yap *et al*., 2009a), mangrove murex *Chicoreous capucinus* (Yap and Edward, 2009).

Mangroves host diverse macroalgal assemblage in the prop roots, dead branch, pneumataphore, and tree trunks (Zhang *et al*., 2014; Melville and Pulkownik, 2007a, Zuccarello *et al*., 2001). Mangrove macroalgae provide substantial proportion of nutrient to the surrounding ecosystems through decomposition processes (Alfaro, 2008; Steinke and Naidoo, 1990). They serve as the primary producer in the coastal estuarine ecosystems and grazed by small fish for their nutritional demand (Kieckbusch *et al*., 2004). In terms of NPP (Net Primary Productivity), macroalgae has higher productivity than that of mangroves (Saifullah and Ahmed, 2007). It also contributes as an important source of carbon and nitrogen in the mangrove ecosystem especially in the food web (Rodriguez and Stoner, 1990). The distribution, tolerance and adaptation of macroalgae associated with mangroves are related to the abiotic and biotic parameters (Oliveira, 1984). Alves and Fernandes (2012) has been documented that abiotic factors especially water pH could be determined as factors contribute the presence and absence of macroalgae in mangrove ecosystems.

1.2 Problem Statement

The species composition of mangroves macroalgae has long been studied in different parts of the world (Cordero, 1978; Coppejans and Gallin, 1989; King and Puttock, 1994; Saifullah *et al*., 1997; Gab-Alla, 2000; Nedumaran and Perumal, 2009). Little information is available regarding the seasonal variability in the structure of mangrove macroalgal assemblages (Zhang *et al*., 2014). Vertical distribution of mangrove macroalgae has been described in Australian (Melville *et al*., 2005; Melville and Pulkownik, 2007a), South African (Phillips *et al*., 1996) and Brazilian (Alves and Fernandes, 2012) mangrove systems. Few studies have been carried out to elucidate the influence of environmental factors such as shade of canopy (Eston *et al.,* 1992), rainfall, temperature and tidal immersion elsewhere (Yokoya *et al*., 1999). In Malaysia, the epibiont mangrove macroalgal communities have received only limited scientific attention to date (Aikanathan and Sasekumar, 1994).

The use of macroalgae in the environmental assessment is not a new concept. A great deal of studies have been described the use of macroalgae for heavy metal assessment in the coastal ecosystems of different regions e.g., Aegean coast (Akcali and Kucuksezgin, 2011), Saudi coast (Al-Homaidan, 2007), Pulicat Lake Southeast India (Kamala-Kannan *et al*., 2008), Tyrrhenian coastal areas (Conti and Cecchetti, 2003), Thermaicos Gulf, Greece (Fytianos *et al*., 1997), Antikyra Gulf, Greece (Malea *et al*., 1995), Lebanese coastal waters (Shiber, 1980) and coastal water of Malaysia (Mashitah *et al*., 2012). Most of these studies have been concluded that *Ulva* and *Enteromorpha* are the most suitable genera for biomonitoring study. However, there is little scientific information on biomonitoring of heavy metals using mangrove macroalgae from coastal waters of Malaysia.

1.3 Significance of the Study

The studies on the seasonal variation of mangrove macroalgae are scare worldwide especially in Malaysia (Melville *et al*., 2005; Melville and Pulkownik, 2007a). Studies by Aikanathan and Sasekumar (1994) recorded ten mangrove macroalgae namely *Catenella nipae, Caloglossa lepreurii, C. adnata, Bostrychia radicans, Enteromorpha* sp.*, Gladophora*s sp.*, Gracilaria blodgetti, Colpomenia* sp.*, Rhizoclonium* sp. and *Dictyota dichotoma* from Selangor mangroves, Peninsular Malaysia. To date there has been very scarce information on the habitat characteristics and influence of hydrological factors on the seasonal variability of mangrove macroalgae in mangrove ecosystems. Besides, there is a lack of scientific information regarding biomonitoring of heavy metals using mangrove macroalgae in the estuarine and coastal ecosystems elsewhere (Melville and Pulkownik, 2006, 2007b).

It is expected that the benthic epiphytic macroalgal communities in the mangrove ecosystems in Malaysia may have wide number of varieties those probably have ecological and biomonitoring significance. Consequently, keeping this view in mind, this study aims to assess the seasonality in the structure of mangrove macroalgal communities in relation to hydrological factors and biomonitoring of heavy metals using dominant macroalgal species associated with mangroves from Miri river estuary, Sarawak.

1.3 Objectives

I. To investigate the seasonal variation of mangrove macroalgal communities in relation to hydrological factors in Miri estuary, Sarawak, Malaysia.

II. To investigate biomonitoring of heavy metal (Cu, Fe, Mn and Zn) using dominant mangrove macroalgal taxon from study area.

REFERENCES

Abdallah, A.M.A., Abdallah, M.A. and Belgaty, A.I. 2005. Contents of heavy metals in marine seaweeds from the Egyptian coast of the Red Sea. *Chemistry and Ecology,* 21: 399–411.

Agusa, T., Kunito, T., Yasunaga, G., Iwata, H., Subramanian, A., Ismail, A. and Tanabe, S. 2005. Concentrations of trace elements in marine fish and its risk assessment in Malaysia. *Marine Pollution Bulletin*, 51: 896-911.

Aikanathan, S. and Sasekumar, A. 1994. The community structure of macroalgae in a low shore mangrove forest in Selangor, Malaysia. *Hydrobiologia, 285*: 131-137.

Akcali, I. and Kucuksezgin, F. 2011. A biomonitoring study: heavy metals in macroalgae from eastern Aegean coastal areas. *Marine Pollution Bulletin, 62*: 637-645.

Alfaro, A.C. 2006. Benthic macro-invertebrate community composition within mangrove/seagrass estuary in northern New Zealand. *Estuarine, Coastal and Shelf Sci*ence, 66: 9-110.

Alfaro, A.C. 2008. Diet of *Littoraria scabra*, while vertically migrating on mangrove trees: gut content, fatty acid, and stable isotope analyses. *Estuarine Coastal and Shelf Science*, 79: 718–726.

Al-Homaidan, A. 2007. Heavy metal concentration in three species of green algae from the Saudi coast of the Persian Gulf. *Journal of Food Agriculture Environment*, 5: 345-358.

Alves, E.D.F.S. and Fernandes, M.E.B. 2012. Occurrence and distribution of macroalgae (rhodophyta) associated with mangroves on the Ajuruteua peninsula, Bragança, Pará, Brazil. *Uakari, 7*: 35-42.

Anon, 1979. Forest reserve base, policy and legislation of Sarawak. *Malaysian Forester,* 42: 311-327.

Awaluddin, A., Mokhtar, M. and Sharif, S. 1992. Accumulation of heavy metals in tiger prawns (*Penaeus monodon*). *Sains Malaysiana,* 21: 103-120.

Baker, A.J. and Walker, P.I. 1990. Ecophysiology of metal uptake by tolerant plants. In: Shaw, A.J. (Ed.), Heavy Metal Tolerance in Plants: Evolutionary Aspects. CRC Press, Florida, pp. 155–178.

Bennett, E.L. and Reynolds, C.J. 1993. The value of a mangrove area in Sarawak. *Biodiversity and Conservation*, *2*:359-375.

Billah, M.M., Abu Hena M.K., Idris, M.H.B., Ismail, J.B and Bhuiyan, M.K.A. 2014. Cu, Zn, Fe, and Mn in mangrove ecosystems (sediment, water, oyster, and macroalgae) of Sarawak, Malaysia. *Zoology and Ecology*, 24: 380-388.

Bouillon, S., Raman, A.V., Dauby, P. and Dehairs, F. 2002. Carbon and nitrogen stable isotope ratios of subtidal benthic invertebrates in an estuarine mangrove ecosystem (Andhra Pradesh, India*). Estuarine Coastal and Shelf Science*, 54: 901–913.

Bouyoucos, G.J. 1962. Hydrometer method improving for making particle size analysis of soils. *Agronomy Journal*, 54: 464–5.

Breeman, A.M. 1988. Relative importance of temperature and other factors in determining geographic boundaries of seaweeds: experimental and phenological evidence. *Helgoland Marine Research*, 42:199–24.

Brito, G.B., de Souza, T.L., Bressy, F.C. and Moura, C.W.N. 2012. A Levels and spatial distribution of trace elements in macroalgae species from the Todos os Santos Bay, Bahia, Brazil. *Marine Pollution Bulletin,* 64: 2238-2244.

Brown, M.T., and Depledge, M.H. 1998. Determinants of trace metal concentrations in marine organisms. In Langston WJ, Bebianno MJ., editors. Metal metabolism in aquatic environments. London: Chapman and Hall, 185-217pp.

Bryan, G.W. and Langston, W.J. 1992. Bioavailability accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environmental Pollution,* 76: 89–131.

Cenci, R.M. and Martin, J.M. 2004. Concentration and fate of trace metals in Mekong river delta. *Science of the Total Environment*, 332: 167-182.

Chakraborty, S., Bhattacharya, T., Singh, G. and Maity, J.P. 2014. Benthic macroalgae as biological indicators of heavy metal pollution in the marine environments: A biomonitoring approach for pollution assessment. *Ecotoxicology and Environmental Safety*, *100*: 61-68.

Chapman, P.M. and Wang, F. 2001. Assessing sediment contamination in estuaries. *Environmental Toxicology and Chemistry*, 20: 3–22.

Cho, Y.G., Lee, C.B. and Choi, M.S. 1999. Geochemistry of surface sediments off the southern and western coast of Korea. *Marine Geology*, 159: 111–129.

Claisse, D. and Alzieu, C. 1993. Copper contamination as a result of antifouling paint regulations. *Marine Pollution Bulletin*, 26:395–397.

Clarke K.R. 1993. Non parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology,* 18:117-143.

Clarkson, D.T. and Hanson, J.B. 1980. The mineral nutrition of higher plants. *Annual Review of Plant Physiology,* 31:231–298.

Conti, M.E.and Cecchetti, G. 2003. A biomonitoring study: trace metals in algae and molluscs from Tyrrhenian coastal areas. *Environmental Research,* 93(1): 99-112.

Cordero, P.A. 1978. Phycological observations. VI. Mangrove associated algae from Aklan, Philippines. *Philippine Journal of Biology*, 7: 275-296

Coppejans, E. and Gallin, E. 1989. Macroalgae associated with the mangrove vegetation of Gazi Bay (Kenya). *Bulletin de la Société Royale de Botanique de Belgique/Bulletin van de Koninklijke Belgische Botanische Vereniging* 47-60.

Crona, B.I., Holmgren, S. and Rönnbäck, P. 2006. Re-establishment of epibiotic communities in reforested mangroves of Gazi Bay, Kenya. *Wetlands Ecology and Management*, *14*: 527-538.

Cutrim, M.V.J., da Silva, E.F. and de Azevedo, A.C.G. 2004. Distribuição vertical das macroalgas aderidas em rizóforos de Rhizophora mangle Linnaeus nos manguezais de Parna-Açu e Tauá-Mirim (Ilha de São Luís / MA-Brasil). *Boletim do Laboratório de Hidrobiologia*, *17*(1).

Dahdouh-Guebas, F., De Bondt, R., Abeysinghe P.D., Kairo J.G., Cannicci S, Triest L. and Koedam, N. 2004. Comparative study of the disjunct zonation pattern of the grey mangrove *Avicennia marina*(Forsk.) Vierh. in Gazi Bay (Kenya). *Bulletin of Marine Science,* 74: 237-235.

Das, S. and Vincent, J.R. 2009. Mangroves protected villages and reduced death toll during Indian super cyclone. *Proceedings of the National Academy of Sciences of the United States of America,* 106: 7357–7360.

Davey, A. and Woelkerling, W.J. 1985. Studies on Australian mangrove algae. III. Victorian communities: structure and recolonization in western Port Bay. *Journal of Experimental Marine Biology and Ecology,* 85: 177-190.

Dawes, C., Siar K. and Marlett D .1999. Mangrove structure, litter and macroalgal productivity in a northern-most forest of Florida. *Mangroves and Salt Marshes, 3*: 259-267.

Dawes, C.J. 1998. Marine Botany. 2nd edn, Wiley, New York.

De Lacerda, L.D., Carvalho, C.E.V., Tanizaki, K.F., Ovalle, A.R.C. and Rezende, C.E. 1993. The biogeochemistry and trace metals distribution of mangrove rhizospheres. *Biotropica* , 25: 252–257.

DOE. 1998. Environmental quality report, Department of Environment, Ministry of Science,Technology and Environment, Malaysia. Maskha Sdn. Bhd., Ampang, Kuala Lumpur.

Donat, J. and Dryden, C. 2001. Transition metals and heavy metal speciation. In: J. Steele, S. Thrope, K. Turekian (Eds.), Encyclopedia of Ocean Sciences, pp. 3027–3035 Academic, Elsevier Science, New York.

Druehl, L.D. and Green, J.M. 1982. Vertical distribution of intertidal seaweeds as related to patterns of submersion and emersion. *Marine Ecology Progress Series,* 9: 163-170.

Duke, N.C. 1992. Mangrove floristics and biogeography. In: Tropical Mangrove Ecosystems" (A.I. Robertson and D.M. Alongi, eds), pp.63-100. American Geophysical Union, Washington DC, USA

El-Sharouny, H.M., Raheem, A.M. and Abdel-Wahab, M.A. 1998. Manglicolous fungi of the red sea in upper Egypt. *Microbiological Research*, 153: 81-96.

EL-Tayeb, H.E.S.M. and Ismail, M. 2001. Macroalgae Associated with Mangroves at Hurghada and Safaga of the Egyptian Red Sea Coast. *Journal of King Abdul Aziz University* 12(special issue), 241-251.

Essien, J.P., Antai, S.P. and Olajire, A.A. 2009. Distribution, seasonal variations and ecotoxicological significance of heavy metals in sediments of cross river estuary mangrove swamp. *Water, Air, and Soil Pollution*, 197: 91-105.

Fang, Y., Zheng, W. J., Wan, Y. J., Chen, C. X., & Sheng, H. X. 2008. Effects of chromium (Cr) on the seedling growth of mangrove species *Avicennia marina*. *Chinese Journal of Ecology*, 27: 429–443.

Eston, V.R., Braga, M.R.A., Cordeiro-marino, M., Fujii, M.T.and Yokoya, N.S. 1992. Macroalgal colonization patterns on artificial substrates inside Southeastern Brazilian mangroves. *Aquatic Botany*, 42: 315-325.

FAO. 2007. The WorldÕs Mangroves 1980-2005. FAO Forestry Paper, 153: 75.

Farnsworth, E.J. and Ellison, A.M. 1996. Scale-dependent spatial and temporal variability in biogeography of mangrove root epibiont communities. *Ecological Monographs,* 45-66.

Fisher, T.R., Peele, E.R., Ammerman, J.W. and Harding, L.W. 1992. Nutri- ent limitation of phytoplankton in Chesapeake Bay. *Marine Ecology Progress Series,* 82:51-63.

Fletcher,R.L. 1996. The occurrence of “green tides” – a review. In Marine benthic vegetation: recent changes and the effects of eutrophication, (W.Schramm, & P.H. Nienhuis, eds.), Springer, Berlin, Heidelberg, New York. pp. 7-43.

Fong, P., Fong, J.J. and Fong, C.R. 2004. Growth, nutrient storage, and release of dissolved organic nitrogen by *Enteromorpha intestinalis* in response to pulses of nitrogen and phosphorus. *Aquatic Botany, 78*: 83-95.

Fuad, M.M., Shazili, N.A.M. and Faridah, M. 2013. Trace metals and rare earth elements in Rock Oyster *Saccostrea cucullata* along the east coast of Peninsular Malaysia. *Aquatic Ecosystem Health and Management*, *16*: 78-87.

Fytianos, K., Haritonidis, S., Albanis, T., Konstantinou, I. and Seferlis, M. 1997. Bioaccumulation of PCB congeners in different species of macroalgae from Thermaicos Gulf, Greece. *Journal of Environmental Science and Health,* 32: 333–345

Gab-Alla, A.A. 2000. Biodiversity and distribution of epiphytes community associated with pneumatophores of the mangal *Avicennia marina* (Forssk.) Vierh., along Egyptian Red Sea coast. *Egyptian Journal of Aquatic Biology and Fisheries*, 4: 179-196.

Gandaseca, S., Rosli, N., Hossain, M.S. and Arianto, C.I. 2014. Assessment of oil palm plantation and tropical peat swamp forest water quality by multivariate statistical analysis. *American Journal of Environmental Sciences,* 10: 391.

Gerhardt, A. 2002. Bioindicator species and their use in biomonitoring. *Environmental Mon-itoring I. EOLSS*.

Gonza´ lez, H. and Torres, I. 1990. Heavy metals in sediments around a sewage outfall at Havana, Cuba. *Marine Pollution Bulletin,* 21: 253–255.

Gotelli, N.J. and Ellison, A.M. 2004. A Primer of Ecological Statistics. Sinauer Associates, Massachusetts.

Guo, X. Y. 2009. Effect of Zn-Cd combined stress on the growth and osmotic adjustment substances in *Kandelia candel* (L.) Druce seedlings. Xiamen: Xiamen University

Gwyther, J. and Fairweather, P.J. 2002. Colonisation by epibionts and meiofauna of real and mimic pneumtophores in a cool temperate mangrove habitat. *Marine Ecology Progress Series,* 229: 137-149.

Hamid, M.Y.A. and Sidhu, H.S. 1993. Metal finishing wastewater: characteristics and minimization. In: B. G. Yeoh, K. S. Chee, S. M. Phang, Z. Isa, A. Idris, M. Mohamed (Eds.),Waste management in Malaysia: Current status and prospects for bioremediation, pp. 41–49. Ministry of Science, Technology and the Environment, Malaysia.

Hanelt, D. and Roleda, M.Y 2009. UVB radiation may ameliorate photoinhibition in specific shallowwater tropical marine macrophytes. *Aquatic Botany*, 91:6–12.

Haritonidis, S. and Nikolaidis, G., 1990. Cd and Zn uptake in macrophyceae from Greek coasts. *Biology of Metals,* 2: 235–238.

Hein, M., Pedersen, M.F. and Sand-Jensen, K. 1995. Size-dependent nitrogen uptake in micro- and macroalgae. *Marine Ecology Progress Series,* 118:247-253.

Helena, B., Pardo, R., Vega, M., Barrado, E., Ferna´ndez, J.M. and Ferna´ndez, L. 2000. Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga river, Spain) by principal component analysis. *Water Research,* 34: 807–816.

Ho, Y.B. 1990. *Ulva lactuca* as bioindicator of metal contamination in intertidal waters in Hong Kong. *Hydrobiologia*, 203: 73-81.

Hopkinson, C.R. Jr. and Vallino, J.J. 1995. The relationships among man's activities in watersheds and estuaries: a model of runoff effects on patterns of estuarine community metabolism. *Estuaries,* 18: 598–621.

Hou, X. and Yan, X. 1998. Study on the concentration and seasonal variation of inorganic elements in 35 species of marine algae. *The Science of the Total Environment,* 222 : 141–156.

Hsu, M.J., Selvaraj, K. and Agoramoorthy, G. 2006. Taiwan's industrial heavy metal pollution threatens terrestrial biota. *Environmental Pollution,* 143: 327-334.

Ikram, M.M., Ismail, A., Yap, C.K. and Nor Azwady, A.A. 2010. Levels of heavymetals (Zn, Cu, Cd, and Pb) in mudskippers (*Periophthalmodon schlosseri*) and sediments collected from intertidal areas at Morib and Remis, Peninsular Malaysia. *Toxicological and Environmental Chemistry*, 92: 1471-1486.

Ismail, A., Jusoh, N.R. and Ghani, I.A. 1995. Trace metal concentrations in marine prawns off the Malaysian Coast. *Marine Pollution Bulletin*, 31: 108-11.

Ismail, A. and Rosniza, R. 1997. Trace metals in sediments and molluscs from an estuary receiving pig farms effluent. *Environment Technology*, 18: 509–515.

Jacobs, B. 1998. Biota Sediment Accumulation Factors for Invertebrates: Review and Recommendations for the Oak Ridge Reservation. *BJC/OR-112, Bechtel Jacobs Company LLC,* Oak Ridge, Tennessee.

Jadeja, R.N. and Batty, L. 2013. Metal content of seaweeds in the vicinity of acid mine drainage in Amlwch, North Wales, UK." *Indian Journal of Geo-Marine Sciences*, 42.1: 16-20.

Jones, C.J. and Murray, J.W. 1984. Nickel, cadmium and copper in the northeast Pacific off the coast of Washington. *Limnology and Oceanography,* 29: 711-720.

Kamala-Kannan, S., Prabhu, B., Dass B., Krishnamoorthy, R., Shanthi K. and Jayaparakash, M. 2008. Assessment of heavy metals (Cr, Cd and Pb) in water, sediments and seaweed (*Ulva lactuca*) in the Pulicat Lake Southeast India. *Chemosphere,* 71: 1233-1240.

Karsten, U., Mostaert, A.S., King, R.J., Kamiya, M. and Hara, Y. 1996. Osmoprotectors in some species of Japanese mangrove macroalgae. *Phycological Research,* 44: 109-112.

Karsten, U., West, J.A. and Ganesan, E.K. 1993. Comparative physiological ecology of *Bostrychia moritziana* (Ceramiales, Rhodophyta) from freshwater and marine habitats. *Phycologia,* 32: 401-409.

Kennish, M.J. 1994. Practical Handbook of Marine Science. (Second edition), New Jersey, CRC Press, Boca Raton, Florida. 566 p.

Kerswell, A.P. 2006. Global biodiversity patterns of benthic marine algae. *Ecology*, 87: 2479–2488.

Kieckbusch, D.K., Koch, M.S., Serafy, J.E. and Anderson, W.T. 2004. Trophic linkages among primary producers and consumers in fringing mangroves of subtropical lagoons. *Bulletien of Marine Science,* 74:271–285.

Kim, H.G., Rho, H.S. and Oh, C.W. 2013. Seasonal and spatial variations in nematode assemblages affected by thermal influence of nuclear power plant in Korea (East Sea, Pacific Ocean). *Marine Biology Research*, *9*: 725-738.

King, R.J. and Puttock, C.F. 1994. Macroalgae associated with mangroves in Australia: Rhodophyta. *Botanica Marina,* 37:181-91.

Kitamura H, Ishitani H, Kuge Y. and Nakamoto M. 1982. Determination of nitrate in fresh water and seawater by a hydrazine reduction method. *Suishitu Odakau Kenkyu* 5:35-42.

Koch M.S. and Madden C.J. 2001. Patterns of primary production and nutrient availability in a Bahamas lagoon with fringing mangroves. *Marine Ecology Progress Series,* 219:109–119

Kuffner, I.B. and Paul, V.J. 2001. Effects of nitrate, phosphate and iron on the growth of macroalgae and benthic cyanobacteria from Cocos Lagoon, Guam. *Marine Ecology Progress Series*, *222*:63-72.

Lamptey, E. and Armah, A.K. 2008. Factors affecting macrobenthic fauna in a tropical hypersaline coastal lagoon in Ghana, West Africa. *Estuaries and Coasts*, 31: 1006-1019.

Langston, W.J. 1990. Toxic effects of metals and the incidence of metal pollution in marine ecosystem. In: Furness, R.W., Rainbow, P.S. (Eds.), Heavy Metals in the Marine Environment. CRC Press, Boca Raton, FL, pp. 101–122

Larison, J.R., Likens, E., Fitzpatrick, J.W. and Crock, J.G. 2000. Cadmium toxicity among wildlife in the Colorado rocky mountains. *Nature,* 406:181-183.

Lau, S., Mohamed, M.C.Y., Tan, A. and Suut S. 1998. Accumulation of heavy metals in freshwater molluscs. *Science of the Total Environment,* 214: 113-121.

Laursen W.J. and King R.J. 2000. The distribution and abundance of mangrove macroalgae in Woolooware Bay, New South Wales, Australia. *Botanica Marina,* 43(4): 377–384.

Leal, M.C., Vasconcelos, M.T., Sousa-Pinto, I. and Cabral, J.P. 1997. Biomonitoring with benthic macroalgae and direct assay of heavy metals in seawater of the Oporto coast (Northwest Portugal). *Marine Pollution Bulletin*, *34*: 1006-1015.

Lee, W.Y and Wang, W.X. 2001. Metal accumulation in the green macroalgae *Ulva fasciata*: effect of nitrate, ammonium and phosphate. *Science of theTotal Environment*, 213:273–277.

Leigh, M. 1998. Political economy of logging in Sarawak, Malaysia." *The Politics of Environment in Southeast Asia*: 93-105pp.

Lewis, M., Pryor, R. and Wilking, L. 2011. Fate and effects of anthropogenic chemicals in mangrove ecosystems: A review. *Environmental Pollution,* 159: 2328–2346.

Little, C. 2000. The Biology of Soft Shores and Estuaries. Oxford University Press Inc., New York, USA, 192pp.

Littler, M.M., Littler, D.S. and Titlyanov, E.A. 1991. Comparisons of N- and P-limited productivity between high Granitic Islands vs low carbonate atolls in the seychelles archipelago: a test of the relative-dominance paradigm. *Coral Reefs*, 10:199–209.

Liu, C.W., Lin, K.H. and Kuo, Y.M. 2003. Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Science of the Total Environment,* 313: 77-89.

Lobban, C.S. and Harrison, P.J. 1994. Seaweed ecology and physiology Cambridge: Cambridge University press. 366pp.

Lwis, J.R. 1964. The Ecology of Rocky Shores, English university press, London.

Macia A., Abrantes, K.G.S. and Paula J., 2003. Thorn fish *Terapon jarbua* (Forskål) predation on juvenile white shrimp *Penaeus indicus* H. Milne Edwards and brown shrimp *Metapenaeus monoceros* (Fabricius): the effect of turbidity, prey density, substrate type and pneumatophore density. *Journal of Experimental Marine Biology and Ecology*, 291: 29– 56.

MacFarlane, G.R., Claudia E.K. and Simon P.B. 2007. Accumulation and partitioning of heavy metals in mangroves: a synthesis of field-based studies.*Chemosphere,* 69: 1454-1464.

MacFarlane, G. R. 2002. Leaf biochemical parameters in *Avicennia marina* (Forsk.) Vierh as potential biomarkers of heavy metal stress in estuarine ecosystems. *Marine Pollution Bulletin*, 44: 244–256.

Malea, P., Haritonidis, S. and Kevrekidis, T. 1995. Metal content of some green and brown seaweeds from Antikyra Gulf (Greece). *Hydrobiologia,* 310: 19–31.

Mamboya, F., Lyimo, T.J., Landberg, T. and Bjo¨rk, M. 2009. Influence of combined changes in salinity and copper modulation on growth and copper uptake in the tropical green *macroalgaUlva reticulata*. *Estuarine Coastal and Shelf Science*, 84: 326–330.

Mann, F.D., and Steinke, T.D. 1988. Photosynthetic and respiratory responses of mangrove-associated red algae, *Bostrychia radicans* and *Caloglossa leprieurii*. *South African Journal of Botany,* 54:203-207.

Marshall, S. and Elliott, M. 1998. Environmental influences on the fish assemblages of the Humber Estuary, U.K. *Estuarine, Coastal and Shelf Science,* 46:175-184

Martins, I., Pardal, M.A., Lillebo, A.I, Flindt, M.R and Marques, J.C 2001. Hydrodynamics as a major factor controlling the occurrence of green macroalgal blooms in a eutrophic estuary: a case study on the influence of precipitation and river management. *Estuarine Coastal Shelf Science,* 52:165–177

Mashitah, S.M., Shazili, NA.M. and Rashid, M.K.A. 2012. Elemental concentrations in Brown Seaweed, *Padina* sp. along the east coast of Peninsular Malaysia. *Aquatic Ecosystem Health and Managemen*t, 15: 267-278.

McAvoy, K.M. and Klug, J.L. 2005. Positive and negative effects of riverine input on the estuarine green alga *Ulva intestinalis* (syn. *Enteromorpha intestinalis*)(Linneaus). *Hydrobiologia*, 545: 1-9.

Mejia, A.Y., Puncher, G.N. and Engelen, A.H. 2012. Macroalgae in tropical marine coastal systems. In *Seaweed Biology* (pp. 329-357). Springer Berlin Heidelberg.

Melville, F., Pulkownik, A.and Burchett, M. 2005. Zonal and seasonal variation in the distribution and abundance of mangrove macroalgae in the Parramatta River, Australia. *Estuarine, Coastal and Shelf Science*, 64(2): 267-276.

Melville, F. and Pulkownik, A. 2006. Investigation of mangrove macroalgae as bioindicators of estuarine contamination. *Marine Pollution Bulletin*, 52(10): 1260-1269.

Melville, F. and Pulkownik, A. 2007a. Seasonal and spatial variation in the distribution of mangrove macroalgae in the Clyde River, Australia. *Estuarine, Coastal and Shelf Science*, *71*:683-690. .

Melville, F. and Pulkownik, A. 2007b. Investigation of mangrove macroalgae as biomonitors of estuarine metal contamination. *Science of the Total Environment*, *387*: 301-309.

Messyasz, B. and Rybak, A. 2011. Abiotic factors affecting the development of *Ulva* sp.(Ulvophyceae; Chlorophyta) in freshwater ecosystems. *Aquatic Ecology*, 45: 75-87.

Meyer, J.S. 2002. The utility of the terms ‘bioavailability’ and ‘bioavailable fraction’ for metals. *Marine Environmental Research*, 53, 417–423.

Middelboe, A.L., Sand-Jensen, K. and Krause-Jensen, D. 1998. Patterns of macroalgal species diversity in Danish estuaries. *Journal of Phycology, 34*: 457-466.

Mistri, M., Fano, E.A.. Rossi, G., Caselli, K. and Rossi, R. 2000. Variability in macrobenthos communities in the Valli di Comacchio, northern Italy, an hypereutrophized lagoonal ecosystem. *Estuarine, Coastal and Shelf Science,* 51: 599–611.

Mohamed, C.A.R. and Shazili, N.A.M. 1998. Recent concentrations of trace elements in coastal sediment of Terengganu, Malaysia. *Sains Malaysiana*, 27: 73–82.

Mohamed, C.A.R.and Shazili, N.A.M. 2000. Sedimentation rate of trace elements in the surface sediment of the South China Sea. *Sains Malaysiana*, 29: 225–232.

Mok, W. J., Senoo, S., Itoh, T., Tsukamasa, Y., Kawasaki, K. I. and Ando, M. 2012. Assessment of concentrations of toxic elements in aquaculture food products in Malaysia. *Food Chemistry*, *133*: 1326-1332.

Moore, J.V. and Ramamurti, S. 1987. Heavy Metals in Near Bottom Water. Mir Publishers, Moscow 285pp.

Nagarajan R., Jonathan M.P., Roy Priyadarsi D., Wai-Hwa L., Prasanna M.V., Sarkar S.K. and Navarrete-Lópeze M. 2013. Metal concentrations in sediments from tourist beaches of Miri City, Sarawak, Malaysia (Borneo Island), *Marine Pollution Bulletin,* 73 :369-373

Nedumaran, T. and Perumal, P. 2009. Temporal and spatial variations in the structure of macroalgal communities associated with mangroves of Pichavaram (South India). *Botany Research International*, *2*:198-205.

Nedwell, D.B., Sage, A.S. and Underwood, G.J.C. 2002. Rapid assessment of macroalgal cover on intertidal sediments in a nutrient-enriched estuary. *The Science of the Total Environment,* 285: 97-105.

NSW EPA. Chapter 5.12– Sediment contamination. New South Wales State of the Environment Report. Sydney, Australia: New South Wales Environmental Protection Authority; 2000

Oliveira, F.E.C. 1984. Brazilian mangal vegetation with special emphasis on the seaweeds. In: POR, F. D.; DOR, I. (Eds.). Hydrobiology of the mangal. Boston: W. Junk Publishers, . pp: 56-65.

Pakker, H., Breeman, A.M., Prud'homme van Reine W.F. and Van den Hoek, C. 1995. A comparativestudy of temperature responses of Caribbean seaweeds from different biogeographic groups.*Journal of Phycology*, 31:499–50.

Parsons, T.R., Maita, Y. and Lalli, C.M. 1984. A manual of chemical and biological methods for sea water analysis. 1st edition ., Pergamon press. Oxford.

Patimah, I. and Dainal, A.T. 1993. Accumulation of heavy metals in Penaeus monodon in Malaysia. International Conference on Fisheries and The Environment: Beyond 2000. 6-9 December 1993 Univ. Pertanian Malaysia Serdang, p. 58 (abstract). Universiti Pertanian Malaysia, Serdang.

Peckol, P. and Rivers, J.S. 1995. Physiological responses of the opportunistic macroalgae *Cladophora vagabunda* (L.) van der Hoek and *Gracilaria tikvahiae* to environmental disturbances associated with eutrophication. *Journal of Experimental Marine Biology and Ecology*, 190: 1-16.

Peckol, P., DeMeo-Anderson, B., Rivers, J., Valiela, I., Maldonado, M. and Yates, J. 1994. Growth, nutrient uptake capacities and tissue constituents of the macroalgae *Cladophora vagabunda* and *Gracilaria tikvahia*e related to site-specific nitrogen loading rates. *Marine Biology,* 121(1): 175-185.

Pedroche, F.F., West, J.A., Zuccarello, G.C., Senties, A.G. and Karsten, U. 1995. Marine red algae of the mangroves in Southern Pacific México and Pacific Guatemala. *Botanica marina*, 38, 111-120.

Pérez, A.A., Farías, S.S., Strobl, A.M., Pérez, L.B., López, C.M., Piñeiro, A., Roses, O. and Fajardo, M.A. 2007. Levels of essential and toxic elements in *Porphyra columbina* and *Ulva* sp. from San Jorge Gulf, Patagonia Argentina. *Science of the Total Environment*, 376: 51–59.

Peters, K.E., Sweeney, R.E. and Kaplan, I.R. 1978. Correlation of carbon and nitrogen stable isotope ratioin sedimentary organic matter. *Limnology and Oceanography*, 23:598-604

Phillips, A., Lambert, G., Granger, J.E. and Steinke, T.D. 1994. Horizontal zonation of epiphytic algae associated with *Avicennia marina* (Forsk.) Vierh. pneumatophores at Beachwoods Mangroves Nature Reserve, Durban, South Africa. *Botanica Marina,* 37:567-576

Phillips, A., Lambert, G., Granger, J.E. and Steinke, T.D. 1996. Vertical zonation of epiphytic algae associated withAvicennia marina(Forsk.) Vierh. pneumatophores at Beachwood Mangroves Nature Reserve, Durban, South Africa. *Botanica Marina,* 39: 167-175.

Phillips, D.J. and Segar, D.A. 1986. Use of bio-indicators in monitoring conservative contaminants: programme design imperatives. *Marine Pollution Bulletin*, *17*: 10-17.

Pielou, E.C. 1977. The latitudinal spans of seaweed species and their patterns of overlap. *Journal of Biogeography,* 4:299–311.

Proches, S. and Marshall D.J. 2002. Epiphytic algal cover*. Journal of the Marine Biological Association of the United Kingdom,* 82: 937-942.

Proches. S., Marshall, D.J., Ugrasen, K. and Ramcharan, A. 2001. Mangrove pneumatophore arthropod assemblages and seasonality patterns. *Journal of the Marine Biological Association of the United Kingdom*, 81: 545-552.

Rahman, R.A. and Surif, S. 1993. Metal finishing wastewater: characteristics and minimization. In: B. G. Yeoh , K. S. Chee, S. M. Phang, Z. Isa, A. Idris, M. Mohamed (Eds.),Waste Management in Malaysia: Current status and Prospects for Boremediation, pp. 3–7. Ministry of Science, Technology and the Environment, Malaysia.

Rainbow, P.S., 1995. Biomonitoring of heavy metal availability in the marine environment. *Marine Pollution Bulletin,* 31: 183–192.

Rajendran, K., Sampathkumar, P., Govindasamy, C., Ganesan, M., Kannan, R. and Kannan L. 1993. Levels of trace metals (Mn, Fe, Cu and Zn) in some Indian seaweeds. *Marine Pollution Bulletin,* 26: 283-285.

Read, D. 2003. *Report on copper, chromium and arsenic (CCA) treated timber*. ERMA, New Zealand.

Rodriguez, C. and Stoner, A.W. 1990. The epiphyte community of mangrove roots in a tropical estuary: distribution and biomass. *Aquatic Botany*, 36: 117-126.

Ronnback, P., Troell, M., Kautsky, N. and Primavera, J.H. 1999. Distribution pattern of shrimps and fish among *Avicennia* and *Rhizophora* microhabitats in the Pagbilao mangroves, Philippines. *Estuarine, Coastal and Shelf Science,* 48: 223–234

Runcie, J.W. and Riddle, M.J. 2004. Metal concentrations in macroalgae from East Antarctica. *Marine Pollution Bulletin,* 49: 1114–1119.

Rybak, A., Messyasz, B. and Łęska, B. 2013. The accumulation of metal (Co, Cr, Cu, Mn and Zn) in freshwater *Ulva* (Chlorophyta) and its habitat. *Ecotoxicology*, *22*: 558-573.

Sadiq, M. and Zaidi, T.H. 1994. Sediment composition and metal concentrations in mangrove leaves from the Saudi coast of the Arabian Gulf. *The Science of the Total Environment,* 155:1–8.

Saifullah, A.S.M., Abu Hena, M.K., Idris, M.S., Halima, A.R., Johan, I. 2014. Seasonal variation of water characteristics in Kuala Sibuti river estuary in Sarawak, Malaysia. *Malaysian Journal of Scienc*e, 33: 9-22.

Saifullah, S.M. and Elahi, E. 1992. Pneumatophore density and size in mangroves of Karachi, Pakistan. *Pakistan Journal of Botany*, *24*: 05-10.

Saifullah, S.M., Aisha K. and Rasool, F. 1997. Algal epiphytes on mangroves of Beluchistan, Pakistan. . *Pakistan Journal of Botany*, 29: 191-197.

Saifullah, S.M. and Ahmed, W. 2007. Epiphytic algal biomass on pneumatophores of mangroves of Karachi, Indus Delta*. Pakistan Journal of Botany,* 39:2097–2102

Sawidis, T., Brown, M.T., Zachariadis, G. and Sratis, I. 2001. Trace metal concentrations in marine macroalgae from different biotopes in the Aegean Sea. *Environment International*, *27*: 43-47.

Say, P.J., Burrows, J.G. and Whitton, B.A. 1990. *Enteromorpha* as a monitor of heavy metals in estuaries. *Hydrobiologia,* 195: 119–126.

Sena, F.S., Menghini, R.P., Cassano, V. and Sebastiani, R. 2012. Macroalgal community of pneumatophores in a mangrove of Barnabé Island (Baixada Santista), SP, Brazil: preliminary analysis. *Communications in Plant Sciences* (2237-4027) 2(3-4): 149-151.

Seng, C.E., Lim, P.E. and Ang, T.T. 1987. Heavy metal concentrations in coastal seawater and sediments off Prai Industrial Estate, Penang, Malaysia. *Marine Pollution Bulletin*, 18: 611-612.

Serfor-Armah, Y., Carboo, D. Akuamoah, R.K. and Chatt, A. 2006. Determination of selected elements in red, brown and green seaweed species for monitoring pollution in the coastal environment of Ghana. *Journal of Radioanalytical and Nuclear Chemistry*, 269: 711-718.

Shazili, N.A.M., Yunus, K., Ahmad, A.S., Abdullah, N. and Rashid, M.K.A. 2006. Heavy metal pollution status in the Malaysian aquatic environment. *Aquatic Ecosystem Health and Management*, *9*: 137-145.

Shiber, J.G. 1980. Trace metals with seasonal considerations in coastal algae and mollusks from Beirut, Lebanon. *Hydrobiologia,* 69: 147–162.

Singh, K. P., Malik, A., Mohan, D. and Sinha, S. 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study. *Water Research, 38*(18):3980-3992.

Snedaker, S.C. and Snedaker, J.G. 1984. *The mangrove ecosystem: research methods*. Unesco.

Steinke, T.D. and Naidoo, Y. 1990. Biomass of algae epiphytic on pneumatophores of the mangroveAvicennia marina, in the St Lucia estuary. *South African Journal of Botany,* 56: 226-232

Stoner, A.W. and Zimmerman, R.J. 1988. Food pathways associated with penaeid shrimps in a mangrove-fringed estuary. *Fisheries Bulletin, U.S*, 86: 543-552.

Sultan, K. and Shazili, N.A. 2009. Distribution and geochemical baselines of major, minor and trace elements in tropical topsoils of the Terengganu River basin, Malaysia. *Journal of Geochemical Exploration*, 103: 57-68.

Sunda, W.G. and Guillard, R.R.L. 1976. The relationship between cupric ion activity and toxicity of copper to phytoplankton. *Journal of Marine Research*, 34:511–529.

Sunda, W.G. 1988–89. Trace metal interactions with marine phytoplankton. *Biological Oceanography*, 6:411–42.

Szefer, P., Ali, A.A.,. Ba-Haroon, A.A, Rajeh A.A., Geldon J. and Nabrzyski.M. 1999. Distribution and relationships of selected trace metals in molluscs and associated sediments from the Gulf of Aden, Yemen*. Environment Pollution*, 106: 299-314.

Tanaka, J. and Chihara, M. 1987. Species composition and vertical distribution of macroalgae in brackish waters of Japanese mangrove forests. *Bulletin of National science Museum Okyo*, Series B 13:141-150.

Thomsen, M.S., McGlathery, K.J. and Tyler, A.C. 2006. Macroalgal distribution patterns in a shallow, soft-bottom lagoon, with emphasis on the nonnative *Gracilaria vermiculophylla* and *Codium fragile*. *Estuaries and Coasts, 29*(3): 465-473.

Townend, I. 2002. Marine science for strategic planning and management: the requirement for estuaries. *Marine Policy*, 26:209–19.

Tuzen, M., Verep, B., Ogretmen, A.O. and Soylak, M. 2009. Trace element content in marine algae species from the Black Sea, Turkey. *Environmental Monitoring Assessment*, 151: 363–368.

Valiela, I., McClelland, J., Hauxwell, J., Behr, P.J., Hersh, D. and Foreman, K. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. *Limnology and Oceanography,* 42:1105-1118.

Van den Hoek, C., Breeman, A.M., Bak, R.P.M. and Van Buurt, G. 1978. The distribution of algae, corals and gorgonians in relation to depth, light attenuation, water movement and grazing pressure in the fringing coral reef of Curac¸ao, Netherlands Antilles. *Aquatic Botany*, 5:1–46.

Vega, M., Pardo, R., Barrado, E. and Deban, L. 1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Research,* 32: 3581-3592.

Villares, R., Puente, X. and Carballeira, A. 2001. *Ulva* and *Enteromorpha* as indicators of heavy metal pollution. *Hydrobiologia*, 462: 221-232.

Villares, R., Puente, X. and Carballeira, A. 2002. Seasonal variation and background levels of heavy metals in two green seaweeds. *Environmental Pollution,* 119: 79-90.

Villares, R., Carral, E., Puente, X. and Carballeira, A. 2005. Metal levels in estuarine macrophytes: differences among species. *Estuaries*, 28: 948-956.

Vogt, H. and Schramm,W. 1991. Conspicuous decline of Fucus in Kiel Bay (western Baltic): what are the causes? *Marine Ecology Progress Series,* 69: 189-194.

Wangersky, J. 1986. Biological control of trace metal residence time and speciation: a review and synthesis. *Marine Chemistry*, 18:269–297.

Weatherburn M.W.1967. Phenol hypochlorite reaction for determination of ammonia. *Analytical chemistry,* 39: 971-974.

West, J.A., Zuccarello, G.C., West, K.A. and Loiseaux-de goër, S. 2008. New records of algae from Efaté, Vanuatu. *Cryptogamie. Algologie*, *29*: 235-254.

Wong, S. C., Muta Harah, Z. and Japar Sidik , B. 2010. Changes in macroalgae species composition, assemblage and coverage at an inter-tidal rocky shore. *Coastal Marine Science,* 34: 113-116.

Wood, A. K., Ahmad, Z., Shazili, N. A. M. Yaakob, R. and Carpenter, R. 1997. Geochemistry of sediments in Johor Strait between Malaysia and Singapore. *Continental Shelf Research,* 17: 1207-1228.

Yap, C.K., A. Ismail, S.G. Tan, and H. Omar. 2002a. Concentrations of Cu and Pb in the offshore and intertidal sediments of the west coast of Peninsular Malaysia. *Environmental International,* 28: 467–79

Yap, C.K., Ismail, A., Tan S.G. and Omar, H. 2002b. Correlations between speciation of Cd, Cu, Pb and Zn in sediment and their concentrations in total soft tissue of green-lipped mussel *Perna viridis* from the west coast of Peninsular Malaysia. *Environment International,* 28 (1–2): 117-126.

Yap, C.K., Ismail, A. and Tan, S.G. 2003a. Can the byssus of green-lipped mussel Perna viridis (Linnaeus) from the west coast of Peninsular Malaysia be a biomonitoring organ for Cd, Pb and Zn? Field and laboratory studies. *Environment International, 29*(4): 521-528.

Yap, C.K., Ismail, A. and Tan, S.G. 2003b. Cd, Cu and Zn concentrations in the Straits of Malacca and intertidal sediments of the west coast of Peninsular Malaysia. *Marine Pollution Bulletin,* 46: 1349–53

Yap, C.K., Ismail, A., Tan, S.G. and Abdul Rahim, I. 2003c. Can the shell of the green-lipped mussel Perna viridis from the west coast of Peninsular Malaysia be a potential biomonitoring material for Cd, Pb and Zn? *Estuarine, Coastal and Shelf Science*, 57: 623-630.

Yap, C.K., Ismail, A. and Tan, S.G. 2003d. Background concentrations of Cd, Cu, Pb and Zn in the green-lipped mussel *Perna viridis* (Linnaeus) from Peninsular Malaysia, *Marine Pollution Bulletin,* 46: 1044-1048.

Yap, C.K., Noorhaidah, A., Azlan, A., Nor Azwady, A.A., Ismail, A., Ismail, A.R. and Tan, S.G. 2009a. *Telescopium telescopium* as potential biomonitors of Cu, Zn, and Pb for the tropical intertidal area. *Ecotoxicology and Environmental Safety,* 72: 496-506.

Yap, C.K. and Edward, F.B. 2009b. Heavy metal concentrations in the different tissues of *Chicoreous capucinus*: The significance as a biomonitor. *Malaysian Applied Biology,* 38 : 17-21.

Yap, C.K., Edward, F.B. and Tan, S.G. 2010. Identification of potential intertidal bivalves as biomonitors of heavy metal contamination by using bivalve-sediment accumulation factors (BSAFs). *Journal of Sustainability Science and Management,* 5: 29-38.

Yap, C.K., Azmizan, A.R. and Hanif, M.S. 2011a. Biomonitoring of trace metals (Fe, Cu, and Ni) in the mangrove area of peninsular Malaysia using different soft tissues of flat tree oyster *Isognomon alatus*. *Water, Air, and Soil Pollution,* 218: 19-36.

Yap, C.K., Chee, M.W., Shamarina, S., Edward, F.B., Chew, W. and TAN, S.G. 2011b. Assessment of Surface Water Quality in the Malaysian Coastal Waters by Using Multivariate Analyses. *Sains Malaysiana,* 40: 1053–1064.

Yarish, C., Edwards, P. and Casey, S. 1980. The effects of salinity, and calcium and potassium variations on the growth of two estuarine red algae. *Journal of Experimental Marine Biology and Ecology,* 47: 235-249.

Yokoya, N.S., Plastino, E.M., Braga, M., Do rosário, A., Fujii, M.T., Cordeiro-marino, M. A. R. I. L. Z. A. and Harari, J. 1999. Temporal and spatial variations in the structure of macroalgal communities associated with mangrove trees of Ilha do Cardoso, São Paulo state, Brazil. *Brazilian Journal of Botany*, *22*: 195-204.

Zayed, A., Gowthaman, S. and Terry, N. 1998. Phytoaccumulation of trace elements by wetland plants: I. Duckweed. Journal of Environmental Quality, 27:715–721.

Zar, J.H. 1996. *Biostatistical Analysis (3rd ed.).* New Jersey: Prentice-Hall.

Zarcinas, S., Fauziah, C.I., Mclaughlin, M.J., Cozens, G. 2003. Heavy metals in soils and crops in Southeast Asia (Peninsular Malaysia). *Environmental Geochemistry and Health*, 26: 343-57.

Żbikowski, R., Szefer, P., and Latała, A. 2007. Comparison of green algae *Cladophora* sp. and *Enteromorpha* sp. as potential biomonitors of chemical elements in the southern Baltic. *Science of the Total Environment*, 387(1): 320-332.

Zhang, Y., Li, Y., Shi, F., Sun, X. and Lin, G. 2014. Seasonal and spatial variation in species diversity, abundance, and element accumulation capacities of macroalgae in mangrove forests of Zhanjiang, China. *Acta Oceanologica Sinica*: 1-10.

Zhou, Q., Zhang, J., Fu, J., Shi, J. and Jiang, G. 2008. Biomonitoring: an appealing tool for assessment of metal pollution in the aquatic ecosystem. *Analytica Chimica Acta,* 606(2): 135-150.

Zuccarello, G.C., Yeates, P.H., Wright, J.T. and Bartlett, J. 2001. Population structure and physiological differentiation of haplotypes of *Caloglossa leprieurii* (Rhodophyta) in a mangrove intertidal zone. *Journal of Phycology,* 37: 235-244.

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LIST OF PUBLICATION

Billah MM, Abu Hena MK, Hanafi I, Johan I, Bhuiyan MKA. Cu, Zn, Fe and Mn in mangrove ecosystems (sediment, water, oyster and macroalgae) of Sarawak, Malaysia. Zoology and Ecology. 2014. 24:4, 380-388.

Billah MM, Abu Hena MK, Hanafi I, Johan I. 2015. Influence of hydrological factors in the seasonal distribution of mangrove macroalgae in a Malaysian Estuary. Botanica Marina (2014 IF=1.40) (Accepted).

Abstract

Billah MM, Abu Hena MK, Bhuiyan MKA, Johan I and Idris MH.2014. Trace Metal Accumulation in the Mangrove Ecosystems of Sarawak, Malaysia. Proceeding of First national conference on non point source pollution (NPS, 2014), 14 and 15 May, 2014, Vivital Hotel, Kuala Lumpur, Malaysia pp 15-16.

Abu Hena MK, Billah MM, Idris MH, Johan I, Hasmida Isa and Nur Raihan. Biomass and habitat characteristics of mangrove macroalgae in Miri Estuary, Sarawak. Proceeding of the Malaysia International Biological Symposium, 28-29th October 2014, Palm Garden Hotel, IOI resort, Putrajaya

Billah MM, Abu Hena MK, Idris MH, Johan I, Nur Anisah. Metal (Cu, Fe, Mn, Zn) pollution assessment of mangrove sediments in Miri estuary, Sarawak, Malaysia. Proceeding of the Malaysia International Biological Symposium, 28-29th October 2014, Palm Garden Hotel, IOI resort, Putrajaya

In preparation

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