Environmental risks and management of polycyclic aromatic hydrocarbons in Philippine aquatic ecosystems using the DPSIR model

[1]Bernhard A. Krah, [2]Andrej Miklosik

[1] Faculty of Management, Comenius University in Bratislava, Odbojárov, Bratislava, Slovak Republic; [2] Department of Marketing, Faculty of Management, Comenius University in Bratislava, Odbojárov, Bratislava, Slovak Republic. Corresponding author: B. A. Krah, krah2@uniba.sk

Abstract. Pollution of polycyclic aromatic hydrocarbons (PAHs) in aquatic ecosystems induced by pyrogenic and petrogenic sources continues to degrade the quality of surface waters and sediments and compromise the physiology, growth and population of aquatic biota. This is magnified with the archipelagic setting and rapid socio-economic developments of the Philippines relative to its rich aquatic resources. As such, this review paper aimed to provide nuanced understanding on the impacts of PAHs in various Philippine aquatic ecosystems using the Driver-Pressure-State-Impact-Response (DPSIR) framework that identifies links among documented PAH pollution and management. The DPSIR model has elicited urbanization and industrialization, especially oil trade and industry, to be the driving forces of human activities resulting into persistent and severe PAH pollution. Research opportunities and management gaps have been highlighted in this synthesis. This current knowledge underscores the need for holistic environmental biomonitoring and strict policy implementation to mitigate and prevent further PAH contamination in aquatic ecosystems of the Philippines and neighboring Indo-Pacific countries.
Key Words: PAHs, fisheries, oil pollution, oil spill, organic pollution, blue economy.

Introduction. Persistent organic pollutants in the Indo-Pacific continue to impose environmental risks in aquatic ecosystems due to extensive use and increased transboundary movement and transportation of these toxic substances (Bedi et al 2018; Ishikawa et al 2019). Oil pollution in freshwater and marine environments, through fuel combustion, industrial discharges, untreated wastewater and shipping mishaps, is known to negatively impact aquatic systems with polycyclic aromatic hydrocarbons (PAHs). Exposure to these toxic pollutants compromise the physiology, reproduction, growth and population of aquatic organisms such as crustaceans, mollusks and fishes (Hussain et al 2018; Landos et al 2021). To date, bioaccumulation and biomagnification of PAHs have been considered as one of the global environmental threats that affect human and ecosystem health systems across food web structures (Balcioglu 2016; Sun et al 2016; Yakan et al 2017).

There are more than a hundred of PAHs known but 16 of which (i.e. naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene and indeno(1,2,3-c,d)pyrene) have been prioritized and standardized in the environmental assessment and monitoring of aquatic ecosystems (USEPA 1977; Alegbeleye et al 2017). These toxicants are either formed or produced by biological and other natural processes (e.g. forest fires, volcanic eruption) or by anthropogenic processes (e.g. automobile emissions, industrial activities, combustion) (Latimer & Zheng 2003; Hussain et al 2018). Anthropogenic PAHs are predominating în the environment, being concentrated in highly urbanized and trafficked areas, and are transported via the water phases (e.g. rain, storm), then distributed in aquatic, terrestrial and aerial environments (Neary & Boving 2011). Consequently, the deposition of PAHs in aquatic environments such as in water column, river beds and marine sediments is considered to be the central path of PAHs accumulation (Manzetti 2013).

As an archipelagic developing country, the aquatic ecosystems in the Philippines are heavily impacted and threatened by organic pollutants driven by urbanization and industrialization (Zafaralla et al 2005; Isobe et al 2007; Taneza & Philip 2009; Peralta et al 2019). The freshwater and marine resources are crucial for the socio-economic stability of coastal communities which accounts for about 85% of the country's total population (World Bank 2005; Briones 2007). The Philippine's ocean-based (blue) economy, sourced from 70% of the country's aggregated geographical area, is valued at US$ 966.6 billion. However, this blue economy struggles to be maximized due to unsustainable human activities in the coast and mismanagement of marine ecosystems (Azanza et al 2017). Holistic and national approaches on strict environmental policy implementation and mitigation must take place at regional and global scales, consistently with the recent call of Ishikawa et al (2019) and Landos et al (2021) on the need of fundamental shifts in industry, economy and governance towards recovery and resiliency improvement of aquatic ecosystems and fisheries from the persistent organic pollutants like PAHs.

This review paper aimed to discuss impacts of PAHs in Philippine aquatic ecosystems. Also, this provides insights on research opportunities and management gaps towards PAHs using DPSIR framework. This current synthesis shall guide government and private agencies in their anti-PAHs pollution management, monitoring and prevention strategies in the aquatic ecosystems of the Philippines.

Material and Method

DPSIR framework. Extensive review of literature has been employed to gather relevant studies on PAH pollution and recovery in Philippine aquatic ecosystems. Standardized keywords (i.e. polycyclic aromatic hydrocarbons; Philippines; pollution; aquatic ecosystems) and search engines (i.e. Google Scholar; ScienceDirect) have been utilized to obtain related research articles. These papers were analyzed using Driver-Pressure-States-Impact-Response (DPSIR) framework which takes into account presumed and known chain of causal relationships. DPSIR model is originally developed by the Organization of Economic Cooperation and Development (OECD 1993) and used by the European Environment Agency (EEA 1995) and United Nations (UNEP 1994, 2007). To date, this approach has been one of the bases of decision-makers on environmental risks and management of aquatic systems (Wantzen et al 2019; Labianca et al 2020). In this review, driver corresponds to socio-economic developments driven by consumption and production patterns. These drivers may intentionally or unintentionally exert pressure on the environment through various human activities and concomitant pollutants. Consequently, the state of ecosystem in terms of its biotic and abiotic condition reflects the pressures exerted on the system. Changes in the ecosystem quality and functioning impose impact on organisms' health and ecosystem services. Eventually, the response takes place through the decisions and actions of the stakeholders from the society and government to mitigate, manage and prevent the former chained elements of the DPSIR framework (Gari et al 2015).

Results and Discussion. Using the DPSIR framework, current knowledge and nuanced understanding on PAH pollution in Philippine aquatic ecosystems have been provided. Table 1 summarizes the studies that have assessed the extent of PAH pollution and recovery in the country. These studies have dealt with freshwater (28.6%) and marine (71.4%) ecosystems that have been contaminated with PAHs at environmental (i.e. water and sediments) and organismal (i.e. individual and population) levels.

Table 1

DPSIR analysis on the collated studies that assessed PAH pollution and recovery in aquatic ecosystems in the Philippines

Author	*Site*	*Driver*	*Pressure*	*State*	*Impact*	*Response*
Zafaralla et al 2005	Napindan River, Sta. Cruz River, San Cristobal River, San Pedro River, and Laguna de Bay	Industrialization and urbanization	Chemical production, food processing, agricultural activities	Contaminated surface water, sediment, fish	Not assessed	Assessment of ecological impact and biomagnification
Hallare et al 2005	Laguna de Bay	Industrialization and urbanization	Petrochemical industries	Contaminated sediments	Embryotoxic and proteotoxic response of test species (*Danio rerio*)	Ecotoxicological testing and monitoring
Isobe et al 2007	Metro Manila, Bataan, Cavite, Bulacan, Capiz, and Samar	Urbanization	Sewage and petrogenic inputs in coastal waters	Contaminated green mussel (*Perna viridis*)	Not assessed	Extensive and systematic monitoring
Uno et al 2007	Panay Island	Industrialization and urbanization	Petrogenic sources	Contaminated bivalves	Not assessed	Not indicated
Kosmehl et al 2008	Laguna de Bay	Industrialization and urbanization	Biogenic and petrogenic sources	Contaminated sediments	Genotoxic on zebra fish (*Danio rerio*) embryo	In situ examination of genotoxicity
Saha et al 2009	Manila Bay	Industrialization and urbanization	Automobile-derived petrogenic sources	Contaminated sediments	Not assessed	Identification of point-sources
Taneza & Philip 2009	Iloilo River	Industrialization and urbanization	Transportation and petrogenic sources	Contaminated surface water and sediments	Water quality degradation	Not indicated
Pahila et al 2010	Taklong Island National Marine Reserve	Oil trade and industry	Oil spill	Contaminated sediments, oyster, squid, and fish	Not assessed	Not indicated
Uno et al 2010a,b	Guimaras and Taklong Islands, Luzaran	Oil trade and industry	Oil spill	Contaminated shellfish, oyster, crab, and fish	Potential health risks for exposed consumers	Continuous investigation and monitoring

Author	*Site*	*Driver*	*Pressure*	*State*	*Impact*	*Response*
Yender & Stanzel 2011	Guimaras Coastline	Oil trade and industry	Oil spill	Contaminated mangrove stands, seagrass beds, coral reefs	Isolated mortality and stress of marine fauna and mangrove species	Extensive cleanup operations and monitoring, chemical dispersant application
Andalencio et al 2014	Nueva Valencia and Sibunag Aquaculture, Guimaras	Oil trade and industry	Oil spill	Contaminated aquaculture fish and shellfish	Fish kills, low survival, decreased fish and shellfish demand, marketing problems	Closure of pond gates, application of dispersants offshore, and continuous flushing of water
Barnuevo & Sadaba 2014	Guimaras Mangrove Coast	Oil trade and industry	Oil spill	Contaminated mangrove ecosystem	Mortality of marine fauna and mangrove species, reduction of mangrove leaf size, and increased in surging waves	Recruitment of mangrove seedlings, and monitoring of long-term impacts and recovery
Peralta & Serrano 2014	Guimaras Mangrove Coast	Oil trade and industry	Oil spill	Contaminated mangrove clam	Potential health risks for consumers	Not indicated
Uno et al 2017	Guimaras Island Coast	Oil trade and industry	Oil spill	Decreased contamination in shellfish as compared with Uno et al 2010a,b	Gradual ecosystem recovery	Long-term monitoring until full ecosystem recovery has been detected

Driver. PAHs pollution is highly driven by human activities through unsustainable urbanization and industrialization. As a developing country, it is expected that increasing demand and production will be accommodated by increased urban, agricultural and industrial areas which consequently drive environmental waste and pollution (Hallare et al 2005; Zafaralla et al 2005). Furthermore, the documented severe PAH contamination in Philippine ocean, river and aquaculture sites were driven by oil trade and industry which resulted to shipping mishaps in 2006 when the Solar 1 tanker has sank in the coast of Guimaras Island (Taneza & Philip 2009; Pahila et al 2010; Uno et al 2010a,b; Yender and Stanzel 2011; Andalencio et al 2014; Barnuevo and Sadaba 2014; Peralta & Serrano 2014). Most recently, another large-scale oil spill has happened last July 3, 2020 due to the explosion of a floating power barge in the coast of Iloilo City, Philippines (Rendon 2020). Regardless if the identified PAH pollution drivers were intentionally or unintentionally induced, stakeholders must remain vigilant towards these sources, compliant in existing environmental policies and proactive in developing contingency plans.

Pressure. The anthropogenic sources of PAHs are more specifically categorized as either pyrogenic or petrogenic. On one hand, pyrogenic PAHs are formed when organic substances are exposed to high temperature under hypoxic to anoxic conditions (e.g. distillation of coal into coke and tar). Unintentional pyrogenic processes may also occur during incomplete combustion of vehicle and heating system fuels as well as wood during forest fires. On the other hand, petrogenic PAHs are attributed to widespread transportation, storage, use and disposal of crude oil and its products. Major pressures include oil spills, underground and aboveground tank leaks and transportation-related release of gasoline, motor oil and other fuels. (Abdel-Shafy & Mansour 2016). DPSIR analysis has revealed that all PAH contaminations in Philippine aquatic ecosystems can be traced back to events due to petrogenic sources such as industrial runoff, transportation-related oil leaks and large-scale oceanic oil spills. The latter have been documented as a total release of 2,100 tons and 170 tons of oil in the coast of Guimaras and Iloilo, in 2006 and 2020, respectively (Uno et al 2017; Rendon 2020). These incidents, on top of other petrogenic sources, challenge the current efforts to mitigate PAH pollution in the country.

State. All 16 PAHs have been documented to contaminate Philippine aquatic ecosystems (Table 1) including its surface waters, sediments, flora and fauna. Surface waters in both freshwater and marine environments were detected with significant concentration of PAHs (Zafaralla et al 2005; Taneza & Philip 2009). Similarly, high deposition of PAHs in the sediments, seagrass beds and benthic environments have been observed (Zafaralla et al 2005; Hallare et al 2005; Kosmehl et al 2008; Saha et al 2009; Taneza & Philip 2009; Pahila et al 2010; Yender & Stanzel 2011). Aquatic biota such as mangroves, crustaceans, bivalves and fishes have been analyzed to contain significant concentrations of PAHs (Isobe et al 2007; Uno et al 2007; Pahila et al 2010; Uno et al 2010a,b; Yender & Stanzel 2011; Andalencio et al 2014; Barnuevo & Sadaba 2014; Peralta & Serrano 2014; Uno et al 2017). These ecosystem conditions reflect a significant contribution of drivers and pressures described above.

Impact. Among the papers analyzed, 57% documented their impact assessments of the PAHs on organisms based on experiments. Aside from water quality degradation (Taneza & Philip 2009), mangrove and fish mortality have been observed due to an immediate ecosystem degradation due to the oil spill incident in Guimaras (Yender & Stanzel 2011; Andalencio et al 2014; Barnuevo & Sadaba 2014). Also, presumed impacts (e.g. bioaccumulation and biomagnification) and risks on human health have been indicated following the PAH contamination of commonly consumed fish and shellfish from Guimaras (Uno et al 2010a,b; Peralta & Serrano 2014). Nearby aquaculture industries and seaweed farms have been economically challenged during the incident, resulting to fish deaths, decreased demands and profit, and marketing problems (Andalencio et al 2014). Interestingly, Hallare et al (2005) and Kosmehl et al (2008) have attempted to further understand the impacts of PAHs pollution in Laguna de Bay, using a model fish organism

(*Danio rerio*). These studies have experimentally shown how the identified PAHs' concentrations in the sediments of Laguna de Bay may induce embryotoxicity, proteotoxicity and genotoxicity in fish embryo. These demonstrations are consistent with the known negative impacts of PAHs on fish bone and liver metabolism, reproduction and immunology (Reynaud & Deschaux 2006; Suzuki et al 2016; Honda & Suzuki 2020).

Response. Most of the analyzed studies (42.9%) have only recommended future directions towards the identified driver, pressure, state and impact of PAHs in Philippine aquatic ecosystems while 28.6% of the papers have not covered documenting or even recommending responses towards the assessed aquatic environment or organism. The remaining 28.6% of the papers have been able to document and recommend further responses, addressing the state and impact determined by PAHs in the studied ecosystems (Yender & Stanzel 2011; Andalencio et al 2014; Barnuevo & Sadaba 2014; Uno et al 2017). The states and impacts induced by the oil spill pressure on the water have been mitigated through extensive cleanup operations and application of chemical dispersants. Mangrove ecosystems have been rehabilitated through recruitment and settlement of seedlings. Affected aquaculture and seaweed farm industries in the area were also salvaged by immediate closure of pond gates, application of dispersants and continuous flushing of water. All these responses were enhanced through regular and extensive ecotoxicological assessment and monitoring of affected aquatic ecosystems. These assessment and monitoring efforts must be further reinforced in areas that have been recently exposed to natural and anthropogenic sources of PAHs such as volcanic eruption in a caldera of Lake Taal (Lagmay et al 2021) and oil spill due to explosion of floating power barge in the coast of Iloilo (Rendon 2020), respectively. Both of these freshwater and marine ecosystems serve as a critical source of open water and aquaculture fisheries. The DPSIR model presents the driver, pressure, state, impact, and corresponding responses on the former elements of the framework (Figure 1).

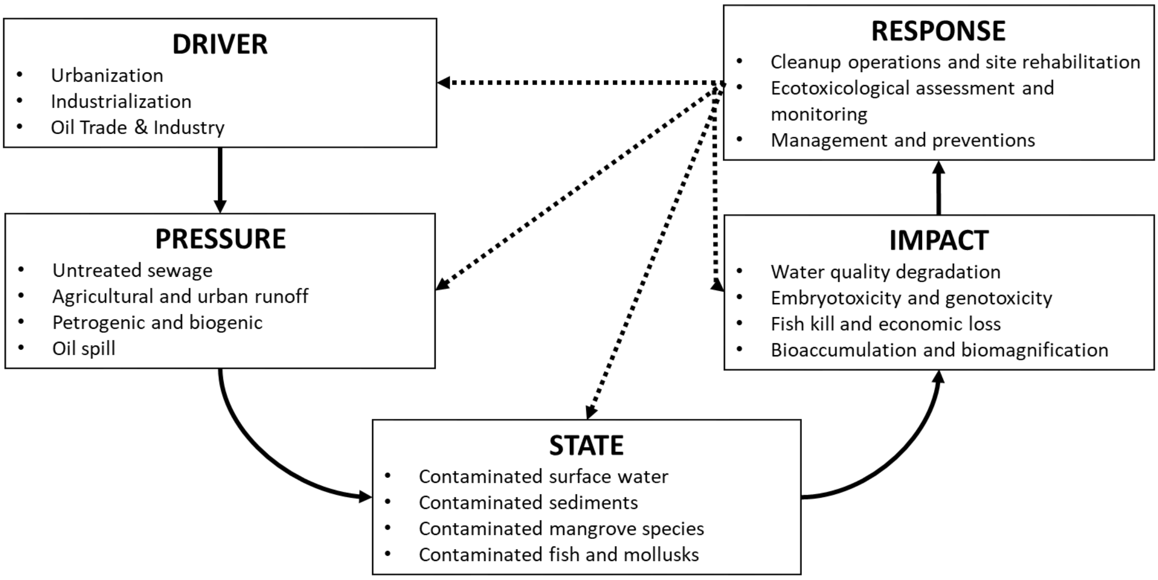

Figure 1. DPSIR model towards PAHs pollution in aquatic ecosystems in the Philippines.

Conclusions. Using the DPSIR model, the driver, pressure, state, impact, and corresponding responses on the former elements of the framework have been clearly identified. Environmental pressures on aquatic ecosystems are driven by the socio-economic developments of the country, urbanization and industrialization. This situation increased the risks of events such as untreated agricultural, residential and industrial effluents, vehicular fuel combustion and oil spillage. Consequently, contamination of aquatic ecosystems with PAHs resulted into water quality degradation, fish deaths and contamination of other biota, economic loss and human health risks relative to potential biomagnification. Appropriate responses discussed in this review must be maintained and improved considering the previous and current PAH pollution scenarios. Aside from the responses toward unintentional PAH pollution, it is imperative to address intentional pyrogenic and petrogenic sources of PAHs. Installation of the appropriate wastewater treatment plants in urban areas shall mitigate the discharges of organic pollutants in various bodies of water. Most importantly, existing environmental policies and regulations on aquatic organic pollutants including PAHs mandated by the country's Department of Environment and Natural Resources and Department of Agriculture–Bureau of Fisheries and Aquatic Resources shall be strictly implemented. This review timely revisits the need for holistic management and strong governance on the rich aquatic ecosystems of the Philippines.

Conflict of interest. The authors declare no conflict of interest.

References

Abdel-Shafy H. I., Mansour M. S., 2016 A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. Egyptian Journal of Petroleum 25:107-123.

Alegbeleye O. O., Opeolu B. O., Jackson V. A., 2017 Polycyclic aromatic hydrocarbons: a critical review of environmental occurrence and bioremediation. Environmental Management 60:758-783.

Andalencio M. N., Napata R. P., Garibay S. S., 2014 Aquaculture response and recovery from the effects of M/T Solar 1 oil spill. Journal of Aquaculture & Marine Biology 1:00008.

Azanza R. V., Alino P. M., Cabral R. B., Juinio-Menez M. A., Pernia E. M., Mendoza R. U., Siriban C. S., 2017 Valuing and managing the Philippines' marine resources toward a prosperous ocean-based blue economy. Public Policy 18:1-26.

Barnuevo A. P., Sadaba R. B., 2014 Recovery of mangrove deforested areas from M/T Solar oil spill in Guimaras, Philippines. International Oil Spill Conference Proceedings, American Petroleum Institute, pp. 2260-2272.

Bedi J. S., Singh V., Gupta A., Gill J. P. S., Aulakh R. S., 2018 Persistent organic pollutants (POPs) in fresh water farm fish species from Punjab (India) and evaluation of their dietary intake for human risk assessment. Human and Ecological Risk Assessment 24:1659-1672.

Briones R. M., 2007 Eating for a lifetime: filling the policy gaps in Philippine fisheries. Asian Journal of Agriculture and Development 4:25-40.

Gari S. R., Newton A., Icely J. D., 2015 A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean & Coastal Management 103:63-77.

Hallare A. V., Kosmehl T., Schulze T., Hollert H., Köhler H. R., Triebskorn R., 2005 Assessing contamination levels of Laguna Lake sediments (Philippines) using a contact assay with zebrafish (*Danio rerio*) embryos. Science of the Total Environment 347:254-271.

Honda M., Suzuki N., 2020 Toxicities of polycyclic aromatic hydrocarbons for aquatic animals. International Journal of Environmental Research and Public Health 17:1363.

Hussain K., Hoque R. R., Balachandran S., Medhi S., Idris M. G., Rahman M., Hussain F. L., 2018 Monitoring and risk analysis of PAHs in the environment. Handbook of Environmental Materials Management, pp. 1-35.

Ishikawa E., Tabucanon M. T., Shibata Y., Morita M., 2019 Managing persistent organic pollutants in the Asia-Pacific region: A multi-level approach. Policy Brief, United Nations University, pp. 1-4.

Isobe T., Takada H., Kanai M., Tsutsumi S., Isobe K. O., Boonyatumanond R., Zakaria M. P. 2007 Distribution of polycyclic aromatic hydrocarbons (PAHs) and phenolic endocrine disrupting chemicals in South and Southeast Asian mussels. Environmental Monitoring and Assessment 135:423-440.

Kosmehl T., Hallare A. V., Braunbeck T., Hollert H., 2008 DNA damage induced by genotoxicants in zebrafish (*Danio rerio*) embryos after contact exposure to freeze-dried sediment and sediment extracts from Laguna Lake (The Philippines) as measured by the comet assay. Mutation Research/Genetic Toxicology and Environmental Mutagenesis 650:1-14.

Labianca C., De Gisi S., Todaro F., Notarnicola M., 2020 DPSIR model applied to the remediation of contaminated sites. A case study: Mar Piccolo of Taranto. Applied Sciences 10:5080.

Lagmay A. M. F., Balangue-Tarriela M. I. R., Aurelio M., Ybanez R., Bonus-Ybanez A., Sulapas J., Baldago C., Sarmiento D. M., Cabria H., Rodolfo R., Rafael D. J., Trinidad J. R., Obillie E., Rosell N., 2021 Hazardous base surges of Taal's 2020 eruption. Scientific Reports 11:1-11.

Landos M., Lloyd-Smith M., Immig J., 2021 Aquatic pollutants in oceans and fisheries. International Pollutants Elimination Network (IPEN), 48 p.

Latimer J., Zheng J., 2003 The sources, transport, and fate of PAH in the marine environment. In: PAHs: An ecotoxicological perspective. Douben P. E. T. (ed), pp. 9-33, John Wiley and Sons Ltd, New York.

Manzetti S., 2013 Polycyclic aromatic hydrocarbons in the environment: environmental fate and transformation. Polycyclic Aromatic Compounds 33:311-330.

Neary K., Boving T. B., 2011 The fate of the aqueous phase polycyclic aromatic hydrocarbon fraction in a detention pond system. Environmental Pollution 159:2882-2890.

Pahila I. G., Taberna H. S., Gamarcha L. T., Rama S., Uno S., Koyama J., 2010 Early monitoring of potentially toxic hydrocarbon species in sediment and biological samples from Southern Guimaras, Phillipines after oil spill. Memoirs of the Faculty of Fisheries, Kagoshima University 59:11-16.

Peralta E. M., Serrano Jr. A. E., 2014 Polycyclic aromatic hydrocarbons (PAHs) in mangrove clam (*Geliona erosa*) from Guimaras, Philippines five years after oil spill. Advances in Environmental Sciences 6:62-68.

Peralta E. M., Belen A. E., Buenaventura G. R., Cantre F. G. G., Espiritu K. G. R., De Vera J. N. A., Perez C. P., Tan A. K. V., De Jesus I. B. B., Palomares P., Briones J. C. A., Ikeya T., Magbanua F. S., Papa R. D. S., Okuda N., 2019 Stream benthic macroinvertebrate assemblages reveal the importance of a recently established freshwater protected area in a tropical watershed. Pacific Science 73:305-320.

Rendon J. P., 2020 Barge explosion leads to oil spill: 48,000 liters of oil leaked into Iloilo City waters-Coast Guard. DailyGuardian, pp. 1-11.

Reynaud S., Deschaux P., 2006 The effects of polycyclic aromatic hydrocarbons on the immune system of fish: A review. Aquatic Toxicology 77:229-238.

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 58:189-200.

Sun R. X., Lin Q., Ke C. L., Du F. Y., Gu Y. G., Cao V., Luo X. J., Mai B. X., 2016 Polycyclic aromatic hydrocarbons in surface sediments and marine organisms from the Daya Bay, South China. Marine Pollution Bulletin 103:325-332.

Suzuki N., Sato M., Nassar H. F., Abdel-Gawad F. K., Bassem S. M., Yachiguchi K., Tabuchi Y., Endo M., Sekiguchi T., Urata M., Hattori A., Mishima H., Shimasaki Y., Oshima Y., Hong C. S., Makino F., Tang N., Toriba A., Hayakawa K., 2016 Seawater polluted with highly concentrated polycyclic aromatic hydrocarbons suppresses osteoblastic activity in the scales of goldfish, *Carassius auratus*. Zoological Science 33:407-413.

Taneza P., Philp R. P., 2009 A preliminary study of the sources of organic pollutants in the Iloilo River, Philippines. Environmental Forensics 10:68-81.

Uno S., Kokushi E., Miki S., Añasco N., Koyama J., Monteclaro H., 2007 Survey of chemical pollution in coastal areas of Panay Island, Philippines. UPV Journal of Natural Sciences 12:9-24.

Uno S., Kokushi E., Pahila I. G., Koyama J., 2010a Changings of polycyclic aromatic hydrocarbons in aquatic organisms and sediment at Guimaras after oil spill. Memoirs of the Faculty of Fisheries, Kagoshima University, pp. 63-66.
Uno S., Koyama J., Kokushi E., Monteclaro H., Santander S., Cheikyula J. O., Miki S., Añasco N., Pahila I. G., Taberna Jr H. S., Matsuoka T., 2010b Monitoring of PAHs and alkylated PAHs in aquatic organisms after 1 month from the Solar I oil spill off the coast of Guimaras Island, Philippines. Environmental Monitoring Assessment 165:501-515.
Yakan S. D., Focks A., Klasmeier J., Okay O. S., 2017 Numerical evaluation of bioaccumulation and depuration kinetics of PAHs in *Mytilus galloprovincialis*. Environmental Pollution 220:1244-1250.
Yender R., Stanzel K., 2011 Tanker SOLAR 1 Oil spill, Guimaras, Philippines: Impacts and response challenges. In: Oil spill science and technology. Fingas M. (ed), pp. 1133-1146, Gulf Professional Publishing.
Wantzen K. M., Alves C. B. M., Badiane S. D., Bala R., Blettler M., Callisto M., Cao Y., Kolb M., Kondolf G. M., Leite M. F., Macedo D. R., Mahdi O., Neves M., Peralta E. M., Rotgé V., Rueda-Delgado G., Scharager A., Serra-Llobet A., Yenguéand J.-L., Zingraff-Hamed A., 2019 Urban stream and wetland restoration in the Global South—A DPSIR analysis. Sustainability 11:4975.
Zafaralla M. T., Barril C. R., Borja A. C. S., Manalili E. V., Dizon J. T., 2005 Water resources. In: Ecosystems and people: The Philippine millennium ecosystem assessment (MA) sub-global assessment: Synthesis report. Lasco R. D., Espaldon M. V. O. (eds), Environmental Forestry Programme, College of Forestry and Natural Resources, University of the Philippines Los Baños. pp. 65-112.
*** EEA, European Environment Agency, 1995 Europe's environment: The debris assessment. European Environment Agency, Copenhagen.
*** OECD, Organisation for Economic Cooperation and Development, 1993 OECD core set of indicators for environmental performance reviews. A synthesis report by the Group on the State of the Environment. Environmental Monograph 83:1-39.
*** UNEP, United Nation Environment Programme, 1994 World environment outlook: Brainstorming session. ENEP/EAMR 94-5, Environment Assessment Programme Nairobi.
*** UNEP, United Nation Environment Programme, 2007 Global environment outlook GEO4. Nairobi.
*** USEPA, United States Environmental Protection Agency, 1977 Analysis procedures for screening of industrial effluents for priority pollutants. US Environmental Protection Agency, Environment Monitoring and Support Laboratory, Cincinnati, USA.
*** World Bank, 2005 Philippines environment monitor 2005: Coastal and marine resource management. World Bank Country Office Philippines, Pasig City.

Received: 27 December 2021. Accepted: 14 February 2022. Published online: 25 February 2022.
Authors:
Bernhard Alexander Krah, Comenius University in Bratislava, Faculty of Management, Odbojárov 10, 10, P.O. BOX 95, 820 05, Bratislava 25, Slovak Republic, e-mail: krah2@uniba.sk
Andrej Miklosik, Comenius University in Bratislava, Faculty of Management, Department of Marketing, Odbojárov 10, P.O.BOX 95, 820 05, Bratislava 25, Slovak Republic, e-mail: andrej.miklosik@fm.uniba.sk

How to cite this article:
Krah B. A., Miklosik A., 2022 Environmental risks and management of polycyclic aromatic hydrocarbons in Philippine aquatic ecosystems using the DPSIR model. AACL Bioflux 15(1):480-488.