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Increasing frequency of large-scale die-off events in the Bay of Bengal: reasoning, perspectives and future approaches

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The Bay of Bengal has been suffering from increasing frequency of large-scale die-off events for the past decades. Most frequently, these events are attributed to high-speed human development and its harmful effects on environment, which is nevertheless, the biggest challenges currently faced by the world. Increasing urbanization, environmental pollution and climate change are leading to unsustainable ecosystem exploitation and raising health and disease management challenges. Considerable modulations in major ecosystems and major disturbances in the global food chain are some of the most significant consequences of this uncontrolled urbanization. Global warming and El Niño events are few particular phenomena that drive mass deterioration of terrestrial foliages and fauna as well as aquatic organisms, respectively. We here review and discuss the die-off events occurring in the Bay of Bengal for the last decades as well as all the data obtained from the analyses of such events to provide a future perspective on potential management and monitoring strategies directed towards the protection of the flora and fauna of several major ecosystems from such die-off events.

[Keywords: Aquatic environment, Bay of Bengal, climate change, conservation strategies, natural disasters, catastrophic events, satellite monitoring].

Introduction

High-speed human development is one of the biggest challenges faced by the world. Increasing urbanization and unsustainable lifestyle often leads to preoccupying levels of waste accumulation and alterations of the physico-chemical properties of the environment, challenging organisms at the lowest biological levels[1]. The loss of sensitive species from impacted ecosystems leads to changes in biodiversity composition, major disturbances in the global food chain, opens windows to biological invasions and the development of pathogens and eventually leads to significant problems with human health and disease management[1-5]. Global warming in particular is a cause for considerable concern due to its multiple and diverse consequences, including the mass deterioration of terrestrial foliage and fauna as well as aquatic organisms[6-8].

As previously mentioned, change in environmental conditions challenges organisms by disturbing energetic balances and triggers changes in their molecular and biochemical pathways[9-11]. As a result of exceeding, for example, the thermal tolerance limits, ectotherms and other homeotherms lose control over the cellular mechanisms responsible for fueling vital processes. This causes organisms to be pushed to their physiological limits, limiting their capacity to withstand small additional shifts in their environmental conditions and eventually leading to unsustainable metabolic rates and finally, collapse[12]. The resulting, sudden large-scale mortality of animals in mega ecosystems such as oceans (including coastal ecosystems) and rivers is increasing in frequency across the world. Thus, identifying the reason(s) behind these events becomes a challenging issue for current ecophysiologists, whilst conservationists seek suitable monitoring programs allowing highlighting potential conditions of vulnerability. There is however, cases where the reason(s) behind large die-off events remained unknown[12], leaving ecophysiologists facing the open challenge of understanding the physiological factors determining the sensitivity of such species, compared to other closely related organisms from catastrophic death

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events[13-17]. In this work, we review the massive die-off events that are increasingly occurring in the Bay of Bengal, and we discuss the possible reasons behind these episodes, which have been scarce until now[13-17].

With all the compiled data, we aim to open discussion on the possible contribution of climatic factors for such death events along the Bay of Bengal, and the usefulness of environmental monitoring in decreasing, if not to arresting such catastrophic events[18, 19].

Materials and Methods

As previously mentioned, the present article focuses on the Bay of Bengal, present in northeast of Indian Ocean. It is the largest bay in the world[20] and is surrounded by India and Sri Lanka to the west, Bangladesh to the north, and Myanmar and the Andaman and Nicobar islands to the east. The total area of the bay is ~2,172,000 km^2. Most of the data on large-scale die off events were collected from the meteorological sites, Govt. of India, New Delhi. Particular attention was paid to the recent mortality event affecting blue button jellyfish (*Porpita porpita*) occurring on the 2nd May 2016[12,20] and affecting a 6 km stretch of coast near Astarang beach (19°51'37.1"N+86°13'30.3"E), between the two Indian heritage sites of Chandravaga and Konark (19°52'04.6"N+86°07'57.8"E 19). Just a day after of this specific event, physic-chemical parameters were recorded in water collected from both surface and bottom (average depth 1,500 m) of the sea. Dissolved oxygen (DO), salinity, turbidity and pH were measured in the collected water samples using specific electrodes in the field (µP based soil and water analysis kit, Esico. Co., New Delhi, India)[20]. NO_3 and chlorophyll-a content were measured using standard spectrophotometric methods[21]. The detailed protocols were described elsewhere[22-24]. Satellite imaging of physical parameters at the Indian sites was done by Dr. Hervé Demarcq, Institut de Recherche pour le Développement, France. The blue button jelly (*P. porpita*) on a 6 km stretch of beach along the Bay of Bengal near Astarang area (19°51'37.1"N+86°13'30.3"E) were calculated manually by dividing the area randomly into different squares of 100 x 100 m^2. Then, from the average value, the total number of carcasses of blue buttons was estimated for the whole stretch of 6 km area. Results corresponding to water analyses are presented as mean ± SEM of 10 samples. SAS version 9.3 was used to conduct PCA and Factor analysis.

Results and Discussion

The Bay of Bengal and its resources have been largely exploited and been source of economic importance since early history. For example, it is well documented how the British East India Company, merchants of London, was one of the first trading ventures that were installed in the Bay of Bengal as early as the 1600[25]. Gopalpur-on-Sea of Odisha (India) was one of their main trading centers. The English East India and French East India Companies were some of the trading companies who operated in India along the Bay of Bengal shorelines. The socio-economic importance of this area is also presently represented by the establishment of the Bay of Bengal Initiative for Multi Sectoral Technical and Economic Cooperation (BIMSTEC), supporting international free trade among countries in the area such as Bangladesh, Bhutan, India, Myanmar, Nepal, Sri Lanka, and Thailand[26]. Aiming to further develop trading and exploitation in the Bay of Bengal, the Indian Government has proposed “The Sethusamudram Shipping Canal Project”, directed towards creating a navigable channel linking the Gulf of Mannar with the Bay of Bengal.

All these major development in the area have been accompanied by the construction of important ports such as Chennai, Paradip, Chittagong, Kolkata, Mongla, Tuticorin, Visakhapatnam and Yangon harbours[26]. Another consequence of this development has been the fast and often uncontrolled growth of cities associated to some major large rivers such as the Ganges, the Brahmaputra, and other rivers such as the IrrawaddyRiver, Godavari, Mahanadi, Krishna and Kaveri, all discharging into the Bay of Bengal[25]. Altogether, the large cities associated to these rivers and the high industrialization are known to result in important pollution episodes with disastrous consequences for local fauna and flora[13]. However, the importance of preserving and understanding the processes through which the Bay of Bengal is being affected by such processes is testified by the fact that approximately 31% of the world’s coastal fishermen exploit its waters and aquatic recourses [25-27]. “Thoni” and catamaran fishing boats of fishing villages thrive along the Bay of Bengal shorelines. The Bay hosts 26 economically important and 44 abundantly marine fish species that are exploited throughout the year resulting into an average fish landing of two million tons[25-27].

Irrespective of the international importance, millions of large-scale mortality episodes observed frequently in this area have become worryingly high in the past two years, as it will be further discussed below. Particularly, the blue button jellyfish (*P. porpita*) may be considered of special relevance[28] due to its magnitude, here estimated to have affected 6 ± 3.34 individuals per square meter (Fig. 1), thus resulting in about 1.8 x 10^5 carcasses.

The water quality analyses carried out by BRP on samples taken up to 3-5 kms from the shore (Fig. 2) indicate no major fluctuations in surface or bottom water quality, thus not likely being significant contributors to the observed mortality episode. Surface atmospheric conditions prior to, and after the event prevented us to access to satellite data (data not shown), such as chlorophyll concentrations or water temperature. Data analysis using SAS indicates that in the rotated factor

pattern, turbidity, DO and salinity come as factor 5 and pH and NO_3 content contribute as factor 6 as a function of temperature change (Fig. 3A-C). Fig. 3D indicates that temperature is not the sole contributory factor but rather all the parameters vary at a time in a season. Scientists from the Central Institute of Fresh Water Aquaculture and from the College of Veterinary Science and Animal Husbandry (Orissa University of Agriculture and Technology, Bhubaneswar, India) sampled the carcasses and could not find any clear explanation for these mortality rates. *P. porpita* are offshore pelagic organisms, and although they have been reported in nearby coastal environments (e.g. along Pakistani coasts[28]), the presence of so many carcasses on the beach is unheard of in this area. Local experts and conservationist such as Prof. Sushil Kumar Dutta suggested possible pollution at deep sea levels, increased ocean temperature, or imbalances in the oceanic food chain and fishing pressure as possible causes of these recent deaths[12].

The endangered olive ridley turtle (*Lepidochely solivaceae*) population in the Bay of Bengal has also suffered from significant impact in the last years, and in 2016 several die-off episodes were recorded[29]. In January 2016,

carcasses of 300 olive ridley turtles and a bottle nose dolphin (*Tursiops aduncus)* were found on the beach of Puri along the Bay of Bengal, Odisha state. In late February 2016, about 40 additional carcasses were found on the shore along Puri beach. Only two months after, another 80 turtles were found dead near Jatadhari river mouth on Paradip beach, close to Gahirmatha Marine Sanctuary[29]. Though these events have most frequently been attributed to the activity of fish trawlers[30] or animal impact with propeller blades[31], the sudden deaths of such large groups of

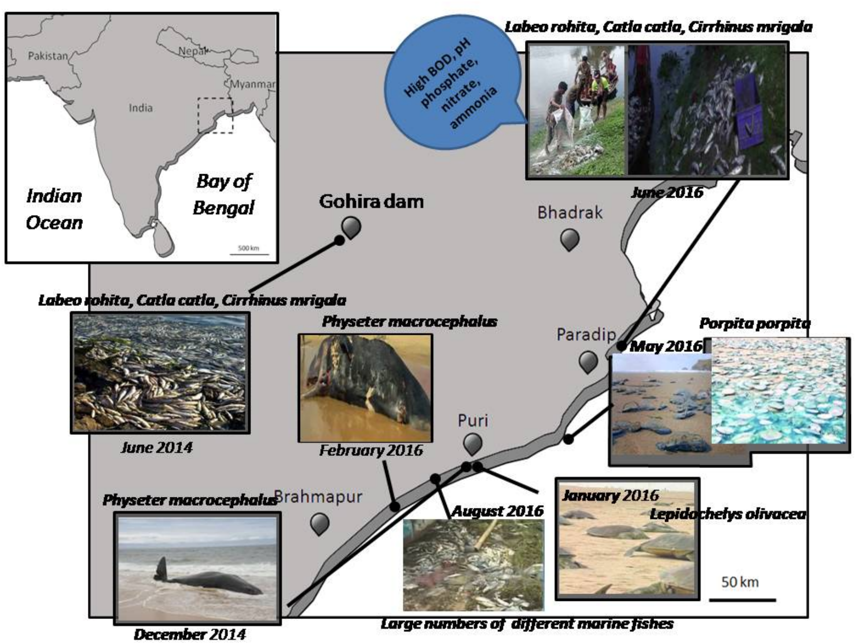

Fig. 1 — Overview of the most recent die-off events along the east-coast of Bay of Bengal in India, which highlights the increasing frequency of these events and the large diversity of species affected. For some of these events, mortalities were associated with alterations of the physic-chemical properties of their environment (e.g. shifts in dissolved oxygen (DO), pH, phosphate, nitrate or ammonia concentrations, etc)[29]

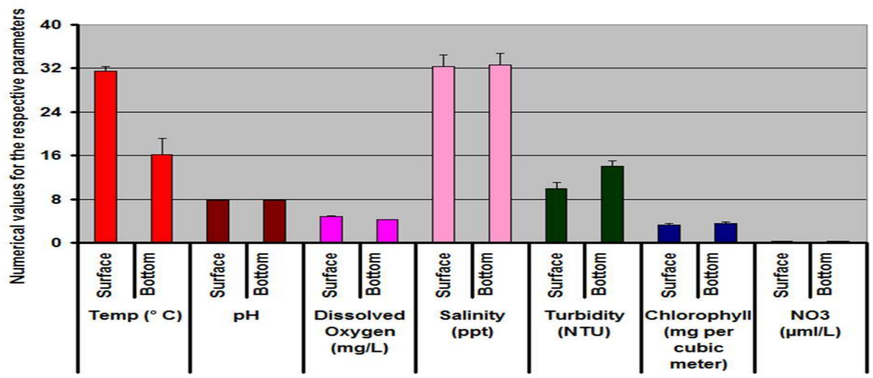

Fig. 2 — Physic-chemical characteristics of the oceanic environments during massive die-off event of *Porpita porpita* in the Bay of Bengal. For further details refer to the materials and methods section

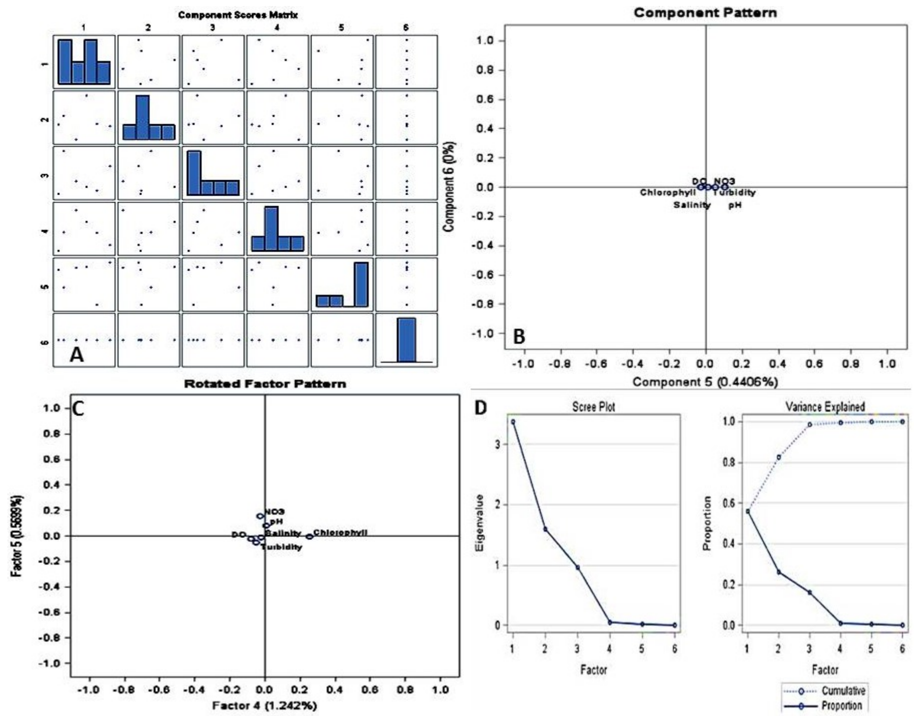

Fig. 3 — PCA and Factor analyses output from SAS. A: component scored matrix for individual data sets, B: PCA output indicating clustering of related variables that vary in similar way in a given sampling site , C: Factor analyses in rotational pattern. D. scree and variance plot

animals suggests that other reasons are behind these mortalities.

In January 2015, 314 dead olive ridley turtles were washed ashore, along the Marina and Elliot's beaches of Chennai[32]. It was considered that they were caught in the fishing nets of trawlers[32]. Within the following months, nearly a thousand turtles were found dead along Gahirmatha, Satyabhaya, Barunei, Pentha while another 15 animals were found dead on the beach of Marina and Elliot of Chennai. These events coincided with the nesting period of this species[33].

The year 2010 was also negative for *L. olivaceae* in the area, as nesting sites were damaged due to an oil spill from the Essar-owned coking coal carrying vessel Malavika near Gopalpur port of Odisha[34]. Probably the most dramatic mortality episode of olive ridley turtles in the area occurred in December 1999, after a super cyclone hit Odisha. Around 1,524 dead turtles were found along the Ekakula and Chinchiri river mouths along the Gahirmatha coast[35]. It was a large-scale die-off as the super cyclone coincided with the nesting time of *L. olivaceae*. Comparing the frequency of die-off events with previous years, enumeration of dead turtles in year 1997 and 1998 was 159 and 59, respectively. The beat houses and wireless network set up along the sea coast to protect the breeding and nesting grounds during that super cyclone were damaged. The die off was due to intensive mechanized trawl fishing and official machineries performing relief operations in the coastal waters of Gahirmatha during the period[30].

There are several places in the Bay of Bengal (e.g. Nagapattinam, Tamil Nadu) that, due to its rich vegetation, are suitable place for nesting of these sea turtles, and are thus a focus of monitoring programs which help keeping track of these events. From a survey carried out in 2001, it was concluded that the turtle mortality rate was the highest at the beginning of the year, and as abovementioned, these are frequently attributed to the impact of fishing nets or mechanized boats and cataramans[36].

However, other reasons for such large-scale die-off and the massive decline in the population of this endangered turtle species have been attributed to different reasons by experts. On the one hand, the development of socio-economic growth of the increasingly growing human populations may be causing the immediate environment to deteriorate. The increasing sources of coastal artificial lights misdirected nearly 90% of the hatchlings in 2004-05 and 50% due to pollution of water[35]. The direct impact of El Niño events on the olive ridley turtles are unknown but the global warming impacts lower trophic levels as a result of which the zooplankton of the marine ecosystem is depleted and hence they change the migration pathways from an unproductive habitat to more productive habitats rich in food[30]. Similarly, changing ecological niche may avoid exposure to warm water and the search of food could drive the turtles deep into the sea. Such behavioral changes could determine their exposure to adverse conditions, leading them to unsuitable habitats, predation and physiological restrictions.

A review of the literature evidences that large marine mammals have also been recently affected in the area. The most recent alarming case concerns a 42-ft long and 18-ft wide carcass of a baleen whale (Systematic name Mysticeti) found at Baidhara Pentha beach of Balukhanda (19°50'03.6"N+85°59'43.9"E) in Puri district of Odisha during the first week of December 2016. In January 2016, 80 short finned pilot whales (*Globicephala macrorhynchus*) beached in Tuticorin along the coasts of the Bay of Bengal[37]. Out of these, 45 whales died while the rest were pushed back to the sea by volunteers and rescuers. The reason of the whales being stranded was believed to be due to disorientation from their usual path, maybe due to the earthquakes under the sea which force them towards the shallow waters of the shore[28]. Carcasses of whales were also found in districts of Puri, Kendrapada and Ganjam of Odisha as mentioned earlier (Fig. 1)[38]. In March 2015, three sperm whales (*Physeter macrocephalus)* were found dead near Puducherry, Alambaraikuppam and Uyyalikuppam. The animal found near Uyyalikuppam was a 50 ft-long male weighting 4 tonnes while the animal found near Alambaraikuppam was a female whale of 35 ft which was nearly 3 tonnes. Both had injuries in their tail, which made experts conclude that the death was due to fishing nets in which they were accidentally caught. The carcass found near Uyyalikuppam measured 52 ft long and was an adult male. This carcass had some superficial injuries and oil globules were found on the dorsal side of its body[39].

The whales are deep-sea divers and excellent navigators. The reason behind the above mentioned die-offs along the Indian coast may be multiple. However, some researchers have hypothesized that this may be due to animals getting disorientated by sonar waves, changes in weather and global warming, water pollution, diseases, abnormalities in earth's magnetic field etc. Despite the numerous reasons suggested, this subject is far from being fully understood [40].

Another important ecologically relevant event along the coast of Bay of Bengal is the reduction in the coral reefs of Palk Bay, Gulf of Mannar and Andamans. A survey carried out in 2001 by UNDP GEF staff in collaboration with the coral scientists from Zoological Survey of India estimated the total area of shallow reef around northern Andaman to extend over 520 km^2. This implied a reduction of 276 km^2 (34.7%) compared to 796 km^2 of previous estimation [41.] About 197 species of coral within 58 genera were recorded during the survey[41]. The island of St. Martin's of Bangladesh has 66 hard coral species with coral cover of 7.6% while the Gulf of Mannar hosts 117 hard coral species. The decline in Bangladesh coral cover was due to high level of sedimentation, unchecked and illegal fisheries, cyclones, storm surges, pollution etc. The threats to the corals of Gulf of Mannar, the Andamans and Sri Lanka are mainly destructive fishing, sand mining, pollution, sedimentation due to deforestation and ornamental fishing[42]. Along with above mentioned reasons, the climate change and global warming has a great impact on the coral reefs[42]. Probably the best known case is the mass coral bleaching in Australia, with around 35% of corals on the northern and central sections of the Great Barrier reef damaged as a result of increased water temperature, according to reports by the Australian Research Council Centre of Excellence for Coral Reef Studies[42]. Coral reefs in the Bay of Bengal are not an exception and have suffered massive deterioration in the last decades[44]. For example, the 1969 cyclone buried in sand the coral reefs of Gulf of Mannar near Rameshwaram along the Bay in India. The 1998 El Niño phenomenon led to coral bleaching and destroyed a significant extension of the coral reefs, an impact which is still today intensively investigated and which results may open important research perspectives for the near future[42].

Mangroves, as corals, are ecosystems that are highly threatened by climate change[44]. They are also key ecological systems, providing for example, feeding habitats for many adult demersal fish and also permanent habitat for numerous species gleaned for subsistence[42, 44]. Furthermore, mangroves constitute buffering systems preventing coast degradation during cyclonic storms[45-46]. The mangrove vegetation of Sunderbans, located along the West Bengal and Bangladesh Coast was declared as a World Heritage site by UNESCO (1997). Cyclone “Sidr” (2007) and “Aila” (2009) caused extensive damage to this mangrove system, a process which was significantly enhanced by the intense human deforestation for exploitation and development of shrimp farming. However, global warming and climate change-related impacts (e.g. salinity and sea-level rise[45]) will have adverse impacts on the mangrove vegetation and associated fauna.

Unfortunately, the mortality episodes are not only affecting marine organisms, but are also frequent in freshwater ecosystems, often due to human-induced alterations of the habitat. For example, barely one month after the blue button event, a large die-off episode occurred in the nearby area of Paradip (Fig. 1), close to one of the largest Indian ports along the Bay of Bengal: early on the 5th June 2016, about 500,000 fish carcasses were found at the Bata River, near Balijhara (20.5136926N, 85.6629975E). The main species affected were Rohu (*Labeo rohita*), Indian carp (*Catla catla*) and Mrigal carp (*Cirrhinus mrigala*), which were quickly removed from the site by official authorities to ensure environmental safety and samples were taken for further analyses. A few weeks later, through an official press conference, the State Government of Odisha expressed the concern of the Central Institute of Freshwater Aquaculture of the Government of India, who collected the data. Sample analyses suggested that water pollution induced by the extremely fast urbanization that is taking place in an area of about 25 acres near Bata River may be responsible for these deaths[47].

Coincidence or not, the events we report here occurred very close to Kendrapara coast, where the Department of Forest and Environment of the Indian Government found earlier in 2016 several dead fin whales (*Balaenoptera physalus*),. Here again, authorities faced difficulties in identifying the cause of the death since these are the first events of this type registered in this area of the Bay of Bengal.

Two years earlier, two similar events of similar magnitude, occurred in the space of a few days. The first occurred at the Deogarh area, around 300 km away from where the blue-button carcasses were found. The second took place on the evening of 18th June 2014, thousands of fish carcasses were found floating (Fig. 1) across a 236 km^2 area at Gohira reservoir (21°28'42.9"N+84°33'03.0"E) on Gohira river, a tributary of the river Brahmani in the Tileibani area of Deogarh district, Odisha state. A team composed of technicians from the Regional Office of Odisha State Pollution Control Board and Government officials sampled the carcasses after advising the local population against using the reservoir water or touching the fish carcasses. The State Pollution Control Board (Govt. of Odisha, India) attributed the massive die-offs to an episode of severe hypoxia for at least one of the two events[14]. On 4th August 2014, a similar event of large scale mortality of a wide varieties of marine fishes was observed in Bada Ayapalli Village shore (19.313740 "N, 84.977382"E) near Gopalpur port, along Bay of Bengal of Odisha, India. After ruling out a possible effects of increased water temperature (coinciding with the rainy season and, water temperature being below 25 °C in the area), pollution was hypothesized to be the causative factor in this case. It is therefore, not possible to speculate about a common cause for all the aforementioned events.

It is widely accepted that anthropogenically-induced climate change is responsible for the increase in frequency of extreme environmental conditions such as droughts or storms. In the last 16 years, about 33 major ecological disasters, mainly being cyclones, tsunami and floods have been recorded along the Bay of Bengal (Table 1-3)[48-75]. Loss has been estimated to be around 320 billion USD, and nearly 450,000 human lives have been lost as a result. Among the

Table 1 — List of the recent catastrophic events in 2016 affecting the coasts of India, Bangladesh and Myanmar and their estimate socio-economic impacts. The values provided in USD were evaluated in the respective years.

Year	Areas	Event name and intensity	Human fatality	Agricultural damage	Other impacts
2016	Sumatra, Andaman, Nicobar Islands, Thailand, Malaysia, South India	VARDAH, Very Severe cyclonic Storm, 140 km h^{-1}	38	Banana, guava plantation and paddy fields.	Huge loss in fishing and tourism industry[47]
2016	Sri Lanka, South India	NADA, Cyclonic storm, 75 km h^{-1}	12	--	-- [48]
2016	Andaman Islands, Myanmar, South India	KYANT, Cyclonic storm, 85 km h^{-1}	--	--	--[49]
2016	Sri Lanka, East-coast of India, Bangladesh, Myanmar	ROANU, Cyclonic storm, 85 km h^{-1}	227	--	$1.7 billion[50]
2016	Tirupati, Chennai, Nellore areas of India	Flash flood due to Vardah Chennai-224mm Tirupati & Nellore- 76 mm	No fatality due to early evacuation	Entire cultivated fields	--[50]

Table 2 — Catastrophic events and their estimate socio-economic impacts along Bay of Bengal from year 2010-2015. The values provided in USD were evaluated in the respective years.

Year	Areas	Event name and intensity	Human fatality	Agricultural damage	Other impacts
2015	Bangladesh, Myanmar, Northern India	KOMEN Cyclonic storm 75-85 km h^{-1}	187-280 (mismatch between official and actual loss	Leaving more than lakhs of people homeless in West Bengal and Bangladesh	Heavy to very heavy rainfall induced damages in Odisha, West Bengal, Madhya Pradesh, Bihar etc. [51]
2015	Tamil Nadu and Andhra Pradesh	Torrential rains led to intensive flood	~500	100,000 acres of crop areas attributing to nearly $190 million loss	Total industrial loss of about $2.18 billion[52]
2014	Andhra Pradesh, Andaman and Nicobar Islands, Odisha, Andhra Pradesh, Chhatisgarh	HUDHUD Very Severe cyclonic storm 220-270 km h^{-1}	124	Standing paddy, sugarcane, groundnut and sugarcane crops before harvested stages were lost.	ROANU $ 3.4 billion[53]
2013	India and Myanmar	PHAILIN Extremely severe cyclonic storm 215-260 km h^{-1}	45	Damage of > 2, 00, 000 hectares of agriculture product in filed. Damage of > 3, 200 hectares of coconut plantation in Andhra Pradesh	Property worth $696 million was damaged along with 40 transmission towers and housing[54]
2013	Indonesia, Sri Lanka, Myanmar, Bangladesh	VIYARU 85 km h^{-1}	107 dead and 6 missing	Damage of 128,000 hectares of crop fields, mainly sweet potato in Bangladesh. 739 hectares of crop lands in Andhra Pradesh were damaged.	Significant flooding in Sri Lanka. 50,000 of homes were damaged. Thousands of trees were uprooted. Loss of $5.24 million[55]
2012	Sri Lanka and South India	NILAM Cyclonic storm 85-100 km h^{-1}	75	Floodwater inundated 51,486 hectares of directly sown land and13, 421 hectares transplanted land.	Transportation, communication and power transmission were disrupted. Many houses were damaged. Loss of $56.7 million[56]
2011	Southern India and Sri Lanka	THANE Cyclonic storm 140-165 km h^{-1}	48	700 fishermen were reported to be stranded.	Fishing Industry severely affected. Loss of $235 million[57]
2010	Sri Lanka and India	LAILA Cyclonic storm 100-120 km h^{-1}	65	--	Loss of $117.49 million[58]

(*Contd*.)

Table 2 — Catastrophic events and their estimate socio-economic impacts along Bay of Bengal from year 2010-2015. The values provided in USD were evaluated in the respective years (*Contd.*)

Year	Areas	Event name and intensity	Human fatality	Agricultural damage	Other impacts
2010	Myanmar and Bangladesh	GIRI Extremely severe Cyclonic storm 195-250 km h^{-1}	157 direct and 10 cyclone induced	Catastrophic damage in parts of Myanmar	Loss of $359 million[59]
2010	Malaysia, Sri Lanka and India	JAL Cyclonic storm 110-120 km h^{-1}	118 dead 12 missing	Affected around 80,000 people	Loss of $1.73 billion[60]

Table 3 — Disastrous events affecting the coasts of India, Bangladesh and Myanmar and their estimate socio-economic impacts from the year 1999-2009. The values provided in USD were evaluated in the respective years.

Year	Areas	Event name and intensity	Human fatality	Agricultural damage	Other impacts
2009	India and Bangladesh 315.7807	AILA, Severe cyclonic storm 110-120 km h^{-1}	339	1 million people were homeless. >7,000 people were infected with diseases (i.e. diarrhoea)	Loss of $ 295.6 billion[61]
2009	India, Bangladesh and Myanmar	BIJLI, Cyclonic storm, 75-95 km h^{-1}	07	Several esidents were lost.	--[62]
2008	Sri Lanka and India	NISHA, 85-100 km h^{-1}	204	90,000 people affected.	Loss of $ 800 million[63]
2008	Northeastern states of India.	RASHMI, Cyclonic storm, 85 Km h^{-1}	28 died, 50 missing.	--	Huge physical damages by the uprooted trees[64]
2008	Bangladesh, Myanmar, India and Sri Lanka	NARGIS, Cyclonic storm, 165-215 Km h^{-1}	1, 38, 366	1.50 million people were "severely affected".	Loss of $10 billion[65]
2007	Bangladesh and West Bengal	SIDR, Cyclonic storm, 215-260 km h^{-1}	~15, 000	Enormous physical damages in Bangladesh.	Loss of $ 1.7 billion[66]
2007	Andaman Islands, Nicobar Islands, Bangladesh, Burma	AKASH, Cyclonic storm, 85-120 km h^{-1}	14 death, 3 fishermen were killed, 50 missed	Destroyed 205 houses and left an additional 845 damaged.	Moderate damages to crop land near coast and damage of 2 ha (4.9 acres) of shrimp farms. Loss of $ 982 million[67]
2006	India	OGNI, Cyclonic storm, 65 km h^{-1}	24	1, 99, 986 acres of crop area damaged.	3, 61, 553 livestock lost. 26, 853 houses damaged completely. Whereas 73,218 houses were partially damaged[68]
2006	Andaman Islands, Myanmar, and northern Thailand	MALA, Very severe cyclonic storm, 185-220 km h^{-1}	37 died and 18 were drowned.	Mala brought heavy rains to northern Thailand.	Loss of $ 6.7 million[69]
2005	Andhra Pradesh Thailand	BAAZ, Cyclonic storm, 83 km h^{-1}	11	Heavy rains destroyed the crop fields.	Heavy rain induced floods in some districts. Many villages were marooned[70]
2005	Andhra Pradesh	PYARR, Cyclonic storm, 65 km h^{-1}	Officially death of 1 person was confirmed	Crops over 4, 82, 000 hectares were damaged.	Death of 291 live stocks. > 12,000 houses were destroyed. Loss of INR 5, 030 lakhs[70]
2004	Indonesia,, Sri Lanka, India, Thailand, Maldives, Malaysia, Madagascar, Somalia, Kenya, Tanzania, South Africa.	Sumatra–Andaman earthquake Tsunami, 9.0 magnitude quake epicentre 3.316°N 95.854°E3.316°N 95.854°E. Magnitude 9.1-9.3 M_W	230,000–280,000	Widespread damage of the infrastructure, shortages of food and water, and economic damage.	Total agricultural loss[71]

(*Contd.*)

Table 3 — Disastrous events affecting the coasts of India, Bangladesh and Myanmar and their estimate socio-economic impacts from the year 1999-2009. The values provided in USD were evaluated in the respective years.

Year	Areas	Event name and intensity	Human fatality	Agricultural damage	Other impacts
2003	Andhra Pradesh	Severe cyclonic storm, 102 km h^{-1}	358	Nearly 62, 000 of agricultural fields faced damage.	Destroyed 1, 637 buildings fully, 7, 453 building destroyed partially. > 2, 000 villages were disconnected. Loss of $163 million[72]
2002	Odisha and West Bengal	Severe cyclonic, storm 102 km h^{-1}	18 in Odisha and 2 in West Bengal	Several acres of crop fields were damaged due to torrential rains and salt water.	Disrupted transport and communication. Thousands houses were damaged. 4 fishing trawlers were missed[73]
2001	Andhra Pradesh	Cyclonic storm, 65 km h^{-1}	108 dead and 21 missing	Damage to cultivated lands of around 125,000 hectares.	Several fishing coasts and 55,000 houses were damaged[73]
2000	Sri Lanka and Tamil Nadu	Very severe, cyclonic storm 167 km h^{-1}	9 in Sri Lanka	Damage to paddy crops over 49,000 acres in Sri Lanka In Tamil Nadu 281 hectares of Paddy and 650 hectares of plantation cultivation was damaged.	Transportation and communication were disrupted. 83, 000 houses in Srilanka were destroyed. Near about 1000 of houses were destroyed in India in Tamil Nadu. The country faced heavy rainfall leading to floods[73]
2000	Tamil Nadu and Pondicherry	Very severe cyclonic Storm, 189 Km h^{-1}	2	Damage to paddy crops, plantain, coconut plantations in Pondicherry and Tamil Nadu.	Nearly 30, 000 houses were damaged. The aftermath flood washed away the brick buildings also[74]
1999	Myanmar, Bangladesh, India (particularly Odisha)	Super cyclone, 260 km h^{-1}	~10, 000	Paddy crops in 16,17,000 hectares and other crops in 33,000 hectares were damaged.	Nearly 3.8 lakhs cattle heads were perished. Thousands of houses were damaged leaving people homeless. Loss of $4.44 billion[75]

cyclones, "Nargis" (2008) was the most deadly, which caused the loss of 140,000 human lives and resulted in extensive agricultural damages across Bangladesh, Myanmar, India and Sri Lanka. Cyclone "Sidr", on the other hand, affected Bangladesh and West Bengal resulting in the death of about 15,000 people. Irrespective of the loss, the frequency of cyclones is gradually increasing, with a new record established in 2016 (Table 1-3)[48-75].

Conclusions

It is clear, from the examples we describe in the Bay of Bengal as well as from the numerous other reports available, that these episodes are a) increasing in frequency and b) affecting a wide variety of aquatic species, both benthic and pelagic, ranging from cnidarians to fish and large marine mammals (Fig. 1). With this comprehensive review of the information regarding the factors leading to massive die-offs, we conclude that, while physical parameters such as increased temperature or hypoxia are affecting ecosystems across the world, pollution is probably the primary factor affecting the Bay of Bengal. Although such phenomena are not new, environmentalists are concerned and are joining their efforts to fully understand and realistically evaluate how to counteract the deleterious effects of increasing urbanization leading to pollution[1,5,76,77], particularly in countries such as India, where rates of anthropization are high. And, it leads to several deleterious effects on different ecosystems[78-83]. Despite these efforts, the information here compiled demonstrates that the reasons behind some of these mortality events are unclear. This highlights the need to investigate by further setting up monitoring protocols for given species/ecosystems along with satellite-based analyses of water parameters aiming to understand and predict large-scale alterations in water quality. Otherwise, human-induced alterations of aquatic environments are likely to continue, with an increasingly negative effect on medium to large-scale biodiversity levels and directly impacting human populations across the world[84].

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