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ORIGINAL PAPER

Ensuring the adaptive potential of Coastal wetlands of India- the need of the hour for sustainable management

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Abstract India is endowed with a variety of coastal wetlands viz., mangroves, seagrasses, saltmarshes, coral reefs, lagoons and tidal flats, and the country is also a signatory to the Ramsar Convention on Wetlands and the Convention of Biological Diversity, besides having a robust framework of laws and policies, governing the wetland conservation. However, the conservation strategies can better be improved in the context of increasing pressures and threats and limited success of restoration/rehabilitation. Land conversion and ecological degradation of coastal wetlands are the stressors, associated with rapid coastal developmental activities and climate change. The coastal wetlands require desired habitat niche and hence, the conversion of coastal wetlands to other land uses (including agricultural and urban lands) may lead to permanent loss, whereas ecologically degraded coastal wetlands may be resilient if supported by effective protection measures. Preventing the habitat conversion and maximizing the adaptive potential (viz., the ability of populations or species to adapt to rapid environmental change with minimal disruption) by preserving the ecological health are the need of the hour to safeguard the existing coastal wetlands and sustain the provisional ecosystem services offered by them rather than short-term increase in area by unproductive restoration/rehabilitation efforts. Since coastal wetlands are flow through ecosystems, preserving the hydrological connectivity, facilitating the connectivity between adjacent ecosystems and protection of natural corridors are potential strategies that are required to enhance the adaptive potential of coastal wetlands. This analysis calls for site-specific, long-term and integrated ecosystem-based protection, management and rehabilitation strategies based on scientific principles and enforcing the effective legislative measures to regularize the coastal developmental activities in India.

Keywords Adaptive potential · Coast · Conservation · India · Sustainability · Wetlands

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Introduction

Coastal wetlands are a unique system of fluctuating water levels, providing a habitat for a vast array of organisms, including endangered species. They play a vital role in carbon sequestration (McLeod et al. 2011; Duarte et al. 2013), coastal protection (Kathiresan and Rajendran 2005; Temmerman et al. 2013), fish resources (Aburto-Oropeza et al. 2008) and water quality improvement (Teuchies et al. 2013), thereby making their protection crucial (Romañach et al. 2018). Some birds are totally dependent on wetlands for breeding, nesting, feeding, or sheltering (Sivaperuman and Venkataraman 2015). Ecosystem services of the coastal wetlands are valued at US$194,000 ha^{-1} yr^{-1} (Costanza et al. 2014). However, coastal wetlands continue to be one of the most threatened ecosystems, experiencing an annual loss of 0.7–1.2% (Davidson 2014). Land reclamation for agriculture and aquaculture activities, uncontrolled upstream developmental activities and climate change-induced extreme events are key drivers of the degradation of coastal wetlands (Jayanthi et al. 2018; Murray et al. 2019). About 25–50% of world's coastal wetlands were reclaimed for agriculture and aquaculture activities in the last century (Kirwan and Megonigal 2013). In addition, the interactive effects of increased extreme events, high winter temperatures, and sea level rise are expected to threaten the resilience and recovery potential of existing coastal wetlands. The recent instances of climate change-induced extreme weather events (Duke et al. 2017; Lovelock et al. 2017) and increasing winter temperatures (Saintilan et al. 2014) are the causes of the massive mangrove dieback in 1000 km stretch of Gulf of Carpentaria, Australia, and the expansion of mangroves towards polar region at the cost of salt marshes respectively. Furthermore, many coastal wetlands become eutrophic and/or hypoxic due to pollution by discharge of heavy metals and organic wastes (Bhattacharya et al. 2003; Agoramoorthy et al. 2007; Vane et al. 2009; Remani et al. 2010; Bala Krishna Prasad 2012; Chowdhury et al. 2017a, b). Thus, health and integrity of existing coastal wetlands are continuously declining due to increasing anthropogenic activities and/or global climate change (Feller et al. 2017; Thomas et al. 2017).

Status of coastal wetlands in India

India has a total wetland area of 15.3 million ha, accounting for nearly 4.7% of the total geographical area of the country; of which, inland wetlands account for 69%, coastal wetlands for 27%, and other wetlands smaller than 2.25 ha account for 4% (SAC 2011; Panigrahy et al. 2012; Bassi et al. 2014). India, with a long coastline of 7517 km, is endowed with a variety of coastal wetlands viz., mangroves, seagrasses, saltmarshes, coral reefs, lagoons and tidal flats (including sand, rock, or mud flats that undergo regular tidal inundation). Of these, only mangroves and coral reefs have been much studied for their ecology and biodiversity, with minimal attention to management-related issues and the rest of the coastal wetlands remain little studied (Ragavan et al. 2019). Further, the coastal wetlands are not regularly mapped except mangroves and coral reefs which are mapped at biennially and decadal intervals respectively (Thangaradjou and Bhatt 2018). The extent of natural coastal wetlands is estimated to be 37,039.71 km^2 that excludes seagrasses and man-made coastal wetland of 4361.45 km^2 as per the Space Application Centre (SAC) (Panigrahy et al. 2012). Another estimate of coastal wetland areas of India is a total of 13,654.79 km^2 that excludes Lagoons and Creeks, as per the National Centre for Sustainable Coastal Management (NCSCM) (Ramesh 2018). The extent of mudflats, saltmarsh and mangroves also varied between the estimates of SAC and NCSCM (Table 1) and they are not concurrent with global estimates (Murray et al. 2019). These variations in remote sensing-based estimations are often attributed to methodological inconsistencies. From this uncertainty, it is apparent that wetland inventory of India needs to be improved by adequate understanding of the definition and characteristics of wetlands. India is signatory to the Ramsar Convention on Wetlands and the Convention of Biological Diversity, besides having a robust framework of laws and policies, governing the wetland conservation (Nayak 2017). However, effective enforcement of existing legislative measures and improvement in the conservation strategies are required in the context of increasing pressures and threats, ineffectiveness of existing conventional conservation measures, and limited success of restoration/rehabilitation (Prasad et al. 2002; Gairola 2014; Bassi et al. 2014).

Table 1 Variation in estimates of extent of natural coastal wetlands of India (km^2)

Habitats	Panigrahy et al. (2012) SAC report	Ramesh (2018) NCSCM report
Mangroves	4714.07	5403.39
Seagrasses	NA	516.6
Saltmarsh	1611.44	465.75
Coral reef	1420.03	1400.92
Mud flats	24,136.42	5621.23
Lagoons	2460.44	NA
Creek	2066.98	NA
Sand/beach	630.33	246.9
Total	37,039.71	13,654.79

NA not assessed

Existing conservation measures

Most of the conservation measures in India are often relied on legal protection of coastal wetlands through declaration of protected areas (PAs). However, some PAs fail to prevent loss and degradation within their ranges (Lavieren et al. 2012; Bassi et al. 2014; Almeida et al. 2016). This is attributed to lack of financial and human resources, poor infrastructure and political will (Singh 2003; Leverington et al. 2010; Das Gupta and Shaw 2013; Bassi et al. 2014; Gairola 2014; Jayanthi et al. 2018). Further, most of the PAs are lacking clear aims and long-term ecological and/or socio-economic data to evaluate the management effectiveness (Bennett and Dearden 2014; Bassi et al. 2014; Addison et al. 2015; Jayanthi et al. 2018). The problem here is the concept of Marine and Coastal Protected Area (MCPA) which is not specific, but is widely used to declare national parks, sanctuaries, or tiger reserves in coastal or marine areas under the Wildlife Protection Act of 1972 (Rajagopalan 2011). Further, there is no significant participatory management of MCPA, causing resentment among public, and the forest department entrusted with management of MCPA also lacks the scientific knowledge of coastal and marine biotopes (Kathiresan 2017). Mangroves are the well recognized coastal wetlands along the Indian coast and nearly about 40% of mangrove areas are under the category of protected areas (Worthington and Spalding 2019). However, ecological degradation is still continuing (Kathiresan 2018). Protected areas prevent some drivers of degradation, such as unsustainable timber extraction. However, other drivers of degradation, such as upstream water abstraction or changes to sediment supplies, cannot be influenced when they occur beyond the protected area boundaries (Worthington and Spalding 2019). So, considering the hydrological and ecosystem connectivity and climate change impacts on protected areas in the existing legalisations is imperative to minimize the ecological degradation within protected areas (Mcleod et al. 2009; Magris et al. 2014).

In India, massive efforts have been taken for rehabilitation/restoration of degraded coastal wetlands such as mangroves by various public and private agencies since the early 1980s (Bhatt et al. 2011; Selvam et al. 2012). Although many of these efforts were claimed successful, acclamation from the scientific research community has not been received much (Datta et al. 2010). Most of the rehabilitation/restoration efforts often based on mono-specific plantations without considering the ecological conditions of habitats, hydrological regimes and suitable species for planting (Kathiresan 2018) and hence, restoration/rehabilitation efforts could not offset the continual destruction of coastal wetlands despite the short-term increases in area cover (Lee et al. 2019). In addition, functionality of rehabilitated/ restored areas are rarely monitored to fully ascertain the success of restoration/rehabilitation based on faunal diversity and vegetation structural (e.g., basal area, species diversity) as well as functional (e.g., net primary productivity, carbon storage, resilience) properties (López-Portillo et al. 2017). Considerable long time-scale (at least of 30 years) of management and monitoring is imperative to ensure the functionality of restored/rehabilitation sites (Datta et al. 2012). But such comprehensive as well as long-term monitoring and management of rehabilitated/restored areas are still very rare globally as well as in India (Datta et al. 2012; Duke et al. 2017; Mazón et al. 2019).

In nations such as India, the coastal wetlands are often regulated under legal frameworks, created originally for specific aspects of forests, environment, water, land, or marine fisheries. Thus, the wetlands lacked exclusive legislative framework. Hence, the Government of India has notified the Wetlands (Conservation and Management) Rules, 2010 based on the directives of National Environment Policy, 2006 and recommendations made by National Forest Commission. The Rules restrict activities such as reclamation, setting up of industries in vicinity, solid waste dumping, manufacture or storage of hazardous substances, discharge of untreated effluents, any permanent construction, etc. within the wetlands. The Rules also regulate the activities not to be permitted without the consent of the State government such as hydraulic alterations, unsustainable grazing, harvesting of resources, releasing of treated effluents, aquaculture, agriculture and dredging. However, recently Ministry of Environment, Forest and Climate Change (MOEF&CC) replaced the Wetlands (Conservation and Management) Rules, 2010 with the new Wetlands (Conservation and Management) Rules 2017. This has decentralised the wetlands management by giving powers to States, not only to identify and notify wetlands within their jurisdiction but also keep a watch on prohibited activities. Further, the Central Wetlands Regulatory Authority (CWRA) suggested in the Wetlands Rules, 2010 has been replaced in the Wetlands Rules 2017 by a national committee, with only an advisory role and hence, it is felt by some conservationists that the new wetland rules have weakened the existing regulations. In addition to Wetlands (Conservation and Management) Rules, 2017, the Coastal Regulation Zone (CRZ) notification (2018) also offers legal protection to coastal wetlands and classified coastal wetlands as ecologically sensitive areas and declared them under the CRZ Category I. Even then, there is no significant progress on the conservation and wise use of the coastal wetlands. Only selected wetlands have received attention for management action plan with financial and technical assistance from the governments under the wetland conservation programmes (National wetland management Programme (NWMP), National Lake Conservation Plan (NLCP), National River Conservation Plan (NRCP), Wetlands (Conservation and Management) Rules, 2010) while the remaining ones continue to be neglected (Bassi et al. 2014). For instance, out of the 55, 862 natural wetlands, just 37 Ramsar sites (0.5%) are given conservation priority.

One of the critical issues in India is weak participatory management especially without involving the local communities. Most of the existing legislative measures and policies are based on global generalization of the given ecosystem to be conserved, while coastal ecosystems structure, function, services and response to climate change are highly site-specific (Duke et al. 1998). Furthermore, climate change and regional peculiarities are not considered in policy making. Thus, the first regulatory measure of conservation is the restriction of activities of local communities. Hence, implementation of the conservation measures often creates conflict with local communities and remains ineffective without public participation. For instance, CRZ notification 2018 is the one of the significant efforts to ensure the sustainability of coastal ecosystem and supports the livelihoods of local coastal communities against the climate change and anthropogenic activities. However, due to the practical difficulties in the process of implementation and disputes arises from different stakeholders it remains the most amended law in the history of India. Sea level rise is a potential climate change threat to coastal ecosystems. However, coastal wetlands have the potential to cope with sea level rise through vertical accretion processes and their ability to migrate inland over successive generations, but both the mechanism are highly site-specific. In this regard, it is imperative to consider the information about rate of vertical accretion and availability of possible accommodation space on coast to decide the limits of No Developmental Zone (NDZ). But NDZ in the CRZ notification 2018 is based on human population density without any consideration of rate of vertical accretion and availability of accommodation space for coastal wetlands to cope up with sea level rise, due to lack of data on these aspects. Environmental pollution caused by upstream anthropogenic activities is another key factor affecting sustainability of coastal wetlands, but no measures have been suggested to minimize this impact. Despite the descriptive regulatory measures to control upstream anthropogenic activities, effective implementation and long-term monitoring is lacking.

In addition, India's very complex and tedious bureaucracy also diminish the success of conservation and development policies. State Forest Departments have been widely blamed for the failure of forest conservation efforts. But the causes for disappointing performance of state forest departments were often little explained and no efforts have been taken to address the problem. Recently, Fleischman (2016) highlighted that the behaviour of forest officials plays a key role in the outcome of conservation and development programs. However, substantial knowledge gap and little attention on implementation process while policy making causes the differential behaviour of forest officials and thereby affect the success of conservation endeavours (Fleischman 2016). Five core reasons which impede the success of India's environmental bureaucracy are (1) the cost of enforcement for local officials, (2) the cost of compliance for polluters, (3) conflicting interests of state and central authorities, (4) rivalry with other state or central departments, and (5) the politicization of bureaucratic structures (Khator 1991; Singh 2007). Overall, lack of quality data, effective implementation and long-term monitoring are the drawbacks in the conservation policies of India.

Need of the hour

The coastal wetlands have an innate potential of adjusting to changing environmental conditions, however, human developmental activities are expected to cause the unpredicted ecological consequences (Kirwan and Megonigal 2013; Blankespoor et al. 2014; Spencer et al. 2016; Crosby et al. 2016; Murray et al. 2019). For example, vertical adjustment and horizontal movement are the important processes of mangroves to cope up with sea level rise (Lovelock et al. 2015; Schuerch et al. 2018). However, these are greatly influenced by local abiotic (sediment inputs and local geomorphic settings) and biotic (plant productivity, peat development, and the accumulation of refractory mangrove roots and benthic mat materials) factors (Schuerch et al. 2018). The vertical adjustment of mangroves is determined by hydrological connectivity viz., amount, quality, quantity, and timing of freshwater and sediment delivery to estuaries and mangrove forests, whereas accommodation spaces such as tidal flats and other adjacent landscapes such as salt marsh, which can act as natural corridors that are needed for horizontal movement (Lovelock et al. 2015; Schuerch et al. 2018). Hydrological connectivity and adjacent landscapes of mangroves are drastically altered by coastal developmental activities. In India, 66% of mangrove cover is experiencing extreme environmental conditions in Sundarbans and Gujarat, and 40% is degrading (Kathiresan 2018), which in turn affects the resilient and recovery potential of mangroves against sea level rise. Conversion of coastal wetlands to other land uses (including agricultural and urban lands) may lead to permanent loss, and the ecologically degraded coastal wetlands may be resilient only when supported by effective protection measures (Lotze et al. 2006; Lin and Yu 2018). So, preventing the habitat conversion and enhancing the adaptive potential of coastal wetlands is need of the hour to safeguard the existing coastal wetlands.

Adaptive potential is often defined as the ability of populations or species to adapt to rapid environmental change with minimal disruption by means of phenotypic or molecular changes (Glick and Stein 2010; Eizaguirre and Baltazar-Soares 2014). The adaptive potential promotes resilience of species to recover from disturbances, and it improves the effectiveness of conservation practices and sustainable management (Turner et al. 2003; Intergovernmental Panel on Climate Change (IPCC) 2014). Thus, determining the physiological, ecological and genetic processes underpinning the adaptive potential of species is key focus for current conservation approach (Osland et al. 2019, Rilov et al. 2019, Wee et al. 2018). Adaptive potential of populations/species is often measured in terms of genetic diversity, and an increased expression of diversity may compensate the loss of genetic diversity and allow the populations to maintain a certain level of phenotypic variation to cope up with sudden environmental change (Liu et al. 2019, Wee et al. 2018). Use of genetic information in conservation is crucial for its long-term effectiveness to preserve the adaptive and evolutionary potential of ecosystem/species (Hoffmann and Sgro 2011). The latest technologies (viz Next Generation Sequencing) are scanning the entire genomes and increasing the levels of spatial and temporal complexity of populations. However, little is translated into on-the-ground conservation (Wee et al. 2018). Effective adaptive marine conservation planning requires better understanding of foundation species of coastal wetlands (Osland et al. 2019) and incorporation of seven key interlinked scientific requirements viz., (1) mapping shifts in species distributions; (2) understanding the physiological and ecological mechanisms behind climate-driven biological change; (3) identifying and predicting critical shifts in ecological states; (4) developing forecasting tools for communities and ecosystem functions; (5) assessing the adaptation capability of key populations and species; (6) developing tools and methods to address climate change in conservation prioritization; and (7) integrating information to develop adaptive conservation planning strategies for multi-stressor environments (Rilov et al. 2019). The above insights can incorporate into future efforts, but there is a need of immediate measures based on the available information. Maintaining the better ecological condition and minimal habitat destruction will facilitate the adaptive potential of coastal wetlands.

Coastal wetlands are highly dynamic, with interconnections among them and adjacent habitats. Thus, the potential strategies of enhancing the adaptive potential of coastal wetlands are facilitating the connectivity between adjacent ecosystems, ensuring the minimum hydrological regime, and protection of natural corridors (Fig. 1). This can be achieved through Ecosystem based management (EBM) by making use of site-specific (biodiversity, habitat characteristics, ecological process) and species-specific information (distribution, habitat requirements). EBM is driven from the failure of conventional management practices to protect marine ecosystems from overexploitation (Crain et al. 2009). EBM is aimed at achieving conservation, sustainable use and fair allocation of benefits from natural resources, thereby striking a balance between short-term needs and sustainability (Cowan et al. 2012). EBM requires more precise information of various components of a given ecosystem to be managed. Thus, it is still a long way to achieve the formulation of EBM for coastal wetlands, but site-specific EBM can be initiated with available information with parallel efforts to fulfil the needs of effective implementation. We have identified some essential measures that are required to safeguard the adaptive potential of existing coastal wetlands and to sustain the provisional ecosystem services for future generation, as detailed below.

Strengthening of the existing legislation

In developing countries such as India, the coastal areas are the hot spots of developmental activities (e.g. Sagar Mala) and hence, it is challenging to meet the requirements of economic development, whilst simultaneously safeguarding the ecological health of the coastal wetlands to sustain their ecological services. The human demand on living resources of the planet is now exceeding its capacity to regenerate by 30% (WWF 2008, 2016). Particularly, wetland ecosystems are among the most affected, with nearly 50% loss since 1900 (Li et al. 2018; Murry et al. 2019). Priority is required on controlling the new coastal developments and designing the developmental activities in sustainable manner.

Exclusive protective measures need to be formulated by declaring Eco-sensitive Zone/buffer zone around the coastal wetlands irrespective of size, because even a small area plays a significant ecological role (Curnick et al. 2019). The rivers—the roots for stability of coastal wetlands—can be declared as protected area and their peripheral bank areas should be declared as eco-sensitive zone/buffer zone for immediate action to halt further developmental activities. It is also necessary to initiate the collection of base line data on how coastal wetlands are affected by anthropogenic activities after industrialization/urbanization and climate change, what are the potential activities that are causing ecological degradation, and what are the ecological consequences for the future. Based on these data, carrying capacity/vulnerability of coastal wetlands should be assessed for making decisions on proposed developmental activities. Further, the developmental activities in the vicinity of rivers and coastal wetlands should be regularly monitored on a long-term basis to avoid violations against the conditions of sanction. Long-term monitoring of the ecological health of rivers and coastal wetlands was difficult and challenging, but now it is easier with advancements of remote sensing technologies, and the monitoring processes are useful to make protective measures to enhance the resilience and recovery to avoid the complete loss (Murray et al. 2019). The existing legislations have detailed regulatory measures to minimize the anthropogenic activities in the vicinity of rivers and wetlands. However, lack of strict enforcement and regular monitoring favours the uncontrolled anthropogenic activities that continue the degradation of water quality in the coastal areas of India. To cite an example, the Indian Sundarbans receives a pollution load of as much as 22,900 kg /day (Mandal et al. 2010). Hence, a strong

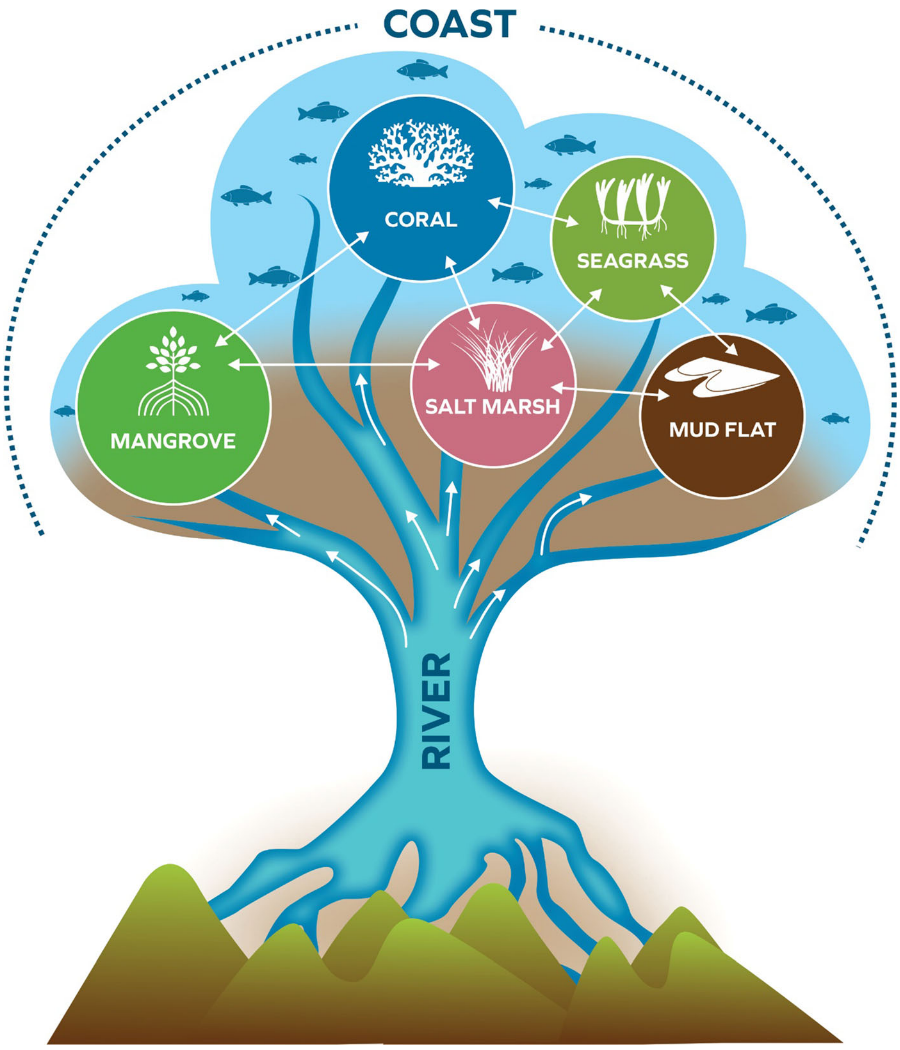

Fig. 1 Tree of Nature showing the ecosystem connectivity needs to be ensured for the sustainability of coast and coastal wetlands

policy framework, effective implementation and long-term monitoring are required to protect the existing coastal wetlands from climate change and environmental pollution, generated from upstream man-made activities.

Caution on compensatory planting

In order to accommodate 23,716 industrial projects across India over the last 30 years, as much of 14,000 km^2 of forests (including coastal wetlands) have been cleared (Anand 2019). To compensate this loss of natural ecosystem, the Government supports planting through the Compensatory Afforestation Fund Management and Planning Authority (CAMPA). In the case of mangroves, compensatory planting with five times the number of plants destroyed is recommended. This compensatory planting, however, seems practically difficult due to frequent failures of mangrove planting efforts. The habitat niche required for the growth of mangroves is limited and is already significantly modified by developmental activities. In addition, compensatory planting is often practiced on the mudflats, which are essential habitat for benthic organisms and birds as well serving as the natural corridors of mangroves for dealing with sea level rise. The planting of mangroves on mudflats is considered to be habitat conversion rather than habitat restoration (Erftemeijer and Lewis 1999). Recently Lee et al. (2019) have argued that large-scale planting, where survival is low or, worse, may result in collateral damage to existing or adjacent habitats, despite the short-term increase in area cover. Thus, instead of random planting, "Ecosystem Design" is to be designed to ensure ecosystem services that are locally or regionally required for the well-being of mankind, considering local habitat conditions (Zimmer 2018; Kathiresan 2018). In addition, it is also necessary to demarcate and safeguard the locations which support the natural succession of coastal wetlands.

Ensuring hydrological regimes

The damming/diversion of tropical rivers, with the subsequent reduction of sediment load reaching the coasts, have highly destructive effects on the stability and productivity of the coastal and estuarine ecosystem (Ezcurra et al. 2019). Further, structure, function and stability of the coastal wetlands are greatly influenced by hydrology, salinity, and sedimentation, which are often modulated by estuarine freshwater supply (Osland et al. 2018). Most of the Indian rivers have already been drained (Selvam 2003), and hence, it is imperative to ensure the minimum freshwater inputs and hydrologic regimes that are needed to maintain the hydrological connectivity of coastal wetlands. The hydrological connectivity is also imperative in the context of increasing coastal salinity especially after the 2004 tsunami that has changed the floral species composition, affected the benthic organisms and suppressed the coastal biodiversity particularly along the east coast of India (Kathiresan 2018). Another issue is reduced free flow of tidal water as most of the river mouths are clogged especially along the east coast of India. Ensuring the minimum hydrological regimes is practically a tedious task; however, it can be maintained at current rate by avoiding inappropriate coastal engineering projects or the damming of rivers and designing of shore structures. In cases of sediment starvation, it is necessary to artificially enhance sediment retention or resort to the use of mud nourishment or agitation dredging. Furthermore, extreme changes in rainfall regime are expected around the world, with substantial regional variations due to climate change. Recent studies have shown that increase in rainfall leads to landward (Eslami-Andargoli et al. 2009) as well as seaward (Ashbridge et al. 2016) expansion of coastal wetlands such as mangroves due to the higher supply of fluvial sediments, nutrients, lower exposure to sulphates and reduced salinity. On the contrary, decrease in precipitation and increase in evaporation are also observed in some places leading to increases in soil salinity and resultant reduced productivity. So, predicting the changes in future rainfall pattern will be useful to take precautionary measures necessary to maintain the hydrological connectivity of coastal wetlands.

Streamlining of future research

Despite strong legal frameworks, the understanding of structure and function of coastal wetlands of India is far from complete and the policy making needs to be adjusted in tune with recent scientific understanding of coastal wetlands. A long-term research on wetlands of India is required to feed right quality of information for updating/modifying the existing protective measures. The primary factor that distinguishes wetlands from other landforms or water bodies is the characteristic vegetation of aquatic plants, uniquely adapted to the unique hydric soil, which modify the abiotic conditions that support entire ecological communities. Such wetland foundation species especially for salt marsh plants, seagrasses, sedges, rushes and grass remain less studied. Furthermore, the coastal wetlands are dominated by algal mats and unvegetated tidal flats (i.e., salt flats, salt pans, salt barrens, sabkhas, salinas) under hypersaline conditions that are stressful to coastal foundation species, and these coastal wetland types have not received much attention. So, the proper definition and delineation of different kinds of coastal wetlands and understanding the species composition of different types of coastal wetlands and their biological characteristics should be given the priority. The coastal wetland responses to climate change are expected to be geographically varied at both a regional and local scale (Ward et al. 2016; Osland et al. 2019). So, there is a need for more site-specific and species-specific research for better understanding of coastal wetland responses to rising sea levels, changing temperature and precipitation regimes and growing developmental activities along the Indian coast. Integrated Coastal Zone Management (ICZM) is an Ecosystem Based Management (EBM) approach based on the concept of sustainability. Many aspects of the coastal zone are needed for effective ICZM, particularly the technical aspects of the coastal zone viz., key physical processes (erosion, along shore drift, estuarine circulation, sediment flows, river delta behaviour etc.), biological processes (mangrove and wetland ecology, variability in fish abundances) and the fate and effects of various types of pollution found in the coastal zone (sewage out falls, industrial effluents, agricultural and urban runoff etc.). So, without site-specific scientific information, the formulation of ICZM often causes serious conflicts, thereby making the plan unimplementable. The key focus of research till date is on structure and diversity of coastal wetlands, but with limited efforts in understanding the functioning of the coastal wetlands, specifically to support the regulating ecosystem services, and mechanisms to address trade off that emerge in decision making in conservation and sustainable management of coastal wetlands (Bhatt et al. 2013). Hence, a multi-disciplinary approach is needed to transform current conservation measures of the coastal wetlands into effective EBM-based measures.

Conclusion

Coastal areas are the hot spots of developmental activities and hence they continue to be threatened, despite the strong legislative measures in the country. It has been experiential that irrespective of climate change and persisting natural calamities, anthropogenic interventions are the root causes of the degradation of coastal wetlands (DasGupta and Shaw 2013). Hence, strengthening the governance and effective implementation of the legislative measures requires immediate action and is as important as restoration/rehabilitation activities, economic improvement, and other technical and data-driven aspects of management (Eriksson et al. 2016). The wetlands of the world can possibly gain up to 60% of the current area, if more than 37% of coastal wetlands have enough accommodation space, and sediment supply (Schuerch et al. 2018). So, ensuring the adaptive potential by safeguarding the ecological health of the existing coastal wetlands is the needs of the hour to sustain the ecological services offered by them. Wetlands are flow through ecosystems, so preserving the hydrological connectivity, facilitating the connectivity between adjacent ecosystems and protection of natural corridors are the potential strategies to enhance the adaptive potential of coastal wetlands. Based on available reports it is apparent that massive rehabilitation/restoration efforts with huge financial support and manpower did not reverse global wetland loss as well as the sustainability, whereas legislative protection, despite the poor enforcement, prevents certain level of the habitat conversion thereby supports the natural succession. Thus, restructuring of legislative framework and strict enforcement and monitoring should be prioritized for better protection of ecological health of existing coastal wetlands. Since structure and functions of coastal wetlands are site-specific, there is no "one size-fits-all solution". So, such polices should be formulated with adequate site-specific information rather than global generalization and should be combined with price-based instruments, such as carbon credits, payments for ecosystem services, taxes on deforestation and certified eco-friendly products, which will raise the value of maintaining and protecting coastal wetlands rather than converting them to other uses (Lee et al. 2019).

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