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Review

A review of stressors, uses and management perspectives for the larger Jakarta Bay Area, Indonesia

Annette Breckwoldt [a,*], Larissa Dsikowitzky [b], Gunilla Baum [a], Sebastian C.A. Ferse [a], Simon van der Wulp [c], Ima Kusumanti [d], Andrian Ramadhan [e], Luky Adrianto [d]

[a] Leibniz Center for Tropical Marine Ecology (ZMT) GmbH, Fahrenheitstrasse 6, 28359 Bremen, Germany
[b] Institute of Geology and Geochemistry of Petroleum and Coal, RWTH Aachen University, Germany
[c] Research and Technology Centre, Westcoast (FTZ), Kiel University, Germany
[d] Faculty of Fisheries and Marine Sciences, Bogor Agricultural University (IPB), Indonesia
[e] Ministry of Marine Affairs and Fisheries, Kementerian Kelautan Dan Perikanan (KKP), Jakarta, Indonesia

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Contents

1. Synthesis of core results and implications for the Jakarta Bay Area

The Special Issue "Impacts of megacities on tropical coastal ecosystems – The case of Jakarta, Indonesia" comprehensively characterized and quantified for the first time the main pressures challenging both the long-term environmental functionality and health of the larger Jakarta Bay (JB) area as well as the large human population depending on its resources. Much-needed information was collected with the objective to better inform the local and regional decision-making processes, including the next steps of the National Capital Integrated Coastal Development (NCICD; Ministry for Economic Affairs, 2015). The objective of this concluding review is to provide readers with a synthesis of the core findings of this special issue, an outlook on the potential implications for the JB ecosystem and its users, and finally with a brief discussion of the possible management perspectives in the context of the ongoing protection measures, infrastructure development and extensive land reclamation plans.

The main anthropogenic stressor – and at the same time the biggest challenge – is the extreme pollution of the JB waters. Most of the 71 organic contaminants identified in river water from the Jakarta area are chemicals used in households. Personal care product ingredients, pharmaceutical drugs and flame retardants were found in exceptionally high concentrations, especially at the river mouths in central Jakarta City. This was attributed to the intensive usage of products containing these compounds by more than 10 million inhabitants of Jakarta City, leading to high concentrations in untreated or only partially treated household wastewaters, which are directly discharged into relatively small rivers and canals (Dsikowitzky et al., 2016). The weathering of

* Corresponding author.
E-mail address: annette.breckwoldt@leibniz-zmt.de (A. Breckwoldt).

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volcanic rocks in the catchment area is the main controlling factor for the occurrence of the trace hazardous elements As, Cr and partly Cu in Jakarta river sediments. Zn, Ni and Pb in contrast mainly originate from anthropogenic inputs, such as industrial wastewaters and street dust, in particular in central Jakarta City (Sindern et al., 2016). Riverine transport of contaminated particulate matter into JB plays the major role for the metal contamination of the bay sediments. Locally, the concentrations of Cr, Zn, Ni, Cu and Cd in the river sediments and of Hg and Cd in the bay sediments exceeded the threshold above which adverse effects on benthic communities can be expected (Sindern et al., 2016; Siregar et al., 2016). Organic contaminants (polycyclic aromatic hydrocarbons (PAHs) and linear alkylbenzene sulfonates (LAS)) from marine sources of pollution (i.e., boats) were found to occur at concentrations likely to result in acute metabolic stress of fishes (Baum et al., 2016a). While these concentrations were highly localized in space (i.e., the harbor of densely populated Pari Island) and time (i.e., following the release of bilge water and washing of boats with detergents), the high population density and boat traffic in JB and the Seribu Islands implies the potentially significant ecological stress these pollutants pose (Baum et al., 2016a). The concentrations of detergent residues (linear alkylbenzenes (LABs)) and chemicals used for paper manufacturing (di-*iso*propylnaphthalenes (DIPN)) were very high in tissue samples of economically important fish and bivalve species from JB, while low concentrations of trace hazardous elements were found (Dwiyitno et al., 2016; Siregar et al., 2016). The uptake of particle-associated contaminants like LABs and DIPN plays a major role in the contamination of fishery resources. Noteworthy, in the tissue samples of the bivalves (being excellent bio-accumulators for some substances), the concentrations of LABs and DIPN were significantly higher than in the fish samples (Dwiyitno et al., 2016).

In addition to the contaminants, the massive input of nutrients and organic matter into JB is a stressor which drives the eutrophication process in the form of frequently reoccurring high biomass algal blooms (Ladwig et al., 2016). Such blooms are predominantly found along the urban south shoreline of JB in the vicinity of riverine discharges from the extensive urban parts of Jakarta (Ladwig et al., 2016). Van der Wulp et al. (2016a) found that the Citarum River is the biggest contributor of total nitrogen (TN) and total phosphorus (TP), responsible for half of the total nutrient loads which is built up by low concentrations and high river discharges. Multiple rivers along the urban shores of Jakarta are characterized by high river nutrient concentrations in combination with relatively low river discharges and account for ~45% of the total nutrient discharge which enters JB. Numerical flow and water quality model simulations indicated retarded flows along the south shore of JB in combination with high initial nutrient concentrations from its direct (urban) tributaries, resulting in a profound localized enhancement of nutrient levels with a steep gradient across JB (Van der Wulp et al., 2016a). Both measurements and flow model simulations confirmed a vertical thermohaline stratification of the coastal waters of JB, leading to a stronger decoupling of the water surface and bottom flows, thus allowing the enhanced (predominantly wind-induced) turbulent mixing of surface layers (Van der Wulp et al., 2016a; Ladwig et al., 2016). The majority of bloom records are located in those nearshore coastal waters where favourable nutrient supply converges with adequate light conditions due to the reduced mixing depth. Algal blooms were occasionally accompanied by events of fish kills in 2004, 2005 and 2007, which was likely due to rapidly dropping oxygen levels. Ladwig et al. (2016) found that over 60% of JB is subject to critical oxygen saturation levels, causing a 'poor' environmental state with respect to eutrophication.

Considering that, throughout the bay (incl. the islands), small-scale and artisanal mariculture and fishing constitute a large source of income (Badan Pusat Statistik, 2012; Prabowo et al., 2008), a direct feedback loop exists from these anthropogenic stressors via the health of the ecosystem and its resources, to the health and livelihoods of the local population. In the inner part of JB, the cultivation of the Asian green mussel (*Perna viridis*) delivers an important income for the local population. Adverse habitat conditions can, however, influence the mussels' resistance to abiotic stress (Huhn et al., 2016). The ability to tolerate stress (e.g., hyposalinity and hypoxia) differed between individuals sampled from JB, which could perform better under hypoxia, and individuals taken from less-impacted natural habitats at the coasts of West Java, which performed better under hyposaline conditions (Huhn et al., 2016).

Oetama et al. (2016) studied the pathogens and diseases of the Asian black tiger shrimp (*Penaeus monodon*), which is also cultivated in JB – less cost-effective than the green mussel cultivation but of equally high economic importance to the local population (Kusumanti, pers. observation). The authors compared the fecal microbiota of shrimps from different locations and showed variances depending on whether samples were taken from the highly polluted waters in JB, or from less polluted waters (from Bali). Pathogens and viral diseases were detected in both sampled areas but in varying combinations and concentrations. The bacterial pathogens were dominated by Proteobacteria (96.08%); the samples from JB were dominated by Vibrionales, and qPCR profiling specifically revealed *Vibrio alginolyticus* and *Photobacteriumdamselae* as two pathogenic species present in most of the samples; both can cause great losses in aquaculture. Alterations in fecal microbiota play an important role due to their high influence on the immunity and metabolism of the shrimp (Lightner, 2003; Poulos and Lightner, 2006). In addition, viral pathogens represent a major problem for both free-living and cultivated shrimp populations. qPCR profiling detected seven viral pathogens in the samples, and viral diseases common in shrimp were discovered: the White Spot Syndrome Virus (WSSV) in all of the JB free-living samples, Yellow Head Virus (YHV) in all of the Bali free-living samples, and the Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) in most samples (100–83%) from both sites (Oetama et al., 2016).

The pollutants originating from the megacity Jakarta therefore affect marine organisms in various ways and on various levels, and the fish of JB are no exception to this. Findings from Prihatiningsih et al. (2016) found that the radionuclide 137Cs is taken up by the widely cultured milkfish (*Chanos chanos*). 137Cs may potentially be released from research power reactors and other nuclear facilities of the Jakarta Metropolitan Area and transported via the Cisadane River into JB (Prihatiningsih et al., 2016). The authors emphasize the urgent need to conduct further research of the bioaccumulation and physiological as well as ecological effects of pollutants such as 137Cs.

As mentioned above, besides aquaculture, intensive exploitation of reef-related fishery resources continues to provide livelihoods for many coastal communities in JB, leading to additional pressures on the ecosystem. A study of coastal communities from both the Jakarta mainland and the Seribu Islands by Baum et al. (2016b) found heavy marine resource exploitation patterns and resource-dependent livelihoods in both areas, with livelihood vulnerability being higher in the mainland sites, mainly related to fewer options to establish alternative livelihoods. The most economically valuable fish species were the Redbelly yellowtail fusilier (*Caesio cuning*) on the islands and the Indian mackerel (*Rastrelliger kanagurta*) on the mainland. Over 80% of all interviewed fishermen regarded the current state of marine resources in JB as declining, mainly due to pollution and overexploitation. While the perceptions of resource decline and degradation were equally high on the islands and the mainland, significantly more interviewed fishers from the mainland listed pollution as the principal cause (Baum et al., 2016b). The local fishing communities were indeed aware of the situation but had or saw no alternative way to make a living.

Several studies identified indicators of environmental conditions and pollution. The standard metabolic rate of the rabbitfish (*Siganus guttatus*), an important herbivore targeted by the majority of fishing households on the Seribu Islands (Baum et al., 2016b), was significantly affected by concentrations of the organic contaminant groups PAHs and LAS (Baum et al., 2016a). Specimens of the orange-spotted grouper (*Epinephelus coioides*) caught in the inner JB had a twenty-fold smaller composite Parasite Index than specimens from the Seribu Islands,