UNIVERSITI PUTRA MALAYSIA

DISTRIBUTION AND SOURCE IDENTIFICATION OF POLYCYCLIC AROMATIC HYDROCARBONS IN MANGROVE SEDIMENTS AND PNEUMATOPHORES IN REMBAU-LINGGI ESTUARY, MALAYSIA

MUHAMMAD RAZA

FPAS 2012 22

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DISTRIBUTION AND SOURCE IDENTIFICATION OF POLYCYCLIC AROMATIC HYDROCARBONS IN MANGROVE SEDIMENTS AND PNEUMATOPHORES IN REMBAU-LINGGI ESTUARY, MALAYSIA

By

MUHAMMAD RAZA

April 2012

Chairman : Prof. Mohamad Pauzi bin Zakaria, PhD

Faculty : Environmental Studies

Polycyclic aromatic hydrocarbons (PAHs) are one of the foremost widespread classes of pollutants which can accumulate in sediments for a long period of time due to their low water solubility and hydrophobicity properties. Mangrove sediment acts as a sink for organic pollutants especially in an estuary environment. The aims of this study are to determine the composition, distribution and sources of PAHs in mangrove sediments and pneumatophores of *Sonneratia* in Rembau-Linggi estuary. The samples were collected from nine stations along Rembau-Linggi estuary, Negeri Sembilan. The samples were then extracted using a soxhlet extractor with dichloromethane followed by silica gel column chromatography to separate the hydrocarbons into fractions. The 17 PAHs were analyzed and identified using GC-MS based on the response factor of a PAH standard. Low molecular weight PAHs were abundant in pneumatophores while high molecular weight PAHs were abundant in sediments. Total PAHs in pneumatophores were significantly higher ($p<0.05$) than in sediments in all eight stations. There is no significant correlation between PAHs and organic carbon which means that the distribution of PAHs was

not affected by the organic carbon content. Total methylphenanthrenes (MP) shows weak correlation with total PAHs ($p<0.05$) implying that petrogenic input has some contribution to the sedimentary PAHs but not a major control over distribution of PAHs within the estuary. CombPAH shows a positive correlation with total PAHs with $R^2=0.9368$ ($p<0.05$) suggesting that pyrogenic input has significant contribution to the sedimentary PAHs. It is suggested that the combustion of petroleum, wood and coal were the main sources of PAHs which have been brought by long-range atmospheric transport and thus, deposited into this estuary. The PAH concentrations increased with distance from upstream of the estuary to the coastal area of Straits of Malacca which implied that river discharge and urban runoff flowing from residential areas centred near the coastline of the Straits of Malacca were the probable source of PAHs. There is a moderate relationship between PAHs of sediments and pneumatophores ($p<0.05$) which implied that sedimentary PAHs have moderate influence on the PAH distribution in pneumatophores. None of individual PAH compounds exceeded the values of ERL-ERM and TEL-PEL guidelines thus PAH level in sediments in Rembau-Linggi estuary are unlikely to cause any adverse biological effects to aquatic organisms.

Keywords: Mangrove Sediments, Pneumatophores, Pyrogenic PAHs, Petrogenic PAHs, Anthropogenic activities, Long-range transport

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

TABURAN DAN PENGENALPASTIAN SUMBER HIDROKARBON AROMATIK POLISIKLIK DALAM TANAH BAKAU DAN PNEUMATOPHORES DI KUALA REMBAU-LINGGI, MALAYSIA

Oleh

MUHAMMAD RAZA

April 2012

Pengerusi : Prof. Mohamad Pauzi bin Zakaria, PhD

Fakulti : Pengajian Alam Sekitar

Hidrokarbon aromatik polisiklik (PAH) ialah salah satu daripada bahan pencemar utama yang tersebar meluas di mana ianya mampu berkumpul di dalam tanah untuk jangka masa yang lama disebabkan tahap kelarutan dalam air yang rendah dan bersifat hidrofobik. Tanah bakau bertindak sebagai tempat berkumpul bagi bahan pencemar organik terutamanya di kawasan kuala sungai. Objektif kajian ini ialah mengenal pasti komposisi, taburan dan sumber pencemaran PAH dalam tanah bakau dan pneumatophores *Sonneratia* di kuala Rembau-Linggi. Sampel diambil daripada sembilan stesen di sepanjang kuala Rembau-Linggi, Negeri Sembilan. Sampel diekstrak dengan menggunakan pengekstrak Soxhlet menggunakan diklorometana dan diikuti dengan kolum kromatografi gel silika untuk memisahkan hidrokarbon kepada beberapa bahagian kecil. Semua 17 PAH dianalisis dengan GC-MS berdasarkan faktor respon. PAH jisim molekul rendah adalah dominan di dalam pneumatophores manakala PAH jisim molekul tinggi adalah dominan di dalam tanah. Jumlah PAH di dalam pneumatophores adalah tinggi secara signifikan

(p<0.05) daripada tanah di semua lapan stesen. Didapati bahawa tiada hubungan yang signifikan diantara PAH dan karbon organik, yang menunjukkan bahawa taburan PAH tidak dipengaruhi oleh kandungan karbon organik. Jumlah metilphenanthrena (MP) menunjukkan hubungan yang lemah dengan jumlah PAH (p<0.05) menandakan bahawa input petrogenik mempunyai pengaruh terhadap PAH dalam tanah tetapi bukanlah pengaruh yang besar kepada taburan PAH di kuala ini. CombPAH menunjukkan hubungan positif dengan jumlah PAH dengan R^2=0.9368 (p<0.05) menandakan bahawa input pirogenik mempunyai sumbangan yang penting kepada PAH dalam tanah. Adalah dicadangkan bahawa pembakaran petroleum, kayu dan arang adalah sumber utama PAH yang mana telah dibawa oleh pengangkutan atmosfera jarak jauh dan termendap di kuala ini. Kepekatan PAH adalah meningkat dengan jarak dari hulu kuala sehingga ke kawasan pesisir pantai Selat Melaka yang mana menunjukkan bahawa sisa buangan sungai dan larian air dari kawasan berpenduduk yang berpusat di kawasan persisir pantai Selat Melaka adalah berpotensi menjadi sumber PAH. Adalah didapati hubungan sederhana diantara PAH di dalam tanah dan pneumatophores (p<0.05) menunjukkan bahawa PAH di dalam tanah mempunyai pengaruh yang sederhana terhadap taburan PAH di dalam pneumatophores. Tiada PAH sebatian individu yang melebihi nilai garis panduan ERL-ERM dan TEL-PEL dan seterusnya menunjukkan bahawa tahap PAH di dalam tanah di kuala Rembau-Linggi adalah tidak akan menyebabkan kesan biologikal yang buruk kepada haiwan akuatik.

Kata kunci: Tanah bakau, Pneumatophores, PAH pirogenik, PAH petrogenik, Aktiviti anthropogenik, Pengangkutan jarak jauh

ACKNOWLEDGEMENT

All praise is to **Allah the Almighty**, for giving me blessing, strength and patient to complete this study. I wish to express my great appreciation to **Prof. Dr. Mohamad Pauzi Zakaria** for being my advisor and believing my abilities to conduct this study. Also I wish to thank my graduate committee member, **Dr. Nor Rasidah Hashim** for her great help, advice and guidance throughout my study. A lot of guidance and great opportunities for going to training and workshops have been given to me in order to gain knowledge and improve skills.

I also thank **Korea Ocean Research and Development Institute (KORDI)**, Geoje-shi, Republic of Korea and **Institut Agro-Bioteknologi Malaysia (ABI)** for their assist in instrumental analysis. I sincerely appreciate my family for the support and encouragement throughout this work. Their prayers gave me strength to complete this study.

I wish to express my special thanks to **Zufarzaana Zulkeflee** for her continues help and support throughout this work. I also thank **Mohd Fazlin Nazli** for his valuable help in sampling and fieldwork. Finally my deepest thank to all colleagues for their assist and support. Hopefully the sweet memories that we shared together will last forever.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ant	Anthracene
Ant/178	Anthracene / (Phenanthrene + Anthracene)
B[a]A	Benzo[a]anthracene
B[a]A/228	Benzo[a]anthracene / (Benzo[a]anthracene + Chrysene)
B[a]P	Benzo[a]pyrene
B[e]P	Benzo[e]pyrene
B[k]F	Benzo[k]fluoranthene
B[g,h,i]P	Benzo[g,h,i]perylene
Chr	Chrysene
Chr-d_{12}	Chrysene-deuterated-12
DB[a,h]A	Dibenzo[a,h]anthracene
DCM	Dichloromethane
dry wt.	Dry weight
ERL	Effect Range Low
ERM	Effect Range Median
Flt	Fluoranthene
Flu/202	Fluoranthene / (Fluoranthene + Pyrene)
GC-MS	Gas Chromatography-Mass Spectrometry
LMW/HMW	Low Molecular Weight PAH/High Molecular Weight PAH
LOD	Limit of Detection
LOQ	Limit of Quantification
Hex	Hexane
IIS	Internal Injection Standard
I[c,d]P	Indeno[1,2,3-cd]pyrene

I[c,d]P/276	Indeno[1,2,3-cd]pyrene / (Indeno[1,2,3cd]pyrene + Benzo[g,h,i]perylene)
MeOH	Methanol
MP/P	Methylphenanthrene/Phenanthrene
Na_2SO_4	Anhydrous Sodium Sulphate
PAHs	Polycyclic Aromatic Hydrocarbons
PEL	Probable Effects Level
Phe	Phenanthrene
ppm	part per million
ppb	part per billion
Pyr	Pyrene
S/N	Signal to Noise Ratio
SIS	Surrogate Internal Standard
SQG	Sediment Quality Guidelines
spp.	Species (plural)
TEL	Threshold Effects Level
TOC	Total Organic Carbon
UPM	Universiti Putra Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Southeast Asia's mangroves are known internationally as being the world's largest and best-developed mangrove forests (Giesen and Wulffraat, 1998; Giesen *et al.*, 2007). In the western part of Peninsular Malaysia, mangroves are a continuous belt of forest area facing the Straits of Malacca which cover the muddy shores of sheltered coasts and river estuaries. Located between land and the sea, mangroves are consistently under threat from both sea-based and land-based pollutants. Studies have shown that mangroves are vulnerable to oil spills which are the main source of the hydrocarbon contamination in marine environments (Dicks 1986; Burns *et al.*, 1993; Burns and Yelle-Simmons 1994; Burns *et al.*, 1994; Levings *et al.*, 1994; Tam *et al.*, 2005; Farias *et al.*, 2006; Farias *et al.*, 2008; Dsikowitzky *et al.*, 2011). Furthermore, the location of mangrove forests in West of Peninsular Malaysia facing the Straits of Malacca and Sumatra, Indonesia regularly experience haze due to biomass burning in southern Sumatra (Radzi *et al.*, 2004; He *et al.*, 2010).

Due to the increasing trend of industrialization and urbanization in Malaysia, mangroves are facing the threat of hydrocarbon accumulation. Polycyclic aromatic hydrocarbons (PAHs) are given more attention among the hydrocarbons since they are one of the most widespread organic pollutants. PAHs are derived from land-based and sea-based sources where most are the result of anthropogenic activities.

Most mangroves occur in estuaries and act as sink for various pollutants where they tend to adsorb to surface sediments.

Anthropogenic activities resulting from industrialization and urbanization i.e. fossil fuel combustion, discharge of domestic sewage and incineration of industrial waste give a great contribution to pollution generation especially in marine and coastal environments. This study aims to investigate hydrocarbon contamination in mangrove sediments and pneumatophores with special focus on polycyclic aromatic hydrocarbons.

The results and findings of the study enhance the knowledge and awareness about hydrocarbons contamination, in directions that are not only meant for conservation of the mangrove forests, but also for the protection of the aquatic organisms that are closely associated with mangrove ecosystems.

1.2 Problem Statement

Mangrove ecosystems are exposed to the threat of hydrocarbon accumulation due to the increase in human activities along the coastline facing the Straits of Malacca. This has lead to pollutions to the marine and coastal environments including the mangrove forests, estuaries and wetlands. The aromatic group of hydrocarbons, PAHs, is able to accumulate and persist in sediments for a long period of time due to their low water solubility and hydrophobic properties. As a result, PAHs tend to adsorb strongly onto sediments and sediment particles in water. Moreover, the unique characteristics of mangrove environments such as rich in organic carbon

content, generally anaerobic condition below the surface sediments layers due to high bacterial activities (Bernard *et al.*, 1996) and the presents of brackish water, result in PAH biodegradation occurs very slowly (Suess, 1976; Hensel *et al.*, 2002). In this instance, PAHs are likely to accumulate and persist in the mangrove environments (Neff, 1979) thus poses threat to the ecosystems.

There is lack of study on PAHs in mangrove ecosystems in Malaysia. There is only one scientific publication available on PAHs study on Malaysian mangroves (Tahir *et al.*, 2011), however, the study was carried out in the eastern part of Peninsular Malaysia in 2001. Hence, there is need recent PAH studies in mangroves especially for the western part of Peninsular Malaysia. What is more, there is no scientific publication available on PAH study on mangrove plant of *Sonneratia* species. Most of the PAH studies in other countries tested on other mangrove species such as *Aegiceras corniculatum, Avicennia marina, Bruguiera gymnorrhiz, Kandelia candel* and *Rhizophora mangle* (Garrity *et al.*, 1994; Ke *et al.*, 2003a; Ke *et al.*, 2003b; Zhi-qiang *et al.*, 2005; Tam and Wong, 2008). It is important to study the distribution of PAHs in *Sonneratia* species since this species is the most abundant species in the mangrove ecosystem in Malaysia. Therefore, a study on PAH contamination in mangrove sediments and pneumatophores of *Sonneratia* species is required in order to determine the current level of PAHs in Peninsular Malaysia especially the mangrove regions located along the Straits of Malacca such as the chosen site, the Rembau-Linggi estuary.

1.3 Objectives of the Study

i. To determine the compositional patterns of PAHs in mangrove sediments and in pneumatophores of *Sonneratia* species

ii. To determine the relationship between sedimentary PAHs and TOC content

iii. To identify the sources of PAHs in mangrove sediments and pneumatophores

iv. To compare the sedimentary PAH concentrations with sediment quality guidelines

1.4 Hypotheses

The hypotheses of this study were built based on the findings and conclusion made from previous studies in the literature review:

i. Sediment is abundant with HMW PAHs and pneumatophores is abundant with LMW PAHs

ii. There is a significant positive correlation between sedimentary PAHs and TOC content

iii. PAHs in mangrove sediments and pneumatophores are mainly originate from petrogenic sources

iv. Sedimentary PAH levels in Rembau-Linggi estuary do not exceed the recommended PAH levels of sediment quality guidelines

1.5 Significance of the Study

Study on PAHs in mangrove sediments and pneumatophores will significantly help to quantify the current level and distribution of these compounds in typical Malaysian mangrove ecosystems. Moreover, it is believed that PAHs have the potential to be major pollutants deposited and accumulated in the mangrove estuaries. Rembau-Linggi estuary was chosen as it is located in the western part of Peninsular Malaysia facing the Straits of Malacca as well as Sumatra, Indonesia. These two regions i.e. Straits of Malacca and Sumatra, Indonesia have great potential to be significant sources in Malaysian mangrove ecosystems. In this case, pyrogenic PAHs originate from biomass burning in Sumatra, Indonesia transferred by long range transport through air masses and wind (Radzi *et al.*, 2004; He *et al.*, 2010), while the petrogenic PAHs derived from ships and tankers in the Straits of Malacca brought by sea tides and wave to these mangrove estuaries.

Moreover, based on previous study by Nazli and Hashim (2010), *Sonneratia caseolaris* in Rembau-Linggi estuary possess the capacity to take up selected heavy metals via its pneumatophores. Thus, further study is required in order to prove the capability of mangrove plants, specifically *Sonneratia* species, to take up and accumulate the PAHs in the pneumatophores. For those reasons, this study is required in order to fill the gap of information on PAH study in Malaysian mangrove ecosystems.

The results of this study will be compared with the proposed PAH levels of sediment quality guidelines in order to evaluate the biological effects of sedimentary PAHs to

the aquatic organisms, especially the ones that are closely associated with mangrove ecosystems. Finally, a number of new findings on PAHs fate in Malaysian mangrove ecosystems will be scientifically shown through this study.

REFERENCES

Abdullah A.R., Tahir N.M., Loong T.S., Hoque T.M., Sulaiman A.H. 1999. The GEF/UNDP/IMO Malacca Straits Demonstration Project: Sources of Pollution. Marine Pollution Bulletin 39 (1-12): 229-233.

Abdullah P., Nainggolan H. 1991. Phenolic water pollutants in a Malaysian River basin. Environmental Monitoring and Assessment 19 (1): 423-431.

Abril, G., M. Nogueira, H. Etcheber, G. Cabec¸adas, E. Lemaire, and M. J. Brogueira, 2002. Behaviour of organic carbon in nine contrasting European estuaries. Estuarine Coastal Shelf Science, 54(2): 241-262.

Agrawala S., Ota T., Risbey J., Hagenstad M., Smith J., Aalst M.v., Koshy K., Prasad B. 2004. Development and Climate Change in Egypt: Focus on Coastal Resources and the Nile. Environment Directorate and Development Cooperation Directorate, Organisation for Economic Cooperation and Development (OECD), Paris, France.

Alongi D.M. 2002. Present state and future of the world's mangrove forests. Environmental Conservation 29 (3): 331-349.

Al-Saad H.T., Al-Timari A.A. 1989. Distribution of polycyclic aromatic hydrocarbons (PAH's) in marsh sediments, Iraq. Bulletin of Environmental Contamination and Toxicology 43 (6): 864-869.

Arias A., Vazquez-Botello A., Tombesi N., Ponce-Vélez G., Freije H., Marcovecchio J. 2010. Presence, distribution, and origins of polycyclic aromatic hydrocarbons (PAHs) in sediments from Bahía Blanca estuary, Argentina. Environmental Monitoring and Assessment 160 (1): 301-314.

Bahry P.S., Zakaria M.P., Bin Abdullah A.M., Abdullah D.K., Sakari M., Chandru K., Shahbazi A. 2009. Forensic Characterization of Polycyclic Aromatic Hydrocarbons and Hopanes in Aerosols from Peninsular Malaysia. Environmental Forensics 10 (3): 240 - 252.

Bai Y.J., Li X.Q., Liu W.X., Tao S., Wang L.G., Wang J.F. 2008. Polycyclic aromatic hydrocarbon (PAH) concentrations in the dissolved, particulate, and sediments phases in the Luan River watershed, China. Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering 43 (4): 365 - 374.

Bakhtiari A.R., Zakaria M.P., Yaziz M.I., Lajis M.N.H., Bi X. 2011. Variations and Origins of Aliphatic Hydrocarbons in Sediments Cores from Chini Lake in Peninsular Malaysia. Environmental Forensics 12 (1): 79 - 91.

Bakhtiari A.R., Zakaria M.P., Yaziz M.I., Lajis M.N.H., Bi X., Rahim M.C.A. 2009. Vertical distribution and source identification of polycyclic aromatic hydrocarbons in anoxic sediments cores of Chini Lake, Malaysia: Perylene

as indicator of land plant-derived hydrocarbons. Applied Geochemistry 24 (9): 1777-1787.

Bakhtiari A.R., Zakaria M.P., Yaziz M.I., Lajis M.N.H., Bi X., Shafiee M.R.M., Sakari M. 2010. Distribution of PAHs and n-alkanes in Klang River Surface Sediments, Malaysia. Pertanika J. Sci. & Technol 18 (1): 167-179.

Baumard P., Budzinski H., Garrigues P. 1998. Polycyclic aromatic hydrocarbons in sediments and mussels of the Western Mediterranean Sea. Environmental Toxicology and Chemistry 17 (5): 765-776.

Becker L., Glavin D.P., Bada J.L. 1997. Polycyclic aromatic hydrocarbons (PAHs) in Antarctic Martian meteorites, carbonaceous chondrites, and polar ice. Geochimica et Cosmochimica Acta 61 (2): 475-481.

Becker L., Glavin D.P., Bada J.L. 1997. Polycyclic aromatic hydrocarbons (PAHs) in Antarctic Martian meteorites, carbonaceous chondrites, and polar ice. Geochimica et Cosmochimica Acta 61 (2): 475-481.

Bell R., Green M., Hume T., Gorman R. 2000. What regulates sediments in estuaries? Water & Atmosphere 8 (4): 13-16.

Bence A.E., Kvenvolden K.A., Kennicutt M.C. 1996. Organic geochemistry applied to environmental assessments of Prince William Sound, Alaska, after the Exxon Valdez oil spill--a review. Organic Geochemistry 24 (1): 7-42.

Bernard D., Pascaline H., Jeremie J.J. 1996. Distribution and origin of hydrocarbons in sediments from lagoons with fringing mangrove communities. Marine Pollution Bulletin 32 (10): 734-739.

Blumer M. 1976. Polycyclic aromatic compounds in nature. Scientific American 234 (3): 35-45.

Boffetta P., Jourenkova N., Gustavsson P. 1997. Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons. Cancer Causes and Control 8 (3): 444-472.

Boonyatumanond R., Wattayakorn G., Togo A., Takada H. 2006. Distribution and origins of polycyclic aromatic hydrocarbons (PAHs) in riverine, estuarine, and marine sediments in Thailand. Marine Pollution Bulletin 52 (8): 942-956.

Budzinski H., Jones I., Bellocq J., Piérard C., Garrigues P. 1997. Evaluation of sediments contamination by polycyclic aromatic hydrocarbons in the Gironde estuary. Marine Chemistry 58 (1-2): 85-97.

Burns K.A., Garrity S.D., Jorissen D., MacPherson J., Stoelting M., Tierney J., Yelle-Simmons L. 1994. The Galeta Oil Spill. II. Unexpected Persistence of Oil Trapped in Mangrove Sediments. Estuarine, Coastal and Shelf Science 38 (4): 349-364.

Burns K.A., Garrity S.D., Levings S.C. 1993. How many years until mangrove ecosystems recover from catastrophic oil spills? Marine Pollution Bulletin 26 (5): 239-248.

Burns K.A., Yelle-Simmons L. 1994. The Galeta Oil Spill. IV. Relationship Between Sediments and Organism Hydrocarbon Loads. Estuarine, Coastal and Shelf Science 38 (4): 397-412.

Burton J.G.A. 2002. Sediments quality criteria in use around the world. Limnology 3 (2): 65-76.

Cardellicchio N., Buccolieri A., Giandomenico S., Lopez L., Pizzulli F., Spada L. 2007. Organic pollutants (PAHs, PCBs) in sediments from the Mar Piccolo in Taranto (Ionian Sea, Southern Italy). Marine Pollution Bulletin 55 (10-12): 451-458.

Cavalcante R.M., Sousa F.W., Nascimento R.F., Silveira E.R., Freire G.S.S. 2009. The impact of urbanization on tropical mangroves (Fortaleza, Brazil): Evidence from PAH distribution in sediments. Journal of Environmental Management 91 (2): 328-335.

Cerniglia C.E. 1992. Biodegradation of polycyclic aromatic hydrocarbons. Biodegradation 3 (2): 351-368.

Chaîneau C.H., Morel J.L., Oudot J. 1997. Phytotoxicity and Plant Uptake of Fuel Oil Hydrocarbons. Journal of Environmental Quality 26 (6): 1478-1483.

Connell D.W., Wu R.S.S., Richardson B.J., Leung K., Lam P.S.K., Connell P.A. 1998. Occurrence of persistent organic contaminants and related substances in Hong Kong marine areas: An overview. Marine Pollution Bulletin 36 (5): 376-384.

DeLaune R.D., Hambrick G.A., Patrick W.H. 1980. Degradation of hydrocarbons in oxidized and reduced sediments. Marine Pollution Bulletin 11 (4): 103-106.

Dicks B. 1986. Oil and the black mangrove, Avicennia marina in the northern Red Sea. Marine Pollution Bulletin 17 (11): 500-503.

Ding X., Wang X.-M., Xie Z.-Q., Xiang C.-H., Mai B.-X., Sun L.-G., Zheng M., Sheng G.-Y., Fu J.-M., Pöschl U. 2007. Atmospheric polycyclic aromatic hydrocarbons observed over the North Pacific Ocean and the Arctic area: Spatial distribution and source identification. Atmospheric Environment 41 (10): 2061-2072.

Domínguez C., Sarkar S., Bhattacharya A., Chatterjee M., Bhattacharya B., Jover E., Albaigés J., Bayona J., Alam M., Satpathy K. 2011. Quantification and Source Identification of Polycyclic Aromatic Hydrocarbons in Core Sediments from Sundarban Mangrove Wetland, India. Archives of Environmental Contamination and Toxicology 59 (1): 49-61.

Dsikowitzky L., Nordhaus I., Jennerjahn T.C., Khrycheva P., Sivatharshan Y., Yuwono E., Schwarzbauer J. 2011. Anthropogenic organic contaminants in

water, sediments and benthic organisms of the mangrove-fringed Segara Anakan Lagoon, Java, Indonesia. Marine Pollution Bulletin 62 (4): 851-862.

Duarte-Davidson R., Jones K.C. 1996. Screening the environmental fate of organic contaminants in sewage sludge applied to agricultural soils: II. The potential for transfers to plants and grazing animals. Science of The Total Environment 185 (1-3): 59-70.

Edwards N.T. 1983. Polycyclic Aromatic Hydrocarbons (PAH's) in the Terrestrial Environment: A Review. J. Environ. Qual. 12 (4): 427-441.

Elias M.S., Wood A.K., Hashim Z., Siong W.B., Hamzah M.S., Rahman S.A., Salim N.A.A., Talib A. 2007. Polycyclic Aromatic Hydrocarbon (PAH) Contamination in the Sediments of East coast Peninsular Malaysia. Malaysian Journal of Analytical Sciences 11 (1): 70-75.

Eong, O. J., 1993. Mangroves - a carbon source and sink. Chemosphere, 27(6): 1097-1107.

Farias C., Hamacher C., Wagener A., Scofield A. 2006. The fate of oil spilled in mangrove sediments--Rio de Janeiro, Brazil. Geochimica et Cosmochimica Acta 70 (18, Supplement 1): A165-A165.

Farias C.O., Hamacher C., Wagener A.d.L.R., Scofield A.d.L. 2008. Origin and degradation of hydrocarbons in mangrove sediments (Rio de Janeiro, Brazil) contaminated by an oil spill. Organic Geochemistry 39 (3): 289-307.

Feller I.C., Sitnik M. 1996. Mangrove Ecology: A Manual for a Field Course. Smithsonian Institution Washington. DC, Washington. DC. 135 pp.

Fu J., Ding Y.-H., Li L., Sheng S., Wen T., Yu L.-J., Chen W., An S.-Q., Zhu H.-L. 2011. Polycyclic aromatic hydrocarbons and ecotoxicological characterization of sediments from the Huaihe River, China. Journal of Environmental Monitoring 13 (3): 597-604.

Fujimoto, K., A. Imaya, R. Tabuchi, S. Kuramoto, H. Utsugi, T. Murofushi, 1999. Below ground carbon storage of Micronesian mangrove forests. Ecological Reserves, 14: 409-413.

Garrity S.D., Levings S.C., Burns K.A. 1994. The Galeta Oil Spill. I. Long-term Effects on the Physical Structure of the Mangrove Fringe. Estuarine, Coastal and Shelf Science 38 (4): 327-348.

Giesen W., Wulffraat S. 1998. Indonesian mangroves part I: Plant diversity and vegetation. Tropical Biodiversity 5 (2): 11-23.

Giesen W., Wulffraat S., Zieren M., Scholten L. 2007. Mangrove Guidebook for Southeast Asia. Food and Agriculture Organization of the United Nations (FAO) Wetlands International, Thailand. 702 pp.

Guildford, J. P. 1956. Fundamental statistics in psychology and education. 3rd revision edition. McGraw-Hill Book Company Inc. New York and London. 565 pp.

Grimmer G., 1983. Environmental carcinogens, polycyclic aromatic hydrocarbons: Chemistry, occurrence, biochemistry, carcinogenicity. CRC Press, Boca Raton, Florida.

Halsall C.J., Sweetman A.J., Barrie L.A., Jones K.C. 2001. Modelling the behaviour of PAHs during atmospheric transport from the UK to the Arctic. Atmospheric Environment 35 (2): 255-267.

Haritash A.K., Kaushik C.P. 2009. Biodegradation aspects of Polycyclic Aromatic Hydrocarbons (PAHs): A review. Journal of Hazardous Materials 169 (1-3): 1-15.

Hashim N.R., Nazli M.F. 2011. SWOT Analysis of Crocodile Conservation in Rembau-Linggi Estuary, Peninsular Malaysia. *in:* Zakaria MP, Mohamed MI, Kasmin S, Hashim NR, Samah MAA, Zainuddin MF, Zaid SSM (Eds.), Contemporary environmental quality management in Malaysia and selected countries. Universiti Putra Malaysia Press, Serdang Selangor, pp. 133-143.

He J., Zielinska B., Balasubramanian R. 2010. Composition of semi-volatile organic compounds in the urban atmosphere of Singapore: influence of biomass burning. Atmos. Chem. Phys. Discuss. 10 (4): 8415-8445.

Henner P., Schiavon M., Morel J.-L., Lichtfouse E. 1997. Polycyclic aromatic hydrocarbon (PAH) occurrence and remediation methods. Analusis 25 56-59.

Ibrahim N.K., Mustafa F.B. 2010. Spatial and temporal variations of silica in a disturbed tropical River Basin. Sains Malaysiana 39 (2): 189-198.

Jacob J. 1996. The significance of polycyclic aromatic hydrocarbons as environmental carcinogens. Pure and Applied Chemistry 68 (2): 301-308.

Jayamann S. C. 2007. Characterisations of Mangroves. In Gattenlöhner, U., Lampert, S. and Wunderlich, K. (Editor) Mangrove Rehabilitation Guidebook. Framework of the EU-ASIA PRO ECO II B Post Tsunami Project in Sri Lanka. Global Nature Fund (GNF), Radolfzell, Germany, 68 pp.

Jiang C., Alexander R., Kagi R.I., Murray A.P. 2000. Origin of perylene in ancient sediments and its geological significance. Organic Geochemistry 31 (12): 1545-1559.

Kannan K., Johnson-Restrepo B., Yohn S.S., Giesy J.P., Long D.T. 2005. Spatial and Temporal Distribution of Polycyclic Aromatic Hydrocarbons in Sediments from Michigan Inland Lakes. Environmental Science & Technology 39 (13): 4700-4706.

Karickhoff S.W., Brown D.S., Scott T.A. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Research 13 (3): 241-248.

Ke L., Wang W.Q., Wong T.W.Y., Wong Y.S., Tam N.F.Y. 2003a. Removal of pyrene from contaminated sediments by mangrove microcosms. Chemosphere 51 (1): 25-34.

Ke L., Wong T.W.Y., Wong A.H.Y., Wong Y.S., Tam N.F.Y. 2003b. Negative effects of humic acid addition on phytoremediation of pyrene-contaminated sediments by mangrove seedlings. Chemosphere 52 (9): 1581-1591.

Ke L., Wong T.W.Y., Wong Y.S., Tam N.F.Y. 2002. Fate of polycyclic aromatic hydrocarbon (PAH) contamination in a mangrove swamp in Hong Kong following an oil spill. Marine Pollution Bulletin 45 (1-12): 339-347.

Ke L., Yu K.S.H., Wong Y.S., Tam N.F.Y. 2005. Spatial and vertical distribution of polycyclic aromatic hydrocarbons in mangrove sediments. Science of The Total Environment 340 (1-3): 177-187.

Keymeulen R., Van Langenhove H., Schamp N. 1991. Determination of monocyclic aromatic hydrocarbons in plant cuticles by gas chromatography-mass spectrometry. Journal of Chromatography A 541 83-88.

Klekowski Jr E.J., Corredor J.E., Morell J.M., Del Castillo C.A. 1994. Petroleum pollution and mutation in mangroves. Marine Pollution Bulletin 28 (3): 166-169.

Labana S., Kapur M., Malik D., Prakash D., Jain R.K., 2007. Diversity, Biodegradation and Bioremediation of Polycyclic Aromatic Hydrocarbons, Environmental Bioremediation Technologies, pp. 409-443.

Levings S.C., Garrity S.D., Burns K.A. 1994. The Galeta Oil Spill. III. Chronic Reoiling, Long-term Toxicity of Hydrocarbon Residues and Effects on Epibiota in the Mangrove Fringe. Estuarine, Coastal and Shelf Science 38 (4): 365-395.

Li, T. C. Mangroves in need of protection. The Star-MIMA, 18 October 2005, http://thestar.com.my/lifestyle/story.asp?file=/2005/10/18/lifefocus/12176710&sec=lifefocus

Li C.-H., Zhou H.-W., Wong Y.-S., Tam N.F.-Y. 2009. Vertical distribution and anaerobic biodegradation of polycyclic aromatic hydrocarbons in mangrove sediments in Hong Kong, South China. Science of The Total Environment 407 (21): 5772-5779.

Liang Y., Tse M.F., Young L., Wong M.H. 2007. Distribution patterns of polycyclic aromatic hydrocarbons (PAHs) in the sediments and fish at Mai Po Marshes Nature Reserve, Hong Kong. Water Research 41 (6): 1303-1311.

Liang Y., Tse M.F., Young L., Wong M.H. 2007. Distribution patterns of polycyclic aromatic hydrocarbons (PAHs) in the sediments and fish at Mai Po Marshes Nature Reserve, Hong Kong. Water Research 41 (6): 1303-1311.

Lipiatou E., Saliot A. 1991. Fluxes and transport of anthropogenic and natural polycyclic aromatic hydrocarbons in the western Mediterranean Sea. Marine Chemistry 32 (1): 51-71.

Liu A., Lang Y., Xue L., Liu J. 2009. Ecological risk analysis of polycyclic aromatic hydrocarbons (PAHs) in surface sediments from Laizhou Bay. Environmental Monitoring and Assessment 159 (1): 429-436.

Liu Y., Chen L., Huang Q.-h., Li W.-y., Tang Y.-j., Zhao J.-f. 2009. Source apportionment of polycyclic aromatic hydrocarbons (PAHs) in surface sediments of the Huangpu River, Shanghai, China. Science of The Total Environment 407 (8): 2931-2938.

Liu Y., Chen L., Jianfu Z., Qinghui H., Zhiliang Z., Hongwen G. 2008. Distribution and sources of polycyclic aromatic hydrocarbons in surface sediments of rivers and an estuary in Shanghai, China. Environmental Pollution 154 (2): 298-305.

Long E., Macdonald D., Smith S., Calder F. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19 (1): 81-97.

Long E.R., Field L.J., MacDonald D.D. 1998. Predicting toxicity in marine sediments with numerical Sediment quality guidelines. Environmental Toxicology and Chemistry 17 (4): 714-727.

Long E.R., MacDonald D.D. 1998. Recommended Uses of Empirically Derived, Sediment quality guidelines for Marine and Estuarine Ecosystems. Human and Ecological Risk Assessment: An International Journal 4 (5): 1019 - 1039.

Long E.R., MacDonald D.D., Severn C.G., Hong C.B. 2000. Classifying probabilities of acute toxicity in marine sediments with empirically derived Sediment quality guidelines. Environmental Toxicology and Chemistry 19 (10): 2598-2601.

Macdonald D.D., Carr R.S., Calder F.D., Long E.R., Ingersoll C.G. 1996. Development and evaluation of Sediment quality guidelines for Florida coastal waters. Ecotoxicology 5 (4): 253-278.

MacDonald D.D., Ingersoll C.G., Berger T.A. 2000. Development and Evaluation of Consensus-Based Sediment quality guidelines for Freshwater Ecosystems. Archives of Environmental Contamination and Toxicology 39 (1): 20-31.

Macek T., Macková M., Kás J. 2000. Exploitation of plants for the removal of organics in environmental remediation. Biotechnology Advances 18 (1): 23-34.

Mahro B., Schaefer G., Kästner M. 1994. Pathways of microbial degradation of polycyclic aromatic hydrocarbons in soil. in: Hinchee RE, Leeson A, Semprini L, Ong SK (Eds.), Bioremediation of Chlorinated and Polycyclic Aromatic Hydrocarbon Compounds CRC Press, Florida, pp. 203–217.

Mai, Qi, Zeng E.Y., Yang, Zhang G., Fu, Sheng, Peng, Wang. 2003. Distribution of Polycyclic Aromatic Hydrocarbons in the Coastal Region off Macao, China: Assessment of Input Sources and Transport Pathways Using Compositional Analysis. Environmental Science & Technology 37 (21): 4855-4863.

Masclet P., Bresson M.A., Mouvier G. 1987. Polycyclic aromatic hydrocarbons emitted by power stations, and influence of combustion conditions. Fuel 66 (4): 556-562.

Masclet P., Hoyau V., Jaffrezo J.L., Cachier H. 2000. Polycyclic aromatic hydrocarbon deposition on the ice sheet of Greenland. Part I: superficial snow. Atmospheric Environment 34 (19): 3195-3207.

Mastaller M. 1997. Mangroves: The Forgotten Forest Between Land and Sea. Tropical Press, Kuala Lumpur. 199 pp.

Matsui, N., 1998 . Estimated stocks of organic carbon in mangrove roots and sediments in Hinchinbrook Channel, Australia. Mangroves Salt Marshes, 2(4): 199-204.

McCready S., Slee D.J., Birch G.F., Taylor S.E. 2000. The Distribution of Polycyclic Aromatic Hydrocarbons in Surficial Sediments of Sydney Harbour, Australia. Marine Pollution Bulletin 40 (11): 999-1006.

Medeiros P.M., Caruso Bícego M. 2004. Investigation of natural and anthropogenic hydrocarbon inputs in sediments using geochemical markers. I. Santos, SP--Brazil. Marine Pollution Bulletin 49 (9-10): 761-769.

Mehta A.J., Hayter E.J., Parker W.R., Tester A.M. 1987. Cohesive sediment transport processes. in: Committee on Sedimentation Control to Reduce Maintenance Dredging in Estuaries MB, National Research Council (Ed.), Sedimentation control to reduce maintenance dredging of navigational facilities in estuaries: report and symposium proceedings. National Academy Press, Washington, D.C. p. 356.

Minai-Tehrani D., Minoui S., Herfatmanesh A. 2009. Effect of Salinity on Biodegradation of Polycyclic Aromatic Hydrocarbons (PAHs) of Heavy Crude Oil in Soil. Bulletin of Environmental Contamination and Toxicology 82 (2): 179-184.

Mirsadeghi S.A., Zakaria M.P., Yap C.K., Shahbazi A. 2011. Risk assessment for the daily intake of polycyclic aromatic hydrocarbons from the ingestion of cockle (Anadara granosa) and exposure to contaminated water and sediments along the west coast of Peninsular Malaysia. Journal of Environmental Sciences 23 (2): 336-345.

Mohammed T.A., Said S., Bardaie M.Z., Basri S.N. 2011. Numerical Simulation of Flood Levels for Tropical Rivers. IOP Conference Series: Materials Science and Engineering 17 (1): 012040.

Moore, T. R. and R. J.Jackson, 1989. Dynamics of dissolved organic carbon in forested and disturbed catchments, wetland, New Zealand. Larry River. Water Resources Research 25(6): 1331-1339.

Murphy P.P., Bates T.S., Curl H.C., Feely R.A., Scott Burger R. 1988. The transport and fate of particulate hydrocarbons in an urban fjord-like estuary. Estuarine, Coastal and Shelf Science 27 (5): 461-482.

Nather Khan I.S.A. 1990. The mineralogy and trace element constituents of suspended stream sediments of the Linggi River Basin, Malaysia. Journal of Southeast Asian Earth Sciences 4 (2): 133-139.

Nazli M.F., Hashim N.R. 2010. Heavy Metal Concentrations in an Important Mangrove Species, *Sonneratia caseolaris*, in Peninsular Malaysia. EnvironmentAsia 3 (special issue): 50-55.

Neff J.M. 1979. Polycyclic Aromatic Hydrocarbons Sources Fates and Biological Effects. Applied Science Publishers, London, UKpp.

Nicholls, P., Ellis, J. 2002. Fringing habitats in estuaries: the sediments-mangrove connection. Water & Atmosphere 10(4): 24-25.

Nikolaou K., Masclet P., Mouvier G. 1984. Sources and chemical reactivity of polynuclear aromatic hydrocarbons in the atmosphere - A critical review. Science of The Total Environment 32 (2): 103-132.

Okuda T., Kumata H., Zakaria M.P., Naraoka H., Ishiwatari R., Takada H. 2002. Source identification of Malaysian atmospheric polycyclic aromatic hydrocarbons nearby forest fires using molecular and isotopic compositions. Atmospheric Environment 36 (4): 611-618.

Omar N.Y.M.J., Mon T.C., Rahman N.A., Abas M.R.B. 2006. Distributions and health risks of polycyclic aromatic hydrocarbons (PAHs) in atmospheric aerosols of Kuala Lumpur, Malaysia. Science of The Total Environment 369 (1-3): 76-81.

Ouyang, Y., J.E. Zhang and L.T. Ou, 2006. Temporal and Spatial Distributions of Sediments Total Organic Carbon in an Estuary River. Journal of Environmental Quality, 35(1): 93-100.

Peixoto R., Chaer G., Carmo F., Araújo F., Paes J., Volpon A., Santiago G., Rosado A. 2011. Bacterial communities reflect the spatial variation in pollutant levels in Brazilian mangrove sediments. Antonie van Leeuwenhoek 99 (2): 341-354.

Perillo G.M.E., Perillo G.M.E. 1995. Chapter 1 Geomorphology and Sedimentology of Estuaries: An Introduction. Developments in Sedimentology. Elsevier, pp. 1-16.

Prahl F.G., Carpenter R. 1983. Polycyclic aromatic hydrocarbon (PAH)-phase associations in Washington coastal sediments. Geochimica et Cosmochimica Acta 47 (6): 1013-1023.

Prevedouros K., Brorström-Lundén E., J. Halsall C., Jones K.C., Lee R.G.M., Sweetman A.J. 2004. Seasonal and long-term trends in atmospheric PAH concentrations: evidence and implications. Environmental Pollution 128 (1-2): 17-27.

Radzi M., Oros D.R., Simoneit B.R.T. 2004. Biomass burning as the main source of organic aerosol particulate matter in Malaysia during haze episodes. Chemosphere 55 (8): 1089-1095.

Rahman A. A. 2009. Mangrove. http://wasterecycleinfo.com/rd.html. Resources Technology. Chennai, India.

Raza M., Zakaria M.P., Hashim N.R. 2011. Hydrocarbon Contamination in Mangrove Sediment of Linggi River: A Pilot Study. in: Zakaria MP, Mohamed MI, Kasmin S (Eds.), Contemporary Environmental Quality Management in Malaysia and Selected Countries. Universiti Putra Malaysia Press, Serdang, pp. 25-33.

Readman J.W., Mantoura R.F.C., Rhead M.M., Brown L. 1982. Aquatic distribution and heterotrophic degradation of Polycyclic Aromatic Hydrocarbons (PAH) in the Tamar Estuary. Estuarine, Coastal and Shelf Science 14 (4): 369-389.

Reilley K.A., Banks M.K., Schwab A.P. 1996. Organic chemicals in the environment, dissipation of polycyclic aromatic hydrocarbons in the Rhizosphere. Journal of Environmental Quality 25 (2): 212-219.

Rogge W.F., Hildemann L.M., Mazurek M.A., Cass G.R., Simoneit B.R.T. 1993. Sources of fine organic aerosol. 2. Noncatalyst and catalyst-equipped automobiles and heavy-duty diesel trucks. Environmental Science & Technology 27 (4): 636-651.

Saha M., Togo A., Mizukawa K., Murakami M., Takada H., Zakaria M.P., Chiem N.H., Tuyen B.C., Prudente M., Boonyatumanond R., Sarkar S.K., Bhattacharya B., Mishra P., Tana T.S. 2009. Sources of sedimentary PAHs in tropical Asian waters: Differentiation between pyrogenic and petrogenic sources by alkyl homolog abundance. Marine Pollution Bulletin 58 (2): 189-200.

Sakari M., Zakaria M.P., Junos M.M., Annuar N.A., Yun H.Y., Heng Y.S., Zainuddin S.M.H.S., Chai K.L. 2008. Spatial distribution of petroleum hydrocarbon in sediments of major rivers from east coast of peninsular Malaysia. Coastal Marine Science 32 (1): 9-18.

Sakari M., Zakaria M.P., Mohamed C.A.R., Lajis N.H., Abdullah M.H., Shahbazi A. 2011. Polycyclic Aromatic Hydrocarbons and Hopane in Malacca Coastal Water: 130 Years of Evidence for Their Land-Based Sources. Environmental Forensics 12 (1): 63 - 78.

Sakari M., Zakaria M.P., Mohamed C.A.R., Lajis N.H., Chandru K., Bahry P.S., Mokhtar M.B., Shahbazi A. 2010. Urban vs. Marine Based Oil Pollution in the Strait of Johor, Malaysia: A Century Record. Soil and Sediments Contamination: An International Journal 19 (6): 644 - 666.

Schoellhamer D.H., William H.M., Ashish J.M. 2000. Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay. Proceedings in Marine Science. Elsevier, pp. 343-357.

Schwab A.P., Banks M.K., 1994. Biologically Mediated Dissipation of Polyaromatic Hydrocarbons in the Root Zone, Bioremediation through Rhizosphere Technology. American Chemical Society, pp. 132-141.

Simpson C.D., Mosi A.A., Cullen W.R., Reimer K.J. 1996. Composition and distribution of polycyclic aromatic hydrocarbon contamination in surficial marine sediments from Kitimat Harbor, Canada. Science of The Total Environment 181 (3): 265-278.

Sims R.C., Overcash M.R. 1983. Fate of polynuclear aromatic compounds (PNAs) in soil-plant systems. Residue Reviews Vol. 88 1-68.

Soclo H.H., Garrigues P., Ewald M. 2000. Origin of Polycyclic Aromatic Hydrocarbons (PAHs) in Coastal Marine Sediments: Case Studies in Cotonou (Benin) and Aquitaine (France) Areas. Marine Pollution Bulletin 40 (5): 387-396.

Sojinu O.S., Sonibare O.O., Ekundayo O., Zeng E.Y. 2010b. Biomonitoring potentials of polycyclic aromatic hydrocarbons (PAHs) by higher plants from an oil exploration site, Nigeria. Journal of Hazardous Materials 184 (1-3): 759-764.

Sporstol S., Gjos N., Lichtenthaler R.G., Gustavsen K.O., Urdal K., Oreld F., Skei J. 1983. Source identification of aromatic hydrocarbons in sediments using GC/MS. Environmental Science & Technology 17 (5): 282-286.

Suess M.J. 1976. The environmental load and cycle of polycyclic aromatic hydrocarbons. Science of the Total Environment 6 (3): 239-250.

Tahir N.M., Rahim H.M.A., Abas M.R., Rashid M.K.A. 2006. Distribution and Characterization of Hydrocarbons in Sediments of Setiu Wetland, Terengganu: A Preliminary Study. Malaysia Journal of Analytical Sciences 10 (1): 177-184.

Tahir N.M., Ariffin J., Maarop H., Wood A.K.H. 2011. Sources of Polycyclic Aromatic Hydrocarbons in Mangrove Sediments of Pulau Cik Wan Dagang, Kemaman. Journal of Sustainability Science and Management 6 (1): 98-106.

Tam N.F.Y., Ke L., Wang X.H., Wong Y.S. 2001. Contamination of polycyclic aromatic hydrocarbons in surface sediments of mangrove swamps. Environmental Pollution 114 (2): 255-263.

Tam N.F.Y., Wong T.W.Y., Wong Y.S. 2005. A case study on fuel oil contamination in a mangrove swamp in Hong Kong. Marine Pollution Bulletin 51 (8-12): 1092-1100.

Tam, N. F. Y. and Y. S. Wong. 1998. Variations of Soil Nutrient and Organic Matter Content in a Subtropical Mangrove Ecosystem. Water, Air, & Soil Pollution 103(1):245-261.

Tamamura S., Sato T., Ota Y., Wang X., Tang N., Hayakawa K. 2007. Long-range transport of polycyclic aromatic hydrocarbons (PAHs) from the eastern Asian continent to Kanazawa, Japan with Asian dust. Atmospheric Environment 41 (12): 2580-2593.

Tao S., Cui Y.H., Xu F.L., Li B.G., Cao J., Liu W.X., Schmitt G., Wang X.J., Shen W.R., Qing B.P., Sun R. 2004. Polycyclic aromatic hydrocarbons (PAHs) in agricultural soil and vegetables from Tianjin. Science of The Total Environment 320 (1): 11-24.

Thia-Eng C., Gorre I.R.L., Adrian Ross S., Bernad S.R., Gervacio B., Corazon Ebarvia M. 2000. The Malacca Straits. Marine Pollution Bulletin 41 (1-6): 160-178.

Tsapakis M., Stephanou E.G., Karakassis I. 2003. Evaluation of atmospheric transport as a nonpoint source of polycyclic aromatic hydrocarbons in marine sediments of the Eastern Mediterranean. Marine Chemistry 80 (4): 283-298.

Wagener A.d.L.R., Carreira R.S., Hamacher C., Scofield A.d.L., Farias C.O., Cordeiro L.G.M.S., Luz L.G., Baêta A.P., Kalas F.A. 2011. Hydrocarbon composition and distribution in a coastal region under influence of oil production in northeast Brazil. Marine Pollution Bulletin In Press, Corrected Proof.

Wang P., Zhang Y., Wu T.-H. 2010. Novel method for in situ visualization of polycyclic aromatic hydrocarbons in mangrove plants. Toxicological & Environmental Chemistry 92 (10): 1825 - 1829.

Wang Y., Field R.D., Roswintiarti O. 2004. Trends in atmospheric haze induced by peat fires in Sumatra Island, Indonesia and El Niño phenomenon from 1973 to 2003. Geophys. Res. Lett. 31 (4): L04103.

Watts A.W., Ballestero T.P., Gardner K.H. 2006. Uptake of polycyclic aromatic hydrocarbons (PAHs) in salt marsh plants Spartina alterniflora grown in contaminated sediments. Chemosphere 62 (8): 1253-1260.

Wild S.R., Jones K.C. 1994. The significance of polynuclear aromatic hydrocarbons applied to agricultural soils in sewage sludges in the U.K. Waste Management & Research 12 (1): 49-59.

Wild S.R., Jones K.C. 1995. Polynuclear aromatic hydrocarbons in the United Kingdom environment: A preliminary source inventory and budget. Environmental Pollution 88 (1): 91-108.

Witt G., Trost E. 1999. Polycyclic aromatic hydrocarbons (PAHs) in sediments of the Baltic Sea and of the German coastal waters. Chemosphere 38 (7): 1603-1614.

Woodhead R.J., Law R.J., Matthiessen P. 1999. Polycyclic Aromatic Hydrocarbons in Surface Sediments Around England and Wales, and Their Possible Biological Significance. Marine Pollution Bulletin 38 (9): 773-790.

Wu, H., Z. Guo, and C. Peng, 2003. Land use induced changes of organic carbon storage in soils of China. Global Change Biology. 9(3): 305-315.

Xu J., Yu Y., Wang P., Guo W., Dai S., Sun H. 2007. Polycyclic aromatic hydrocarbons in the surface sediments from Yellow River, China. Chemosphere 67 (7): 1408-1414.

Yang X.-Y., Okada Y., Tang N., Matsunaga S., Tamura K., Lin J.-M., Kameda T., Toriba A., Hayakawa K. 2007. Long-range transport of polycyclic aromatic hydrocarbons from China to *Japan*. Atmospheric Environment 41 (13): 2710-2718.

Yim U.H., Hong S.H., Shim W.J. 2007. Distribution and characteristics of PAHs in sediments from the marine environmentsof Korea. Chemosphere 68 (1): 85-92.

Yim U.H., Hong S.H., Shim W.J., Oh J.R., Chang M. 2005. Spatio-temporal distribution and characteristics of PAHs in sediments from Masan Bay, Korea. Marine Pollution Bulletin 50 (3): 319-326.

Youngblood W.W., Blumer M. 1975. Polycyclic aromatic hydrocarbons in the environment: homologous series in soils and recent marine sediments. Geochimica et Cosmochimica Acta 39 (9): 1303-1314.

Yuan D., Yang D., Wade T.L., Qian Y. 2001. Status of persistent organic pollutants in the sediments from several estuaries in China. Environmental Pollution 114 (1): 101-111.

Yuan S.Y., Chang J.S., Yen J.H., Chang B.-V. 2001. Biodegradation of phenanthrene in river sediments. Chemosphere 43 (3): 273-278.

Yunker M.B., Macdonald R.W., Vingarzan R., Mitchell R.H., Goyette D., Sylvestre S. 2002. PAHs in the Fraser River basin: a critical appraisal of PAH ratios as indicators of PAH source and composition. Organic Geochemistry 33 (4): 489-515.

Zakaria M.P., Geik K.H., Lee W.Y., Hayet R. 2005. Landfill leachate as a source of polycyclic aromatic hydrocarbons (PAHs) to Malaysian waters. Coastal Marine Science 29 (2): 116-123.

Zakaria M.P., Okuda T., Takada H. 2001. Polycyclic Aromatic Hydrocarbon (PAHs) and Hopanes in Stranded Tar-balls on the Coasts of Peninsular Malaysia: Applications of Biomarkers for Identifying Sources of Oil Pollution. Marine Pollution Bulletin 42 (12): 1357-1366.

Zakaria M.P., Takada H., Tsutsumi S., Ohno K., Yamada J., Kouno E., Kumata H. 2002. Distribution of Polycyclic Aromatic Hydrocarbons (PAHs) in Rivers

and Estuaries in Malaysia: A Widespread Input of Petrogenic PAHs. Environmental Science & Technology 36 (9): 1907-1918.

Zemo D.A. 2009. Use of Parent Polycyclic Aromatic Hydrocarbon (PAH) Proportions to Attribute PAH Sources in Sediments: A Case Study from the Pacific Northwest. Environmental Forensics 10 (3): 229 - 239.

Zhang J., Cai L., Yuan D., Chen M. 2004. Distribution and sources of polynuclear aromatic hydrocarbons in Mangrove surficial sediments of Deep Bay, China. Marine Pollution Bulletin 49 (5-6): 479-486.

Zheng G.J., Lam M.H.W., Lam P.K.S., Richardson B.J., Man B.K.W., Li A.M.Y. 2000. Concentrations of Persistent Organic Pollutants in Surface Sediments of the Mudfat and Mangroves at Mai Po Marshes Nature Reserve, Hong Kong. Marine Pollution Bulletin 40 (12): 1210-1214.

Zheng G.J., Man B.K.W., Lam J.C.W., Lam M.H.W., Lam P.K.S. 2002. Distribution and sources of polycyclic aromatic hydrocarbons in the sediments of a sub-tropical coastal wetland. Water Research 36 (6): 1457-1468.

Zheng G.J., Richardson B.J. 1999. Petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) in Hong Kong marine sediments. Chemosphere 38 (11): 2625-2632.

Zhi-qiang L.U., Wen-jiao Z., Li M.A. 2005. Bioconcentration of polycyclic aromatic hydrocarbons in roots of three mangrove species in Jiulong River Estuary. Journal of Environmental Sciences 17 (2): 285-289.