THE ENVIRONMENT IN ASIA PACIFIC HARBOURS

The Environment in Asia Pacific Harbours

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FOREWORD

In the USA, Asia and Europe, as well as worldwide, trade is growing rapidly and much of it depends on shipping. This is leading to the development of mega-cities and mega-harbours. The marine environment is degrading. Is increasing trade ecologically sustainable? This book addresses this question through harbours in the Asia Pacific region, including Tokyo Bay, the Pearl Estuary, Hong Kong, Shanghai, Ho Chi Minh City, Manila Bay, Jakarta Bay, Bangkok, Singapore, Klang, Pearl Harbour, and Darwin. Much of the world trade goes through these harbours. This book demonstrates, through the writing of eminent scientists in each of these countries, the oceanography and ecosystem science necessary to understand how these urbanised marine ecosystems function. It offers science-based solutions to achieve ecologically sustainable development. These lessons are important not only for the Asia Pacific Region, including Australia, but also worldwide.

The book is a wake-up call that all the countries in the Asia Pacific are facing the same, serious socio-economic and environmental problems with varying scales. Each of these countries addresses these issues differently. This book shows that we have much to learn from each other to ensure that development does not need to be at the cost of the environment. I commend this book for its comprehensive coverage of the links between oceanography, ecosystem processes, and socio-economic issues. I hope it will create constructive discussion and awareness of the potential pitfalls and possibilities for the Asia Pacific region and the need for integration our efforts to deal with these issues.

This book by Eric Wolanski, a leading scientist at the Australian Institute of Marine Science should be taken seriously by all governments throughout the region.

The Right Honourable Malcolm Fraser, A.C., C.H.
Former Prime Minister of Australia

PREFACE

We live in a world that is increasingly dependent on international trade and transport. Measured both by volume and by value, most imports and exports travel by sea. Ports and harbours are the essential gateways through which all this marine traffic must pass. Expansion is leading to the development of mega-cities and mega-harbours. Inevitably, these are under further pressures to expand, and to work more efficiently. At the same time there is increased awareness of the need for maintaining healthy marine environments in and around these busy coastal areas. In many cases, these marine environments are degrading. Coastal managers and politicians are asking whether, and if so how, increasing trade can be balanced with ecologically sustainable environments.

This book addresses this challenge by presenting a series of studies of harbours in the Asia Pacific region, including Tokyo Bay, the Pearl Estuary, Hong Kong, Shanghai, Ho Chi Minh City, Manila Bay, Jakarta Bay, Bangkok, Singapore, Klang, Pearl Harbour, and Darwin. Much of the world trade goes through these harbours. Each individual harbour has its own special circumstances. Nevertheless, internationally there is much to be learned by exchange of information on existing management practices in different ports, and within different coastal areas.

These detailed examples demonstrate, through the writing and insights of eminent scientists in several countries, the oceanography and ecosystem science necessary to understand how these urbanised marine ecosystems function. The book offers science-based solutions to achieve ecologically sustainable development. These lessons are fundamentally important for the Asia Pacific Region, but they will also substantially inform similar analyses of port and harbour management and practices worldwide.

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CHAPTER 1

INCREASING TRADE AND URBANISATION OF THE ASIA PACIFIC COAST

ERIC WOLANSKI

1. INTRODUCTION

Is increasing trade environmentally sustainable? My introduction to this question started in 1969 on a road trip from Princeton to New York City. The bus went along estuaries that were heavily industrialised and polluted; the water was black and litter was everywhere to be seen in intertidal areas. My professors at Princeton University told me that this was normal but that the pollution footprint of the harbours was small because people lived elsewhere. In other words, harbours and urbanisation did not simultaneously degrade the marine environment at the same sites.

Over the last twenty years I developed a scientific collaboration with leading marine scientists in the Asia Pacific region. It became apparent to us that the footprints of harbours and urbanisation have now merged. Environmental degradation is exacerbated in this region where urbanization has already reached unprecedented levels in the coastal zone where mega-cities and mega-harbours have developed and are still rapidly growing. This generates dramatic, complex, and dynamic human-induced changes in coastal ecosystems, where environmental degradation is significant and growing. This degradation ranges from the loss of biodiversity to the ecosystem collapse and toxic algae blooms.

On a scientific level, the challenges are enormous to understand the cumulative impacts on the aquatic ecosystems of urbanization and harbour development and operations. Yet science is needed to provide long-lasting solutions to environmental degradation. When the idea was first mooted to produce this book, some prospective authors expressed their concerns that the issues were politically sensitive. Yet all the authors produced thorough, well researched chapters openly detailing the environmental and socio-economic issues facing their waters.

What emerged is this book demonstrating the different solutions and pitfalls, successes and failures in a large number of ports and harbours in the Asia Pacific Region shown in Figure 1, and this is based on process-oriented ecosystem science and it is aimed at management. The study sites include Tokyo Bay, the Pearl Estuary, Hong Kong, Shanghai, Ho Chi Minh City, Manila Bay, Jakarta Bay,

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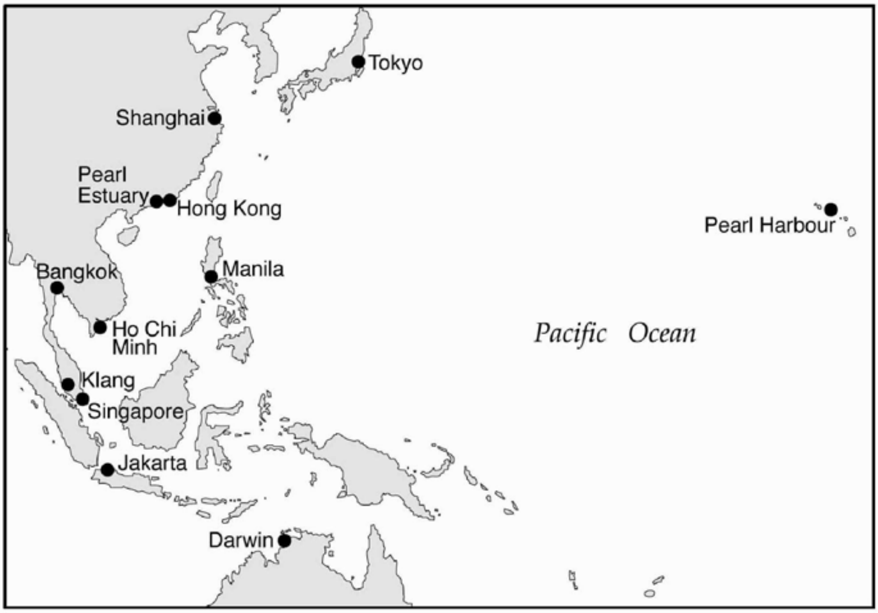

Figure 1. *A location map of harbours described in this book.*

Bangkok, Singapore, Klang, Pearl Harbor, and Darwin. About seventy million people live on their shores, and 600 million people in their watershed. The authors of these chapters are eminent, leading scientists in their respective countries; they bring an immense body of knowledge and experience. They demonstrate the range of multi-disciplinary sciences and the experience that is needed to enable ecologically sustainable development.

This book demonstrates how these urbanised water bodies function as ecosystems, by focusing on the links between physical and biological processes. In most of these environments many life history stages are planktonic. As a result, physical transports and processes play a key role in the transport of nutrients and pollutants, while biological and chemical processes determine the ecosystem community response to the stresses. Thus physical processes exert a profound influence on biological processes and their combination determines the ecological services – and the public health risks - that these waters deliver to the human population on its shore.

By bringing together these leading scientists, this book highlights the many similarities and dissimilarities brought upon by different scientific and management approaches, governance and socio-economic issues and different levels of development. Ecosystem management is shown to have developed rapidly – with local convergences and divergences in approaches, techniques and support funding. These experts provide hints of long-term solutions to enable socio-economic developments while maintaining, or restoring, the vital ecosystem services provided by the estuarine and coastal waters and ensuring public health.

2. CASE STUDIES

2.1. Tokyo Bay

Chapter 2 by Keita Furukawa and Tomonari Okada describes the environmental issues in Tokyo Bay. The bay is an enclosed, most heavily populated, and densely utilized bay in Japan. It is vulnerable to environmental degradation. A new government initiative was initiated in 2001 to promote environmental restoration in coastal zones. The Tokyo Bay Restoration Plan was adopted in March 2003 to clarify objectives and action plans. Sharing a good understanding of the scientific and engineering background of wetland restoration projects with stakeholders and their involvement of them are keys to achieving the wise use of the coastal environment.

Chapter 3 by Hirofumi Hinata and Keita Furukawa shows that the ecosystem health of Tokyo Bay depends on the presence of tidal flats – most of which have been destroyed by harbours. To undertake the task of identifying where and how to restore tidal flats as an important coastal ecosystem, the "Asari Project" was initiated to determine the existence of an ecological network in Tokyo Bay. The project maps the distribution patterns of the Asari short-necked clam larvae. The series of distribution of D-shaped larvae (juvenile Asari clam larvae typically 100 μm in size) and umbo larvae (fully grown Asari clam larvae typically 170-180 um in size) show successive advection by currents in the bay. This suggests the existence of an ecological network. The quantification of this network was made possible by numerical modelling that supports the existence of an ecological network.

In chapter 4, Keisuke Nakayama demonstrates that the oceanography is a dominant process determining ecosystem health. Both long-term (e.g. seasonal) and short-term (e.g. days to weeks) processes control the water circulation in Tokyo Bay. Two dominant processes that control the water circulation in Tokyo Bay, namely the fortnightly modulation of the estuarine circulation, and the change over several days of the horizontal circulation around the head of Tokyo Bay. In chapter 5, Hinata demonstrates that the intrusion of oceanic water in Tokyo Bay has a significant impact on the environmental health of the bay. This intrusion occurs as a series of events, with the dominant ways being a classical, two-layer, estuarine circulation, and a three-layer flow structure. These have quite different environmental consequences in terms of the net fluxes of heat, nutrients and suspended matter.

2.2. Shanghai and the Changjiang Estuary

In chapter 6, Jianrong ZHU and colleagues describe the impacts of the deep waterway project on the Changjiang Estuary. The improved 3-D ECOM model was applied to simulate the impact of the project on saltwater intrusion. The saltwater intrusion after the deep waterway project has been distinctly decreased in the North

Channel and at the lower section of the North Passage, while it has worsened at the upper section of the project site and in the South Passage. The resulting estuarine dynamics processes are discussed. The impacts of the deep waterway project on planktons and benthos are also analysed. It is suggested that the degradation of biodiversity in the estuary is due to the cumulative impacts of a number of human activities including eutrophication from agriculture and sewage discharge, land reclamation, and estuarine engineering projects.

In chapter 7, Jing ZHANG and colleagues describe how anthropogenic perturbations over the last five decades have changed the landscape and hydrographic features over the Changjiang (Yangtze River) drainage Basin, following rapid population increases. Coastal ecosystems responded by changes in food-web structure and function. In the delta region, human being influence has been identified over a broad context of studies, either for natural science and social activities. Relative high levels of organic pollutants (e.g. DDTs, PCBs and PAHs) have been found in the river channel affected by the directed waste drainage, while in the coastal areas pollutants in bottom sediments show a gradient of decrease. Core sediment samples in the Changjiang delta region show the maximum of pollutant concentrations in 1970s and provide with evidence of relief of pollution effect after 1990s. Reclamation in the delta region has induced rapid adjustment of tidal flat and affects the landscape of wetland, shown by the profiles from salt marsh to bare-flat. Although the nutrient concentration is rather high in the Changjiang, the reported harmful algal bloom events take place in the area of offshore waters, i.e. 50-100 km off the river mouth, owing to high turbidity in the delta region. Constructions of harbour and jetty have caused eternal loss of habitats in the Changjiang Delta Region, which is of critical importance in recruitment of fishery species (e.g. spawning ground), resulting in unsustainability of living resources. While human settlement in the Changjiang Delta Region is expected to be continued in the near future, the conflicts of shortage of land surface area and industrialization is becoming one of the bottlenecks for the sustainability of social society. While reclamation of wetlands in the coastal area is required to maintain the progress of urbanization in coastal region of China (e.g. Shanghai), the consequence is the loss of habitats for the wildlife, spawn and hatch grounds for marine living resources, which change the community structure and put those species of economic values in danger or extinction.

Pollution by trace metals and synthetic organic materials can cause the problems at molecular level and induce the genetic diseases, which in turn alter the strategy at genetic level and change the whole system via food-chain. An increased discharge from the Changjiang into the East China Sea has caused frequent HABs (i.e. harmful algal blooms) in coastal waters further offshore from delta region, and a serious hypoxia problem has recently reported in literature, which induces the concern of public society. Dredging in the Changjiang Estuary for navigation and construction of jetty in the main channel have been reported to further destroy the fishing ground and growing filed, and block the migratory route of traditional economic species in the region. In that case, the Changjiang Estuary is losing its traditional values at ecosystem level, and the role of providing multiple functions of the delta region is turning to the simplified service system, e.g. land area for settlement and water-way for transportation and trade for economics.

The on-going engineering constructions in the Changjiang Delta Region are expected to further modify the habitats and affect community structure of wildlife, which can affect the whole ecosystem via food-web interactions, unless proper management is made to protect the habitats and to improve water environment at ecosystem level.

2.3. Pearl River estuary

The Pearl River Estuary is densely distributed with ports. Guangzhou, Shenzhen and Hong Kong are the three principal ports in the region. The Guangzhou Port has 140 berths and 22 mooring areas. General cargo ship of 13.5 m draught and container ship of 4th and 5th generation's ships can navigate through during the flood tides. The Shenzhen Port has 102 berths with capacity over 500 tons, in which 23 are above 10,000 t. Shenzhen is the fourth largest container transportation base in the world. Wastewater discharge in the Pearl River Delta is about 31.6 x 10^8 m^3 yearly, mainly from the rapidly developing cities on the Chinese mainland.

Mingjiang ZHOU and colleagues in chapter 8, Lixian DONG and colleagues in chapter 9, and Yian LI and colleagues in chapter 10, describe the geographic setting and the physical oceanography of the Pearl River estuary. The river discharges into the South China Sea (SCS) through eight distributaries, locally called "the eight Gates". The four eastern gates discharge their waters into the "Lingdingyan", called here the "Pearl River Estuary" (PRE). The PRE has two deep channels used for shipping, the western channel and the eastern channel. The average yearly discharge of the Pearl River is around 330 x 10^9 m^3. The annual sediment load is about 88.72 x 10^6 t. The estuary is poorly flushed and environmental degradation is severe.

The Pearl River Delta is one of the most populated areas in the Chinese mainland with a population over 28 million and a density of 674 people km^{-2}. The delta's per capita GDP exceeded US$ 3600 in 2000. In 1999, the exported goods from the Pearl River delta valued at US$ 67 billion.

This estuarine ecosystem is profoundly degraded. Total pollutant load and some organic pollutant loads carried to the Pearl River Estuary (PRE) from the Pearl River, as well as concentrations of dissolved heavy metals, oil and grease in the PRE, are presented. The most prominent characteristic of the water quality of the PRE is the high nitrate to phosphate ratio. In the upper estuary, this ratio (N:P) can be up to 200:1 in the surface layer. About 300 phytoplankton species have been recorded for the PRE, including diatoms, dinoflagellates, and other species, There is a rapid increase of the frequency of harmful algal blooms (HABs) in this area over the last two decades. Most of these HAB events happened in Hong Kong waters and in bays further east of Hong Kong and in Shenzhen Bay at the east side of the middle PRE.

The fast human population growth and the rapid expansion of the mariculture industry have exerted much stress on the coastal environment off the Pearl River delta. As in elsewhere of China, there is a rapid increase of the frequency of harmful algal bloom (HAB) in this area over the last two decades. Most of these

HAB events happened in Hong Kong waters and in bays further east of Hong Kong. However, outbreaks of HAB in the PRE itself also happened more frequently in recent years, especially in Shenzhen Bay at the east side of the middle PRE. HABs in PRE are mostly caused by dinoflagellate species, accounting for 72.7% of the total events. The high concentration of inorganic nitrogen, i.e., eutrophication, is the direct cause for the increase of HAB frequency in the PRE. However, phosphate and turbidity are both important factors influencing the HAB occurrence. Nutrients are high in the northern part of the estuary, but the chlorophyll a concentration is generally low there because of the high turbidity. There are two relatively high concentration of chlorophyll a in the estuary, one near the Shenzhen Bay and the other southwest of Hong Kong. The concentration in the two areas is in general relatively low. In fact, HAB events in the PRE often occur at these two sites. However, relationship between the HAB and the environmental conditions in the PRE has not yet been established.

2.4. Hong Kong

In chapter 11, Nora TAM describes the findings of pollutions studies in mangroves. Mangroves are important inter-tidal wetlands found along the coastlines of tropical and subtropical regions. Historically, many urban and industrial centers were established adjacent to estuaries fringed by mangroves, and mangrove swamps have been used as convenient dumping sites for waste generated from human activities. In recent years, rapid development in coastal areas, urbanization and industrialization have led to significant increases in anthropogenic inputs of pollutants to the mangrove ecosystems in Hong Kong and mainland China. Elevated concentrations of nutrients, heavy metals and toxic organic pollutants have been recorded in mangrove sediments, and the degree of accumulation is found to be related to the sources of pollution and characteristics of the sediments. Mangrove sediments act as pollutant sinks, and mangrove plants that are specially adapted to stressed environments are able to tolerate pollution to a certain extent. It seems that mangrove ecosystems have a considerable capacity to withstand domestic, poultry and industrial discharges, their sediments, plants and microorganisms are capable of retaining and transforming pollutants. This chapter reviews the concentrations of nutrients, heavy metals and persistent toxic organic pollutants in mangrove sediments in Hong Kong and mainland China, identify the sources of pollution, evaluate the impacts, and explore the potential of employing mangrove wetlands for waste and wastewater treatment.

In chapter 12, Kwok-Leung PUN describes the characteristics of the Hong Kong coastal environment. The increase in pollution loads entering the harbour causes eutrophication of the coastal waters leading to the increase in red tide incidents affecting many fish culture zones in Hong Kong. The large-scale development projects involving a massive reclamation and export of effluent may also impact on the fish culture zones and the other water-sensitive receivers. The feasibility and planning of the projects relies on the application of water quality models to undertake impact assessment. Relevant water quality standards and approach for water quality model validation are presented. The experience in applying water quality models for prediction of water quality impacts associated with land reclamation, bridge construction, and export of effluent projects in Hong Kong is described. This chapter presented the general characteristics of the Hong Kong coastal environments and the potential impacts associated with large-scale developments. The approach for water quality model validation and application of the validated models for prediction of water quality changes in reclamation, bridge construction and export of effluent projects are described in this chapter. Dredging and filling activities are of major concern in the reclamation and bridge construction projects. Export of effluent from sewage treatment works to less sensitive water bodies on one hand reduces the eutrophication in the originally affected water body and on the other hand introduces additional loads into the receiving water body. Through the application of water quality modelling, the potential impacts and benefits of the project can be examined providing accurate data for decision making on the feasibility of the development project.

In chapter 13, Joseph LEE and collaborators describe the ecosystem dynamics of Hong Kong coastal waters. Hong Kong is a mega-city with a population of 6.7 million; it is situated at the mouth of the Pearl River Estuary in southern China. The marine resources in the 1800 km^2 of coastal waters are intensively utilized. The water quality has been deteriorating as a result of the high nutrient loads from the rapidly urbanised and industrialised Pearl River Delta (PRD) region, and significant sewage discharges into Victoria Harbour. Hong Kong waters are relatively unique because of the frequent occurrence of harmful algal blooms, and the complexity and richness in eutrophication dynamics within a relatively small area. Viewed against the increasing nutrient loads, it is surprising that the eutrophication impacts on Hong Kong waters are not worse than they are. This paper gives an overview of the temporal and spatial dynamics of algal blooms. The tidal current and salinity structure in the partially-mixed estuary are elucidated using numerical results from a calibrated three-dimensional hydrodynamic model. Physical and biological interactions are discussed in relation to seasonal phytoplankton ecology as well as episodic events. It is shown that key factors that govern the eutrophication dynamics in Hong Kong waters and Victoria Harbour include: tidal mixing, wind, stratification and vertical stability, flushing rate, nutrient and light limitation.

2.5. Pearl Harbor

In chapter 14 Steve Coles describe the environmental setting of Pearl Harbor. This is the largest and most enclosed harbour or embayment in the Hawaiian Islands and consists of three main coves that receive most of the freshwater runoff from central O‘ahu. Traditionally the harbour was highly utilized for fish pond culture, but water quality degraded through the nineteenth and much of twentieth century. The harbour has been controlled by the U.S. Navy since the annexation of Hawai‘i in 1898, and enlargement of the entrance channel and construction of the Pearl Harbor Navy Base began in 1910-11. Development of the Navy base and the surrounding urban areas through the next 60 years resulted in elimination of most of the fishponds, hardening of shorelines by construction of piers and dry docks, disposal of sewage and other pollutants, sedimentation from land runoff, and periodic dredging to remove accumulated sediments. Along with changes to the marine community that can be assumed to have resulted from these stressors, opening the harbour to Navy shipping provided a vector for the introduction of nonindigenous species from ships and other vessels such as barges and floating dry docks. Studies evaluating the occurrence and estimated time of arrival of introduced species indicated that approximately 23% of the identifiable marine biota in 1996 were composed of known or suspected introduced species. Introduced species have been increasing in the harbour since 1900, with decadal peaks in new introductions relative to total newly reported taxa apparently occurring during wartime periods in 1910-20 and 1940-50 when ship traffic in the harbour would been maximal. These findings are compared with information available for other harbours in Hawai‘i and the tropical Pacific, and a need is indicated for similar studies of introduced marine species in harbours elsewhere in the Asia-Pacific region.

2.6. Bangkok and the upper Gulf of Thailand

In chapter 15 Suphat Vongvisessomjai provides information on the physical environment and the oceanographic conditions is required to understand the physical processes in the gulf and the coastal zone for purpose of infrastructure development including port construction and coastal management. This information includes (A) the tracks and strength of cyclones, (B) winds and waves, and (C) tides and tidal currents including flushing time of pollutants. These conditions are included in the design parameters for the construction of three important ports of Thailand.

In chapter 16 Gullaya Wattayakorn presents an overview of the environmental problems of the Gulf of Thailand from the rapid population and economic growth. The available information indicates that the main degradation issues in the Gulf of Thailand are overexploitation of fisheries, loss of habitat and marine pollution. Among these, loss of habitat is considered a serious problem throughout the Gulf. Mangrove destruction is the most obvious and has probably had the greatest loss. Coral reefs are subjected to a number of disturbances, which are often irreversible. Seagrass beds are destroyed by fishing gear and by sediment from bad agricultural and engineering practices, forest clearing and runoff from cities. In addition, the increased frequency of red tides in recent years may be an indication of the changing conditions of coastal aquatic environment. There is a need to accentuate and develop compatible and sustainable policies in resource management to retain the systems indefinitely and also to enhance continuous economic returns.

2.7. Ho Chi Minh City

In chapter 17 Nguyen Huu Nhan describes the environmental setting of Ho Chi Minh City (HCMC), including the Thi Vai–Vung Tau (TV-VT); this area had, has, and will have for the foreseeable future the largest harbour network in Vietnam. This network plays a very important role in Vietnam’s social and economic development. All shipping routes operate in very sensitive regions such as wetlands, mangroves, urban centers with high population density, and industrial zones. The environment faces serious challenges. At present, the environment in harbours of HCMC suffers from pollution caused by domestic, industrial, aquaculture and shipping route wastes; all these wastes are almost untreated before discharge. The pollution status of water and bottom sediment in Sai Gon and Thi Vai harbour groups is alarming. The risk and frequency of accidents with severe environmental impact are high. Urgently needed remedial measures include (1) the construction of treatment facilities for wastes from domestic and industrial areas, from ships, and aquaculture activities; (2) cleaning polluted bottom sediments in HCMC, Go Dau and Thi Vai harbours; (3) stopping the destruction of the Can Gio Mangrove Reserve and the decline of its biological resources by human activities and shipping routes; (4) to set up effective tools to prevent and respond to environment pollution accidents.

2.8. Manila Bay

In chapters 18 and 19, Gil Jacinto and colleagues describe the environmental setting and issues of Manila Bay. The bay has a surface area of 1,700 km^2 with a 190 km coastline that opens to the South China Sea. There are seven rivers surrounding the bay with two of the biggest rivers contributing 70% of the freshwater runoff. It has a drainage area of 17,000 km^2 with approximately 16 million in population. More than 3,000 years ago, Manila Bay was connected to Laguna Lake, which in recent years have separated except for a small interaction through the Pasig River. Shoreline positions of the bay have changed due to land reclamation, conversion of mangrove and mudflat areas into fishponds, soil erosion, siltation, and sea level rise. Estimates of sedimentation for different parts of the bay have ranged from 0.6 to 9 cm yr^{-1}. Wet and dry periods are the two pronounced seasons in the bay, and the prevailing wind patterns are the NE monsoon, Trades, and SE monsoon. Tides are mixed diurnal with an average range of 1.2 m during spring and 0.4 m during neap. Freshwater discharge, tides and winds affect the circulation patters in Manila Bay. Manila Bay is the most strategically and economically important body of water in the Philippines. It has a significant socio-economic role for Metro Manila and the surrounding provinces that share its long coastline. It is recognized under the Manila Bay Declaration in 2001 as a source of food, employment and income for the people, the local and international gateway of the country to promote tourism and recreation. It is also important because of its cultural and historical heritage. It is major fishing ground and being almost completely landlocked, Manila Bay is considered one of the world's great harbours. The biggest shipping ports, ferry terminals, fish port and yachting marina are found in the bay. An average of 30,000 ships arrive and depart from these ports annually to transport passengers, manufactured goods and raw materials. The beaches along parts of the bay encourage tourism in the area. However, the bay has undergone significant changes in its water and sediment chemistry, linked heavily to the increase in population and other human activities. The bay has become a receiving site for domestic and industrial sewage. Levels of total and fecal coliform, dissolved oxygen, oil and grease, and nutrients are the indicators of the decline in water quality. Heavy metals such as Cd, Hg, Zn, Pb, and Cr; and total polyaromatic hydrocarbons in the sediments showed localized contamination.

Fisheries resources have measurably declined from the 1940's onward, primarily due to over-fishing or over-collection. There has been a decline in trawl catch per unit effort or CPUE (kg h^{-1}) from 46 in 1947 to 10 in 1993. The demersal biomass decreased from 4.61 mt km^{-2} or 8,290 tons in 1947 to 0.47 mt km^{-2} or 840 tons in 1993. In some areas the poor management of shellfisheries resulted to unstable production of commercially valuable mussels and oysters, disappearance of the windowpane oyster and contamination of shellfish particularly with fecal coliforms.

Manila Bay has a wide range of environmental problems that need to be addressed - from land-based and sea-based sources of pollution to harmful algal blooms, subsidence and groundwater extraction, overexploitation of fishery resources, and habitat conversion and degradation. However, there are reasons to be optimistic. There is greater accountability expected of public officials vis-a-vis environmental laws, significant and increasing infrastructure investments to treat and reduce domestic sewage discharges into the bay, the implementation of the Manila Bay Environmental Management Project, and the adoption of Integrated Coastal Management by local government units and communities around Manila Bay. Time will tell if the political will to implement these measures is sufficient to allow the bay to revert to be a clean, safe, wholesome, and productive ecosystem for the present and future generations.

2.9. Port Klang

In chapter 20 Choon-Weng Lee and Chui-Wei Bong analyse the carbon flux through bacteria in Port Klang waters, a eutrophic tropical environment from September 2004 until February 2005. Water quality was poor due to low dissolved oxygen (DO) concentration (<200 µM), and high total suspended solids (TSS) (>260 mg l^{-1}). TSS was mainly inorganic in nature, with particulate organic matter <5% of TSS. Two episodes of hypoxia (DO<125 µM) were observed in early December 2004 and February 2005. Based on marine water quality data collected by the Department of Environment of Malaysia, the water quality at and around Port Klang deteriorated from 1990 to 2003. Over 10 years (1994–2003), TSS increased 132 mg l^{-1}, and DO decreased by 48 µM. The NO_3:PO_4 ratio was low, ranging from 0.05 to 0.38, suggesting nitrogen limitation for the phytoplankton. Gross primary production (GPP) correlated significantly with NO_3 (R^2=0.867, n=5, $p<0.05$). The low NO_3 concentration in February 2005 could have limited GPP, and indirectly triggered hypoxia. GPP correlated with community respiration (R^2=0.956, n=5, $p<0.01$) except in February 2005 when there was uncoupling between primary production and heterotrophy. Heterotrophic metabolism was probably supported by other sources of allochthonous organic matter (e.g. the Klang River) during this period.

2.10. Singapore

In chapter 21 Karina Yew-Hoong GIN and colleagues present an overview of the phytoplankton composition in Singapore coastal waters and their relationships with nutrient and environmental conditions. A variety of techniques were employed to determine the structure of the phytoplankton community, including sophisticated methods such as flow cytometry and high performance liquid chromatography (HPLC) but also traditional methods, such as microscopy and extracted chlorophyll measurements. Using data collected in the last six years, waters in the Johor Strait were found to be more eutrophic than the Singapore Strait, with chlorophyll levels reaching as high as 60 μg l^{-1}, consistent with the higher nutrient concentrations measured in the Johor Strait. Nutrient enrichment tests showed that Singapore waters are generally nitrogen limited although for the Johor Strait, nutrient limitation can also switch to phosphorus. The size structure of phytoplankton in the Johor Strait is skewed to larger microplankton whereas for the Singapore Strait, smaller pico- and nano-plankton dominate. Compared to the Singapore Strait, algal blooms are a frequent occurrence in the Johor Strait although there are few documented cases of harmful algal blooms (HAB). To help alleviate eutrophication problems, an integrated approach is needed where control measures are used in conjunction with monitoring and numerical modeling.

In chapter 22 Loke Ming Chou describe the marine habitats of Singapore waters. Shipping activities and port infrastructure development are intense. Most of the country's limited marine territory is under port authority. Coastal reclamation, seabed dredging to deepen shipping lanes or extract sand deposits, and the dumping of dredged spoils at sea all add further impacts to marine biodiversity. Natural habitats are reduced in extent or degraded, while newly created ones favour biological communities of different species composition. Species eliminations are highly localised and species distribution patterns are altered in response to changing environmental conditions, especially below 6 m depth. Overall, complete species extinction from Singapore waters is limited and less than expected considering the scale, variety and intensity of impacts. Abundance, however, is reduced with many species now less common or rare. The lower than expected rate of species richness decline is attributed to habitat resilience from the originally rich biodiversity and strong marine pollution control measures. Port development and marine biodiversity are not mutually exclusive. Further reduction of impact effects on marine biodiversity is possible provided that some attention is focused on marine conservation.

In chapter 23 Eng Soon CHAN and colleagues present an overview of the physical oceanography of Singapore coastal waters. Flows in this domain are driven mainly by tides and seasonal net pressure gradients. The interaction of tidal streams from the Java Sea, the Malacca Strait and the South China Sea is complex and the transport of discharges such as oil spills into the domain is typically trans-boundary. Whilst the physical processes are important in the prediction of oil spill trajectories and dilution, the coupling of these processes to the biology and chemistry of the water body is important in determining the fate and environmental impact of spills. A comprehensive oil spill-food chain model, which combines a multi-phase oil spill model with a simple food-chain model, has been applied to the Evoikos-Orapin Global oil spill in the Singapore Strait. The results of the simulation showed that the concentrations of anthracene in phytoplankton, zooplankton, small fish, large fish and benthic invertebrates one day after the spill were below the lethal toxicity levels (LC_{50}). Fertilization experiments to examine the bioremediation capabilities of tropical sands demonstrated that nutrient addition was able to significantly accelerate the natural degradation process. For the more persistent organics in the marine environment, baseline studies showed that concentrations of polycyclic aromatic hydrocarbons (PAHs) measured in Singapore's coastal waters were generally higher than levels reported elsewhere, whereas organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) were generally lower than the reported levels for other Asian countries.

2.11. Jakarta Bay

In chapter 24 Dietriech Bengen and colleagues describe the 400-year long environmental legacy of Jakarta Bay. In that period Jakarta Bay rose to international prominence as a leading harbour in Southeast Asia. During the rapid economic growth during the l980s the port facilities were rapidly expanded and large areas of the bay foreshore and wetlands were reclaimed to accommodate industrial and urban development. The resulting ecological and social costs are high. Jakarta Bay is perhaps the most polluted harbour in Asia and has very little intact fisheries. What fisheries still exist has a non-original structure and comprises opportunistic species that can exist in the now heavily polluted waters. The combination of inappropriate past development and continuing lack of coordinated bay governance has created a legacy of severe environmental damage – several of the former "thousand islands" that comprised a small archipelago of coral cays in the outer arc of the bay have disappeared due to sand mining and those that remain are among the most threatened coral reefs in Asia. The authors describe how, through a combination of neglect and ignorance, Indonesian society now faces major challenges to sustain the economic, social and ecological values of the bay. There are growing calls to reduce pollution, protect traditional fishing communities, restore coral reefs and mangrove systems and optimize bay use for industrial, urban, tourism and conservation uses. However, efforts to address bay management on a more integrated and long-term basis are only now emerging and will require a far greater level of political commitment if current degrading influences are to be reversed and an effective and comprehensive management regime introduced.

2.12. Darwin

In chapter 25 David McKinnon and colleagues describe the environmental setting and health of Darwin harbour. This is Australia's only tropical harbour and is Australia's closest port to South East Asia. The environment within Darwin Harbour is still relatively pristine, with extensive mangrove forests fringing the harbour and a diverse range of ecosystems within the harbour itself, including some coral-dominated communities. The harbour is macro-tidal (7.8 m tidal range) and characterised by high turbidity. Standing stocks of nutrients are low (e.g. NO_3 ~0.3 μM in the dry season, 1.5 μM in the wet season). In spite of light limitation and low nutrient status, water column primary production is high - net primary production exceeds 2 g C m^{-2} d^{-1} in the wet season. Current anthropogenic inputs into the harbour amount to <2% of the nutrient demand necessary to sustain primary production by phytoplankton and mangroves. Ambitious plans to expand the port, including construction and dredging activities, combined with a large fish catch by recreational fishers present emerging threats to the ecosystem health of Darwin Harbour.

In chapter 26 David Williams and colleagues describe the water circulation in Darwin Harbour, focusing on its flushing properties and the fate of sand and mud. It is shown that (1) the wet season runoff is important to flush the harbour and to redistribute fine sediment, (2) that the upper reaches of the harbour are very poorly flushed during the eight-month long dry season with a residence time estimated to be at least twenty days, (3) that the harbour traps most of the fine sediment from runoff and redirects it into mud banks in embayments and mangroves wetlands, (4) that eddies shed by the complex bathymetry maintain sand shoals, (5) the harbour is an inverse estuary that imports oceanic water during the dry season, and (6) the harbour is a stratified estuary for a few days to a few weeks during the wet season, and a vertically well-mixed estuary the rest of the time. These findings have profound implications on development strategies for ecologically sustainable development.

In chapter 27 with colleagues I propose a simple ecohydrology model that has been developed, calibrated, and applied to Darwin Harbour. The model integrates physical and biological processes in the estuary and it predicts the ecosystem health as determined by the following variables: salinity, nutrients, detritus, suspended particulate matter, phytoplankton (two size classes), zooplankton (two size classes), detritivores, zooplanktivorous fish and carnivorous fish. The model is used to assess to what degree the estuarine ecosystem health may degrade as a result of possible future human activities in the catchment, particularly land clearing, nutrient enrichment, and destruction of mangroves. The model is a tool that may enable an interaction between scientists, economists, the public, and decision makers to enable the ecologically sustainable development of Darwin Harbour catchment based on ecohydrological principles.

3. LESSONS FOR THE FUTURE

In chapter 28 I attempt to synthesise the results from these case studies and to answer the question: are increased trade and urbanisation of the coastal zone ecologically sustainable? I also propose a strategy for ecologically sustainable harbours and coastal urbanisation.

CHAPTER 2

TOKYO BAY: ITS ENVIRONMENTAL STATUS – PAST, PRESENT, AND FUTURE

KEITA FURUKAWA AND TOMONARI OKADA

1. INTRODUCTION

1.1. Natural conditions

Tokyo Bay is centrally located in Japan, between latitude 35 00'N and 35 40'N, and longitude 139°40' E and 140°05'E (Figure 1). This region has a temperate, humid climate. The lowest temperature is approximately 5 $^{\circ}$C during January and February, and the highest temperature is approximately 30 $^{\circ}$C during July and August. The months with the least precipitation are January and February. There is heavy precipitation during the rainy season in June, and during September and October, when typhoons often hit Japan. The monthly precipitation is approximately 50 mm and 150 mm in, respectively, January and September.

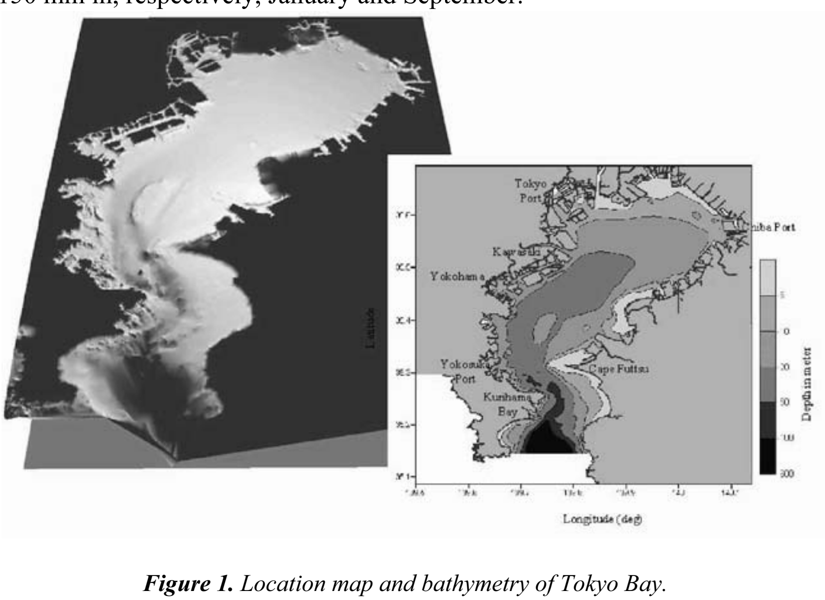

Figure 1. *Location map and bathymetry of Tokyo Bay.*

E. Wolanski (ed.), The Environment in Asia Pacific Harbours, 15–34.

The bay is the area north of the broken line connecting the eastern and western points of Suzaki and Kenzaki (see Figure 2a). The bay has an open interchange with the Pacific Ocean. The Kuroshio Current in the Pacific Ocean flows near the mouth of the bay.

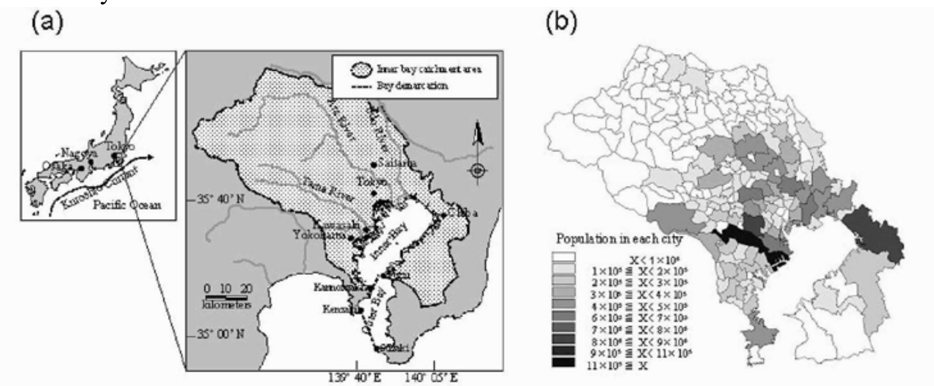

Figure 2. *Tokyo Bay catchment area. (a) location, (b) population in 2000.*

The bay has the shape of the letter "S." The narrowest width of the bay is 6 km on a line connecting the points of Futtu and Kannonzaki. Generally, the side to the North of that line is called the "inner bay", and the side to the South the "outer bay". In addition, the inner bay is often called simply "Tokyo Bay." In this chapter, "Tokyo Bay" refers to the inner bay. The inner bay has a length of 50 km and a width of 20 km. The average depth of the inner bay is 15 m, and its surface area is 960 km^2. The volume of the inner bay is 15 km^3. The catchment area of the inner bay is 7548 km^2. Its depth increases gradually from the head of the bay toward the mouth of the bay. The maximum depth of the inner bay is 50 m at its mouth. The seafloor is covered by silt or sand. The outer bay is deeper than the inner bay (Figure 1), with a maximum depth of approximately 600 m. The seafloor has a steep profile and is covered by rock or sand. The surface area of the combined inner bay and outer bay is 1380 km^2.

Rainwater falling in the catchment area of Tokyo Bay flows into the bay mainly through the Edo and Ara Rivers. Both rivers discharge into the head of the bay. The combined water discharge of both rivers accounts for approximately 50 % of all fresh water entering the bay. This water discharge forms a clear estuary circulation from the head of the bay toward its mouth.

The currents in the bay are caused mainly by tides, density gradients, wind stress, and the input of oceanic water.

The tides are typically semidiurnal, with tidal ranges of about 1.5 m during the spring tide and about 0.5 m during the neap tide. The maximum tidal current is about 1.2 m s^{-1} around Kannonzaki and about 0.2 m s^{-1} in the center of the bay. Generally, the residual current forms a clockwise circulation in the inner bay during summer.