The Second World Ocean Assessment

WORLD OCEAN ASSESSMENT II

Volume I

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Chapter 7F
Estuaries and deltas

Contributors: Colin D. Woodroffe (convener), Bing Qiao, Ronaldo Christofoletti, Dana E. Hunt, Pablo Muniz and Moriaki Yasuhara.

Keynote points

- Human populations, fishing, shipping, engineering activities, including upstream river dams, and recreation and tourism exert pressures on the resources and health of estuaries and deltas.
- Interactions between multiple stressors on estuary and delta habitats are not fully understood.
- A key gap remains in identifying measurable indices of ecosystem health and human well-being across diverse estuarine and deltaic systems.

1. Introduction

Estuaries and deltas, where major rivers meet the sea, are highly productive systems supporting diverse biota that are structured by temporally variable gradients in salinity, nutrients and other factors. The variability reflects both natural (e.g., precipitation, tides) and anthropogenic (e.g., development, contaminant loading) drivers. While they are often heavily populated and perturbed systems in their natural state, estuaries and deltas typically maintain biodiversity within a variety of ecosystems, many of which are the subject of other chapters in the present Assessment, such as mangroves (chap. 7H), salt marshes (chap. 7I), seagrass meadows (chap. 7G), sand and mud substrates (chap. 7B) and an often extensive intertidal zone (chap. 7A). The mouths of rivers are locations where fresh water mixes with the ocean, thus they are the receiving bodies for land-derived nutrients, sediments and pollutants (chaps. 10–13) and they often host invasive species, in particular from ballast water (chap. 22). Estuaries and deltas are valuable for their intrinsic biota and the commercial and subsistence fisheries they support (chap. 15), as well as the tourism and recreation activities they attract. Their total economic value was estimated at over $6.1 trillion in 2014, as outlined in the first *World Ocean Assessment* (United Nations, 2017).

Economically important, urbanized and industrialized, most estuaries and deltas have been transformed by human interventions. They are increasingly affected by the impacts of global change, including sea level rise, changes in precipitation and related natural hazards, such as cyclones and storm surges (Renaud and others, 2013). Most megacities are coastal, with the attendant heavy industry, urbanization and recreation activities that can harm such areas (Todd and others, 2019). The first Assessment contained a preliminary global, integrated assessment of the condition of estuaries and deltas. Based on limited data, few waterbodies were qualitatively assessed to be in very good condition, whereas the condition of 62 per cent of them was considered poor or very poor, and the quality of most was in decline.

The present chapter contains an update to the first Assessment, with an emphasis on the fact that estuaries and deltas provide unique habitats for many organisms, both of marine and coastal origins, as well as recreation, food provisioning and water sources for humans. Such environments are affected by short-term, event-driven disturbances, such as storms, and longer-term trends, such as climate change (Doney and others, 2012; Harris and others, 2018), which are often interconnected (e.g., storms that result in nuisance flooding, which is exacerbated by sea level rise). Advances have been made in observing systems, such as satellites, global observing networks and buoys, which are designed to capture rapid changes in environmental conditions. However, the capacity to monitor, model or interpret those observations is still inadequately developed for the optimal management of estuary and delta environments.

2. Documented changes in the state of estuaries and deltas

2.1. Environmental changes between 2010 and 2020

2.1.1. Water and sediments

There has generally been a continuing decline in the delivery of both water and sediments by rivers as a result of anthropogenic activities in catchments across the world, such as changing land management practices and the construction of dams (Li and others, 2018; Day and others, 2019; Dunn and others, 2019); however, the melting of terrestrial ice and permafrost may also increase freshwater inputs to high-latitude estuaries (chap. 3). Reduced sediment input accelerates the loss of coastal wetlands caused by erosion and affects soft-sediment deposit and suspension feeders, which is augmented by sand extraction (Anthony and others, 2015), whereas high levels of sedimentation can shade primary producers, such as seagrasses, and smother benthic organisms. Urbanization increases peak flow and decreases base flow into estuaries, resulting in potentially harmful variations in salinity and threatening intertidal ecosystems (Freeman and others, 2019).

2.1.2. Eutrophication

Nutrient loading (largely of nitrogen and phosphorous) remains a serious problem in estuaries, owing to their proximity to large cities and ever-increasing agriculture, silviculture and aquaculture (Pesce and others, 2018; Todd and others, 2019), along with domestic wastewater, fertilizers and animal wastes, which result in bottom-water hypoxia (Yasuhara and others, 2017; Breitburg and others, 2018a, 2018b). Eutrophication can also lead to blooms of cyanobacteria, dinoflagellates and sometimes macroalgae (Teichberg and others, 2010), including harmful algal blooms. The situation is stabilized or partly recovering in developed countries (e.g., Chesapeake Bay, United States; Osaka Bay, Japan) owing to improvements in sanitation and reduced nutrient loading (Lefcheck and others, 2018) but is rapidly getting worse along the coasts of populous Asian countries, owing to poor sanitation, elevated nutrient flux and further population growth (Boesch, 2019). Bottom-water hypoxia can lead to fish kills that affect local economies (Breitburg and others, 2018a, 2018b; Yasuhara and others, 2019).

2.1.3. Global change

Global change is already affecting estuaries and deltas. Poleward extension of fish and crustacean ranges has been observed (Hallett and others, 2017; Pecl and others, 2017). More frequent storms and weather extremes affect salinity and sedimentation (Prandle and Lane, 2015; Day and Rybczyk, 2019). Future increased temperatures could lead to localized extinctions and intensify microbial pathogen concentrations and public health risks (Robins and others, 2016). Higher sea levels will be compounded by riverine flooding, resulting in more extensive inundation of coastal areas (Moftakhari and others, 2015, 2017; Kumbier and others, 2018; Ikeuchi and others, 2017; Nichols and others, 2019). The annual cost of the flooding of coastal cities could be in the order of $60 billion–$63 billion by 2050 (Hallegatte and others, 2013), and it is projected that 1.46 per cent of the world population will be displaced by permanent flooding by 2200 (Desmet and others, 2018). Flooding may lead to significant habitat losses owing to coastal squeeze, where fixed infrastructure impedes landward migration of intertidal ecosystems (Doody, 2013; Phan and others, 2015).

2.1.4. Delta subsidence

Anthropogenic stresses are having a particular impact on deltas owing to high rates of relative sea level rise and socioeconomic

vulnerability (Tessler and others, 2015; Hiatt and others, 2019). The impact of rising sea levels is exacerbated by subsidence in large deltas (megadeltas) owing to human activities, primarily groundwater extraction (Syvitski and others, 2009; Erban and others, 2014; Auerbach and others, 2015; Brown and Nicholls, 2015; Schmidt, 2015; Minderhoud and others, 2017, 2019; Wright and Wu, 2019). Protective infrastructure may be able to limit present-day threats; however, engineering solutions may not be feasible in densely populated or lower-income countries (Tessler and others, 2016).

2.1.5. Invasive species

Many estuaries and deltas host large ports and have serious invasive species issues related to ballast water discharge from ships (Astudillo and others, 2014; Shalovenkov, 2019). Invasive species can directly influence the decline of resources and the health of estuaries and deltas, affecting their ecology and balance, posing significant dangers to the biodiversity of both systems. The rate of invasive species introduction has been accelerating, reflecting increased shipping (Seebens and others, 2017). Overall, numbers of invasive species are approximately 30 times greater in high-income countries than in low-income countries, owing to trade and population, and the capacity to detect such invasions (Seebens and others, 2018). The observed rate of introductions has been getting slower in European seas, including the Mediterranean (Korpinen and others, 2019).

2.1.6. Degradation and restoration of ecosystem services

Estuaries and deltas provide essential provisioning, regulating, supporting and cultural ecosystem services (chap. 44 of the first Assessment). The systems provide recreation through such activities as boating, swimming, wildlife watching and fishing (Whitfield, 2017). Some organisms perform important roles as foundational members and create, modify and maintain habitats. Oysters, for example, form reefs that construct habitat, reduce erosion and improve water quality. However, in degraded estuaries, oysters are affected by overfishing, sediment loads and disease, as well as increased ocean acidity (Janis and others, 2016; Day and Rybczyk, 2019). The loss of seagrasses, salt marshes and mangroves, as well as water quality degradation (Reynolds and others, 2016; Schmidt and others, 2017), lead to a decline in juvenile fish diversity and abundance (Whitfield, 2017). Restoration efforts have been successful in relatively few estuaries but can also be integrated into natural shoreline protection strategies (Bilkovic and others, 2016; Ducrotoy and others, 2019).

2.2. Factors associated with the changes: drivers, pressures, impacts and response

Many human activities have degraded the health and productivity of estuaries and deltas, ranging from direct impacts, such as development that destroys habitat, to longer-term indirect impacts caused by global climate change (Cavallaro and others, 2018). There are increasing pressures from human habitation, intrusive coastal infrastructure, recreation, fisheries (finfish and shellfish), land reclamation and the filling of wetlands (Sengupta and others, 2018), resulting in environmental degradation and the loss of sensitive marine organisms (Buttigieg and others, 2018), which have led to increasing efforts to protect ecosystems for their intrinsic worth, for human health and for sustainable resource use. Additional human pressures, such as the development of large container ports with deep-draft shipping, also modify estuarine environments through dredging and the use of dredge spoils to nourish beaches or modify shorelines (Intergovernmental Panel on Climate Change (IPCC), 2019).

It is still difficult to predict the intensity and scale of drivers and pressures or the response of biological communities and ecosystem

functions. Temperature, rainfall anomalies and sea level rise cause substantial impacts on estuarine ecosystems over both the short and the long term (Elliott and Whitfield, 2011; McLeod and others, 2011; Condie and others, 2012; Turra and others, 2013; Bernardino and others, 2015, 2016). Both long-term averages and shorter-term exceedances of physiological ranges will affect the metabolism, growth and reproduction of estuarine biota, which, combined with local eutrophication, may lead to acute oxygen depletion and the mass mortality of organisms (Gillanders and others, 2011). On longer timescales, ecological pressures from fishing activities are affecting fish populations and ecosystems (Muniz and others, 2019). For example, in Río de la Plata, fishing effort for artisanal and industrial fleets has remained constant or even declined slightly, but catches for the two most important species have reached their lowest values in the past 35 years (Gianelli and Defeo, 2017; García-Alonso and others, 2019).

Although many human activities have negative consequences for the health of individual estuaries and deltas, recent efforts have been made to restore the productivity of coastal waters, notably by developing nutrient and pollutant management plans, restoring ecosystems and keystone species, and protecting estuaries and deltas in parks and marine protected areas (Lefcheck and others, 2018; Boesch, 2019). In some places, such as the United States and Hong Kong, China, oyster reefs have been restored, so they now protect shorelines and filter the water column (Morris and others, 2019). In other locations, seagrasses, salt marshes or mangroves may serve similar purposes in protecting the coastline from storms and sea level rise, as well as providing critical habitat for juvenile fish and other biota.

3. Consequences of the changes for human communities, economies and well-being

Estuaries and deltas have socioeconomic and cultural importance, as they provide goods and services, including fishing resources and ecosystem processes. There are local traditional communities that rely on those resources for their livelihood, including subsistence fishing and income from tourist activities. Therefore, to understand changes and manage their impacts on estuaries and deltas, an integrated consideration of environmental, biological, cultural, economic and anthropologic issues is essential.

The World Health Organization has advocated the One Health concept to integrate the human-animal-ecosystem interface because it has been recognized that changes in any of those elements will affect the others. Declines in estuarine health owing to increased pollutants or invasive species can pose a direct threat to human health. The level of impact on humans depends on socioecological factors. Whereas urban populations may suffer from reduced storm protection and from the consumption of contaminated fish, local indigenous communities may also suffer from the loss of cultural values, sanitation issues and social inequality. Indigenous populations and local coastal communities have developed traditional knowledge and skills relevant to the conservation, sustainable use and management of estuaries (Breitburg and others, 2018b). Changes in estuaries owing to urbanization can lead to the loss of identity and cultural practices in communities that depend on such resources for their livelihoods.

There is now greater awareness regarding ecosystem services in estuaries and conflicts that have arisen owing to changes in

the ecosystems (Nicholls and others, 2018). Science can be a powerful tool at the interface with policy to inform decision-making at local, regional and national levels and to integrate it into global goals, such as the 2030 Agenda for Sustainable Development[1] (Dietz, 2013; Howarth and Painter, 2016). The integration of public participation, including of indigenous peoples and local communities, with scientific analyses can lead to effective scientific communication, socialization and decision-making. Improved communication among stakeholders can enable an effective transfer of knowledge and adaptive management, for example, with social scientists helping to build trust among actors (Fischhoff, 2013). Citizen science, an innovative area with benefits for environmental and social sciences, could link traditional and scientific knowledge and help to develop integrated management in estuaries by including indigenous populations and local communities in scientific studies. Ecosystem complexity and connections with other habitats make joint management and collaboration between governments and local communities essential for maintaining coastal biodiversity and ecosystem functions (Teixeira and others, 2013; Brondizio and others, 2016).

Changes in estuarine and deltaic environments, ecosystem services and socioeconomic dynamics have implications for achieving the Sustainable Development Goals of the 2030 Agenda. For example, socioecological conflicts in estuaries, mainly related to indigenous peoples and local communities, are linked to aims related to poverty (Goal 1), gender equality (Goal 5), sanitation (Goal 6), resilient cities (Goal 11) and safe seafood resources (Goal 14). If it is possible to reverse impacts through positive actions consistent with the 2030 Agenda, a series of benefits for society could be achieved in a short time. The conservation of estuaries and their biodiversity and cultural diversity is particularly relevant to Sustainable Development Goal targets 14.2 and 14.5, which are related to promoting the protection and conservation of coastal resources (Neumann and others, 2017), and could also provide other services, such as increased ecotourism. The promotion of human engagement with nature strengthens efforts towards nature conservation in associated ecosystems. To achieve that goal, it is valuable to adopt an innovative approach, together with decision makers and society, to supporting the adaptive management, conservation and sustainable use of estuaries that will benefit human well-being for future generations (Szabo and others, 2015).

4. Key region-specific changes and consequences

Estuaries and deltas are widespread around the world, but there is no global inventory, and the category encompasses a range of geomorphological types. It was suggested in the first Assessment that there may be about 4,500 estuaries in total. However, a gridded global digital elevation model gives a more recent estimate of more than 53,000 estuaries (McSweeney and others, 2017). There are an estimated 1,200 intermittently closed partially saline lakes and lagoons, in particular along the swell-dominated coasts of southern Africa and eastern Australia. They will experience a different set of responses to climate change than estuaries that are continually open to the sea, including altered opening regimes, increased flooding and saltwater intrusion into surface water and groundwater (Carrasco and others, 2016). Adopting a similar approach, a recent study has suggested that there are about

[1] See General Assembly resolution 70/1.

11,000 deltas worldwide; of those, 25 per cent have undergone a net land gain over recent decades as a consequence of deforestation-induced increases in fluvial sediment supply, whereas damming has resulted in reduced sediment and land loss in approximately 1,000 delta systems (Nienhuis and others, 2020).

The first Assessment contained a preliminary assessment of the condition of selected estuaries, with a classification by continent. There remain inadequate data to improve on that evaluation or to consider estuaries and deltas following the region-specific framework of the present Assessment. Several recent compilations do provide data for several regions that were previously poorly documented. For example, little information was available on Arctic estuaries, which are likely to become increasingly important as global warming opens up access to shipping in those regions (Kosyan, 2017). Regional compilations have provided more information for the southern hemisphere, including a focus on estuaries on the east coast of Africa and the western Indian Ocean (Diop and others, 2016), and a review of Brazilian estuaries (Lana and Bernardino, 2018). Relatively little information was previously available on the numerous estuaries and deltas along the 18,000-km coastline of China, which contains many large megacities, such as Shanghai and Guangzhou, that are very susceptible to coastal hazards from sea level rise and storm surges (Yin and others, 2012; Kuang and others, 2014; Chen and others, 2018). Those urbanized megadeltas are home to millions of people and often contain rich biodiversity, which faces threats, including from eutrophication, pollution, coastal modification and invasive species (Lai and others, 2016).

5. Outlook

Based on trends over recent decades, coastal zone populations will increase, with ongoing urbanization focused on estuaries and deltas. Those human stresses will be the principal pressures that continue to affect the biodiversity and habitat health of such coastal ecosystems. Climate change will exacerbate the stresses – increased frequency of storms appears likely and sea level rise is anticipated to accelerate, in particular in the case of large deltas that are experiencing subsidence. Good governance has the potential to maintain or improve the status of ecosystems, although protection of low-lying metropolises will require upgraded engineering infrastructure.

Estuarine and deltaic sustainability can be considered in terms of functional processes using geomorphic, ecological or economic perspectives (Mahoney and Bishop, 2018). Changes can lead to either enhanced or diminished sustainability, but most changes have been detrimental (Day and others, 2016). Ecosystem consequences that can be anticipated include the alteration of food webs owing to the loss of keystone, top predator or ecosystem engineer species; habitat losses owing to sea level rise and land reclamation; and the poleward migration of marine species to adapt to climate change. A reduction in wetlands through coastal squeeze and aquaculture activities is already apparent in many estuaries and deltas. Further increases in invasive species can be expected, although considerable progress has been made in identifying, setting priorities for and eradicating invasive organisms.

It is more difficult to predict the socioeconomic consequences of continued change in the system. However, greater population pressures and expanding urbanization around estuaries and on deltas are likely to mean more dredging to maintain navigability, the silting of channels and the erosion of shorelines, as well as losses

of wetlands, with reduced access to recreation, fishing grounds and clean water. The desire to protect extensive residential, industrial and agricultural areas against storm surges and sea level rise will require huge investments in engineering solutions, and the risks of failure of such infrastructure appear catastrophic. In many areas, it will eventually become necessary to move inland. Even where the pressures of expanding human populations can be contained, significant investments will be required to restore critical habitats. Assessments of changing ecosystem services and implications for human well-being would benefit from improved monitoring and investment in scientific research. Integrated coastal planning is necessary for sustainable use and to extend conservation beyond protected areas, which may require broader strategies for funding, for example from public sources, and multisectoral cooperation. Coastal management may need to include new standards for building and construction, eco-labelling, innovative economic instruments for financing conservation and payments for ecosystem services, such as blue carbon sequestration.

6. Key remaining knowledge and capacity-building gaps

There are major challenges in managing land use in estuaries and deltas so that future generations can also enjoy the aesthetic, cultural and sustaining services that they provide (Elliott and others, 2019). Existing models lack sufficient spatial and temporal resolution to simulate future extreme events (Haigh and others, 2016; Robins and others, 2018), including compound flooding from both fluvial and oceanic sources. Such floods result in environmental degradation, including wetland erosion and eutrophication, and expose people to harmful waterborne pathogens (Yin and others, 2018). Relatively little is known about the long-term effects of rapid human interventions in deltas. The characterization of socioeconomic tipping points will have to be improved to avoid unacceptable changes. More evidence is needed to target coastal wetland conservation in those areas where it can be most beneficial or might alleviate the need for engineered protection works (Van Coppenolle and others, 2018; Van Coppenolle and Temmerman, 2019). The future resilience of megadeltas, and megacities within them, will depend on advances in resource and emergency strategies and investments in flood protection through engineered and living shorelines. Modelling, engineering and natural sciences need to be integrated with social science and public outreach (Bonebrake and others, 2018). Innovative technologies and nature-based solutions are already helping to reduce vulnerability to coastal hazards but collaborative science is needed so that people living in estuarine and deltaic locations have environmental information, reliable short-term and long-term predictions and appropriate observations to validate models, thus improving data-driven approaches to coastal resilience (Nichols and others, 2019).

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