14

Marine Dynamics and Productivity in the Bay of Bengal

Susan Kay, John Caesar, and Tamara Janes

14.1 Introduction

The Bay of Bengal is an important provider of ecosystem services for people in the coastal part of the delta, but tropical cyclones formed in the Bay can lead to highly destructive flooding. This chapter describes the physical conditions and patterns of biological production in the Bay and outlines current trends and changes. The monsoon climate drives seasonal changes in currents and causes large inputs of fresh water from rain and rivers. A fresh water layer on the sea surface suppresses circulation of nutrients for much of the year and so the central Bay has low productivity. The coastal areas are much more productive, driven by inputs of nutrients from rivers and from vertical mixing due to coastal currents. Strong stratification encourages the development of tropical cyclones. Sea-level rise is already occurring in the Bay and is likely to be the most

S. Kay (✉)
Plymouth Marine Laboratory, Plymouth, UK

J. Caesar • T. Janes
Met Office Hadley Centre for Climate Science and Services,
Exeter, Devon, UK

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important effect of climate change for people in coastal Bangladesh. Sea-level rise in the twenty-first century is projected to be in the range of 0.5–1.7 m with associated impacts of increased flooding depth, area and maximum wave height. Other changes are less certain, but could include increased stratification, small changes in biological production and alterations in the frequency and intensity of tropical cyclones.

For the people of coastal Bangladesh, the sea is both a support and a threat. Marine fisheries ecosystem services provide a vital contribution to livelihood and to diet, while flooding associated with storm surge events has regularly caused devastation. This chapter describes the current bio-physical situation in the northern Bay of Bengal and the factors influencing change, while Chap. 25 presents the future prospects for fisheries as projected in this research. The research is also linked to Chap. 8 which discusses flooding from both rivers and the sea and Chap. 16 which discusses possible changes in tropical cyclones and coastal flooding.

14.2 Physical Description and Major Influences on Circulation in the Bay

The Bay of Bengal lies in the far north-east of the Indian Ocean, surrounded by land except on the south side, where it is open to the influence of the wider Indian Ocean. The Ganges-Brahmaputra-Meghna (GBM) delta is the northern boundary of the Bay, with delta sediments forming a shallow area that extends about 200 km south from the shoreline (Fig. 14.1). On the western side, along the Indian coast, the sea bed dips quickly to 2,000 m or more after a narrow coastal strip. On the eastern side, there is a wider area of shallower water, the Andaman Sea.

The monsoon atmospheric circulation is a dominating influence on the Bay, with south-west winds and heavy rain in the summer, north-east winds and low rainfall in the winter. Fresh water and nutrient inputs from a number of large rivers also have a strong impact. The GBM system and the Irrawaddy rank 4^{th} and 15^{th} globally in their discharge of water to the sea, an annual average of 1032 km^3 and 393 km^3, respectively (Dai and Trenberth 2002). On the east coast of India, the Godavari discharges another 97 km^3 and the Mahanadi 73 km^3. Monsoon-driven changes in

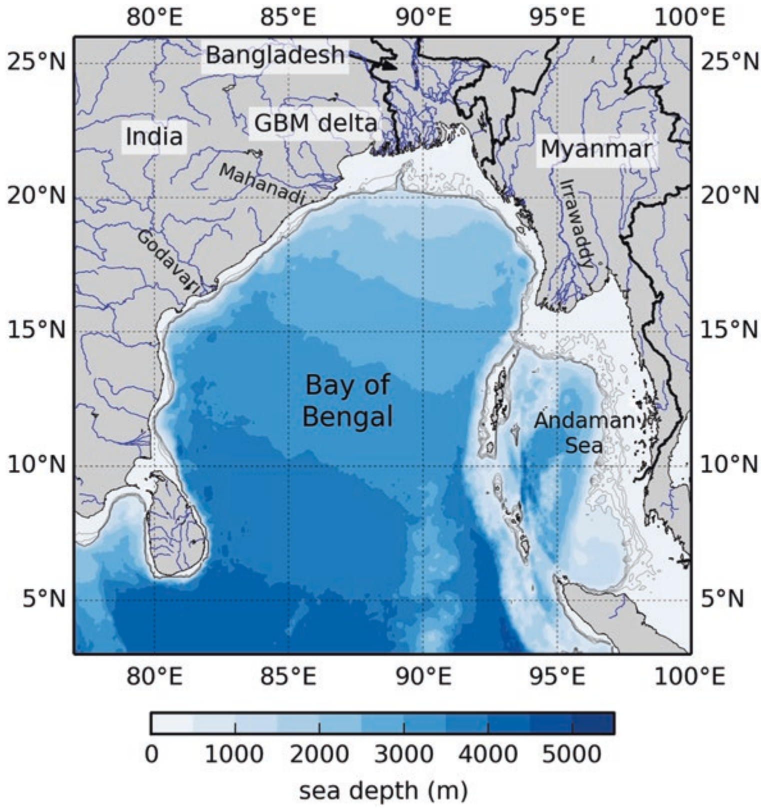

Fig. 14.1 Overview of the Bay of Bengal, showing bathymetry and the location of features mentioned in the text. Contours are shown at 100 m intervals to 500 m; greater depths are shown by colour shading, as in the key. Bathymetry data is taken from the GEBCO 1′ dataset, www.gebco.net

rainfall mean that these discharges are strongly seasonal: the winter discharge rate of the GBM is less than ten per cent of its summer peak (Dai and Trenberth 2002).

The Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) are additional, but weaker, sources of influence on the Bay of Bengal circulation patterns, associated with changes in wind patterns and rainfall at the surface and unusual circulation patterns within the sea (Aparna et al. 2012; Currie et al. 2013).

14.3 Water Structure, Circulation and Productivity

The strongest feature of circulation in the Bay is the East India Coastal Current, which flows north-eastwards along the Indian coast from February to September and south-eastwards from October to January, under the influence of monsoon winds and rain (Chaitanya et al. 2014; Durand et al. 2009; Shankar et al. 1996). The reversal of this current in late summer is partly driven by the influx of river water from the north of the Bay (Diansky et al. 2006); an area of low salinity water moves south along the Indian coast between August and December (Akhil et al. 2014; Chaitanya et al. 2014; Shetye 1993). The current is also influenced by wider circulation in the Indian Ocean (Schott et al. 2009). For example, positive IOD is associated with a weaker southward East India Coastal Current and lower salinity in the northern Bay (Pant et al. 2015).

The Bay of Bengal is a net exporter of fresh water. Salinity is lowest in the north, where monsoon rains and flow from the GBM delta combine to give a great input of fresh water, especially between June and October. Fresh water is dispersed southwards by surface currents along both coasts and by gradual mixing with saltier waters below (Behara and Vinayachandran 2016; Benshila et al. 2014; Shetye 1993). The mixing process is slow and in the post-monsoon season fresh water creates a thin layer of low salinity at the sea surface, overlying the constant-temperature layer below (Felton et al. 2014; Vinayachandran et al. 2002). The warm but saltier water below the surface layer is often referred to as the barrier layer because it inhibits convection and so restricts the vertical mixing of water and heat flow to the deeper water column.

The strong stratification associated with the barrier layer limits the movement of nutrients from deep waters to the sunlit zone near the surface. This lack of nutrients inhibits growth of photosynthesising plankton (phytoplankton) and so biological production is low in the central Bay (Martin and Shaji 2015 and references therein). Nearer the coast, nutrients reach the sunlit zone from river inputs and from vertical mixing due to upwelling caused by coastal currents; this means that productivity is much higher, as shown by patterns of chlorophyll concentration (Fig. 14.2). Observational evidence on chlorophyll and nutrient levels is limited

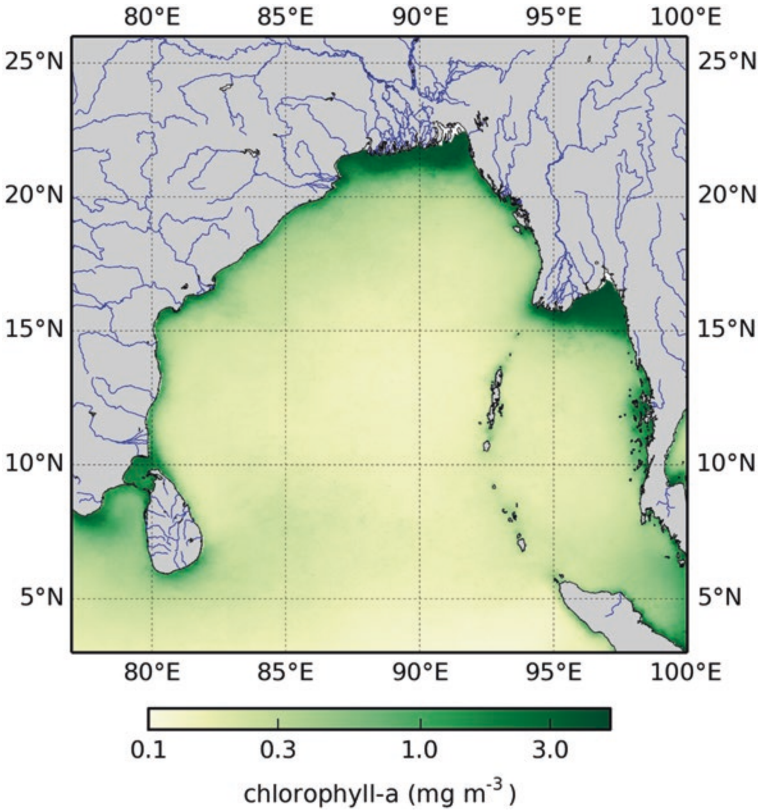

Fig. 14.2 Mean monthly surface chlorophyll concentration in the Bay of Bengal for 2000–2009. The data is taken from the composite satellite dataset compiled by the Ocean Colour Climate Change Initiative, version 2, European Space Agency, available online at http://www.esa-oceancolour-cci.org/

(Narvekar and Kumar 2014; Kumar et al. 2010), but satellite data shows evidence of two chlorophyll peaks, in July–August and in December–February, with the second being higher (Martin and Shaji 2015). The seasonal cycle of phytoplankton growth can be explained by a combination of nutrient and light limitation. Although stratification is relatively weak in the spring, winds are too light to cause much mixing and so productivity is low. Summer brings stronger stratification but also a supply of riverborne nutrients that trigger a bloom, which is then suppressed as sediment in the water limits the supply of light. The waters clear during the autumn and the north-east winds of winter lead to mixing of the water column and a new supply of nutrients, leading to the second and stronger bloom (Narvekar and Kumar 2014; Kumar et al. 2010). The winter bloom starts later and persists longer in the north-east than the north-west; this has been attributed to a combination of the eastward advection of river-sourced nutrients and an upwelling of nutrients due to subsurface currents in the east in winter (Martin and Shaji 2015). IOD/ENSO events can influence phytoplankton distribution patterns in the southern Bay of Bengal through changes in circulation and hence nutrient distribution (Martin and Shaji 2015; Currie et al. 2013).

Phytoplankton from the fertile areas that is not consumed by other organisms falls and decays at lower levels, leading to low oxygen levels in the deeper water. An estimated area of 389,000 km^2 of sea bed in the Bay of Bengal has dissolved oxygen levels below 0.5 ml/l, forming one of the largest oxygen minimum zones in the world (Helly and Levin 2004).

Tides in the Bay of Bengal are dominated by a semidiurnal (twice-daily) signal, with tidal amplitudes increasing south to north through the Bay (Murty and Henry 1983; Sindhu and Unnikrishnan 2013), as discussed in Chap. 8.

14.4 Climate Change Trends

Climate change will bring multiple changes to the Bay of Bengal. The most significant for coastal Bangladesh is sea-level rise, which is already being experienced at rates of up to 5 mm/year in the GBM delta (Antony et al. 2016; Unnikrishnan and Shankar 2007). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Church et al. 2013) includes projections for sea-level rise at Haldia in the northern Bay (22.0°N, 88.1°E), for different Representative Concentration Pathways (RCPs) of greenhouse gases. The mean estimates for sea-level rise over the twenty-first century are 0.38 m, 0.48 m and 0.63 m under RCPs 2.6, 4.5 and 8.5 respectively, with a range of uncertainty approximately ±0.2 m (+0.3 m for RCP 8.5). These projections do not include the possible collapse of parts of the Antarctic ice sheet, which could add around 0.5 m more (Church et al. 2013; Levermann et al. 2014). Subsidence will also add to the sea-level rise experienced locally; this has been estimated for the GBM delta as about 3 mm/year (Brown and Nicholls 2015). The worst case rise from these figures, using the highest RCP 8.5 estimate and including the ice sheet melt, is 1.72 m by 2100. A more conservative estimate, using the mean RCP 4.5 rise but including Antarctic melting, gives a local rise of 1.27 m; the best case, lowest RCP 2.6 and no Antarctic contribution, would be 0.47 m. Any of these scenarios would have a considerable effect on the coastal zone, but the details of its impact will depend on the actions taken to adapt to the changing sea levels, such as raising of embankments and capture of river sediment (Brammer 2014). The effect of sea-level rise on coastal flooding is discussed in Chap. 16.

Rising sea surface temperatures have already been observed in the southern part of the Bay of Bengal, below 15°N, with an increase of about 0.2 °C between the late 1980s and the first decade of the twentieth century (Balaguru et al. 2014). Temperatures in the northern part of the Bay did not increase significantly in this period; however, a temperature rise is projected across the whole Bay in the twenty-first century, in the range 1–2 °C by mid-century and 2–3 °C by the end of the century under a medium greenhouse gas emission scenario (Fernandes et al. 2016 and see Chap. 25, Fig. 25.2). Increased temperatures are expected to lead to stronger stratification, which could reduce nutrient flows to the surface and hence give lower productivity. This has been reported for the western Indian Ocean (Roxy et al. 2016), but projections for the Bay of Bengal suggest that changes there will be small (Bopp et al. 2013; Fernandes et al. 2016, see also Chap. 25). There have been few modelling studies for this area and, as noted above, understanding of production in the Bay is based on limited observational evidence, so any conclusion must be tentative. In addition, productivity in the northern Bay will be sensitive to changes in riverborne nutrients, which will be affected by changes in precipitation and by other anthropogenic pressures. Changes in population, land use and sewage treatment can all affect nutrient loadings at the river mouth, and upstream dams can affect the amount and seasonal pattern of discharge to the sea (see Chap. 13 and Whitehead et al. 2015a, b). Any changes in primary production could have an effect on potential fish catch, but research carried out in the study area suggests that the effects of fisheries management policies are likely to be more important (Chap. 25).

14.5 Tropical Cyclones in the Bay of Bengal

The GBM region experiences relatively few tropical cyclones compared with other terrestrial basins: the number of named storms in the North Indian Ocean for 1980–2009 was only seven per cent of the global total (Knapp et al. 2010; Diamond and Trewin 2011). However, the large coastal population around the Bay of Bengal means that the impact of cyclone-induced storm surge can be very large. The main seasons for tropical cyclones in the northern Indian Ocean are April–May (pre-monsoon) and October–November (post-monsoon), with the strongest cyclones tending to occur post-monsoon when the available heat energy in the upper levels of the ocean is the greatest (Balaguru et al. 2014; Karim and Mimura 2008). The strong stratification of the sea surface following the monsoon rain and river input has been linked to the development of intense cyclones, as it limits the loss of heat from the cyclone system to the sea (Neetu et al. 2012).

Observation-based studies have generally shown no significant change in the overall number of tropical cyclones and depressions, but an increase in the frequency of intense tropical cyclone events in the Bay of Bengal during the month of November (Unnikrishnan et al. 2006; Karim and Mimura 2008). The observed increase in intensity since the 1970s has been related to increasing sea surface temperatures in the Indian Ocean, which provides more energy to fuel cyclones (Webster et al. 2005; Balaguru et al. 2014). Changes in tropical cyclone frequency, track and intensity could have significant implications for coastal Bangladesh, but changes in storminess are among the most uncertain of IPCC projections (IPCC 2013), and tropical cyclones are particularly difficult to forecast. Projected change in the frequency and intensity of tropical cyclones is discussed further in Chap. 16.

14.6 Summary of Issues for the Bay of Bengal

Climate change will have multiple effects in the Bay of Bengal. Current work suggests that changes in primary production will be small, but this is based on a limited understanding of present-day production and should be considered tentative. Changes in tropical cyclones are to be expected but little is known with confidence. Relative sea-level rise is expected to be in the range of 0.5–1.7 m by 2100, and this will undoubtedly have a significant effect on the lives of people in the coastal zone of the delta.

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