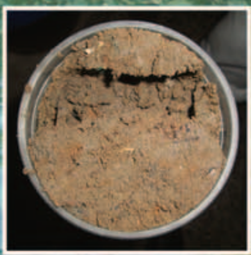
SCIENCE FOR THE PROTECTION OF INDONESIAN COASTAL ECOSYSTEMS (SPICE)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Impact of megacities on the pollution of coastal areas—the case example Jakarta Bay

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Abstract

The rapid development of Indonesia over the past 20 years and also its increasing negative impact on the environment are by far best to be seen at the metropolitan area and the corresponding coastal ecosystems of Jakarta. All the information and facts reported in this chapter regarding the environmental state of Jakarta Bay demonstrate impressively the huge anthropogenically induced pressure and stress this ecosystem is exposed to. Additionally, an intact ecosystem is a basic

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precondition for many aspects directly impacting human beings around the Bay covering, e.g., seafood health, drinking water accessibility, or recreation needs. Noteworthy, the investigations reported here do not remain on the description of the environmental status but explored also the relevant processes behind inducing the pollution problems and, consequently, point to potential solutions.

Abstrak

Pesatnya pembangunan di Indonesia selama 20 tahun terakhir, termasuk dampak negatifnya pada lingkungan dapat dilihat pada kawasan metropolitan Jakarta maupun ekosistem pesisir di sekitarnya. Data dan informasi yang ditampilkan pada chapter/bab ini menunjukkan adanya ancaman dan cekaman antropogenik yang serius pada lingkungan Teluk Jakarta. Sementara itu, sebuah ekosistem yang terpelihara dengan baik merupakan faktor penting bagi berbagai aspek yang berpengaruh langsung pada kehidupan masyarakat di sekitar pesisir, seperti keamanan produk perikanan, akses air bersih, maupun kegiatan rekreasi. Oleh karena itu, hasil penelitian ini tidak hanya menjelaskan kondisi lingkungan Teluk Jakarta, tetapi juga melihat lebih dalam faktor-faktor yang menyebabkan terjadinya pencemaran serta memberikan alternatif solusinya.

Chapter outline

8.1 Introduction

The rapid development of Indonesia over the past 20 years and also its increasing negative impact on the environment are by far best to be seen at the metropolitan area and the corresponding coastal ecosystems of Jakarta. The Indonesian capital is a center of ongoing industrialization, economic growth, and rapidly increasing population (Fig. 8.1). More than 10 million inhabitants are living in the central part of Jakarta City,

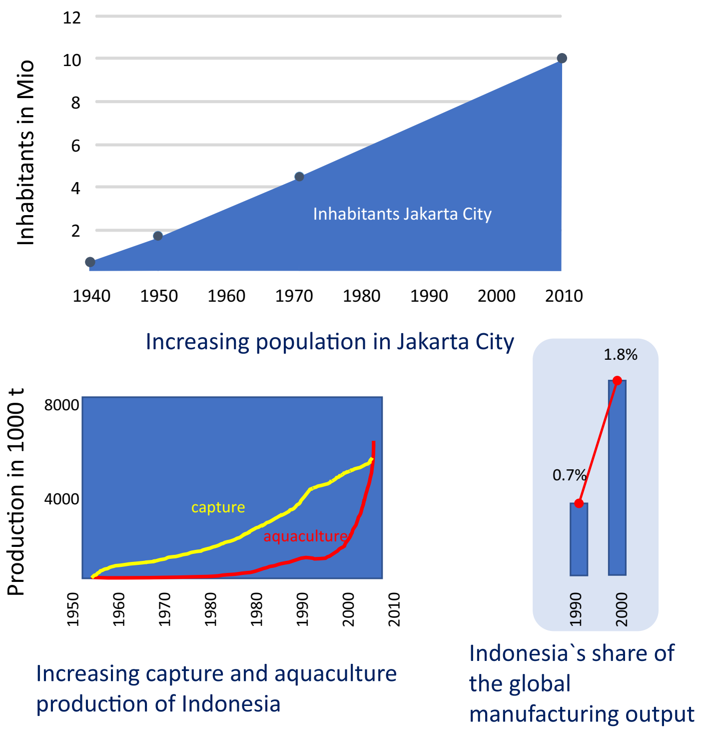

FIGURE 8.1 Indications for the economic growth of Indonesia and its capital Jakarta. *Sources: FAO.*

and the currently much more expansive wider metropolitan area (Jabotabek region, conurbation representing the city area of Jakarta, Bogor, Depok, Tangerang, and Bekasi) covers an area of about 6700 km^2 with a population of some 28 million inhabitants according to the census in 2010 (BPS, 2010). As a result, Jakarta has become one of the 10 biggest megacities in Asia (Blackburn et al., 2014). In parallel, Jakarta faced in the past decades a tremendous increase of pollution by industrial and municipal emissions. Rough calculations point to a discharge of approximately 8.000 t of solid waste per day (BPLHD, 2012), from which a significant fraction is dumped into the rivers and canal systems due to the lack of organized rubbish collection systems. With respect to liquid waste discharged by sewage systems, it has to be noted that only a very low proportion of all households (ca. 15%–20%) are connected to a central or local sewage treatment installation. In addition, wastewater from more than 20,000 industrial facilities located in Jabotabek region is continuously discharged. All these sources contribute to the enormous waste emergence in Jakarta.

Notably, Jakarta Bay (JB) represents the receiving ecosystem of by far the largest proportion of sewage and waste via the urban riverine discharge. JB is bordered by the Thousand Islands in the North, some of which are part of the Kepulauan Seribu Marine National Park and the metropolitan area of Jakarta in the South (Fig. 8.2). The

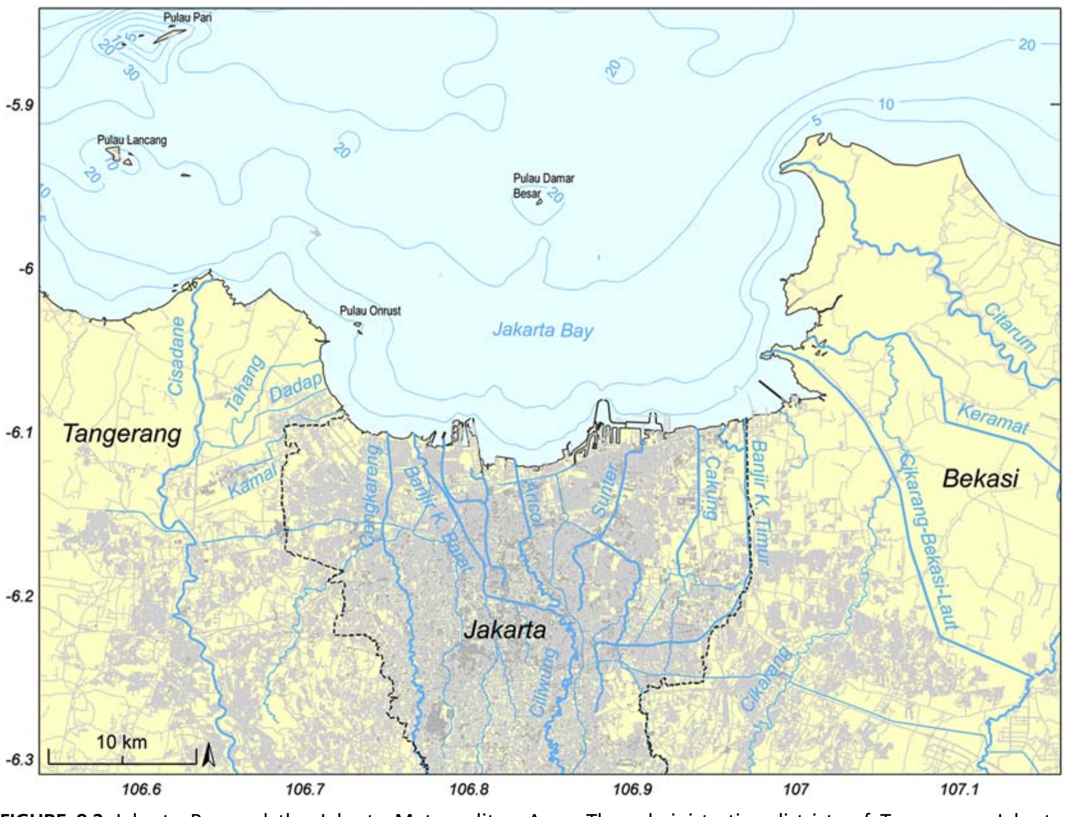

FIGURE 8.2 Jakarta Bay and the Jakarta Metropolitan Area. The administrative districts of Tangerang, Jakarta, Bekasi, but also Bogor and Depok, situated more south, are drained by a ramified system of rivers and channels which ends up in Jakarta Bay.

corresponding shoreline faced a huge transition from natural conditions to an intensively used coastline. This is effective for industrial facilities, traffic infrastructure, urban settlements, aquafarming, agriculture, and many other developments.

The resulting pollution of industrial and municipal origin has an important impact on the environmental quality of these coastal ecosystems and affects in particular the aquatic biocoenosis. Since JB is also an important site for aquafarming as well as fishery and is used as recreation area for the metropolitan region, the pollution also impairs these relevant functions of the marine systems. Traditional fishery by more than 2500 fishermen is accompanied by modern aquafarming, in particular producing the green mussel *Perna viridis*. Finally, the aquatic pollution of riverine and coastal regions at Jakarta has also negative effects on drinking water resources, since riverine surface water and groundwater, highly affected by riverine infiltration, are the dominant sources for drinking water production, in particular for Jakarta city.

In summary, the aquatic ecosystems of JB represent an excellent example of a fundamental conflict between economic and ecological demands. As a consequence, this sensitive coastal region attracts not only political but also scientific attention. The described anthropogenic impacts and the complementary resource demands affect a complex system influenced by hydrological, geochemical, microbiological, hygienic, and many more parameters. Hence, understanding the principal mechanisms of pollution transport, dissemination and resulting effects on the ecosystems represents a huge scientific challenge.

It becomes dramatically obvious that there is a need for improvement of the environmental quality at JB. The enormous effects of anthropogenic pollution on the ecosystem JB have been continuously reported. As an example, in December 2015, a massive fish mortality along Ancol Beach has been chronicled in the *Jakarta Post*.

Many scientific studies also pointed to the disruption of the ecosystem functioning as the result of anthropogenic impact. Negative effects are visible at mangroves and coral reefs or by repetitive harmful algae blooms. Further observed ecological impairments cover enhanced fish mortality, harm to marine species by pollutants and reduced biodiversity (summarized and referenced in Dsikowitzky et al., 2016a,b).

For substantial changes of the ecological quality of JB, the extent and quality of pollution need to be determined as a basic precondition. However, in the past, studies focusing on contamination of JB and its linkage to long-term implications have been performed only more or less sporadically. As a consequence, Science for the Protection of Indonesian Coastal Ecosystems (SPICE) research activities have been focused inter alia on JB, its pollution, and the ecological implications. This chapter highlights a more comprehensive and complementary approach, considering the different geological, biological, microbial, and chemical aspects of anthropogenic impacts on the JB coastal ecosystems.

8.2 Hydrological system and nutrient dispersion

The susceptibility of a specific area to develop eutrophication symptoms such as algal blooms and hypoxia strongly depends on the scale of terrestrial nutrient loading relative to the local dilution capacity (Vollenweider, 1976; von Glasow et al., 2013). This, in turn, is a function of water volume and the rate of water exchange. Hence, it is important to understand the hydrodynamic processes of advective flux and turbulent diffusion, which control the transport of matter and the exposure time available for biological processes such as phytoplankton growth or microbial decomposition.

There are numerous studies predominantly from temperate regions focusing on the evaluation of nutrient discharge from point and nonpoint sources as well as on its impacts (e.g., De Jonge et al., 1994; EEA, 2001; Howarth et al., 2000; Schaub and Gieskes, 1991). Over the past few decades, a number of models have been developed to simulate nutrient fluxes in the catchment basins (e.g., Alexander et al., 2002; Behrendt et al., 2000; Marcé et al., 2004; Van Drecht et al., 2003) and the dispersion of nutrients and their effects in the coastal ecosystem (e.g., Moll, 1998; Lenhart, 2001; Skogen et al., 2004; Lancelot et al., 2005; Pätsch and Kühn, 2008). The quantification of nutrient transport to the coastal bays and estuaries is essential for understanding the consequences of nutrient pollution and for developing adequate nutrient management strategies.

This is not much different for Jakarta, as it is for many other coastal megacities. A ramified system of rivers and canals drains the Jakarta Metropolitan Area (Fig. 8.2). The most important rivers are the Citarum river discharging at the eastern flank of the bay with a catchment area of about 6600 km^2 and the Cisadane river at the periphery of the western cape with a catchment basin of 1400 km^2. Several smaller rivers, notably Angke, Ciliwung, Sunter, Bekasi, and Cikarang, with a combined total catchment area of ca. 2000 km^2, discharge into the central sector of the bay. These rivers drain Jakarta's urban center through mostly canalized downstream sections with several rivers sometimes merged into one canal. They form an integral part of the stormwater and sewage transport network within the city. The most important canals are the Cengkareng drain (dominated by Angke river), the West Banjir Canal (BKB, dominated by Ciliwung), the Sunter, the Cakung drain, the East Banjir Canal (BKT, diverting water from the Cipanang, Sunter, Cakung and Buaran river), and the Cikarang-Bekasi-Laut Canal (CBL, dominated by the Bekasi and Cikarang). In total, the coastline of JB comprises 16 river and canal mouths, which are the main gateways of pollutants from the JMA to the coastal ecosystem of the shallow JB.

Discharge and retention of water from the Jakarta area is regulated by a comprehensive network of barrages, weirs, retention basins, pumping stations, and artificial canals with their tributaries, mainly concentrated in the low lying plain of the densely populated Jakarta Province. The river water is deviated on demand for a variety of reasons, such as for flood prevention during times of high run-off in the rainy season as well as for irrigation (mostly paddy fields), domestic, municipal, and industrial water supply. As an example, the Citarum river provides up to 80% of Jakarta's raw surface water demand, which is channeled through the West Tarum canal to the tap water producing plants near the city (Fulazzaky, 2010).

Jakarta regularly experiences severe flooding events during the rainy season in January and February. To reduce flooding during times of heavy rainfall, river water from

FIGURE 8.3 The rivers and canals of Jakarta receive a considerable amount of domestic and industrial wastewater and garbage due to the lack of proper solid and liquid waste management systems, leading to appearances such as the photo above, taken along the banks of the Cakung River.

the Ciliwung and Cengkareng drainage system is diverted to the West Banjir Canal, whereas water from the Cipinang, Sunter, Buaran, and Cakung rivers is bypassed to the recently finalized East Banjir canal. By contrast, during drought periods, water from the Citarum and the Ciliwung is drained to provide enough flushing to smaller canals and rivers, such as the Kali Baru river flowing through central Jakarta. Flow in the downstream area of the waterways is thus heavily influenced by interbasin transfer.

The rivers and canals receive a considerable amount of domestic and industrial wastewater and garbage due to the lack of proper solid and liquid waste management systems. This leads to a strong deterioration of these surface waters causing critical conditions for the natural ecosystem, public hygiene, and also esthetic values and blocking of the water drainage (see Fig. 8.3). The pollution received by the rivers and streams gradually finds its way to the river mouth and ends up in JB.

To date, less than 3% of Jakarta's population is connected to a centralized sewage treatment plant (the Setiabudi WWTP), which discharges the treated wastewater into the Ciliwung river (Apip Sagala and Luo, 2015). Instead, most households (>70%) rely on septic tanks, which are often poorly maintained because they are not emptied on a regular basis but overflow and leach into the soil. In addition, considering the high density of septic tanks in Jakarta, the draining fields are too small, resulting in the pollution of drinking water, groundwater, canals, and rivers (Vollaard et al., 2005). Besides, it is estimated that about 11% of Jakarta's population directly drain their wastes to neighboring watercourses (Apip Sagala and Luo, 2015). The lack of sufficient infrastructure to transport and treat domestic wastewater results in a flow of sewage into the public channels and rivers that cross the metropolitan area of Jakarta making them a major source for nutrients to the bay.

The impact of elevated nutrient levels becomes apparent as increasing frequencies of high biomass algae blooms (HBBs). Excessive blooms lead to undesired eutrophication effects where increased concentrations of biomass and subsequent microbial breakdown cause recurrent oxygen deficiencies in the water column and underlying sediments (Ladwig et al., 2016). Oxygen deficiencies on their turn are suspected to have triggered reoccurring fish kills (Wouthuizen et al., 2007). These high biomass blooms are reported to occur predominantly along the city shoreline of Jakarta (Damar, 2003; Mulyani Widiarti and Wardhana, 2012; Thoha et al., 2007; Yuliana, 2012).

Adverse eutrophication effects are driven not only by the level of nutrient concentrations but also by the physical characteristics of JB and its tributaries. A numerical model study by Koropitan et al. (2009) concluded that the influence of river discharge is limited to the coastal area with conformity to observed HBB occurrences. Quantification of nutrient loads to JB indicated a somewhat contradicting view where the largest rivers, such as the Cisadane and Citarum rivers, are the highest contributor to JB in terms of nutrient load. These rivers are situated along the northwest and northeast edges of the bay. By contrast, urban rivers and channels along the city shoreline are characterized by considerate, but relatively small loads of dissolved nutrients (Van der et al., 2016a). Also, the large rivers can be characterized by high river discharges with relatively low nutrient concentrations, whereas city bound rivers and channels have relatively low discharges, but very high concentrations of anthropogenic nutrient. More information on how river loads can be quantified can be found in “Determination of river loads for Jakarta Bay”.

A numerical model for flow and dispersion of these land-based nutrients was set up within the framework of the SPICE project on impacts of marine pollution on biodiversity and coastal livelihoods. Simulations showed that nutrient loads from the Citarum and Cisadane resulted in a smaller elevation of nutrient concentrations, with respect to their urban counterparts. Favorable dispersion due to a larger interaction with offshore currents allowed these loads to be more rapidly assimilated than the rivers situated at the inner bay. Along the city shoreline, horizontal circulation was found to be limited, and pollutants are dispersed at a slower rate than along the outer ridge of JB, resulting in hot spots with elevated nutrient levels. In addition, dense water masses from the Java Sea in combination with less dense river discharges result in a profound horizontal and vertical density gradient. The vertical stratification leads to a stronger decoupling between surface and bottom flows allowing stronger turbulent mixing of the surface layers due to tides and wind-induced currents (Van der Wulp et al., 2016a). More information on the use of numerical models to simulate the dispersion of dissolved substances can be found in “Hydrodynamic and dispersion models to study pollution”.

As discussed so far, quantified nutrient flux from rivers and channels do not reveal the actual source of pollution. No discrepancy can be made, whether nutrients originate from municipal wastewater, industrial wastewater, or other sources such as agriculture.

Elevated nutrient levels and localized eutrophication effects, however, can be attributed to those river inputs, which originate from catchment areas and which lie in predominantly urban areas and receive considerable amounts of wastewater. In addition, Dsikowitzky and Schwarzbauer (2014) found high levels of the insect repellent DEET (*N*,*N*-diethyl-*m*-toluamide) in urban rivers and nearshore coastal waters and proposed this substance as a molecular marker for municipal wastewater. The measurements of this study in combination with a simulated dispersion of molecular traces of DEET by Van der Wulp et al. (2016b) indicate that the distribution of municipal waste is limited to the city shoreline, making it more than likely that untreated municipal wastewaters are a key source for eutrophication effects.

The governmental authorities in Jakarta are well aware of this situation and set up a master plan to reinforce the city's infrastructure by expanding the sewerage system and constructing new treatment plants. It is planned to establish in a step-by-step procedure in total 15 sewerage zones with off-site treatment facilities expected to be ready to serve 80% of the population by 2050 (PD Pal Jaya, 2012). By 2020, off-site treatment capacity should cover 10% of the city's liquid waste mainly from the central area. In addition, on-site sanitation will be improved. New houses have to be equipped with modern septic tanks provided with filters, which promote bacterial degradation of organic matter in a closed system. Considering that currently up to 26% of human excreta are disposed of untreated into surface waters or gutters (Vollaard et al., 2005), it is further intended to strengthen enforcement of regulations on adequate desludging and proper sludge disposal. The target of a 100% coverage of regular desludging of on-site facilities and a complete conversion of conventional septic tanks into modern septic tanks shall be achieved by 2050 (PD Pal Jaya, 2012).

Determination of river loads for Jakarta Bay

The river load of any given substance can be defined as the product of river discharge and concentration at a given time. This information is optimally provided by measurements and, where possible, at a frequent time interval to learn more about the temporal variation. Having all required data is more exception than the rule. For a complex hydrological system such as Jakarta, coinciding measurements of both river discharges and water quality measurements proved to be unavailable. Quantification of nutrient flux per individual tributary could only be done in combination with a numerical modeling approach. A hydrological model was used to approximate individual river discharges to quantify the nutrient flux, per tributary, into JB. The hydrological model was set up for the Jakarta Metropolitan Area providing river discharges entering JB (see the following figure).

Figure: Hydrodynamic model domain with drainage basins (*red lines*). Accumulation of runoff results in river discharges at the river mouths, indicated by *red dots*.

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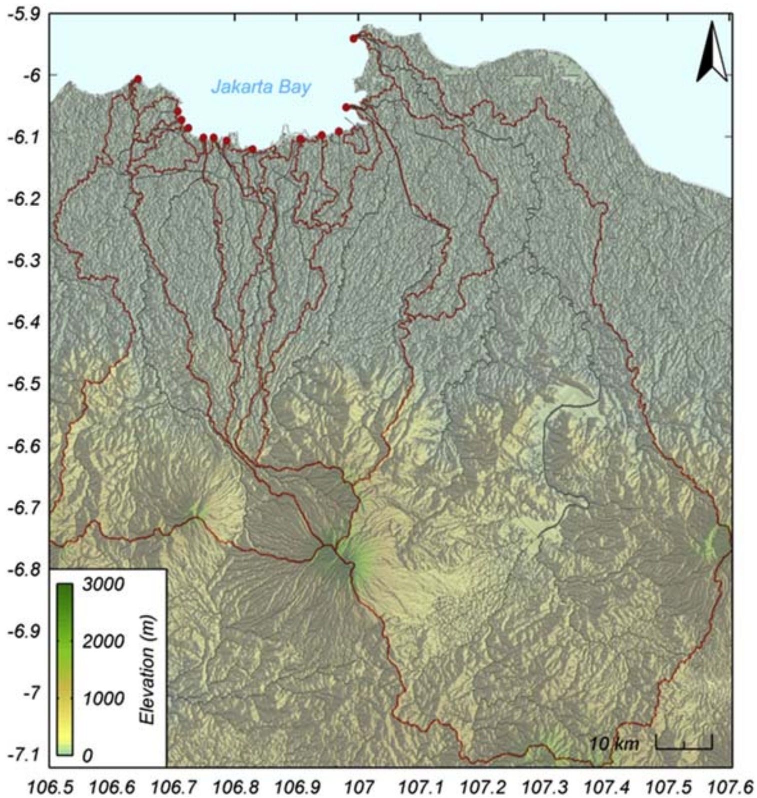
Determination of river loads for Jakarta Bay—cont'd

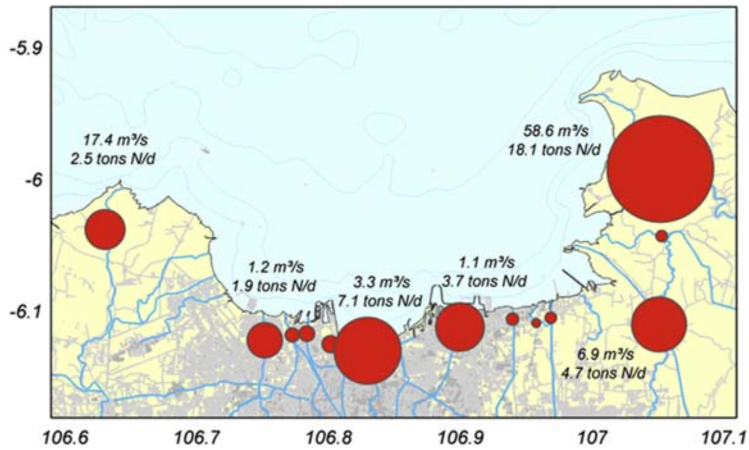


This grid-based model uses spatiotemporal precipitation and climate data to compute water balances considering various compartments including soil storage, groundwater storage, evapotranspiration, and potential runoff. The accumulation of runoff can be calculated spatially based on the topography, yielding an increased discharge with increasing downstream distance as illustrated in the illustrated figure. In addition, water samples were collected at the downstream end of selected rivers and channels and analyzed for nutrients. Among others, total nitrogen loads could be specified per tributary (see the following figure).

Figure: Based on modeled river discharges and field measurements, an approximation of river nutrient loads could be made as shown here for total nitrogen (TN).

From Van der Wulp, S. A., Damar, A., Ladwig, N., & Hesse, K. J. (2016). Numerical simulations of river discharges, nutrient flux and nutrient dispersal in Jakarta Bay, Indonesia. Marine Pollution Bulletin, 110*(2), 675–685.*

Determination of river loads for Jakarta Bay—cont'd



Hydrodynamic and dispersion models to study pollution

The study of pollution, anthropogenic sources, and fate of relevant substances requires a lot of field measurements to obtain an insight into the underlying mechanisms, which drive the transport cycle. Numerical models can complement field observations by its capability to reveal the underlying processes, which are difficult or not possible to observe through measurements. There are a variety of modeling systems (a.o. ROMS, POM, MIKE, and Delft3D) available to simulate flows, transport, and processes of decay of selected substances. To set up a model of a given region and with a given research objective, all relevant parameters and processes should be considered. For instance, the flow and dispersion of nutrients toward JB need a specification of river discharges, nutrient loads, bathymetry and forcing of tides + sea surface height, wind, sea temperature, and salinity enacting on the defined region. The following diagram shows the approach to simulate the flow and dispersion of total nitrogen (TN) and total phosphorus (TP) as conservative substances.

Figure: Diagram of the modeling approach for Jakarta Bay.

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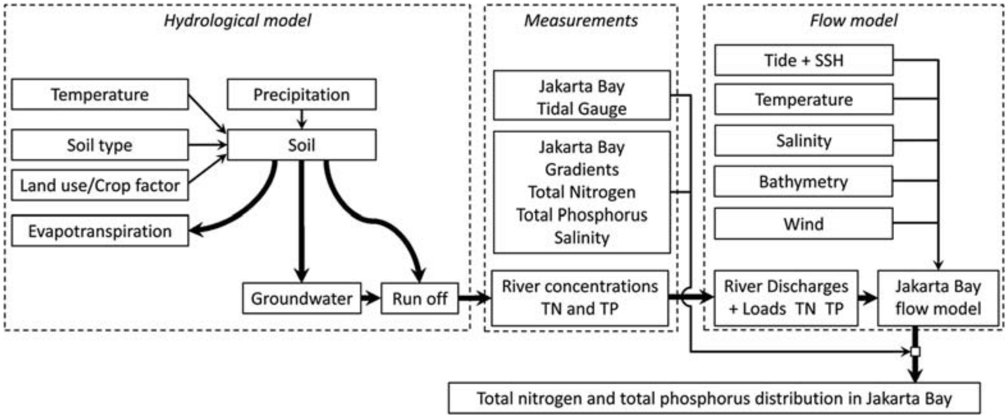
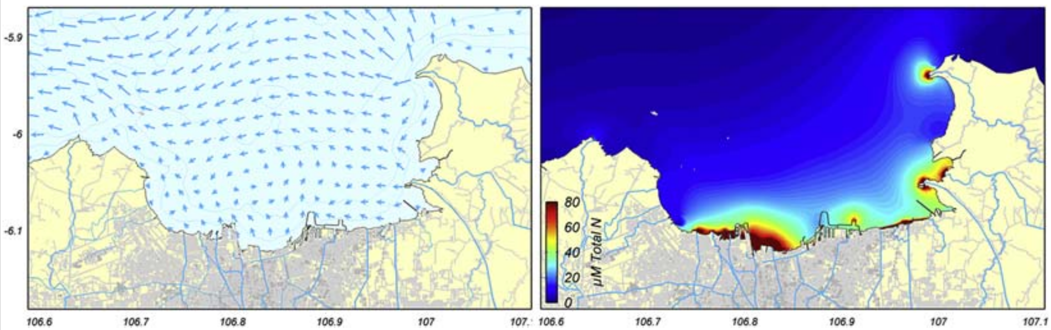
Hydrodynamic and dispersion models to study pollution—cont'd



Simulations of this model setup yielded time-varying three-dimensional flows (bottom left) and nutrient gradients (bottom right) shining a light on how pollutants are transported through JB and hot spots arise, which are coherent with eutrophication occurrences.

Figure: Illustration of model results with surface flows (left) and total nitrogen (TN) gradients of Jakarta Bay.

From Van der Wulp, S.A., Damar, A., Ladwig, N., Hesse, K.J., 2016. Numerical simulations of river discharges, nutrient flux and nutrient dispersal in Jakarta Bay, Indonesia. Marine Pollution Bulletin 110 (2), 675–685.



8.3 Organic and inorganic pollution in Jakarta Bay

The huge anthropogenic impact on the ecosystem is related to the emission of pollutants from the urban and riverine systems toward the marine environment at JB. The Jakarta river systems therefore receive enormous amounts of untreated or partially treated municipal wastewaters and transport these contaminant loads toward JB.

8.3.1 Types, quantity, and distribution of pollutants

8.3.1.1 Trace hazardous elements

Trace hazardous elements build up a highly relevant pool of pollutants at JB. Therefore, their spatial distribution and seasonal variation is an important aspect for characterizing the state of pollution of JB (see also Arifin et al., 2012). Siregar et al. (2016) studied the dynamical distribution of the hazardous metals Hg, Pb, Cd, Cu, Cr, Co, and As. The levels of these selected trace hazardous elements in water, surface sediments, and animal tissues were determined in samples collected during two different seasons. A detailed interpretation of the data revealed two important aspects: trace hazardous element contamination in JB differed (1) between the considered metals and (2) for most of the metals also between premonsoon and postmonsoon time. Here, concentrations of most elements were lower after the wet season and higher at the end of the dry season. Further on, a quality assessment of the sediments showed that the concentrations of Hg, Cu, and Cr at some stations exceeded previously reported toxicity thresholds for benthic species. Noteworthy, not only river and canal sediments within Jakarta City but also sediments in canals of the industrial center Bekasi City are characterized by metal concentrations (mainly Zn) in excess of sediment quality guidelines. Consequently, adverse effects on benthic communities can be expected at all of these stations.

Contaminants in sediments and water are also the source for pollutants in biotic species living in the corresponding ecosystems. Hence, the level of pollution with hazardous elements in organisms is an essential criterion for environmental assessment of aquatic ecosystems. In JB, the order of element concentrations in tissue samples of economic important bivalve and fish species reflected very well the element concentrations found in water and sediment samples from the bay.

Generally, a thorough picture of the spatial distribution considering also the origin of the contamination, seasonal variations, and possible accumulation of the selected elements in economic important bivalve and fish species in JB was depicted for trace hazardous elements in JB. However, beside hazardous elements, organic contaminants play a major role for aquatic pollution. Organic pollutants cover a wide range of molecular structures and related physicochemical properties determining their environmental fate. Due to their partly unique structures, a clear linkage of occurrence to emission source is often possible remarking so-called marker or indicator substances.

8.3.1.2 Organic pollutants

Applying a nontarget screening approach, numerous site-specific or indicative compounds have been identified in Jakarta river water samples (Dsikowitzky et al., 2016a,b). Noteworthy, pollutants detected in river waters from Jakarta area are also suspected to be main contaminants in JB as main receiving system for the urban discharge. Most of the identified organic contaminants can be linked with specific applications, e.g., usage in households or industry. As examples, the detected plasticizers, flame retardants, antioxidants, ingredients of personal care products, disinfectants, surfactant residues, pharmaceutical drugs, and stimulants were previously reported as constituents of municipal wastewaters (Dsikowitzky et al., 2014; Loraine and Pettigrove, 2006; Bueno et al., 2012; Rodil et al., 2010). In terms of concentrations and detection frequency, the flame retardant TCEP (tris(1-chloroethyl)phosphate), the disinfectant chloroxylenol, the personal care product ingredients oxybenzone, DEET (*N*,*N*-diethyl-*m*-toluamide), HHCB (1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[g]-2-benzopyrane) and AHTN (7-acetyl-1,1,3,4,4,6-hexamethyl-1,2,3,4-tetrahydronaphthalene), the stimulants caffeine and nicotine, and the pain reliever ibuprofen and mefenamic acid were the most important source-specific compounds from municipal sources. These compounds occurred in exceptionally high concentrations as compared with other river systems across the globe. It is likely that these compounds are also relevant water contaminants in other Indonesian urban areas. This spectrum of pollutants reflects clearly the impact of partly untreated municipal discharge and its high implication for the water quality of Jakarta rivers and the adjunctive bay.

However, for some substances, an unambiguous discrimination between municipal and industrial sources is not possible, as these compounds may stem from both sources. This accounts, e.g., for selected plasticizers, flame retardants, and technical antioxidants that are used for paper and polymer manufacturing. The can derive not only from paper manufacturing but also from the leaching of solid waste (leaching of dumped waste papers and plastic materials).

Finally, only a few compounds could unequivocally be attributed to an application in agriculture or to the usage for industrial manufacturing. These include, e.g., the pesticides chlorpyrifos and carbofuran as well as the industrial derived pollutant triphenylphosphine oxide.

8.3.2 Characterizing emission sources

A main base for reducing pollution in ecosystems is the identification of the emission sources and their impact on the distribution and level of contamination. This knowledge is a key information for possible technical or political measures for reducing or mitigating the pollution. For inorganic and organic pollutants, two different approaches are followed: discrimination of influences from geogenic and anthropogenic sources as well as the usage of organic indicators.

8.3.2.1 Source apportionment of trace elements

In more detail, to characterize the main sources of hazardous elements, two different sources have to be differentiated: the geogenic from the anthropogenic one. Analyses of major and trace elements in river and canal sediments of the Greater Jakarta area (in combination with published data on sediments of the JB as well as on volcanic rocks of the river catchment areas) showed that chemical characteristics of the river sediments are significantly controlled by the precursor volcanic rocks and the weathering in the catchment area (Sindern et al., 2016). The major element composition of river and canal sediments reflects the dominance of quartz, clay minerals, and Fe oxides/hydroxides. This marks a difference to the composition of the volcanic rocks that show a higher abundance of mafic minerals, which are most affected during weathering. Also trace metals and semimetals in the bay area are inherited from the volcanic rocks. The abundance of Cu and Cr is to various degrees, and the abundance of As is totally controlled by geogenic factors.

Beside these elements and metals of more geogenic origin, some elements such as Zn, Ni, Pb, and to lower degrees Cu are clearly emitted by anthropogenic sources, most of all in central Jakarta City. The marked contrast in enrichment of these elements points to the high variability of local sources, among which metal processing industries may be important, as well as fertilizers or untreated animal waste. In particular, the role of street dusts, which are transported to the rivers with rain water and which are characterized by extremely high Zn concentrations, has to be emphasized.

8.3.2.2 The insect repellent N,N-diethyl-m-toluamide as tracer for municipal sewage and the implications for coastal management

One of the most prominent organic compounds in terms of concentrations and detection frequency found in water samples from Jakarta rivers and from JB was DEET. DEET is the active component of most commercial insect repellents worldwide. Because there is concern about adverse effects on human health, it was replaced in most formulations sold in the European Union. This contaminant was frequently detected in surface waters in all areas of the world, indicating its mobility and persistence (Merel and Snyder, 2016). However, data from coastal areas are sparse, and data from tropical megacities have not been reported as yet.

Exceptionally high concentrations were analyzed in river water and seawater from Jakarta that exceeded by far all published concentrations in surface waters worldwide (Dsikowitzky and Schwarzbauer, 2014). This can be explained by its massive usage, lack of adequate wastewater treatment, and low average river flow. Due to its high source specificity, elevated concentrations, and its persistence, DEET is an ideal marker to trace the spatial distribution of municipal wastewater inputs into surface water systems.

Consequently, the distribution of DEET in JB mirrored the pattern in the rivers with highest DEET concentrations in the southern and western part of the bay—receiving the river discharges from the central part of Jakarta City—and lower concentrations in the eastern part. In the central part of the bay, which is ~10 km away from the coastline, still relatively high concentrations were found. These results show that the water quality of the whole inner JB is influenced by the municipal wastewater inputs from the metropolitan area.

As a continuing example, DEET was picked up as water-related indicator substance to estimate the impact of the phased construction of a giant seawall and large storage basins as idea to protect Jakarta City against floods from sea and rivers. A flow and mass tracer model was adapted to simulate scenarios similar to three phases of the construction of the Great Sea Wall to illustrate the fate of river-bound nutrients and municipal wastewater. DEET flux was introduced as an additional suitable tracer substance for municipal wastewaters (Van der Wulp et al., 2016c). The findings stressed that a phased construction should prioritize a parallel development of structural treatment of municipal wastewater to control the illustrated water quality deterioration.

8.3.3 Industrial emissions in the Greater Jakarta area and their role for the contamination of the Jakarta Bay ecosystem

The Greater Jakarta metropolitan area hosts the biggest Indonesian industrial manufacturing center. This center is located in Bekasi Regency and Bekasi City, a district with a population of ~5.7 Mio inhabitants (BPS, 2014). The industrial branches include in detail steel manufacturing, glass manufacturing, automotive industry, electrical industry, computer manufacturing, chemical industry (polymer synthesis), personal care product manufacturing, toy industry, and paper industry. The industrial wastewaters of the facilities are discharged into a system of small streams/canals that flow into the JB. These streams/canals are crossed by the West Tarum Canal, an artificial channel of 70 km length designed for irrigation, and serve the largest part of the public water supply of Jakarta City (Fares and Ikhwan, 2001).

As an example for the industrial impact on the aquatic system of Jakarta, Fig. 8.4 shows the concentrations of compounds used for paper manufacturing in the river system receiving discharges from the industrial area. The concentrations of these contaminants along the Western Tarum Canal were significantly lower than in the industrial area. The extremely high concentrations in the industrial area are striking. They were as high as in raw process waters from the paper industry (Dsikowitzky et al., 2015). An explanation for this extreme river pollution is the discharge of immense amounts of untreated or only partly treated wastewaters into the small river/channel system in the industrial area. Some of the contaminants from the industrial point sources are subject to transport into the coastal waters. DMPA (2,2-dimethoxy-2-phenylacetophenone), TMDD (2,4,7,9-tetramethyl-5-decyne-4,7-diol), DIPN (di-*iso*-propylnaphthalenes), and phenylmethoxynaphthalene were detectable in the water located ~30 km downstream the industrial discharges. These contaminants are obviously persistent enough to be transported in the aqueous phase over a distance of several kilometers and are therefore relevant for the water quality of the whole river section downstream the industrial area. All of them were also detectable in the seawater samples from JB, in the area of the river that transports the pollutant loads from the industry discharges into the bay. Hence, the paper industry wastewaters contribute to the contamination of the coastal ecosystem.

DIPN and phenylmethoxynaphthalene were present in the aqueous phase as well as in the sediments downstream the industrial area and in JB. The accumulation of these particle-associated contaminants in economic important mussels and fish species from JB was reported in Dwiyitno et al. (2016). From this it follows, that the paper industry

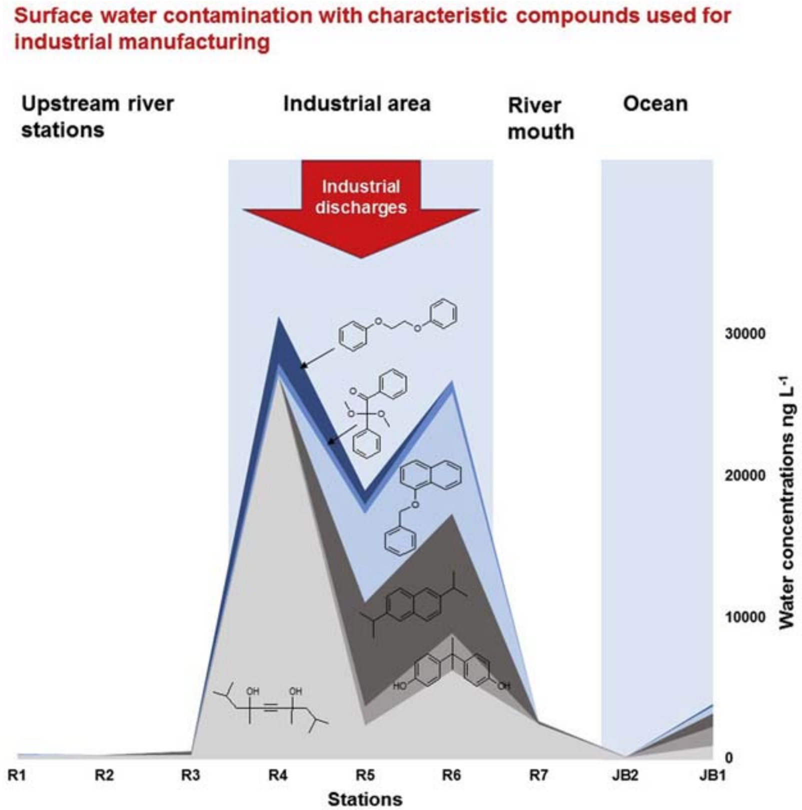


FIGURE 8.4 Concentrations of chemicals that are used for paper production in water samples taken upstream the industrial area (R1–R3) and in the area receiving the industrial wastewaters (R4–R6). One station downstream was also sampled (R7) as well as two stations in JB, where the river receiving the industrial wastewaters discharges into the bay (JB1 and JB 2).

contributes to the contamination of fishery resources in the coastal waters. A comparison with toxicity thresholds shows that the bisphenol A concentrations in river water from the industrial area pose a threat to macrobenthic invertebrates. Exposure experiments with the freshwater snail *Marisa cornuarietis* revealed adverse effects of bisphenol A on reproduction and survival at EC_{10} 13.9 ng L^{-1} (concentration with response of 10% of the members of the tested population). At stations R5 and R6, the recorded maximum bisphenol A concentrations of 7500 and 8000 ng L^{-1}, respectively, were higher than the determined effect value of 998 ng L^{-1}.

8.3.4 The flushing-out phenomenon

Sewage contamination is a major cause for a deteriorated quality of surface waters, in particular in the rapidly growing coastal megacities of the developing and emerging economies (e.g., Peng et al., 2005; Phanuwan et al., 2006). Chemical marker compounds such as fecal steroids are useful to trace the water contamination by untreated municipal sewage (e.g., Furtula et al., 2012; Grimalt et al., 1990). Thereby, the concentrations of the chemical marker coprostanol show a good correlation with the number of fecal bacteria (e.g., Nichols et al., 1993).

This fecal marker approach was applied to water and sediments from the rivers and canals flowing through Jakarta as well as to figure out the spatial distribution of fecal pollution in JB as the coastal ecosystem that receives all urban river discharges (see Fig. 8.2). The concentrations of the fecal steroid coprostanol in river water ranged from 0.45 to 24.2 μg L^{-1}, and in sediments from 0.3 to 650 μg g^{-1}, reflecting the problem of inadequate sewage treatment capacities in Jakarta (Dsikowitzky et al., 2016a,b).

The spatial distribution of coprostanol in surface sediments from JB at different time periods is summarized in Fig. 8.5. In October 2012 and 2013, coprostanol was detected dominantly at nearshore samples, with a maximum concentration of 56 μg g^{-1} (dry sediment). Interestingly, significant higher coprostanol concentrations up to 600 μg g^{-1} (dry sediment) were found in May 2013. Here, coprostanol was detected even at stations in central JB, approximately 10 km offshore.

The steroid distribution in JB in May 2013 as compared with dry season data (October 2012 and 2013) indicates a flushing out of particle-associated pollutants from the urban rivers far offshore during the preceding rainy season, where the city experienced a severe flood. This flushing out of particle-associated pollutants during times of heavy rainfall as observed in this study is a discontinuous pollutant transport mechanism that is important for all tropical coastal systems. Overall, the pulsed pollutant transport into coastal areas that are normally not prone to urban pollution during flood events can strongly affect sensitive coastal habitats such as coral reefs.

8.3.5 Accumulation in biota

Uptake of particle-associated contaminants is one important exposure route for some aquatic organisms. Hence, an accumulation of organic contaminants by economic important fish and macrobenthic invertebrate species from JB might be the result of

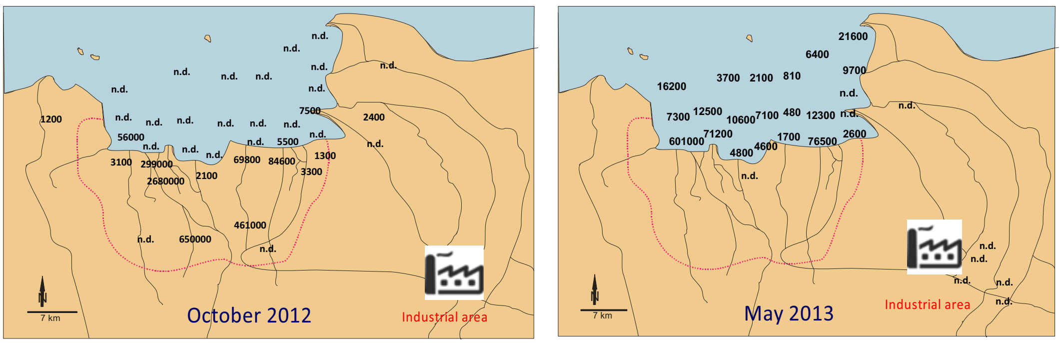


FIGURE 8.5 Coprostanol distribution at two different times representing wet and dry season conditions. The concentrations of the fecal steroid in the sediments is given as ng g$-^{1}$ dw.

sediment contamination. Corresponding analyses of biota and sediments revealed those organic contaminants, which are highly relevant in terms of concentrations and detection frequency for the contamination of fisheries resources from JB (Dwiyitno et al., 2016).

High concentrations of DIPNs, linear alkylbenzenes (LABs) and polycyclic aromatic hydrocarbons (PAHs) were detected in all samples, whereas phenylmethoxynaphthalene (PMN), DDT, and DDT metabolites (DDX) were detected at lower concentrations. A comparison of the concentrations of DIPN, LABs, and PAHs in green mussels (*Perna viridis*) and selected fish species sampled in the bay revealed that the concentrations of all considered contaminant groups were significantly higher in the investigated mussel samples than in the fish samples. It was assumed that the higher concentration levels in mussels as compared with fish species can be attributed to higher exposure of the mussels to the contamination of the JB and the analyses of different tissue types. In addition, mussels might have a higher uptake rate of contaminants due to a different feeding mode. Mussels might also have a lower capacity to metabolize nonchlorinated aromatic hydrocarbons than fishes, as previously demonstrated for PAHs.

DIPNs, LABs, and PAHs are not single contaminants, but contaminant groups consisting in the case of DIPNs of eight different isomers and in the case of LABs of homologs with different chain lengths. PAHs are polycyclic aromatic compounds consisting of two or more condensed benzene rings. The different compounds within these contaminant groups exhibit different physicochemical properties. The processes organic contaminants undergo after their release into the environment such as distribution, uptake by organisms, accumulation, degradation, and transformation are strongly influenced by the physicochemical properties of compounds. Therefore, not only the concentration levels but also the patterns of the three contaminant groups DIPNs, LABs, and PAHs in sediments and animal tissue samples were considered.

DIPNs showed a low degree of degradation in the sediments, whereas an isomer-specific uptake or metabolization by the investigated species was evident. LABs in the sediments were more degraded than in animal tissue samples, suggesting the microbial degradation of LABs in the coastal sediments as predominant process. A preferential bioaccumulation of low-molecular weight PAHs as compared with high-molecular weight PAHs was observed. In addition, during the accumulation process, a shift in the proportion of parent PAHs to their methylated derivatives occurs, so that some common source-indicative PAH ratios cannot be applied to animal tissue samples.

In summary, different and compound-discriminating environmental processes are most relevant for organic contaminants on their way to bioaccumulation. Besides PAHs and LABs, also DIPNs are relevant for the contamination of marine fishery resources at JB.

8.4 Water quality and biological responses

8.4.1 Water pollution in Jakarta Bay and the Thousand Islands

JB has become one of the most polluted marine water bodies in Asia (Bengen et al., 2006). Various marine and coastal environmental impacts including decreased water

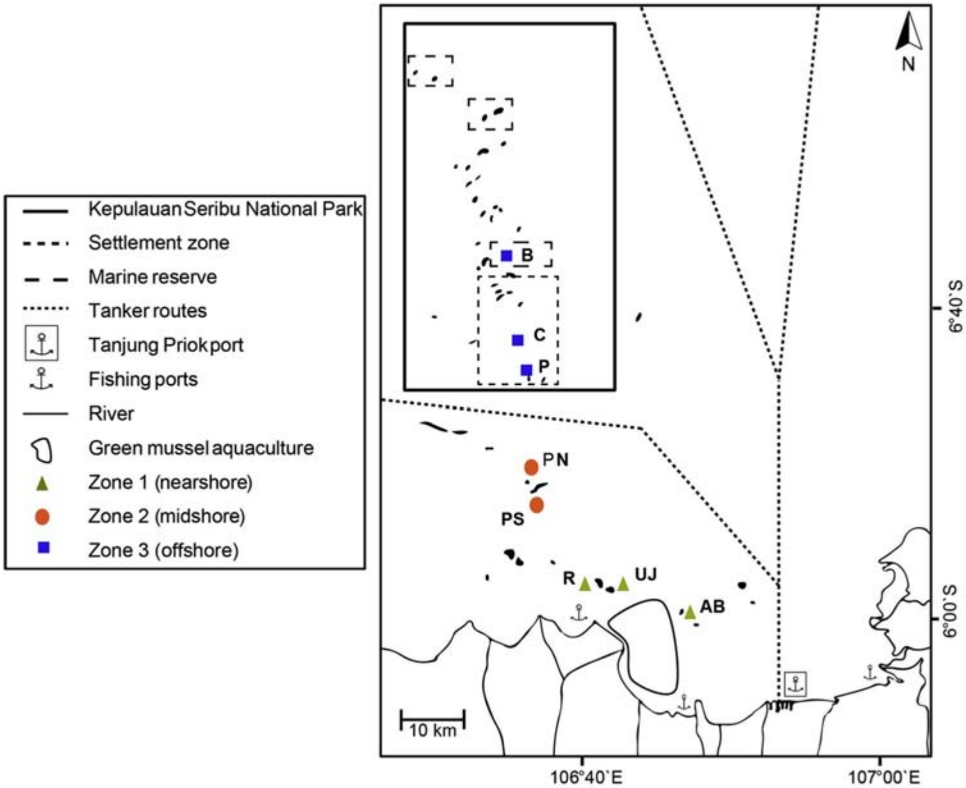


FIGURE 8.6 Jakarta Bay and the Thousand Islands (Indonesian: Kepulauan Seribu). Map includes study sites (Baum et al., 2015) from nearshore reefs (within Jakarta Bay), as well as from the outer Thousand Islands (mid- and offshore): *AB*, Ayer Besar; *B*, Bira; *C*, Congkak; *P*, Panggang; *PN*, Pari North; *PS*, Pari South; *R*, Rambut; *UJ*, Untung Jawa.

quality, seafood contamination, depletion of fishery resources, land reclamation, coastal littering, land subsidence, loss of habitat as well as eutrophication and increased sedimentation rates are currently affecting the mega city of Jakarta. Directly to the north of JB is the island chain Kepulauan Seribu ("Thousand Islands") (Fig. 8.6). This island chain extends up to 80 km off the coast and is situated within the main impact area of anthropogenic stressors originating from Jakarta. Different ecosystems including coral reefs and mangroves that are crucial for the survival of marine organisms and that form the basis for the livelihoods of local communities can be found along the islands (Arifin, 2004). However, large amounts of untreated sewage and industrial effluents, with high pollutant levels, are transported by several rivers directly into JB (Rees et al., 1999). Many studies within the SPICE program have observed elevated concentrations of pollutants, especially within the bay (Dsikowitzky et al., 2016a,b).

Thousands of people such as fishermen in North Jakarta and along the Thousand Islands depend on the ecosystem goods and services provided by local coral reefs (Baum et al., 2016c). Coastal livelihoods, especially those that rely mainly on marine resources like in the JB/Thousand Islands complex, are vulnerable to long-term changes such as increasing pollution with toxic chemicals (Ferrol-Schulte et al., 2015). Here, we summarize findings on the impacts of declining water quality on reef organisms and communities, focusing on physiological impacts.

8.4.2 Biological responses to anthropogenic stressors

Local anthropogenic stressors such as pollution with toxic chemicals, eutrophication, and increased sedimentation are some of the most pressing stressors on coral reefs (Burke et al., 2012; Fabricius, 2005; Van Dam et al., 2011), affecting key functions such as community calcification (Silbiger et al., 2018). Chemicals enter the marine environment most commonly via terrestrial runoff from rivers or through urban runoff carrying large amounts of domestic wastes and industrial effluents. These pollutants can then accumulate in marine organisms such as fish or invertebrates like corals (bioaccumulation), which can lead to various physiological impairments varying from subcellular changes such as direct effects on DNA to metabolic stress (see reviews of Logan, 2007; Van Dam et al., 2011). Within the field of chemical stressors, the intensity and diversity of anthropogenic stressors has increased rapidly over the past decades. Organic contaminants such as hydrocarbons, surfactants, pesticides, and herbicides as well as inorganic pollutants such as sodium cyanide mixtures used in cyanide fishing (Arifin and Hindarti, 2006), metals, and organometallic compounds from industrial waste products are the most common groups (see review of Van Dam et al., 2011).

Scientists use a wide array of different response indicators, from subcellular to metabolic indicators, to determine stress responses in marine organisms (Logan, 2007). Stressed animals need additional energy to recover and maintain homeostasis (Calow and Forbes, 1998). By estimating the metabolic condition or fitness, i.e., the physiological status during changing environmental conditions, the stress level of an organism can be revealed (Fanslow et al., 2001; Lesser, 2013) by, e.g., respirometry (Fig. 8.7).

In general, organisms are able to tolerate stress to a certain extent; however, exposure to multiple stressors can pose additional threats to them and their ecosystems such as reefs. This in turn could lead to a higher sensitivity to other additional stressors (Beyer et al., 2014). So far, effects of multiple stressors have mainly been assumed to be additive (Halpern et al., 2007). However, recent literature indicates that multiple stressors tend to interact with each other (synergism, antagonism; Ban et al., 2014). Such combined effects can happen at the species level as well as on community or population levels (Fig. 8.7).

8.4.3 Impacts on the physiology of key coral reef organisms

Organic toxic pollutants are of growing concern to marine ecosystems (Arifin and Falahudin, 2017; Logan, 2007; Van Dam et al., 2011). PAHs are the most widespread class of organic pollutants, and some PAHs are considered to have mutagenic, carcinogenic, and endocrine-disrupting characteristics (Logan, 2007). Common sources for PAHs are

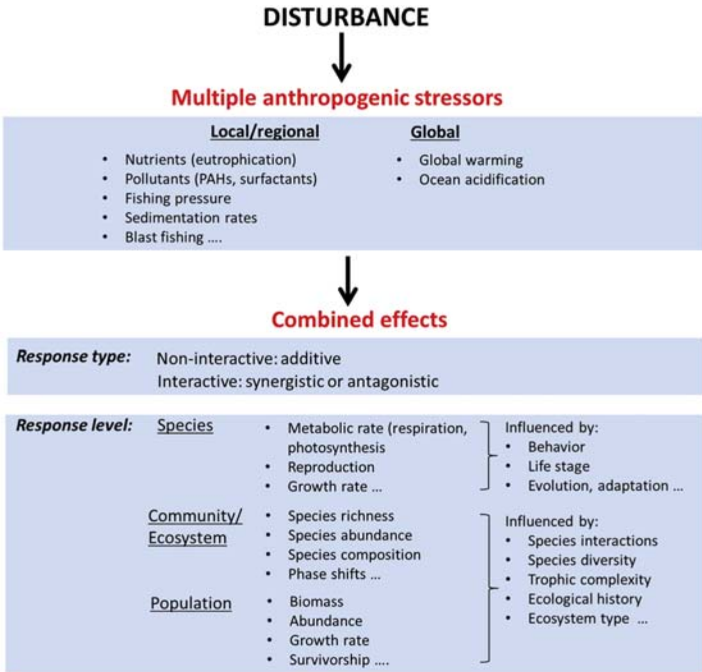


FIGURE 8.7 General overview of multiple anthropogenic stressors (local and global) and combined effects of these stressors including biological response types and levels.

biomass burning, forest fires, internal combustion engines, and garbage incineration, as well as crude oil and petroleum products (Rinawati et al., 2012). Through the release of bilge and ballast water from boats, from both large tankers and small fishing boats alike, organic contaminants such as PAHs from diesel can enter marine waters as part of the water-accumulated fraction (WAF). This is of concern since many coral reefs are in close proximity to shipping lanes, where contaminated bilge water is disposed off (Halpern et al., 2007). Besides PAHs, another ubiquitous pollutant class is surfactants (LAS), which are contained in detergents and soaps and applied by households and industries in large amounts. Especially in untreated effluents, some surfactants can be present at concentrations that may be toxic to aquatic organisms (Ankley and Burkhard, 1992). The amount of LAS can be used as indicator for environments affected by sewage (Rinawati et al., 2012).

Other research groups within SPICE III found that higher concentrations of PAHs, as well as LABs, can be found within JB (Dsikowitzky et al., 2016a,b; Dwiyitno et al., 2016), and in green mussel and fish samples from JB (Dwiyitno et al., 2016).

Here, results from two different physiological studies (Baum et al., 2016a; Kegler et al., 2015) are presented in which the effects of PAHs and the surfactant LAS (linear alkyl benzene sulfonate) were analyzed on key coral reef organisms. Results from Baum et al. (2016a) show that both the surfactant LAS from sewage runoff and diesel-borne compounds such as PAHs from bilge water discharges are two very common local pollutants, not only within JB, but also along the outer Thousand Islands due to lack of sewage treatment and high boat traffic. Short-term exposure of sublethal concentrations of WAF-D (water-accumulated fraction from diesel) and LAS caused metabolic stress to various degrees in the commercially important herbivore coral reef fish *Siganus guttatus* (Baum et al., 2016a) and the hard coral *Pocillopora verrucosa* (Kegler et al., 2015). Exposure to WAF-D led to lower metabolic rates in *S. guttatus*, while no visible effect on hard coral metabolism of *P. verrucosa* could be found. In contrast, LAS exposure led to a significant increase in standard metabolic rates in *S. guttatus*, indicating an increased energy demand as a result of the higher stress (Sloman et al., 2000). The coral *P. verrucosa* reacted to LAS with a severe tissue loss and a decreased photosynthetic efficiency. Furthermore, the experiments could show that both pollutants interacted with each other. This highlights the need to account for stressor interactions in future management and conservation plans. Under combined exposure to both WAF-D and LAS, metabolic depression was observed in *S. guttatus*. LAS led to a significantly higher PAH concentration in the water, therefore suggesting that the effect of WAF-D (decrease in respiration) may have counteracted and neutralized the effect of LAS (increase in respiration).

Results also showed that a 3−4°C increase in temperature, reflecting predicted global warming effects for the end of this century (IPCC, 2013), caused more severe metabolic stress with regard to LAS and WAF-D toxicity for *S. guttatus* and *P. verrucosa*. However, in *S. guttatus*, a synergistic, i.e., amplified reduced (WAF-D) or increased (LAS) change in metabolic rates was not observed. Nonetheless effects were additive during combined exposure to high temperature and LAS, which further decreased the metabolic condition of *S. guttatus*. In the coral *P. verrucosa*, the combination of WAF-D and high temperature led to an increase in dark respiration, and the combination of LAS and high temperature to severe tissue loss and subsequent high mortality.

So far, effects of diesel or other oil products and of surfactants on both corals and fish seem to be ambiguous (DeLeo et al., 2015; Maki, 1979; Zaccone et al., 1985). The underlying physiochemical processes causing the toxicity of these pollutants are still barely understood. Even though the exact physiological mechanisms could not be discovered using only metabolic rates as indicators, the two studies presented here still indicate the severity of the toxicity.

While studies in the past focused primarily on pollutants such as heavy metals (e.g., Guzmán and Jiménez, 1992), single PAHs (e.g., Oliviera et al., 2008), and pesticides (e.g., Richmond, 1993), lesser studied pollutants such as surfactants and WAF-D should also be in the focus of future studies. Especially considering the frequency and amount of bilge water discharge and untreated sewage runoff in the JB/Thousand Islands complex and all over Indonesia, these two pollutants may be a regional rather than a local problem for marine organisms. Moreover, the two studies also highlight that to avoid long-term effects on fish and coral health, the import of these pollutants into coastal areas has to be reduced.

8.4.4 Impacts on reef composition

As a result of mounting anthropogenic stressors, the reefs in the JB/Thousand Islands reef complex have been significantly degraded, particularly within the bay. Here, historically rich coral communities declined to around 10% coral cover in the 1980s and to less than 5% by 2011 (Cleary et al., 2014). By differentially affecting the physiology of key benthic organisms, stressors can result in shifts in the overall composition of benthic communities. In JB and the Thousand Islands, the composition of benthic communities is strongly structured by environmental factors, resulting in a marked inshore/offshore gradient (Cleary et al., 2016). By assessing the physiological response of soft corals in the JB/Thousand Islands reef complex to levels of key pollutants and assessing benthic community composition and levels of water pollution, Baum et al. (2016b) concluded that water quality may control abundance and physiology of dominant soft corals (*Sarcophyton* sp. and *Nephthea* sp.) in JB. Water quality, mostly inorganic nutrient concentrations and sedimentation rates, affected photosynthetic yield and electron transport system activity of the two soft coral species, indicating that metabolic condition in both species is affected by reduced water quality. The abundances of both species were moreover directly linked to declining water quality. This in turn was hypothesized to have facilitated phase shifts from hard to soft coral dominance. The findings highlight the need to improve management of water quality to prevent or reverse phase shifts.

8.4.5 Local versus regional stressors in Jakarta Bay and the Thousand Islands

Both local and regional factors interact and have caused severe reef degradation in the JB/Thousand Islands reef complex, including shifts to soft coral dominance in the bay. A little over a decade ago, Cleary et al. (2016) concluded that large-scale environmental gradients played the strongest role in structuring benthic communities, noting no effect of local factors related to land use on the Thousand Islands on coral cover or diversity. In November 2012, during the transition time between northwest and southeast monsoon, a large coral reef survey was performed as part of the SPICE III project, and eight sites across the Thousand Islands chain were visited (see Fig. 8.6). Results from that study (Baum et al., 2015) confirm that the bay is facing extreme eutrophication coupled with increased primary production and turbidity. PO_4 levels in the upper layer of JB reached 4 $\mu M\ L^{-1}$ and DIN (dissolved inorganic nutrient) levels up to 13 $\mu M\ L^{-1}$. Similarly, Ladwig et al. (2016) showed that inorganic and organic nutrient concentrations in the nearshore area of JB are highly increased. The river discharges from the urban area of Jakarta were identified as the largest contributors to nutrient concentrations within the nearshore area of JB (Van der Wulp et al., 2016a). During the survey in 2012, at all sites in JB, Chl a levels were between 5 and 15 $\mu g\ L^{-1}$, far above the Eutrophication Threshold Concentration for Chl a of 0.2–0.3 $\mu g\ L^{-1}$ (Bell et al., 2007), indicating high primary productivity. Phytoplankton bloom formations are fostered within JB, and an oxygen

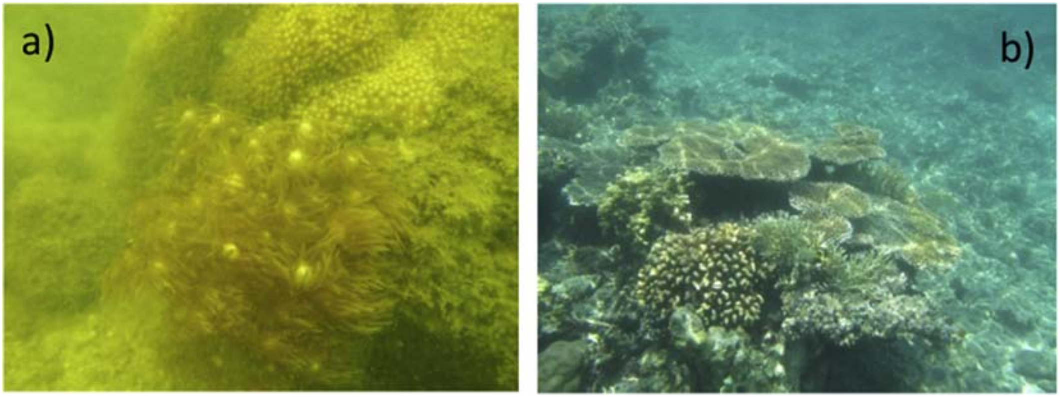


FIGURE 8.8 A highly degraded reef in Jakarta Bay at the island Rambut (A) and a still relatively intact reef further offshore at Pari Island (B).

deficiency area of 20 km^2 was found in the eastern part of JB (Ladwig et al., 2016). In addition, sites within JB had significantly higher sedimentation rates compared with offshore sites in the Thousand Islands, with up to 30 g m^{-2} d^{-1} (Baum et al., 2015).

This decline in water quality, especially in JB, went hand in hand with severe changes in reef communities (Fig. 8.8). The reef condition along the Thousand Islands has dramatically declined since the first scientists conducted investigations in the area in the beginning of the 20th century and described reef systems with high species diversity (Umgrove, 1939). In 2012, hard coral cover was around 2% at sites within JB. But also along the outer Thousand Islands, the overall reef condition is poor, since total coral cover at most sites was <25%. Furthermore, shifts to soft coral dominance were found in the bay. Even though shifts to soft coral dominance are far less common than those to macroalgae dominance, such shifts have been reported for other degraded reefs in the Indo Pacific (Chou and Yamazato, 1990; Fox et al., 2003). Severe changes were also found for fish communities in the area, with currently 80% lower fish abundance in the bay compared with sites from the outer Thousand Islands (Baum et al., 2015). A subsequent study assessing traits of fish species along the JB/Thousand Islands reef complex concluded that eutrophication and pollution have resulted in depauperated fish communities on inshore reefs, selecting for fast-growing and short-lived species (Cleary, 2017).

The results from Baum et al. (2015) furthermore showed a clear difference in benthic and fish communities between sites in JB and the outer Thousand Islands (Fig. 8.9). A direct impact on shallow coral reefs may be restricted to within the bay itself. In contrast to findings from earlier studies, localized effects of anthropogenic stressors rather than regional gradients appear to have gained in importance and now shape the spatial structure of reefs in the outer Thousand Islands. Furthermore, results showed that over 80% of variation in benthic community composition was linked to factors related to terrestrial runoff and eutrophication, especially NO_3, sedimentation, turbidity, PO_4, and Chl a. Local anthropogenic stressors can become the dominant factors shaping benthic

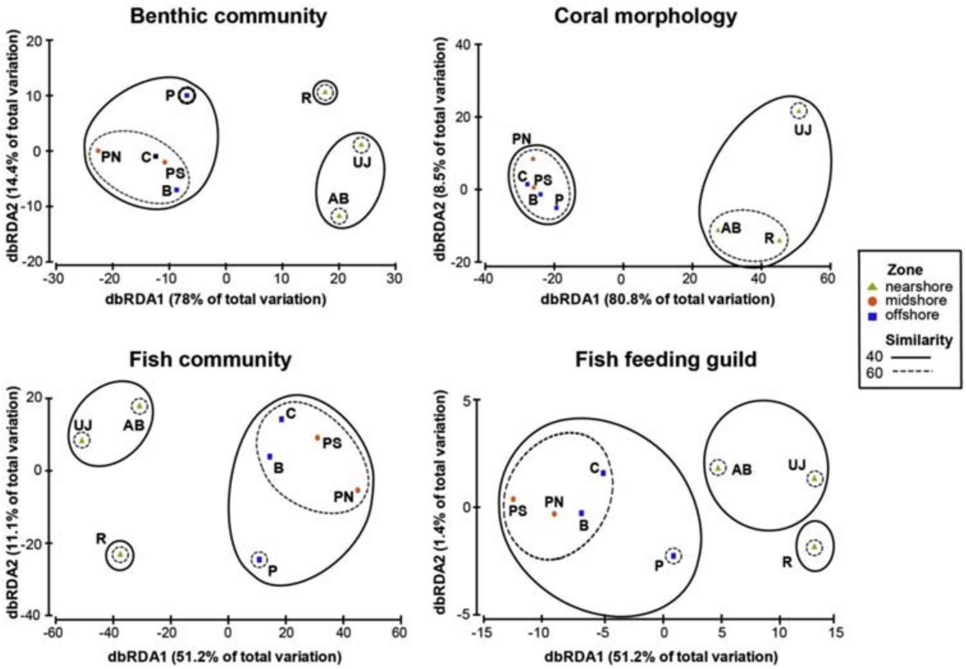


FIGURE 8.9 Visualization of fish and benthic community composition based on distance-based redundancy analysis (dbRDA). Benthic community composition (A), coral morphology composition (B), fish community taxonomic composition (C), and fish feeding guild composition (D) are shown. Study sites: *AB*, Ayer Besar; *B*, Bira; *C*, Congkak; *P*, Panggang; *PN*, Pari North; *PS*, Pari South; *R*, Rambut; *UJ*, Untung Jawa (Baum et al., 2015).

reef communities (Williams et al., 2015), and this trend appears to be reflected in the Thousand Islands. Overall, the spatial structure of reefs in the JB/Thousand Islands reef complex is directly related to both local and regional anthropogenic sources.

In summary, the degradation of coral reefs in JB and the Thousand Islands is caused by a combination of multiple anthropogenic stressors acting in concert. Especially within JB, pollution and sedimentation have become disastrous, leading to extremely degraded coral reefs. Further offshore along the Thousand Islands, reefs are in a slightly improved condition; however, the increasing threat due to overfishing, global warming, eutrophication due to highly densely populated islands and a lack of sewage treatment, and chemicals released from increasing shipping traffic and urban runoff from islands will pose a severe challenge for those reefs in the future.

8.5 Microbial diversity in Indonesian fish and shrimp: a comparative study on different ecological conditions

Indonesia, as an archipelago country has numerous and different coastal ecosystems, which are of great importance concerning natural resources for people's livelihoods. Therefore, sea products play a crucial role as a source of income and foreign exchange.

This is a major reason why the Indonesian government strives to sustain marine and coastal affairs. Consequently, this chapter focuses on metagenomes and microbiomes of two food industry-relevant marine organisms, i.e., *Epinephelus fuscoguttatus*, a marine grouper and *Penaeus monodon*, well known as giant black tiger shrimp, respectively. There were two broad objectives using functional metagenomics: (1) elucidating the genes of different community members that affect host–microbe and microbe–microbe interactions and (2) identifying relevant functions regarding pathogenicity in different microbiome communities (Mandal et al., 2015). Here, detailed information on cultivatable and noncultivatable prokaryotic and eukaryotic organisms, derived from food and environment, i.e., pathogenic, nonpathogenic microbes, parasites, and others will be discussed. Furthermore, this chapter provides insights into the microbiome, the function of complex microbial communities, and their role in host health (Srivasta, 2007). The elucidation of the bacterial community composition further leads to the recognition of bacterial pathogens that might be harmful for hosts and consumers. Moreover, knowing the composition of the gut microbiome, the presence of parasites and feeding habits under different environmental conditions lays the groundwork for future application of, for example, probiotics to improve fish and shrimp immunity to recurrent bacterial infections that are critical for aquaculture in Indonesia.

As reported in various studies, there are many different factors that affect the gut microbiome (Asplund, 2013; Chaiyapechara et al., 2012; Sullam et al., 2012; Xia et al., 2014; Zhang et al., 2014). Apart from the factors that can alter the composition of bacterial communities, the core microbiome remains stable. A core is typically defined as the suite of members shared among microbial consortia from similar habitats. Discovering a core microbiome is important for understanding the stability, i.e., consistent components across complex microbial assemblages (Shade and Handelsman, 2012). The host phylogeny shapes core microbiome predominantly (Hennersdorf et al., 2016a,b). *Proteobacteria* are the dominant phylum, whereas *Vibrionales* are the dominant order (Chaiyapechara et al., 2012; Liu et al., 2011; Rungrassamee et al., 2014). Diet also plays a significant role in shaping the gut microbiome under starvation or under rapid variations in food sources and have been shown to have altered gut bacterial communities (Xia et al., 2014). Ecological and environmental conditions have also been reported to influence the stability of gut microbiome composition (Ronnback, 2002; Sullam et al., 2012). In fish and shrimp aquaculture, the gut microbiome plays an important role in host immunity and as a defense mechanism against pathogenic infections (Balcázar et al., 2006; Balcázar et al., 2007; Guarner and Malagelada, 2003). Invertebrates, such as shrimp, and fish have only innate immunity and, therefore, require the support of commensal bacteria that are part of the gut microbiome to defend against pathogenic infection. In developing countries such as Indonesia, where a large number of traditional aquaculture facilities do not have proper aeration, food control, and effective disease management, improving host metabolism and immunity through understanding and controlling the gut microbiome is necessary to ensure success in the aquacultural industry.

8.5.1 Microbial diversity in *Epinephelus fuscoguttatus*

E. fuscoguttatus was chosen as a model fish, because it is widespread over the Indo-Pacific Ocean. It is of great economic value and a common protein resource in Indonesia. However, this species has been added to the IUCN Red List of Threatened Species due to overfishing and increasing pollution leading to destruction of seagrass and coral reefs crucial for juvenile growth. Free-living and mariculture samples were collected in two different regions, respectively. Free-living samples originated from the Thousand Islands (Pulau Seribu) Marine National Park, whereas the mariculture samples were collected from the open water mariculture facility Nusa Karamba Aquaculture. Using both 16S amplicon sequencing and whole metagenome analysis, it was observed that free-living and mariculture showed similar overall gut microbiomes. They consisted predominantly of *Proteobacteria*, *Firmicutes*, *Spirochaetes*, and *Actinobacteria* at phyla level. At order level (Fig. 8.10A), free-living samples were dominated by *Vibrionales* and *Bacillales*, whereas the mariculture samples were dominated by *Pseudomonadales* and *Enterobacteriales*. The mariculture samples were found to have a low intragroup relative abundance variability compared with free-living samples, which strongly varied among samples.

The microbial diversity has been explored using three statistical methods, i.e., observed taxonomic richness (Gotelli and Colwell, 2011), Chao1 method (Chao, 1984), and Shannon–Wiener diversity index (Shannon, 1948) (Fig. 8.10B–D). Overall, the free-living samples revealed higher observed taxonomic richness in comparison with the aquaculture samples. Similarly, the unobserved taxonomic richness using the Chao1 method (nonparametric richness estimator, providing a statistical estimation of true species richness, including unobserved species within a community) showed similar results. The Chao1 method showed a greater taxonomic richness in free-living samples when compared with mariculture samples. Shannon–Wiener diversity index demonstrated that free-living samples have a greater index, i.e., a greater microbial biodiversity than mariculture samples. Finally, the Bray–Curtis distances method, a statistical analysis, which is used to quantify the compositional dissimilarity between two different sites, based on counts at each site was used to measure the differences between bacterial compositions under the two environmental conditions (Beals, 1984). As shown in Fig. 8.10E, the mariculture samples constructed one cluster revealing their low intragroup relative abundance, whereas the free-living samples spread around this cluster pointing toward the large variability between samples.

Metagenomic analysis allowed to assess the eukaryotic composition (Hennersdorf et al., 2016a,b). The eukaryotic composition showed most reads belonging to the host species. Reads corresponding to nine fish taxa endemic to the Java island region were found. In addition, the reads corresponding to parasitic phyla such as *Platyhelminthes*, *Arthropoda*, and *Acanthocephala* were found. The results showed that the eukaryotic content of both environments was not significantly different. Moreover, metagenome analyses revealed functional components of the observed microbial composition. This was done using the gene ontology database (Gene and Consortium, 2000), which designates a series of biological events performed by a number of organized assemblies of

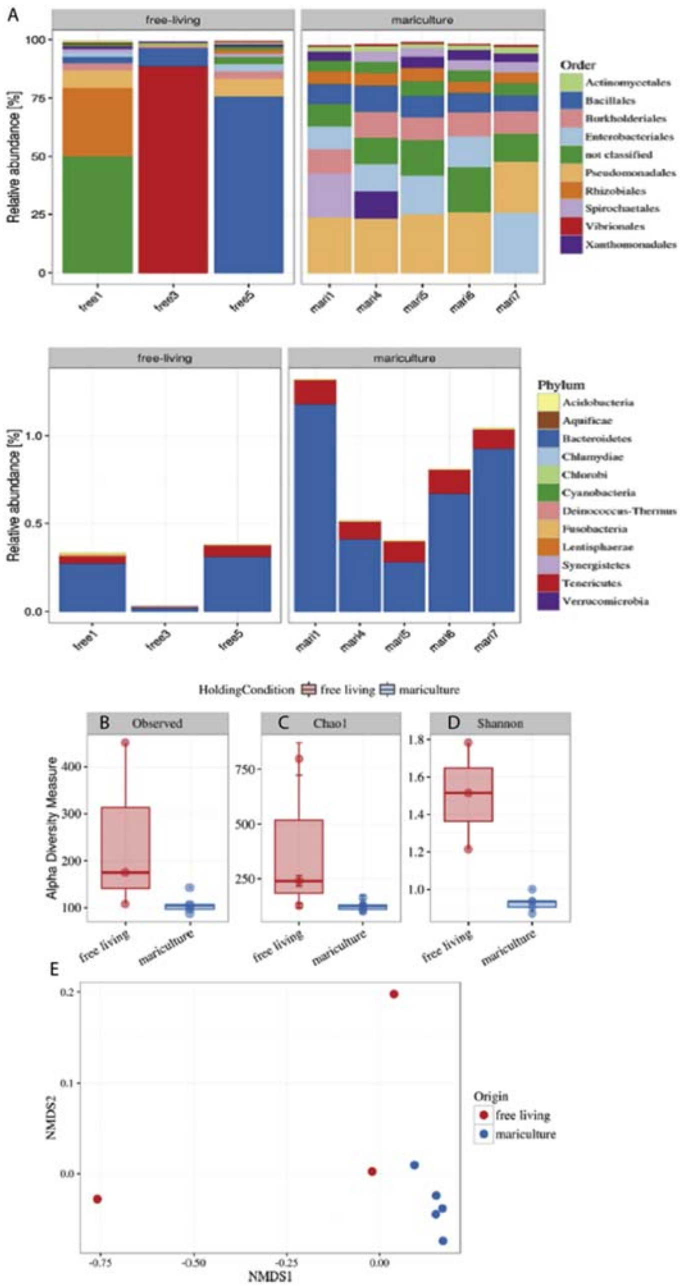


FIGURE 8.10 (A): Relative abundance of bacterial communities in order level from free-living and mariculture *Epinephelus fuscoguttatus* samples (Hennersdorf et al., 2016a,b). Alpha diversity observations from different conditions (red: free-living samples, blue: mariculture samples; (B): observed OTUs richness; (C): Chao1 richness estimator; (D): Shannon indices; boxes represent the quartile, bars represent the interquartiles, dots represent single sample, and solid lines represent median from all samples; E: NMDS (nonmetric multidimensional scaling) measurement aims to ordinate the between-sample dissimilarities. *OTU*, operational taxonomical unit.

molecular functions. This was evident as most of the functional reads were linked to the phylum *Proteobacteria* (Hennersdorf et al., 2016a,b). The results revealed an increased enrichment of genes corresponding with DNA damage and other DNA repair functions specifically in the free-living samples. These functions were obtained from genes assigned to *Vibronales*, *Pseudomondales*, and *Enterobacteriales*, while samples from mariculture were enriched for metabolic processing mostly assigned to *Proteobacteria*. The link observed between potentially pathogenic bacteria and the enrichment of functions relating to DNA repair point toward the role of the environment on microbial composition as opposed to that of the controlled mariculture facility where it was absent (Hennersdorf et al., 2016a,b).

8.5.2 Microbial diversity in feces of *Penaeus monodon*

The microbial diversity in feces of *P. monodon* was investigated in Oetama et al. (2016). *P. monodon* is a high-value shrimp species that is widespread in the Indo-Pacific. It is a worldwide consumed seafood and is exported mainly to Japan, Europe, and the United States (FAO, 2012). Free-living shrimp samples were collected from two different locations: JB and Bali. Concurrently, the aquaculture shrimp samples were collected from traditional aquaculture in Pejarakan, Bali. Abiotic factors that could influence microbial diversity and shrimp health such as salinity, temperature, pH, nitrate, and phosphate concentration were measured (Sullam et al., 2012). The Illumina Miseq sequencing platform was occupied. On average, there were 304,800 obtained mapped reads and assigned to 935 operational taxonomical units (OTUs), which is an operational definition used to classify groups of closely related individuals (Oetama et al., 2016). The most abundant phyla are *Proteobacteria* (96.08%), *Bacteriodetes* (2.32%), *Fusobacteria* (0.96%), and *Firmicutes* (0.53%). On the order level of taxonomy, *Vibrionales* (66.20%) was the most detected order among the samples and was followed by the order of *Alteromonadales* (24.81%) (Fig. 8.11A). The complete sequence information can be found in NCBI's Short Read Archive under accession number SRP059721.

Observed OTUs in taxonomical richness showed a high median number of taxa in both Bali free-living samples (295 taxa) and aquaculture samples (269 taxa), whereas Jakarta free-living samples included only 122 taxa as a median (Fig. 8.11B). The Chao1 method showed similar trends under three environmental and regional conditions: Bali free-living samples included 329.29 taxa, aquaculture samples 303.23, and Jakarta free-living samples 140.47 samples (Fig. 8.11C). The Shannon–Wiener diversity index revealed similar results as obtained by the other two methods. Bali free-living (2.57) and aquaculture samples (2.58) showed a higher index in comparison with Jakarta free-living samples (0.93) (Fig. 8.11D). However, the individual samples of Jakarta free-living shrimp resulted in a higher variation of diversity. Conclusively, Bray–Curtis distance was applied to access the cluster based on dissimilarities. Three out of five samples from Jakarta free-living shrimp are in one cluster, independently from another cluster of Bali free-living and aquaculture samples (Fig. 8.11E). Finally, 4 out of 17 samples from Bali free-living and aquacultured shrimps were observed as outliers, i.e., not belonging to any cluster (Oetama et al., 2016).

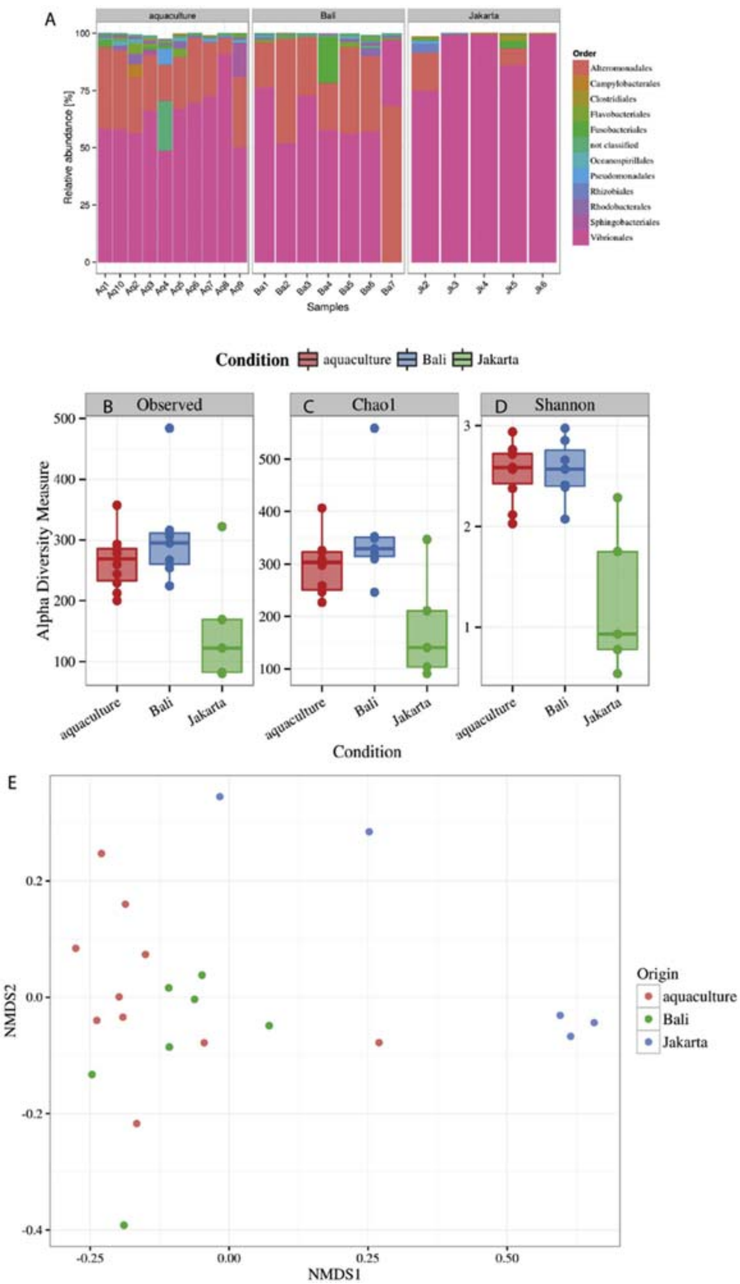


FIGURE 8.11 (A): Relative abundances of bacterial communities in order level of free-living and aquacultured *Penaeus monodon* samples (Oetama et al., 2016). (Aq: shrimp samples collected from aquaculture; Ba: free-living shrimp samples derived from Bali; Jk: free-living shrimp samples derived from Jakarta bay). Alpha diversity observations under different conditions (red: samples derived from aquaculture, blue: free-living samples from Bali bay, green: free-living samples from Jakarta Bay). (B): observed OTUs richness; (C): Chao1 richness estimator; (D): Shannon indices; E: NMDS (nonmetric multidimensional scaling) measurement. *OTU*, operational taxonomical unit.

On the species level, nonpathogenic *Vibrio alginolyticus* bacteria and the pathogens *Vibrio vulnificus* and *Photobacterium damselae* were detected. *V. alginolyticus* is commonly used in probiotics for aquaculture (Gomez-Gil et al., 2002; Krupesha Sharma et al., 2010). The coculture of *V. alginolyticus* C7b and phytoplankton (microalgae) produces polyunsaturated fatty acids and vitamins, which are crucial for shrimp health (Krupesha Sharma et al., 2010). It has been described that healthy and robust gut microbiomes avail the host immunity against bacterial and viral pathogens (Gomez-Gil et al., 2002). Thus, nowadays, farmers apply probiotics to improve production rates. Regarding a healthy gut microbiome, the infections by opportunist pathogens could be inhibited.

The attempt to determine the presence of common pathogenic *Vibrio* species, such as *Vibrio cholerae* and *Vibrio parahaemolyticus*, was made with quantitative PCR, although they were absent in all samples. *V. cholerae* secrete cholera toxin that causes diarrhea, which can lead to death due to dehydration.

As mentioned earlier, *V. vulnificus* and *P. damselae* were detected almost in all samples. The reason might be due to frequent alterations in environmental parameters such as pH conditions, temperature, salinity, and so on resulting in stress and thus increasing probability of infection (Jones and Oliver, 2009; Lee and Rangdale, 2008; Venkateswara-Rao, 1998). Therefore, the findings regarding *V. vulnificus* and *P. damselae* are essential, not only for aquaculture farmers, but also for seafood consumers (Oetama et al., 2016). *V. vulnificus* causes systemic infection starting with fever, chills, and nausea, especially patients suffering from chronic liver disease or diabetes, and is dangerous for immuno-compromised patients. Infection occurs not only via consumption of corresponding marine organisms, but also via direct contact with open wounds. For example, there have been many known cases in the United States, especially during periods of strongly increased water temperature (Jones and Oliver, 2009).

P. damselae is found in a broad variety of marine organisms. Its virulence factors have not yet been elucidated. It has been hypothesized that phospholipase-D Dly (damselysin) and the pore-forming toxins HlyApl and HylAch are relevant virulence factors in *P. damselae* (Hundenborn et al., 2013; Vaseeharan et al., 2007). In our studies, more than 50% of the aquaculture and Jakarta free-living samples were infected by *P. damselae*, and all free-living samples from Bali were infected as well. However, larger sample sizes are needed to verify these findings.

8.5.3 Comparison of microbial diversity between fish and shrimp from Jakarta and Bali

Most predominant phyla observed in the gut microbiome of both *E. fuscoguttatus* and *P. monodon* from all sampling sites were *Proteobacteria*. In addition, three other phyla with more than 1% abundance were determined. *Firmicutes*, *Spirochaetes*, and *Actinobacteria* were found in *E. fuscoguttatus*, whereas *Bacteriodetes*, *Fusobacteria*, and *Firmicutes* were present in *P. monodon*. As reported in other studies, *Proteobacteria* and *Firmicutes* are the two phyla, which are found in all marine organisms (Liu et al., 2011; Rungrassamee et al., 2014; Sanchez et al., 2012). Therefore, these two phyla belong to the core microbiome. Surprisingly, we could not detect any common pathogens in marine organisms, such as *V. cholerae* and *V. parahaemolyticus*. However, we detected *V. vulnificus* and *P. damselae* in all samples of cultured shrimp. These pathogens have virulence factors that could initiate severe diseases in host and consumers. The presence of well-known probiotics, e.g., *V. alginolyticus* was also determined. Moreover, the composition of the gut microbiome in free-living and aquaculture samples is very similar, but with a marked decrease in diversity in the aquaculture samples. With respect to the environmental factors that influence the gut microbiome, traditional aquacultures share similar conditions with natural habitats. Conjointly, traditional aquaculture does not involve food additives, and therefore, diet of aquacultured shrimp and fish is composed of microalgae and phytoplankton present in the ponds. Thus, diet and ecological conditions do not play a big role in shaping the bacterial populations in all samples of our study.

In summary, the diversity in free-living fish and shrimp is greater than in the corresponding aquacultures. Location is a crucial factor, which leads to differences in the origin of evolutionary ancestors and genetic diversity among *P. monodon*, although the impact of environmental conditions on alterations of the microbiome cannot be dismissed. The substantial distinction of microbial diversity under different conditions could be explained, because of less environmental changes in aquaculture than in natural habitats; hence, it shapes more stable host microbiomes (Ronnback, 2001, 2002; Sullam et al., 2012).

8.6 Fish parasites in Indonesian waters: new species findings, biodiversity patterns, and modern applications

As already pointed out in Chapter 6.5, the fisheries industry with its valuable food products is a driver for the future economic development of the maritime nation Indonesia. Consequently, food safety and security are consumer's main interest. Marine fishes can be a source for foodborne, parasitic human diseases (zoonoses), primarily when larval helminths are ingested through the consumption of semicooked or uncooked fisheries products (e.g., Petersen et al., 1993). Anisakid nematodes of the genus Anisakis have been reported to cause the Anisakiasis, an inflammation of the human gastrointestinal tract (Ishikura and Kikuchi, 1990; Klimpel and Palm, 2011). Other parasite taxa such as the trypanorhynch cestodes are commonly found inside the fish musculature (Palm, 2004, p. 724) and can offend consumers (Palm and Overstreet, 2000) or cause allergic reactions (Ivanovic et al., 2015).

The Indonesian marine habitats host one of the highest biodiversity's on earth (Palm, 2011; Roberts et al., 2002; Yuniar et al., 2007). This includes the fish parasite fauna, though only few local studies have been recognized outside the country (e.g., Yamaguti, 1952, 1953, 1954). After the first record of the potential zoonotic Anisakis in 1954, several

Indonesian researchers studied the Anisakidae based on morphology (e.g., Asmanelli and Muchari, 1993; Burhanuddin and Djamali, 1978; Humoto and Burhanuddin, 1978; Ilahude et al., 1978; Koesharyani et al., 2001; Martosewojo, 1980). Comprehensive taxonomic treatments (e.g., Palm and Bray, 2014) as well as fish ecological studies on fish parasites from Indonesia occurred only recently mainly as a result of SPICE I–III (Kleinertz and Palm, 2015).

The biodiversity of fish parasites and their complex life cycles allow them to be used as indicators for a wide range of biological and environmental applications (Palm, 2011; Palm and Bray, 2014). Because of the direct linkage and dependence of parasites with multiple-host life cycles to the surrounding animal communities (Hechinger et al., 2007), these organisms have been considered as sensitive bioindicators for aquatic ecosystem health (Dzikowski et al., 2003; Overstreet, 1997). They are useful to indicate food web relationships especially in unaffected marine habitats (e.g., Klimpel et al., 2006; Lafferty et al., 2008a; Palm, 1999), where the full range of their required hosts is present (Lafferty et al., 2008b). Consequently, they can serve as indicators for environmental change and pollution (Diamant et al., 1999; Dzikowski et al., 2003; Kleinertz and Palm, 2015; Palm, 2011) or environmental stress (Landsberg et al., 1998). While the occurrence of endoparasites often decreases in polluted waters (Nematoda, Kiceniuk and Khan, 1983), ectoparasites can increase (Monogenea, Khan and Kiceniuk, 1988; Trichodina, Khan, 1990; Ogut and Palm, 2005). Some ectocommensals with direct life cycles such as trichodinid ciliates favor polluted waters and can additionally indicate high bacterial load (Palm and Dobberstein, 1999).

Many methods have been used to assess real and potential hazards of contaminants by using target organisms (Kang et al., 2014). They involve evaluation of ecological health by using key bioindicators at the population and community levels (de la Torre et al., 2007). Other approaches aim at analyzing biomarkers on their molecular, physiological, and cellular levels, which are sensitive to ecosystem degradation (Chèvre et al., 2003) and contamination. As an example, according to Sures (2008) and Sures and Reimann (2003), acanthocephalans can be used as accumulation indicators for heavy metals, because they accumulate 1000 times higher amounts of heavy metals compared with their host tissues.

This chapter summarizes the German–Indonesian joint research effort on fish parasites from Indonesian coastal waters during the third phase of SPICE, also summarizing the earlier phases (e.g., Kleinertz, 2010; Rückert, 2006; Theisen, 2009; Yuniar, 2005).

8.6.1 Species descriptions and taxonomic treatments

Comprehensive collections of fish parasites during the 10 years of SPICE revealed the discovery of new species and increased our taxonomic knowledge. The most comprehensive treatment of the tropical fish parasitic Trypanorhyncha Diesing, 1863 by Palm (2004), already utilized material sampled under this program and added several new species from Indonesian waters, totaling about 20% of the then known biodiversity in that group. Kuchta et al. (2009) studied the four then known bothriocephalidean cestodes from Indonesia and provided redescriptions of species that were earlier reported from the Indo-Pacific region.

Bucephalids are the most common fish trematode family in commercially important groupers. Bray and Palm (2009) provided a taxonomic treatment including two new species, *Rhipidocotyle danai* and *Rhipidocotyle jayai*. Dewi and Palm (2013) described two new species of philometrid nematodes, *Spirophilometra endangae*, and *Philometra epinepheli*, from the orange spotted grouper *Epinephelus coioides*, and Dewi and Palm (2017) added *Philometra damriyasai* from the tetraodontiform *Tylerius spinosissimus*. The papers described the first opercula-infecting species of *P. damriyasai* from the Epinephelinae, with a total of 14 philometrids that so far have been identified from marine fishes in Indonesia. Theisen et al. (2017) for the first time identified a new endoparasitic monogenean from Indonesian marine fishes (*Nibea soldado*, *Otolithes ruber*; both Sciaenidae). Monogeneans are mainly ectoparasitic, and the infection of inner organs is scarce. In all these studies, identification keys and a summary of the current state of knowledge on these parasite taxa from Indonesia were provided.

8.6.2 Zoonotic *Anisakis* spp. in Indonesian waters

A high prevalence of infestation (97%–100%) of the economically important *Trichiurus lepturus* as well as other oceanic and pelagic fish with the potentially zoonotic *Anisakis* spp. at the southern coast of Java demonstrated a high risk of Indonesian predatory fish getting infested (Jakob and Palm, 2006). Because that study did not use molecular identification, the real species identity and potential risk for the human consumer remained unclear. Palm et al. (2008) genetically identified *Anisakis* spp. from Bali and recorded the distribution of Anisakis larvae in Indonesia, based on the available literature and a sample from five fish species from Kedonganan, Bali, and Pelabuhan Ratu, South Java. The larvae mainly belonged to *Anisakis typica*. Because the musculature infection in *Auxis rochei rochei* was low (2.5%), no major risk for the fish consumers was concluded.

Palm et al. (2017) genetically identified 118 *Anisakis* spp. and established 16 new host records. To date, 53 Indonesian teleosts harbor *Anisakis* spp., 32 of them with known sequence data. The analyses identified three specimens of *Anisakis* sp. HC-2005 and 39 (16%) *A.* typica (s.s.). *Anisakis berlandi* and *Anisakis pegreffii* were reported for the first time from teleosts in the equatorial region and *Anisakis physeteris* from the Pacific Ocean. 193 worms (~79%) belonged to the already-detected genotype by Palm et al. (2008) and were nominated as a new *Anisakis aff. typica* var. *indonesiensis* until the description of the adults. The musculature infection was very low, resulting in minor risk of Anisakiasis in Indonesia.

8.6.3 Parasite biodiversity in wildlife and maricultured fish

These studies during SPICE focused on sampling of commercially important fish from Segara Anakan lagoon, the Java Sea, and Balinese waters. Jakob and Palm (2006) examined five oceanic fish species from the southern Java coast. An overlapping infestation pattern in fish from entirely different families underlined a low specificity of many helminths in their second intermediate hosts and their ability to infest fishes without respect to their host phylogeny.

Yuniar et al. (2007) carried out a first thorough investigation on ectoparasites of commercial important fish from Segara Anakan. Eight economically important marine fish species were examined for crustaceans. A diverse copepod fauna consisting of 23 different species and two isopods was found. Rückert et al. (2009a) reported the metazoan fish parasites also from Segara Anakan lagoon. Again, a highly diverse parasite fauna was found, consisting of 43 species/taxa. Kleinertz et al. (2014) examined *Epinephelus areolatus* off the anthropogenic influenced Segara Anakan lagoon and a relatively undisturbed reference site in Balinese waters. Kleinertz and Palm (2015) studied *E. coioides* from Segara Anakan and Bali. Regional differences for *E. coioides* were found in terms of different used parameters. Neubert et al. (2016a) provided the first comprehensive information on the parasites of the white-streaked grouper *Epinephelus ongus* from Karimunjawa, Java Sea. For comparison, the parasite community of *E. areolatus*, *E.coioides*, and *E. fuscoguttatus* from previous studies was analyzed. The ectoparasite fauna was predominated by the monogenean *Pseudorhabdosynochus quadratus*. The endoparasite fauna was predominated by generalists, which were already known from Indonesia, demonstrating the potential risk of parasite transmission through *E. ongus* into grouper mariculture and *vice versa*. Rückert et al. (2008) stated that fish parasites have been repeatedly reported to be a major threat to the developing industry of finfish mariculture. They sampled the metazoan parasite fauna and trichodinid ciliates from *Lates calcarifer* in a representative mariculture farm in Lampung Bay, South Sumatra.

Rückert et al. (2009b) studied differently fed groupers *E. coioides* from an Indonesian finfish mariculture farm. Pellet-fed *E. coioides* were infested with 13 parasite species/taxa. The use of pellet food significantly reduced the transfer of heteroxenous endohelminths. Trash fish was held responsible for the transmission of these parasites, though the endohelminth infestation of pellet fed fish demonstrated that parasite transfer also occurred via organisms that naturally live in, on, and in the surroundings of the net cages. Rückert et al. (2010) examined *E. fuscoguttatus* during three consecutive seasons from floating net cages of the National Sea Farming Development Centre (Balai Budidaya Laut) and from wild catches in Lampung Bay, South Sumatra. The parasite findings contrasted wild grouper, where heteroxenous parasites occurred at a similar prevalence compared with the fairly abundant *Pseudorhabdosynochus* spp. No seasonality of infestation was observed for both cultured and wild fish. Palm et al. (2015) summarized the results from *E. fuscoguttatus* from four mariculture facilities in Lampung Bay (South Sumatra) and one in Pulau Seribu (North of Jakarta). Their results demonstrated that one of the major future tasks in Indonesian mariculture is the search for alternative feed sources and feeding strategies to prevent parasite spread and pathogenic outbreaks.

8.6.4 Fish parasites as biological indicators and new applications

The use of fish parasites as biological indicators required adaptation of a stargraph to visualize different parasite metrics on a single figure and to provide a "holistic view in sustainable development" (Bell and Morse, 2003). Palm and Rückert (2009) used three different indicators to visualize ecosystem health by using marine fish parasites. Palm et al. (2011) added further characters and applied this system to indicate long-term changes in a grouper mariculture facility. Kleinertz et al. (2014) used reef-associated grouper *E. areolatus* to demonstrate regional differences. The authors included further parameters to the system such as the hepatosomatic index to indicate high enzymatic activity of stressed fish (Munkittrick et al., 1994). Finally, Kleinertz and Palm (2015) adjusted this system to *E. coioides*. For the first time, it was possible to visualize regional differences between Indonesian coastal waters (Kleinertz et al., 2014; Palm and Rückert, 2009) and long-term annual change (Palm et al., 2011) by using fish parasites.

During the final SPICE Phase, Neubert et al. (2016b) were able to assess the environmental conditions of a heavily polluted Indonesian marine habitat (JB as well as off JB, star graph, Fig. 8.12), and compared it with already existing data. The data were normalized and transferred into a colored traffic light, assessing the environmental conditions in the range from poor (= red), medium (= yellow), and good (= green) (pollution light, Fig. 8.13).

Kleinertz et al. (2016) for the first time applied nontargeted Py-FIMS analyses on fish parasites, using the acanthocephalan *Rhadinorhynchus zhukovi* from *A. rochei* and *Auxis thazard* as a potential accumulation indicator for organic pollutants, such as fuel residues like diesel as indicated by the Py-FI mass spectra within this study.

In summary, from an estimate of about 10.500–14.000 marine fish parasite species occurring in Indonesia, so far, not more than about 500 species have been scientifically reported and/or correctly identified, demonstrating the little knowledge in this field. This is astonishing considering the increasing importance of aqua- and mariculture in Indonesia, necessitating a thorough knowledge on potential harmful organisms that threaten the cultivated fish. At our main sampling sites in Indonesia, the parasite biodiversity was expectedly high. One surprising result was the different species richness according to the fish ecology. The comparison of wild and maricultured fish demonstrated a high risk to gain and accumulate fish parasites also from the wild into the cultivated fish.

8.7 Seafood consumption and potential risk

Nowadays, aquaculture contributes predominantly to seafood production, compared with capture/wild fishery. In JB, approximately 35,000 tons year^{-1} are produced from capture fishery (mollusk species, pelagic fish, demersal species, and crustaceans) and 2500 tons from marine/coastal culture (green mussel, milkfish, grouper and shrimp).

Seafood is the main source of protein (54%) for the majority of Indonesian people. Currently, national fish consumption is between 20 and 40 kg person^{-1} year^{-1}, with an average 36 kg person^{-1} year^{-1} (MMAF, 2015). The consumption level in megapolitan Jabodetabek (Jakarta, Bogor, Depok, Tangerang and Bekasi) is around 25–30 kg person^{-1} year^{-1}. Governmental campaigns such as the "*Gemar Makan Ikan*" ("Eating Fish")

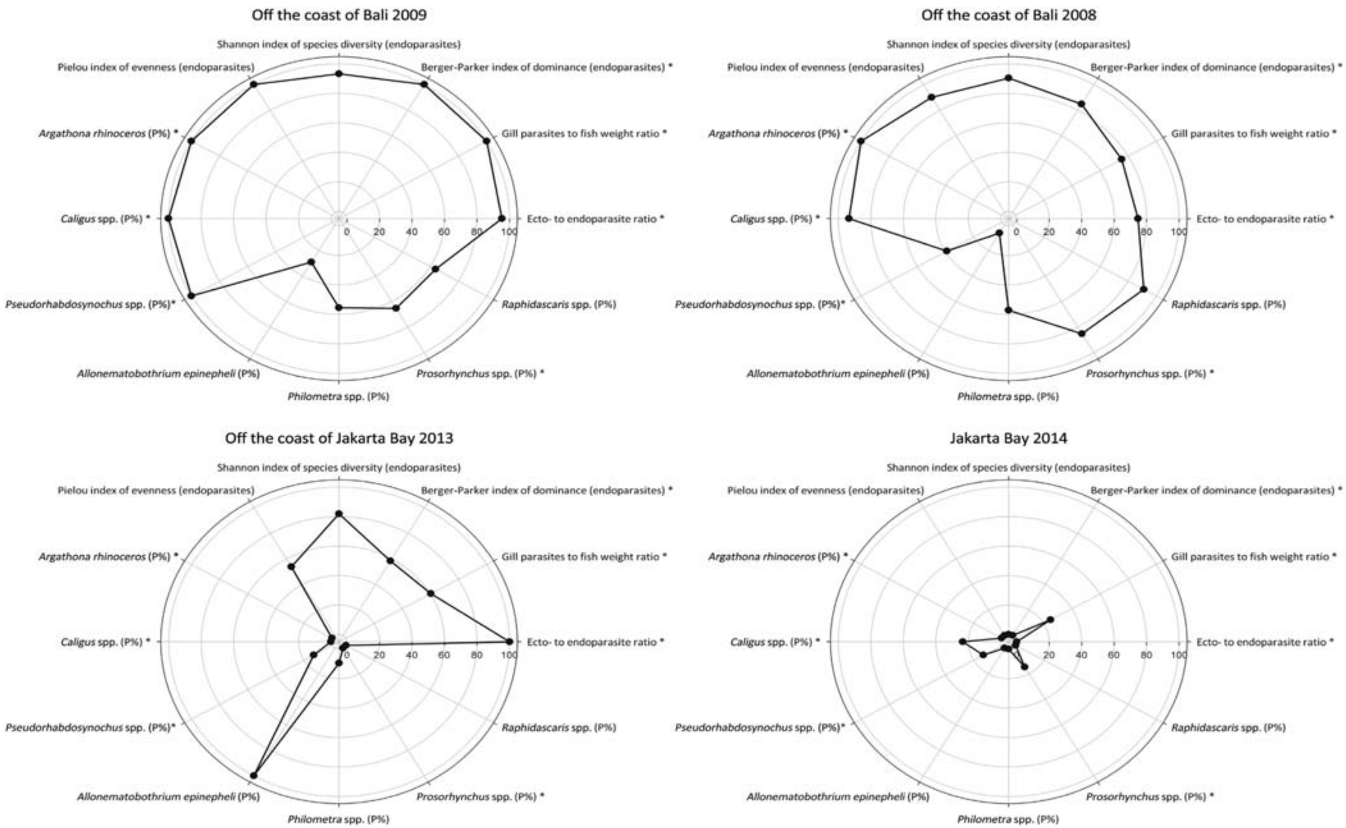


FIGURE 8.12 Visual integration of normalized parasitological parameters from *Epinephelus coioides* for Indonesian coastal waters. Large areas reflect near-natural conditions, small areas unnatural conditions. Comparison is made between the coast off Bali, Jakarta Bay, and off Jakarta Bay. * Inverse parameter (Neubert et al., 2016b). *Modified after Kleinertz (2010) and Kleinertz and Palm (2015).*

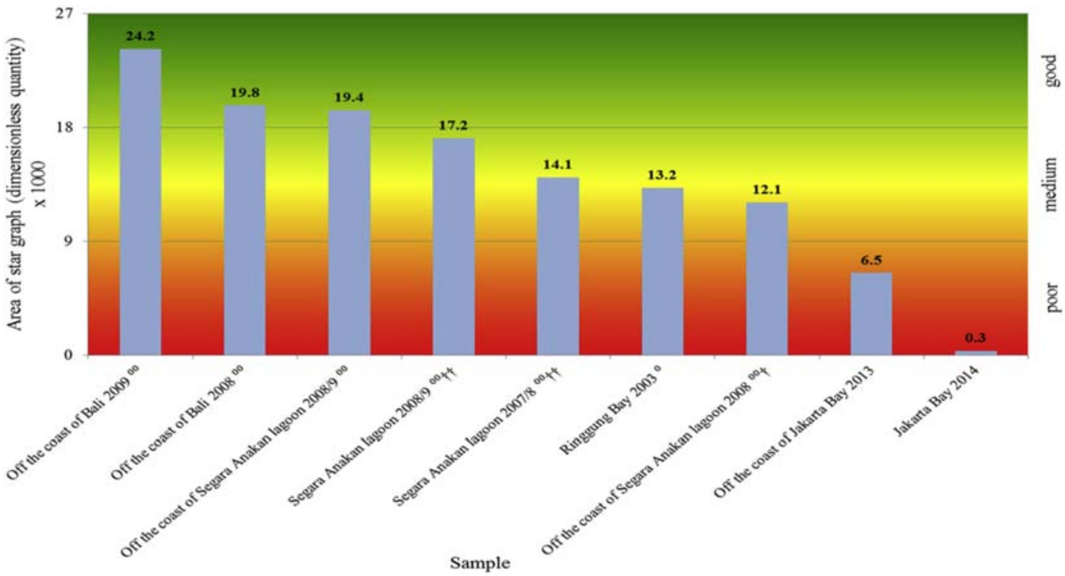


FIGURE 8.13 Pollution light: Areas of star graphs calculated from normalized parasitological parameters of *Epinephelus coioides*. ° data from Rückert (2006, p. 240), °° data from Kleinertz (2010, p. 263) and Kleinertz and Palm (2015), † identified as sample from inside Segara Anakan lagoon, †† identified as sample from off the coast of Segara Anakan lagoon (Neubert et al., 2016b).

campaign have contributed in elevating seafood consumption. Furthermore, fishery and aquaculture are important livelihoods for coastal inhabitants of JB and the Thousand Islands, with few available livelihood alternatives to local fishers (Fauzi and Buchary, 2001).

Contrarily to the health benefit of seafood consumption (e.g., Al et al., 2000; Clandinin, 1999; Kawarazuka and Béné, 2011; Otto et al., 2001), there are possible opposite effects related to harmful contaminants. For example, there is evidence of risk of coronary heart disease associated with methyl-mercury contamination (FAO/WHO, 2007, 2010) or neurodevelopment disorder (Lynch et al., 2011). Potential cancer risks associated with persistent organic pollutants (POPs) such as dioxins (PCDD/F) and dioxin-like PCBs (polychorinated biphenyls) as well as carcinogenic PAHs may negate the coronary heart disease benefits from fish consumption (EC, 2011).

Due to their possible adverse effects, harmful contaminants in seafood have received increasing awareness. This includes organic contaminants (mainly residue of pesticides and PAHs), inorganic pollutants (heavy metals), and organometallic pollutants such as butyl tin derivatives (e.g., Monirith et al., 2003; Rumengan et al., 2008; Sudaryanto et al., 2007; Williams et al., 2000). Additionally, biological contaminants such as pathogenic microbes, biotoxins, and biogenic amines also potentially contaminate seafood from JB (Andayani and Sumartono, 2012; Makmur et al., 2014). Finally, illegal additives and preservatives frequently misused during handling and processing of seafood need to be considered (Dwiyitno et al., 2009).

Concern of adverse effects due to chemical residues in seafood is reflected in several exposure assessments conducted recently for the JB region. Agusa et al. (2007) estimated exposure of 15 heavy metals (V, Cr, Mn, Co, Cu, Zn, Se, Sr, Mo, Ag, Cd, Sn, Pb, Hg, and Ba) from seafood consumption based on the concentration in 12 seafood species from JB, Lada Bay, and Cirebon Bay. The assessment revealed an average of estimated daily intakes of the contaminants below the guideline values based on JECFA (2003) and US-EPA (2005). However, the maximum exposure of Hg (detected in Talang queenfish, *Scomberoides commersonnianus*, from JB) was found to be 15 μg day^{-1}, which is 136% and 118% over these limits, respectively. Noteworthy, dietary intake of heavy metals from seafood in Indonesia is lower than that, e.g., of Malaysia and Cambodia, but higher than in Thailand (Agusa et al., 2007).

Sudaryanto et al. (2007) studied the potential exposure of organochlorine residues in the JB region. The results showed that the residues were dominated by PCBs and total DDT in all fish samples, followed by hexachlorocyclohexanes (HCHs), chlordane compounds (CHLs), and hexachlorobenzene (HCB). Based on the concentration in mussels, DDT and HCHs were particularly higher in samples from suburban area, but PCBs and CHLs were more abundant in samples from JB (Monirith et al., 2003). The calculated daily intake of these organochlorines did not reach the TDIs, suggesting a low risk. The mean daily intake of PCBs was 0.81 μg $person^{-1}$ day^{-1} via fish consumption, which was less than 2% of the FAO/WHO (2007) values. For total DDT, the dietary intake by Indonesians was 1.1 μg $person^{-1}$ day^{-1}, less than 1% of the FAO/WHO guideline.

Potential exposure of similar organochlorines from seafood, collected in traditional markets in Jakarta, Bogor, and Yogyakarta, has been also studied by Shoiful and Colleagues (2013). They estimated the daily intake of HCB and DDT contaminants through milkfish (*Chanos chanos*) to be 0.35 and 0.5 ng kg BW^{-1} day^{-1}, respectively. However, these exposures also were far below the guideline of acceptable daily intake (ADI) (according to FAO-WHO, 2010).

Recently, Dwiyitno et al. (2015) have identified more than 40 organic contaminants in selected seafood species in JB, including persistent pollutants and emerging contaminants. A survey on the corresponding exposure in four districts around JB (Cilincing, Penjaringan, Untung Jawa, and Tanjung Pasir) showed that the potential risk of organic contaminants from seafood was below the thresholds of moderate and serious risk limits suggested by RIVM (2001) and ATSDR (2002), indicating that they may not cause any serious health risk (Dwiyitno et al., 2017).

Dwiyitno et al. (2017) estimated a daily intake of total DDT and dichlorobenzenes by residents of around 2 ng day^{-1} (maximum limit is 10 μg kg BW^{-1} according to FAO/WHO, 2000), much higher than PAH_4 (0.8 ng day^{-1}). DDT-related contamination of green mussels and the majority of fish samples was related mainly to *p,p*'-DDE. This result is in line with an earlier study reporting *p,p*'-DDE in fish samples from several locations in Indonesia (Shoiful et al., 2013; Sudaryanto et al., 2007).

Furthermore, the exposure of PAH_4 (sum of the four most carcinogenic, mutagenic, and estrogenic isomers, see Fig. 8.14) was dominated by BaA and BbF in green mussels

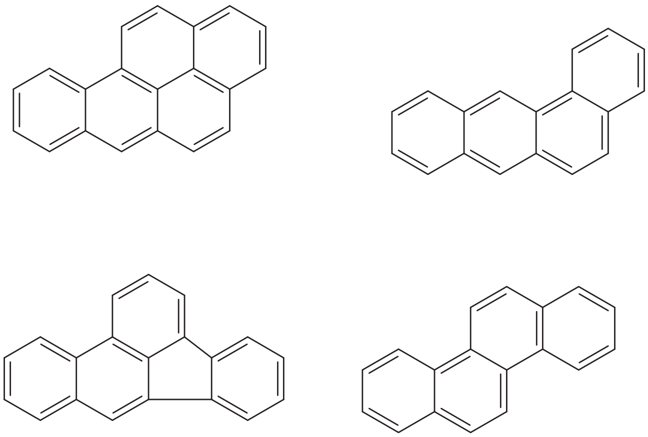


FIGURE 8.14 PAH_4—(benzo[a]pyrene; benzo[a]anthracene; benzo[f]fluoranthene; chrysene).

as well as certain pelagic and benthic fish such as milk fish, Spanish mackerel, and mullet (Dwiyitno et al., 2017). Maximum concentrations of PAH_4 in green mussel and fish species were 7 and 3 μg kg^{-1}, which were below the threshold of 30 and 12 μg kg^{-1}, respectively (EC, 2011). The calculated dietary intake of PAHs was comparable to that of various fish species in Mumbai, India (1.8–10.7 ng kg BW^{-1} day^{-1}), Korea (13.8–16.7 ng kg BW^{-1} day^{-1}), Kuwait (231 ng day^{-1}), and Spain (627–712 ng day^{-1}) (Dhananjaya and Muralidharan, 2012; Falcó et al., 2003; Saeed et al., 1995).

A tolerable daily intake (TDI) of 1,4-dichlorobenzene (DCB), used as deodorizer and disinfectant, is suggested to be 107 μg kg BW^{-1} day^{-1} (WHO, 2010). RIVM (2001) adopted this level to define TDI level of *1,4*- and *1,2*-DCB as 100 and 430 μg kg BW^{-1} day^{-1}, respectively. Accordingly, Dwiyitno et al. (2017) estimated that DCB intake via seafood consumption from JB is below the TDI. Important species captured in JB and the risk of potential contaminants are presented in Table 8.1.

According to a survey of 84 households on the Thousand Islands and 140 in coastal communities of JB, the main target species differ between JB and Thousand Island households (Table 8.2). The species ranked highest in importance on average on the islands, and caught by the majority (around 90%) of households there, is the fusilier, *Caesio cuning*. For coastal households in JB, however, this species ranks last in mean importance. The most important species in JB, caught in about 85% of households, is *Rastrelliger kanagurta*. This species ranks third in importance on the islands and is caught by 60% of households there, indicating that it is the most important species overall for coastal households in the JB/Thousand Islands area (Baum et al., 2016c). The important role of green mussels, *Perna viridis*, for coastal households in JB underlines their particular exposure to pollution risks (Table 8.1), as well as their economic exposure in case culture and sale of these mussels becomes difficult or illegal due to high contaminant levels. This economic exposure of marine resource-dependent households to pollution risks is further underlined by a significantly lower level of livelihood diversity

Table 8.1 Important seafood species in Jakarta Bay and the risk of potential contaminants.

Seafood group	Common name/*Scientific name*	Potential[a] contaminants	Risk Level[b]	References
Mollusks	Green mussel	OCPs	L	Monirith et al. (2003)
	Perna viridis	PCBs	L	Sudaryanto et al. (2009)
		PAHs	M	Dwiyitno et al. (2015)
		BFRs	L	
		HMs	M	
		OTs	L	
		STX	M	
	Blood cockle	HMs	M	Andayani and Sumartono
	Anadara granosa	STX	L	(2012)
	Feathers cockle	STX	L	Andayani and Sumartono
	Anadara antiquata			(2012)
Pelagic fish	Indian mackerel	OCPs	L	Agusa et al. (2007)
	Rastrelliger kanagurta	PAHs	L	Dwiyitno et al. (2015)
		HMs	L	
	Spanish mackerel	OCPs	L	Sudaryanto et al. (2005)
	Scomberomorus commerson	PCBs	L	Sudaryanto et al. (2007)
		PAHs	L	Dwiyitno et al. (2015)
		OTs	L	
	Slender shad	OCPs	L	Dwiyitno et al. (2015)
	Ilisha elongate	PAHs	L	
	Milkfish	OCPs	L	Shoiful et al. (2013)
	Chanos chanos	PCBs	L	Dwiyitno et al. (2015)
		PAHs	L	Sudaryanto et al. (2007)
	Talang queenfish	HMs	M	Agusa et al. (2007)
	Scomberoides	OTs	L	Sudaryanto et al. (2005)
	commersonnianus			
Demersal fish	Mahogany snapper	OCPs	L	Dwiyitno et al. (2015)
	Lutjanus johnii	PAHs	L	Sudaryanto et al. (2009)
		BFRs	L	
	Croaker	OCPs	L	Dwiyitno et al. (2015)
	Argyrosomus amoyensis	PAHs	L	
	White emperor	OCPs	L	Dwiyitno et al. (2015)
	Lethrinus lentjan	PAHs	L	
	Blue-tail mullet	OCPs	L	Dwiyitno et al. (2015)
	Valamugil buchanani	PCBs	L	Sudaryanto et al. (2007)
		PAHs	L	
	Rabbitfish	OCPs	L	Dwiyitno et al. (2015)
	Siganus javus	PAHs	L	Sudaryanto et al. (2009)
		BFRs	L	
	Sea catfish	OCPs	L	Dwiyitno et al. (2015)
	Netuma thalassina	PAHs	L	Sudaryanto et al. (2009)
		BFRs	L	
	White-spotted spinefoot	OCPs	L	Sudaryanto et al. (2005)
	Siganus canaliculatus	PCBs	L	Sudaryanto et al. (2007)
		PAHs	L	Dwiyitno et al. (2015)
		OTs	L	

Table 8.1 Important seafood species in Jakarta Bay and the risk of potential contaminants.—cont'd

Seafood group	Common name/*Scientific name*	Potential[a] contaminants	Risk Level[b]	References
	Telkara perchlet	OCPs	L	Sudaryanto et al. (2005)
	Ambassis vachelli	OTs	L	Sudaryanto et al. (2007)
	Slender ponyfish	OTs	L	Sudaryanto et al. (2005)
	Leiognathus elongatus			
	Jarbua terapon	OCPs	L	Sudaryanto et al. (2007)
	Terapon jarbua	PCBs	L	
	Pugnose ponyfish	OCPs	L	Sudaryanto et al. (2007)
	Secutor ruconius	PCBs	L	
	Little jaw fish	OCPs	L	Sudaryanto e al. (2007)
	Johnius vogleri	PCBs	L	
Crustaceans	Banana shrimp	OCPs	L	Dwiyitno et al. (2015)
	Penaeus marguiensis	PAHs	L	
	Blue crab	OCPs	L	Dwiyitno et al. (2015)
	Callinectes sapidus	PAHs	L	

[a]*BFRs*, brominated flame retardants; *HMs*, heavy metals; *OCPs*, organochlorine pesticides; *OTs*, organotins; *PAHs*, polyaromatic hydrocarbons; *PCBs*, polychlorinated biphenyl; *STX*, saxitoxin.
[b]L (low) < 50% of maximum residue limit (MRL); M (moderate): 50%–100% of MRL; H (high) >MRL.

and lack of alternative income: While 80% of surveyed island households relied on fishing as primary source of income, about half of these households had secondary sources of income, notably in tourism. In contrast, although fishing was the primary source of income for only 60% of surveyed coastal households in JB (with another 20% depending on fish processing), only about one-seventh of JB coastal households had secondary sources of income (Baum et al., 2016c). These observations underline that pollution of marine resources poses not only an immediate risk to the health of coastal households and consumers, but also furthermore that threats to the safety of marine food resources pose significant risks to marine resource-dependent households.

There are several other contaminants that can harm the consumer through seafood consumption. They include organotins (OTs), brominated flame retardants (BFRs), and marine biotoxins. Among OTs, tributyltin (TBT) is essential due to its former use in various industrial purposes such as slime control in paper mills, as biocide in antifouling paints for ships and boats, for aquaculture nets and in wood protection. Total BT residues have been observed in six fish species collected from JB at concentrations of 21–84 ng g^{-1} wet weight (Sudaryanto et al., 2005). Based on recent estimates of average daily seafood consumption of 77.71 g $person^{-1}$ day^{-1} in Jakarta (Dwiyitno, 2017), the estimated maximum daily intake of BTs is about 6.5 μg $person^{-1}$ day^{-1}, which is lower than the TDI of 15 μg 60 kg $person^{-1}$ day^{-1} (0.25 μg TBT kg body $weight^{-1}$ day^{-1}). Based on the study of Sudaryanto et al. (2005), BT concentrations in seafood from JB were higher compared with those collected from Lada Bay (4.2–18 ng g wet wt^{-1}) and Cirebon

Table 8.2 List of target species of island (Tab. 2A, $n = 84$) and coastal households in Jakarta Bay (Tab. 2B, $n = 140$) with local and latin names, mean rank of importance to the surveyed households, as well as number of households, in which the respective species is important. Table 8.2A.

(A)

Local name	Latin name	Rank	Number of households	% of all households
Ekor kuning	*Caesio cuning*	1.29	75	89.3
Tongkol	*Euthynnus affinis*	1.91	66	78.6
Banyar	*Rastrelliger kanagurta*	1.95	58	69.0
Kerapu	*Epinephelus* sp./*Plectropomus* sp.	2.06	32	38.1
Selar kuning	*Selaroides leptolepis*	2.33	51	60.7
Baronang tompel	*Siganus guttatus*	2.69	48	57.1
Tembang	Clupeidae: *Sardinella albella*, *Sardinella brachysoma*, *Sardinella fimbriata*	2.74	38	45.2
Lemuru	*Sardinella lemuru* (*Amblygaster leiogaster?*)	2.80	49	58.3
Tenggiri	*Acanthocybium solandri*	2.95	38	45.2
Kerang hijau	*Perna viridis*	3.00	7	8.3

(B)

Local name	Latin name	Rank	Number of households	% of all households
Banyar	*Rastrelliger kanagurta*	1.41	118	84.3
Lemuru	*Sardinella lemuru* (*Amblygaster leiogaster?*)	1.68	102	72.9
Kerang hijau	*Perna viridis*	1.75	85	60.7
Tembang	Clupeidae: *Sardinella albella*, *Sardinella brachysoma*, *Sardinella fimbriata*	1.87	94	67.1
Selar kuning	*Selaroides leptolepis*	1.97	94	67.1
Tenggiri	*Acanthocybium solandri*	2.60	91	65.0
Tongkol	*Euthynnus affinis*	2.82	88	62.9
Kerapu	*Epinephelus* sp./*Plectropomus* sp.	2.85	13	9.3
Baronang tompel	*Siganus guttatus*	2.94	36	25.7
Ekor kuning	*Caesio cuning*	2.98	53	37.9

Bay (3.3–25 ng g wet wt^{-1}), indicating a heavier boat traffic and ship building activities in JB than in other areas in Indonesia. Concentrations of BTs in fish from Indonesia were generally similar, or slightly higher than those from Vietnam, Thailand, Taiwan, and Oceanian countries, but lower than those from the Malacca Strait, Malaysia (Kannan et al., 1995; Sudaryanto et al., 2005).

BFRs have been detected in seafood samples collected from JB at concentrations of 0.42–42 ng g^{-1} lipid (Sudaryanto, 2009). BFR residues were dominated by polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecanes (HBCDs). Compared with fish species, mussels tends to accumulate more congeners that may be due to the different feeding behavior. PBDEs and HBCDs have received global concern due to their persistency, bioaccumulative nature, and possible adverse effects on wildlife and humans.

Saxitoxin (STX) is a common biotoxin contaminant present in shellfish species due to accumulation from saxitoxin-producing dinoflagellates (Dam et al., 2009). Consumption of STX contaminated shellfish could promote paralytic shellfish poisoning (PSP) with various symptoms from mild tingling, numbness, headache, dizziness, nausea, vomiting, and diarrhea to respiratory paralysis and possible death (EFSA, 2009; FAO, 2004). Determination of STX of green mussels collected from JB has been conducted by Kusnoputranto and Colleagues (2013). The results showed that STX concentrations of shellfish samples ranged from 6.92 to 17.34 μg STXeq 100 g^{-1}, which is below the maximum residue limit of STX in most countries, i.e., 80 μg STXeq 100 g^{-1} (BSN, 2009; FAO, 2004). The concentration was higher than that reported earlier by Andayani and Sumartono (2012), which was 0.87–5.39 μg STXeq 100 g^{-1}. With reference to the general mussel consumption in Jakarta of approximately 185 g $portion^{-1}$ (Makmur et al., 2014), the maximum exposure of STX is approximately 31.45 μg $person^{-1}$, which is above the acute Rf dose of EFSA (2009) 30 μg $person^{-1}$ and 75% of FAO/WHO (2007) guideline of 42 μg $person^{-1}$. However, the exposure is lower than the guideline of the Australia New Zealand Food Authority, which suggests 120–180 μg STX can produce moderate symptoms and 400–1060 μg can cause death (ANZFA, 2001).

A number of regulations have been established by the Indonesian government to support the quality and safety assurance of fish products distributed either inside or outside the country. Based on law No.18/2012, Chapter 4, the central and local governments are obliged to assure the safety of food items along all supply chains. Additionally, Chapter 7 of the law No.45/2009 asks the Ministry of Marine Affairs and Fisheries (MMAF) to prevent the contamination and destruction of marine and fishery resources, including the environment. Furthermore, decree No.52A-/KEPMEN-KP/2013 deals with the requirements of quality assurance and safety of fishery products in production, processing, and distribution. The decree elaborates the general structure and hygiene requirements of the whole chain including during fishing, landing, storage, fish markets, as well as food security and health standards. Furthermore, monitoring of chemical residues, biological material in aquaculture, including marine aquaculture, has been mandated by the ministerial decree No. PER.02/MEN/2007. With reference to persistent organic pollutants, Indonesia has adopted the Stockholm Convention on POPs in September 2009 as law No.19/2009. The law is followed by related regulations, such as the management of toxic and hazardous waste in law No.101/2014. This law regulates many aspects including transporting, dumping, mitigating, and monitoring of the waste. Generally, the levels of maximum residue limit (MRL) of certain contaminants have been established by the National Standardization Board (BSN) and implemented as national standard.

To monitor the quality and safety of Indonesia's aquaculture products, the MMAF has implemented a management system to control residues, namely the National Residue

Monitoring Plan (NRMP). In 2013, for example, Indonesia had cooperated with the European Commission on a mitigation program through the Commission Decision 2011/163/EU, resulting in aquaculture products free of residue and the inclusion of Indonesia in the list of countries to export aquaculture products to the EU. Quality inspections of fishery products are conducted by official laboratories both of the end products and during the production process.

With regard to the potential contamination of seafood from JB, the general level is not yet seen to generate public health problems. However, the increasing level of certain contaminants in recent years, such as heavy metals, hexachlorobenzene, and biotoxin, should alarm the authorities to mitigate the anthropogenic pollution load. Notably, the potency of multicontaminants in certain seafood could indicate that consumption of those products might be hazardous to residents around JB due to either additive or synergistic effects among the toxicants.

8.8 Implications

All the information and facts reported in this chapter regarding the environmental state of JB demonstrate impressively the huge anthropogenically induced pressure and stress this ecosystem is exposed to. Additionally, an intact ecosystem is a basic precondition for many aspects directly impacting human beings around the Bay covering, e.g., seafood health, drinking water accessibility, or recreation needs. Noteworthy, the investigations reported here do not remain on the description of the environmental status, but explored also the relevant processes behind inducing the pollution problems and, consequently, point to potential solutions.

These scientific efforts are not only relevant for JB or, more general, for Indonesia. Most big cities around the globe evolved from settlements, located close to rivers, which in past and present times function as water suppliers, transport routes, and dumping sites (such as it is the case for Bangkok, Shanghai, Manila, Hanoi or even Jakarta). And especially in rapidly developing countries, urbanization and industrial development is progressing faster than the development of environmental services, infrastructure, and emission controls. As a result, the quality of surface water systems significantly declines along with population growth and economic development in these regions in general (e.g., He et al., 2014; Hosono et al., 2009).

Consequently, the gained knowledge about the anthropogenic impact on JB as derived from the SPICE project is not solely of regional interest, but has relevance for many vulnerable ecosystems near coastal megacities worldwide.

The degradation of coral reefs in JB and the Thousand Islands is caused by a combination of multiple anthropogenic stressors acting in concert. Especially within JB, pollution and sedimentation have become disastrous, leading to extremely degraded coral reefs. Further offshore along the Thousand Islands, reefs are in a slightly improved condition; however, the increasing threat due to overfishing, global warming, eutrophication due to highly densely populated islands and a lack of sewage treatment, and chemicals released from increasing shipping traffic and urban runoff from islands will pose a severe challenge for those reefs in the future.

Increased stress, as seen in the experiments by Baum et al. (2016a) and Kegler et al. (2015), may culminate in responses at population and ecosystem levels and reduce reef resilience and the potential for recovery (Hoegh-Guldberg et al., 2007). Therefore, there is a need for more controlled factorial experiments in the future, investigating physiological and ecological stress responses of marine organisms to different pollutants simultaneously and together with other environmental stressors to detect possible interactions.

Combined effects of multiple stressors are still barely understood (Ban et al., 2014), and studies as in Section 8.4 are needed to determine responses of organisms and ecosystems to these stressors and understand potential interactions against a background of ongoing environmental change. Similarly, ocean management can no longer focus on individual stressors (Halpern et al., 2007), but must account for combined stressor effects, as shown in Section 8.4.

Section 8.5 provided detailed information about the microbiome and its functional and metabolic diversity in Indonesian fish and shrimps. In addition, metagenomics and metatranscriptomics combined with corresponding functional analyses should be also performed to address differential expression under different ecological and environmental conditions in future. A metaproteome-based analysis is a further approach to elucidate functionality of the proteins within the environments under different conditions (Mandal et al., 2015; Prakash and Taylor, 2012; Srivasta, 2007).

Section 8.6 summarized the current state of knowledge on Indonesian mariculture fish. It is evident that all thoroughly studied fish species have a diverse parasite fauna and many of these records still require further taxonomic work. Detailed overviews on the potential parasites infecting these fish are given, guiding the farmers to safeguard their aquaculture activities also with new coming parasite species and threats in future. Rückert et al. (2010) compared free-living and maricultured *E. fuscoguttatus* and demonstrated the transmission pathways into the net cages (e.g., fouling organisms, crustaceans, trash fish feed). The fish pathogens *Vibrio* sp., *Flavobacterium* sp., and *Photobacteria* sp. were found, especially in those specimens that were parasite free and kept in mariculture. This opens new possibilities for a disease prevention and treatment management of maricultured finfish in future. Palm et al. (2015) recommended that one of the major future tasks is the search for alternative feed sources and feeding strategies to prevent parasite spread and pathogenic outbreaks. Finally, a new method to use grouper fish parasites as biological indicators was demonstrated to be a useful tool to compare different aquaculture sites as well as ecosystems (Neubert et al., 2016a). It is evident that this methodology will be useful not only in Indonesia, but also in other southeast Asian regions, allowing recommendations on the carrying capacity at different locations.

With regard to the potential contamination of seafood from JB (Section 8.7), the general level is not yet seen to generate public health problems. However, the increasing level of certain contaminants in recent years, such as heavy metals, hexachlorobenzene, and biotoxin, should alarm the authorities to mitigate the anthropogenic pollution load. Notably, the potency of multicontaminants in certain seafood could indicate that consumption of those products might be hazardous to residents around JB due to either additive or synergistic effects among the toxicants.

In conclusion, marine spatial planning adjusted to local conditions is an alternative to current management strategies (MPAs and NTAs, Wilson et al., 2010). Monitoring key biological and environmental parameters continuously over several years and across seasons is crucial for the establishment of successful management and conservation plans. The involvement of local communities in reef management is needed (Ferse et al., 2010), and marine awareness and local education campaigns could aid the enforcement of protection areas (Breckwoldt et al., 2016). Any conservation and management plan, however, will only be successful if pollution in Jakarta is reduced, e.g., by implementing sewage treatment and waste disposal plans (Clara et al., 2007).

Knowledge gaps and directions of future research

Jakarta faced in the past decades a tremendous increase of pollution by industrial and municipal emissions, and consequently, the JB as the receiving ecosystem is affected by a large proportion of sewage and waste via the urban riverine discharge. Thereby, the bay ecosystem faced a huge transition from natural conditions to an intensively used coastline as effective for industrial facilities, traffic infrastructure, urban settlements, aquafarming, agriculture, and many other developments.

Since the aquatic ecosystems of JB represent an excellent example of a fundamental conflict between economic and ecological demands, this chapter deals with the following key research questions related to the overall consequences:

- How do the anthropogenic modifications of the hydrological system at JB impact the local nutrient dispersion?
- What are the most important organic and inorganic pollutants? What are the dominant emission sources?
- How is water pollution affecting sensitive ecosystems at JB? What are the biological answers to anthropogenic stressors?
- Can microbial diversity in aquatic organisms reflect ecological conditions on different quality levels?
- Does the pollution at JB impact the quality of products of the fishery industry—as exemplified for fish parasites?
- What is the overall impact of the JB pollution on the quality of seafood quality and the corresponding risk of consumption?

Implications/recommendations for policy and society

Based on the discussed relation between pollution and ecological impact, an overall aim of management at JB should be a significant decrease of anthropogenic stress. Main stressors are hereby complex mixtures of pollutants derived from sewage effluents and industrial emissions. Effective management can imply the following:

- Implementation of sewage treatment and waste disposal plans
- Local marine spatial planning
- Continuous monitoring of key biological and environmental parameters
- Local education campaigns

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SCIENCE FOR THE PROTECTION OF INDONESIAN COASTAL ECOSYSTEMS **(SPICE)**

Edited by Tim C. Jennerjahn, Tim Rixen, Hari Eko Irianto and Joko Samiaji

A synthesis of a 12-year German-Indonesian research program addressing the scientific, social, and economic issues related to the management of Indonesian coastal ecosystems and their resources, ***Science for the Protection of Indonesian Coastal Ecosystems (SPICE)*** provides key information on all aspects of the preservation of coastal ecosystems. This includes the coastal management involved, the ecology of this area, and the relationship between humans and the environment found here.

Indonesia is home to the world's largest mangrove ecosystem. It holds 17% of the world's total coral reef areas and has an estimated total seagrass area of 30,000 square kilometers. However, there is very little in the way of published Information about Indonesia's coastal ecosystems. ***Science for the Protection of Indonesian Coastal Ecosystems (SPICE)*** provides guidelines, defined by scientific experts, which detail the proper application of science products into ecosystem management. The bio-geo-physical importance of the coastal ecosystems of Indonesia makes this a book of global importance and interest.

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