Malayan Nature Journal 2020, 72(4), 551-576

Three decades of global mangrove conservation - An overview

P. RAGAVAN[1]*, K. KATHIRESAN[2], M. ZIMMER[3], RENCHAO ZHOU[4], A. ALDRIE AMIR[5], P. M. MOHAN[6] and T. S. RANA[1]

Abstract: The ecosystem services offered by mangroves have made their protection critical. Last three decades of mangrove conservation are often relied on legal protection of existing mangroves and massive restoration/rehabilitation of degraded/reclaimed areas. Legislative protection measures are based on declaration of protected areas and descriptive regulatory measures in the form of acts or laws, whereas restoration/rehabilitation efforts are often based on mono-specific plantation. Despite various legislative protections, habitat conversion is still continuing, and ecological health of existing mangrove areas are degrading. Furthermore, the massive restoration/rehabilitation efforts could not offset for the continual destruction of established forests, but only short-term increase in area. This calls for evaluating effectiveness of the existing conservation measures and then formulating better management measures in the context of increasing pressures and threats. Land conversion and ecological degradation of coastal wetlands are the primary stressors, associated with rapid coastal developmental activities and climate change. Mangroves require desired habitat niche and hence, their conversion to other land uses may lead to permanent loss, whereas ecologically degraded areas may be resilient if supported by effective rehabilitation measures. Hence, preventing the habitat conversion and preserving the ecological health are the need of the hour to safeguard the existing mangroves and sustain the ecosystem services offered by them. Better ecological conditions also support the adaptive potential of mangroves (viz., the ability of populations or species to adapt to rapid environmental changes with minimal disruption) to cope with the climate change. Since mangroves are flow-through system, preserving the hydrological connectivity of existing mangroves, facilitating the connectivity between adjacent ecosystems and protecting the natural corridors are the potential strategies to enhance the ecological health of mangroves. This can be achieved by an effective site-specific, long-term and integrated ecosystem-based protection, management and rehabilitation strategy with sound scientific knowledge and drastic legislative measures to regularize the coastal developmental activities.

Key words: Conservation, ecosystem-based management, mangroves, protected areas, restoration**.**

[1]CSIR- National Botanical Research Institute, Rana Pratap Marg, Post Box No. 436, Lucknow 226001, India, +91-9476030770, email:van.ragavan@gmail.com.
[2]Centre of Advanced study in Marine Biology, Annamalai University, Parangipettai-608 502, Tamil Nadu, India.
[3]Department of Ecology, Leibniz Centre for Tropical Marine Research, Bremen, Germany
[4]State Key Laboratory of Biocontrol and Guangdong Provincial Key Laboratory of Plant Resources, School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China
[5]Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[6]Department of Ocean studies and Marine Biology, Pondicherry University, Brookshabad Campus, Port Blair-744112, Andaman and Nicobar Islands, India
*Corresponding author: van.ragavan@gmail.com

INTRODUCTION

Mangrove forests provide valuable ecosystem services, making their protection critical (Huxham *et al*., 2017; Romañacha *et al*., 2018; Friess *et al.*, 2020). The recent slowdown in average rate of loss or even an increase in cover, partly being feigned by changing methods in quantifying the mangrove areas in global-scale remote-sensing studies (Giri *et al*., 2011; Bunting *et al*., 2018) is often attributed to conservation measures in the past decades. However, mangroves still experience an annual loss of 0.2–0.7% between 2000 and 2012, and remain the most threatened ecosystem of the world (Hamilton and Casey, 2016). Mangroves have the ability to cope up with short-term oscillations and long-term fluctuations of climatic conditions, but the uncontrolled upstream developmental activities and consequences of global climate change, such as increased extreme events, will have unprecedented effects on biota and threaten the resilience and recovery potential of ecosystems (Harris *et al.*, 2018, Sippo *et al*., 2018). The recent massive mangrove dieback in Gulf of Carpentaria, Australia, for instance, is considered to be an impact of climate change-induced extreme weather events (Duke *et al.*, 2017; Lovelock *et al.*, 2017). Environmental pollution, especially the discharge of heavy metals and organic wastes, is also reported to have severe impacts on mangrove health (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). Further, disease and pest impacts (Kathiresan, 2002; Osorio *et al.*, 2006, Kathiresan *et al*., 2020) and seaquake-induced tsunamis have also threatened the mangrove ecosystems (Doyle *et al*., 1995; Roy and Krishnan, 2005; Sippo *et al*., 2018;). Thus, health and integrity of existing mangroves are continuously degrading due to increasing anthropogenic activities and global climate change (Feller *et al*., 2017; Thomas *et al*., 2017). This calls for evaluating the effectiveness of existing conservation measures and formulating the better management measures with sound scientific understanding of mangroves.

MATERIALS AND METHODS

A critical appraisal on effectiveness of existing conservation measures and betterment which is required for ensuring the sustainability of global mangroves is presented here based on a review of the recent published literature, Government information from articles and official websites and comparative studies of mangrove restoration/rehabilitation initiatives. This work does not attempt to review in detail all existing measures of mangrove conservation; instead, it intends to organize and update current situation, examples and possibilities of successful management and multiple factors involved in the mangrove management. It points out the shortcomings, suggests remedial measures and highlights the need for consideration of scientific information available for restructuring the existing measures and formulation of policies and programmes in the context of adaptive ecosystem-based management.

EFFECTIVENESS OF EXISTING CONSERVATION MEASURES

Legislative protection of existing mangroves and massive restoration/rehabilitation of degraded mangroves are the measures suggested for improving the mangrove management in many countries (Lewis *et al*., 2016, Figure 1).

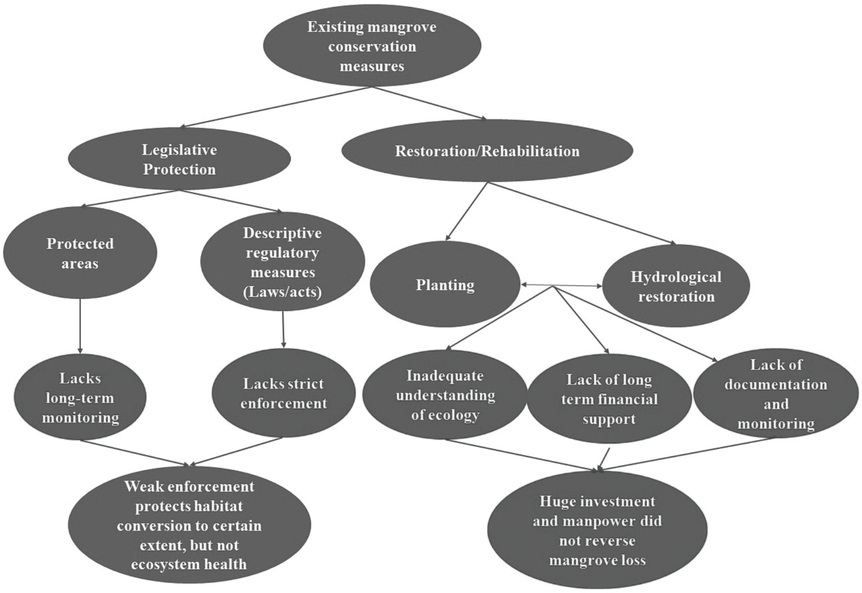

Figure 1. Schematic representation of effectiveness of existing conservation

Legislative measures

Legislative protection of mangroves often relies on declaration of protected areas and descriptive regulatory measures in the form of acts or laws. The laws are either not strictly enforced or remaining as paper policy in many countries (Duke, 2007; Amir, 2018; Castellanos-Galindo, 2017). In addition, many existing legislative arrangements for mangrove conservation are not yet full proof and also contradictory in nature. In one hand, many local governments promote developmental activities in coastal areas; on the contrary, mangrove conservation is also simultaneously prioritized (DasGupta and Shaw, 2013). Thus, malpractices, such as encroachment of virgin mangroves, illegal logging, poaching of wildlife, or using banned and destructive fishing practices, e.g., poison- and fine-meshed nets and catching undersized specimens, are still common in mangrove forests of many countries (Islam *et al*., 2018), where economic resource objectives at the regional level conflict with broader national obligations for habitat conservation (Friess *et al.*, 2016). It is pertinent to note that weak enforcements of legal measures and improper monitoring are the major drawbacks in conservation and restoration initiatives in South and Southeast Asia (DasGupta and Shaw, 2013). Country like India has a very strong legislative arrangement towards conservation of mangroves; however, significant progress has not been made in the field due to practical difficulties in the implementation process.

An important critical issue in implementation of legislative measure is the lack of public participation, particularly local coastal communities. One of the reasons may be that most of the existing legislative measures and policies are based on global generalization of the given ecosystem to be conserved, while structure, function, services and response of coastal ecosystems to climate change are highly site-specific. Furthermore, climate change and regional peculiarities are not generally considered in policy making. Thus, the first regulatory measure of conservation would be the restriction of the activities of local communities. Hence, implementation of the conservation measures often creates conflict with local communities and remains ineffective without public participation. In addition, very complex and tedious bureaucracy also diminish the success of conservation and development policies. Forest Departments have been widely blamed for the failure of forest conservation efforts. But the causes for disappointing performance of forest departments were often little explained and no efforts have been taken to address the problem. Recently, Fleischman (2016) has highlighted that the behaviour of forest officials plays a key role in the outcome of conservation and development programmes. However, substantial knowledge gap and little attention on implementation process while policy making causes the differential behaviour of forest officials and thereby affecting the success of conservation endeavours (Fleischman, 2016). Consequently, pressures on mangrove ecosystems are still ubiquitous and persistent, and the best endeavors of conservation fail frequently.

Protected areas

Early conservation measures of natural ecosystems, including mangroves, relied on the establishment of protected areas (PAs) at largely undisturbed sites, and this approach is still dominant ideology even today (Mace, 2014). Worldwide there are about 2,500 protected areas that include mangrove forests within their boundaries, which represent over 39% (around 54,000 km^2; Table 1) of world's remaining mangroves; 34 countries have placed more than half of their mangroves under such protection (Worthington and Spalding, 2019; IUCN and UNEP-WCMC 2019; Table 2). The extensive coverage of mangroves by protected areas represents a strong positive trend in coastal conservation. However, Southeast Asia -a hot spot of mangroves in terms of area cover, species diversity and deforestation rate, has only 20% area under protection (Table 1). Particularly countries like Indonesia, with the largest mangrove extent in the world, has only 24% of its mangroves within the protected areas, while Nigeria, Myanmar, Malaysia and Papua New Guinea have only between 2% and 5% of their mangroves incorporated into protected areas, ranking among the lowest coverages of any mangrove nations (Worthington and Spalding, 2019). Furthermore, many of these PAs are poorly designed or poorly enforced due to inadequate manpower, lack of infrastructure facilities and absence of formal management plans (Singh, 2003; Lavieren *et al.*, 2012, Leverington *et al*., 2010), and some PAs fail to prevent mangrove loss and degradation within their ranges (Lavieren *et al*., 2012; Almeida *et al.*, 2016).

Recently it has been estimated that rate of mangrove degradation in the protected areas is 0.57%, and about 6% of mangrove areas have been lost since 1996 within protected areas, at a lower rate than outside protected areas (7.1%), but not significantly different (Worthington and Spalding, 2019; Table 1). Thus, the effectiveness of PAs with respect to ecological and/or socio-economic factors is debatable (Bennett and Dearden, 2014), and most of the PAs lack both clear aims and long-term biological data to evaluate the management effectiveness (Addison *et al.*, 2015). Furthermore, the ecosystem connectivity and climate change considerations are often lacking in the PAs of coastal and marine environments (McLeod *et al.*, 2009; Magris *et al.*, 2014). 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 is imperative to minimize the ecological degradation within the protected areas.

Table 1. Statistics of global mangroves (net loss and gain, protected areas, restorable areas and degraded areas.)

Region	**Area (km^2) in 1996**	**Area (km^2) in 2016**	**Loss (km^2)**	**Gain (km^2)**	**Area of mangrove protected (km^2) in 2016**	**Proportion of Area protected**	**Area restorable (km^2) in 2016**	**Proportion of original mangrove areas restorable**	**Extent of highly restorable mangrove areas (km^2)**	**Area of degraded mangrove areas (km^2) in 2016**	**Proportion of mangrove degraded**
Australia and New Zealand	10,332	10,037	370	74	4,553	45.4%	350.9	3.3%	328.6	54.6	0.5%
East and Southern Africa	7,630	7,329	424	122	3,112	42.5%	412.0	5.3%	407.0	133.0	1.6%
East Asia	159	159	12	13	21	12.9%	7.0	4.0%	6.5	2.6	1.8%
Middle East	334	319	19	4	100	31.3%	11.4	3.3%	7.9	2.7	0.8%
North and Central America and the Caribbean	22,702	21,072	2,196	566	12,411	58.9%	2,277.2	9.6%	1,636.3	140.2	0.7%
Pacific Islands	6,410	6,327	146	63	563	8.9%	166.6	2.6%	147.1	5.0	0.1%
South America	19,632	19,063	1,106	537	13,649	71.6%	1,068.2	5.2%	794.9	92.6	0.5%
South Asia	8,701	8,492	435	226	5,428	63.9%	352.7	3.9%	279.7	32.4	0.4%
Southeast Asia	46,789	44,060	3,308	579	8,769	19.9%	3,037.1	6.4%	2,591.2	847.0	1.9%
West and Central Africa	20,107	19,857	422	171	5,317	26.8%	437.1	2.1%	430.5	78.5	0.4%
Total	**142,795**	**136,714**	**8,437**	**2,356**	**53,923**	**39.4%**	**8,120.0**	**5.5%**	**6,629.9**	**1,388.6**	**1.0%**

(Source Worthington and Spalding 2019)

Table 2. Protected areas of mangroves in selected countries

Country	Area of 2016 mangrove protected (km^2)	Proportion protected
Australia	4,528	46.6%
Bangladesh	3,780	91.9%
Brazil	9,419	85.9%
Cameroon	1,077	47.3%
Colombia	1,054	46.5%
Cuba	1,764	52.3%
Dominican Republic	154	81.6%
El Salvador	283	86.3%
French Guiana	350	70.9%
Gabon	919	54.4%
India	1,381	39.8%
Indonesia	6,529	24.2%
Iran	77	98.3%
Mexico	6,072	62.3%
Mozambique	1,750	59.5%
Nicaragua	653	74.5%
Tanzania	935	80.0%
United States	1,707	90.4%
Venezuela	1,404	50.0%

(Source : Worthington and Spalding 2019)

Restoration/Rehabilitation

In the last three decades, massive efforts were globally made to restore/rehabilitate degraded mangrove areas. Incorporation of mangroves into engineered hard coastal defence structures, monoculture plantations and "ecological mangrove restoration" (EMR) approaches are common methods of mangrove restoration/rehabilitation (Ellison *et al.* 2020). However, despite of existing guidance for successful restoration/rehabilitation effort (Lewis and Brown, 2014), most of the mangrove restoration/rehabilitation efforts are not successful and successful cases are rare (Stubbs and Saenger, 2002; Lewis *et al*., 2005; Bosire *et al*., 2008; Rey *et al*., 2012; Dale *et al*., 2014; Brown *et al*., 2014 a; Brown *et al*., 2014b; Begam *et al*., 2017).

Since commercial aquaculture activities are the major cause for the loss mangroves worldwide, many restoration/rehabilitations have been undertaken in the sites where shrimp farming or aquaculture activities were abandoned. In such cases, reversing the habitat condition suitable for the growth of mangroves requires adequate site-specific ecological knowledge, strategy and, most importantly, time. But most of the rehabilitation/restoration efforts are often undertaken in short duration and are based on mono-specific plantation without understanding the species-specific information or habitat characteristics and are often focused on increasing the coverage of existing mangroves. Thus, many attempts of mangrove rehabilitation used the "wrong species" in the "wrong environment" and resulted in massive failure (Zimmer, 2018; Lewis *et al.* 2019). In the past, most mangrove conservation or rehabilitation measures did not consider consequences on the structure, functioning or service-provisioning of the ecosystems.

Eliminating the environmental stressors and assisting the natural regeneration are the success of effective mangrove restoration/rehabilitation. However, global assessments of restoration/ rehabilitation practices and methods over 90 sites around the world (Figure 2 a and b) confirm that planting, rather than eliminating the stressors and assisting natural regeneration, remains the main strategy (López-Portillo *et al.*, 2017). Similarly, a survey of 14 locations in 11 countries has revealed that large investments in planting, as indicated by planting area, number of propagules planted and project costs, generally did not result in significant long-term increase in mangrove area or tree survival (Lee *et al*., 2019). In addition, lack of documentation of either positive/negative outcomes or recommendations for modifications of the original planting design, absence of monitoring plan to assess the functionality of mangroves, short duration and limited funding to support the community participation of volunteer planting and monitoring are the major obstacles of successful restoration (López-Portillo *et al.*, 2017).

For instance, recent review of more than 160 documented mangrove restoration efforts in 24 countries, which includes a total recorded extent of almost 2,000 km^2 planted over the last 40 years, revealed that not all projects recorded exact areas, or given sufficient data to assess success or failure (Worthington and Spalding, 2019). Unsuccessful rehabilitation is a waste of time, money and human resources. Further, the habitat characteristics altered for the purpose of mangrove rehabilitation render these corridors unsuitable for natural migration of mangroves to cope up with the impacts of climate change. Large-scale planting, where survival is low or, worse, is likely to result in collateral damage to existing or adjacent habitats (Lee *et al*., 2019). Hence, another approach suggested by Lewis *et al.* (2016) is called "Early detection and pre-emptive rehabilitation" to prevent complete loss of plant community structure and ecological function through long-term monitoring of changes in hydrological and ecological status of mangroves. However, the long-term monitoring efforts are not generally implemented in any country (Duke *et al*., 2017; Mazón *et al*. 2019).

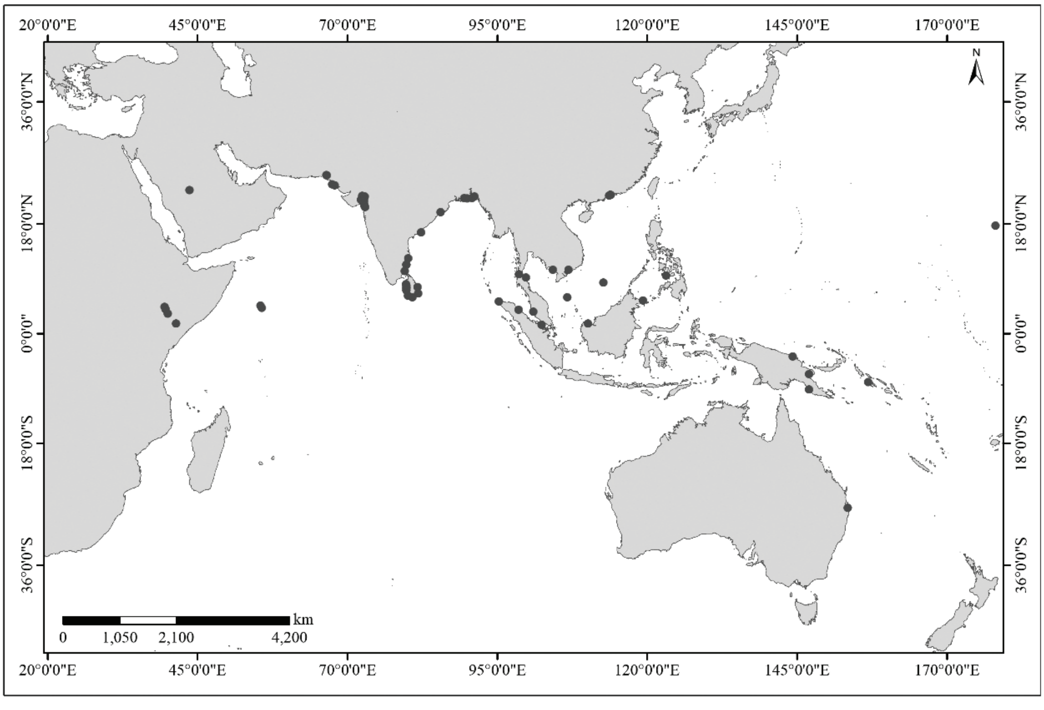

Figure 2a. Major mangrove restoration/rehabilitation sites in Indo-west Pacific (Source López-Portillo *et al*., 2017)

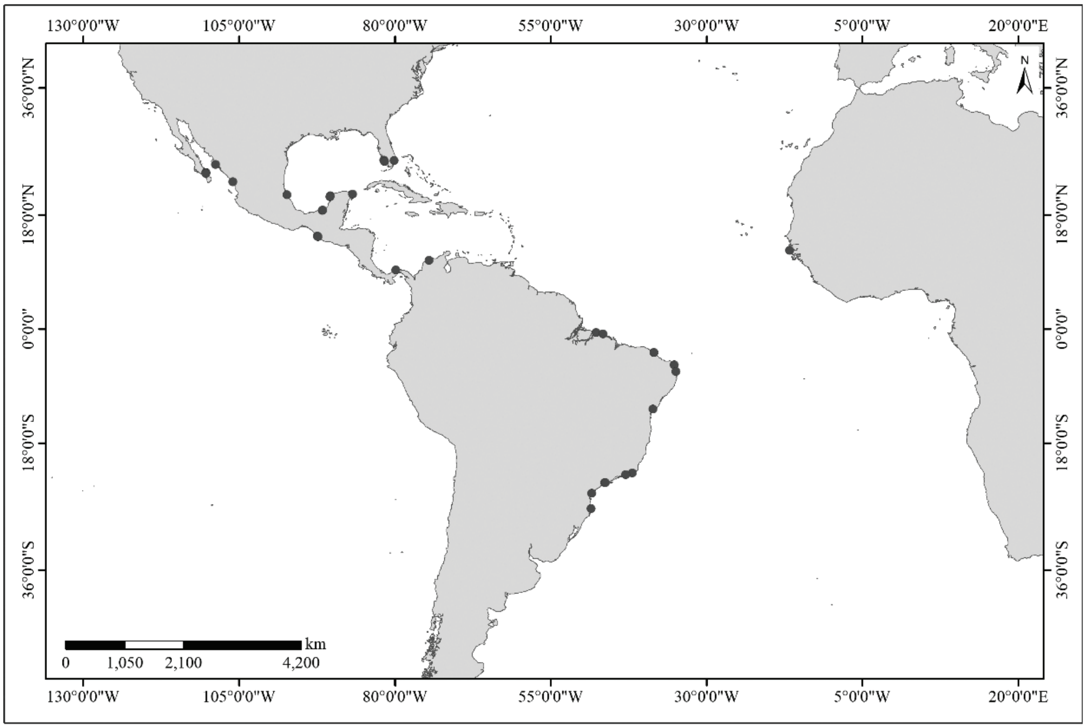

Figure 2b. Major mangrove restoration/rehabilitation sites in Atlantic-East Pacific (López-Portillo *et al.,* 2017)

In a world of diminishing natural ecosystems, preserving biological diversity, ecosystem integrity and health are the fundamental priorities for conservation (Trombulak *et al.*, 2004). Thus, the scale of nature conservation changed from the species to the ecosystem level, and recent efforts are focused on ecosystem-based management approaches (Mace, 2014). However, conservation measures of mangroves have not been changed much, despite of our improved understanding of their ecological and economic benefits. Mangroves are species-poor compared with other tropical ecosystems (Alongi, 2002) and the mangrove plants are considered to be the foundation species that create habitat, modulate ecosystem functions, and support entire ecological communities (Ellison *et al.* 2005). Due to the critical role of plants in mangrove ecosystems, changes in plant coverage and composition have important implications for the provision of coastal wetland ecosystem services (Osland *et al.*, 2018).

However, we know only little about functional species-redundancy of these ecosystem engineers. Yet, about 16% of mangrove species are at elevated threat of extinction (Polidoro *et al*. 2010). Loss of these keystone species of mangrove ecosystems will have devastating economic and environmental consequences for coastal communities (Polidoro *et al.*, 2010). However, far little effort has been made to increase the population size of the species at elevated risk of extinction. Globally, current management and policy-making efforts have not been fully successful in ensuring the conservation and sustainable use of mangrove resources (Romañacha *et al.*, 2018). Among many reasons, the important one is the failure to integrate differing spatial and temporal scales at which mangrove ecosystem services are provided (ecological provisional scale) with the scales at which the management, policy and utilization institutions operate (social demand scale) (Duke *et al.*, 2007; Friess *et al.*, 2016; Dharmawan *et al.*, 2016; Romañacha *et al.*, 2018; Amir, 2018).

SITE-SPECIFICITY VERSUS GLOBAL GENERALIZATION

Mangrove research over the last several decades has revealed that biodiversity, structure and processes of mangrove ecosystems are site-specific (Duke *et al*., 1998; Binks *et al*., 2018). Within a given mangrove habitat, local abiotic and biotic factors (e.g. hydrology, geomorphology, salinity, competition, facilitation etc.) greatly influence the diversity, structure and processes, despite climatic drivers (i.e., temperature and precipitation regimes) that control the distribution and species richness on global scale. For instance, mangrove zonation, once presumed to be a feature of mangroves worldwide (Chapman, 1975; Snedaker, 1982), turns out to be site specific rather than the regional generalization (Bunt *et al*., 1991; Bunt, 1996, 1999; Bunt and Bunt, 1999; Bunt and Stieglitz, 1999; Ellison *et al*., 2001; Schmiegelow *et al*., 2014). Similarly, it was previously assumed that mangroves are genetically undifferentiated throughout their range due to long-distance dispersal of propagules by sea currents (Duke *et al*., 1998; Maguire *et al*., 2000).

However, recent molecular studies show strong genetic differentiation among populations of many mangrove species (Yang *et al*., 2016; Guo *et al*., 2016; Yang *et al*., 2017; Guo *et al*., 2017; Guo *et al*., 2018), indicating reduced gene flow among populations and potentially strong local adaptation. This low genetic diversity warrants low resilience of mangroves against climate change (Guo *et al*., 2018). The provisioning of ecosystem services by mangroves, such as coastal protection (Lee *et al*. 2014) and carbon storage (Atwood *et al*., 2017; Perez *et al*., 2018; Rovai *et al*., 2018; Twilley *et al*., 2018), vary among mangrove stands with respect to species composition and environmental settings. Mangrove responses to climate change differ between regions (Ward *et al*., 2016). For instance, many recent studies have described that vertical adjustment and horizontal movement of mangroves to cope up with sea-level rise 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. Thus, even along the same coast, mangrove response to climate change varies.

In addition, impacts of coastal developmental activities are spatially differentiated, time-dependent, and linked to varying sets of proximate activities and causal drivers (Chowdhury *et al*., 2017b). The causal drivers of mangrove degradation often operate in combination rather than separately and they are spatially limited. Thus, the gradual decrease and eventual loss of mangroves due to small scale disturbances are a major threat to mangroves globally (Lewis *et al*., 2016). Conservation and policymaking should be based on data and knowledge. However, mangrove conservation measures are triggered by intensive unsustainable utilization and they have rarely been adjusted according to recent improvement in the scientific understanding of mangroves. Based on the available literature, it is apparent that structure and processes of mangrove ecosystems are site-specific, and knowledge of generalizations on a global scale remains limited in mangrove conservation endeavours. So, site specific understanding of various components of mangroves (viz., species composition and distribution, forest structure, genetic diversity, faunal diversity, microbial diversity, and environmental settings and physico-chemical properties of soil), incorporating adjacent coastal ecosystems and their responses to environmental stressors, is imperative to ensure the sustainability of mangroves.

SHIFT IN MANGROVE CONSERVATION ENDEAVOURS

Recently, the ineffectiveness of many existing conservation measures became widely recognised. Several approaches to tackle this were proposed for mangrove management, specifically to better incorporate hitherto often unaccounted aspects such as biodiversity, complexity of social-ecological systems, ecosystem processes, and the need for stakeholder participation (Figure 3). For instance, Borges *et al.* (2017) have emphasised the integration of social-ecological data, anthropogenic threats and regional peculiarity in policymaking to enhance the sustainable use of mangrove resources. Helfer and Zimmer (2018) have highlighted the prioritization of spatial conservation for sustainable use and provisioning of ecosystem services of mangroves and proposed a "Traffic Light Concept", assigning distinct conservation priorities and levels (e.g., strict closure vs sustainable use) to distinct areas, based on biodiversity and ecosystem processes assessed through high-throughput techniques (Environmental DNA Metabarcoding and Environmental Metabolomics).

Zimmer (2018) proposed "Ecosystem Design" - an approach to design intended novel functioning of ecosystems in degraded areas to ensure particular services that are locally or regionally required for the well-being of mankind, taking into account of local habitat peculiarities and other environmental conditions (natural or man-made), as well as the pool of regionally available native species as service-providing units. Faridah-Hanum *et al.* (2019) formulated Mangrove Quality Index (MQI) to assess mangrove ecosystem health, which took into consideration of the mangrove forest, contributing components of a mangrove forest, soil, surrounding marine ecosystem, hydrology and socio-economic variables. Ellison *et al.* (2020) proposed the adaptive management of restored/rehabilitated mangroves areas - a structured, iterative process of "learning-by-doing" and decision-making in the face either of continuous change (environmental, social, cultural, or political) or uncertainty, through regular monitoring of key indicators of the objectives and goals of a rehabilitation /restoration project and identifying the clear triggers or decision-points for appropriate intervention and action if the objectives or goals are not being met.

All these considerations are reflected to some extent in the widely-accepted shift to the more holistic approach known as 'Ecosystem-Based Management' (EBM), making use of site-specific (biodiversity, habitat characteristics, ecological process) and species-specific information (distribution, habitat requirements) to ensure the persistence of mangroves in a given area. EBM is driven by recognition of the failure of conventional management practices to protect marine ecosystems from over-exploitation (Crain *et al*., 2009) and aims at achieving conservation, sustainable utilization and fair allocation of benefits from natural resources, thereby striking a balance between short-term needs and sustainability (Cowan *et al.*, 2012). EBM is emphasising the connectivity within and among systems, focussing on the consequences of human actions within a specific ecosystem (or linked adjacent ecosystems), providing prominence to the protection and restoration of ecosystem structure and key processes, and integrating the biological, socioeconomic and governance perspectives (Clarke and Jupiter, 2010). However, EBM lacks a universal implementation framework, taking many different forms with various combinations of principles.

Recently Long *et al.* (2015) brought up a set of 15 key principles of EBM, from a theoretical and conceptual perspective that is considered necessary for successful implementation. Further, they identified five key principles viz., Ecosystem Connection, Appropriate Spatial and Temporal Scales, Adaptive Management, Use of Scientific Knowledge, and Stakeholder Involvement and Integrated Management as the most important for EBM. Some principles that directly emerge out from these key principles are "Consider Cumulative Impacts", "Apply the Precautionary Approach" and "Explicitly Acknowledge Trade-Offs". It is apparent that EBM requires more precise information of various components of a given ecosystem to be managed. Thus, we are still a long way from the formulation of EBM with adequate knowledge of various components of mangrove ecosystem, but the urgency of the situation demands "informed guesswork" based on the available information with parallel efforts to fulfil the needs of effective implementation of site-specific EBM.

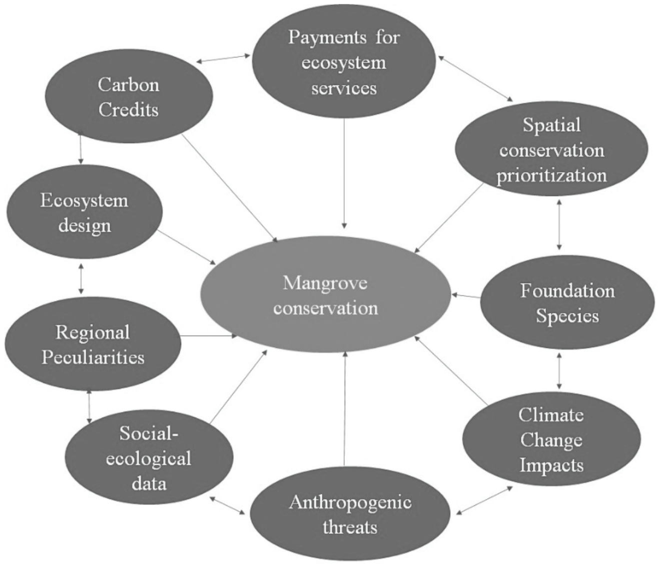

Figure 3. Schematic representation suggested for better management of mangroves

NEED OF THE HOUR

It is widely recognized that adaptive potential promotes resilience of species to recover from disturbances, and thereby improving the effectiveness of conservation practices (IPCC, 2014). Thus, determining the physiological, ecological and genetic processes underpinning the adaptive potential of species is a key focus for conservation approach (Wee *et al.*, 2018; Osland *et al*., 2019; Rilov *et al*., 2019). 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).

Despite being threatened by human developmental activities and climate change, the mangrove forests are highly resilient ecosystems that have the potential to adapt and adjust to changing conditions (Woodroffe *et al*., 2016). This is evident by recent expansion of mangroves towards polar regions in response to increasing minimum winter temperature (Saintilan *et al.*, 2014) as well expansion and contraction in response to temperature fluctuations and Pleistocene sea level drop and rise in the long past (Ludt and Roacha, 2014). Vertical adjustment and horizontal movement across the landscape are the processes that govern the responses of mangrove forest to sea-level rise (Woodroffe *et al*., 2016; Krauss *et al*., 2014; Lovelock *et al*., 2015). Furthermore, the observed higher expression diversity than the genetic diversity and smaller genome size warrants the significant evolutionary potential of mangroves (Lira-Medeiros *et al*., 2010; Wee *et al*., 2018; Lyu *et al*., 2018).

Adaptive potential of populations/species is often measured in terms of genetic diversity. Thus, 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). However, little has been translated into on-the-ground conservation (Wee *et al*., 2018). The emerging new technologies like NGS (Next Generation Sequencing) need to be incorporated into future efforts. Since ecological condition and evolutionary processes act at overlapping time scales, maintaining the better ecological condition and minimal habitat destruction will facilitate the adaptive potential of mangroves. Hence, preserving the ecological health of the existing mangroves is need of the hour for maximizing the adaptive potential of mangroves and sustaining the manifold services.

Three decadal restoration/rehabilitation efforts taught the lesson that understanding the ecology and hydrology is the key for effective restoration initiatives worldwide, and when appropriate hydrological conditions are restored, mangroves can fully develop and function as natural stands without the requirment of futher human intervention (Lewis *et al*., 2016). Thus, preserving the hydrological connectivity of existing mangroves, facilitating the connectivity between adjacent ecosystems, and protecting the natural corridors are the potential strategies to enhance the ecological health of existing mangroves. To achieve this, an effective site-specific, long-term and integrated ecosystem-based protection, management and rehabilitation strategy with sound scientific knowledge and effective legislative measures to limit/regularize the coastal developmental activities is imperative. In this regard, a few essential measures are suggested as given-below.

Strengthening the legislation to control coastal developmental activities

Coastal areas are the hot spots of developmental activities and hence they continue to be threatened, despite the strong legislative measures. It has been experiential that irrespective of climate change and persisting natural calamities, anthropogenic interventions are the root causes of the degradation of mangroves worldwide (DasGupta and Shaw, 2013; Table 3). According to recent estimates, the net loss of global mangroves is over 6,000 km^2, or 4% of the 1996 coverage. In addition, an area of 1,389 km2 has been degraded (Table 1). The conversions of mangrove forests to aquaculture and rice plantations are the biggest drivers of loss (>50%) and fragmentation in Southeast Asia, a global hotspot of mangrove loss (Bryan-Brown *et al*., 2020). So, it is also apparent that rapid coastal development has a considerable and lasting effect on coastal ecosystems like mangroves (Murray *et al*., 2019).

Thus, controlling new coastal developments requires immediate priority. Certainly, compared to the situation in the past decades, mangrove degradation rates have slowed down in recent times. This can be attributed to expanded rehabilitation and natural regeneration. However, considering the massive failure of restoration/rehabilitation efforts and lack of proper documentation of functionality of restored/rehabilitated mangroves, it is evident that the role of restoration/rehabilitation in the slowdown of degradation rates of mangroves is not straightforward. The key driver of the recent slowdown can be the increased resilience/natural regeneration, attributed to significant reduction in the resource extraction by local communities and agencies resulting from legislative measures. Hence, strengthening the legislative measures requires immediate action and is as important as mangrove rehabilitation, economic improvement, and other technical and data-driven aspects of management (Eriksson *et al*. 2016).

Mangroves are often regulated under legal frameworks created originally for forests, environment, water, land, or marine fisheries (Rotich *et al*., 2016), and laws and policies of mangroves are rarely designed for the specific management requirements (Table 4). In many nations, the legislative definition of mangroves covers only the wooded component of the forest ecosystem. Thus, the existing legislation indirectly facilitates developmental activities such as aquaculture, construction of ports, industries, thermal power stations etc., in the vicinity of a mangrove area, particularly mudflats and intertidal flats like salt pans, under the umbrella of national development. These developmental activities are a potential threat to mangroves, although not creating immediate effects. In the long run, they have the potential to gradually reduce health and integrity, and thus ecosystem service-provisioning of the mangroves. Particularly, hydrological connectivity viz., amount, quality, quantity, and timing of freshwater and sediment delivery to estuaries and mangrove forests has drastically altered by coastal developmental activities (Howard *et al*., 2017). Further the damming of tropical rivers, with the subsequent reduction of sediment load reaching the coasts, has highly destructive effects on the stability and productivity of the coastal and estuarine ecosystems particularly mangroves (Ezcurra *et al*., 2019).

Table 3. The most common threats to specific mangrove regions (Source: Lavieren e*t al*., 2012).

Region	Threats
North and Central America	Development (coastal, tourism, urban), hurricanes, land conversion to agri/aquaculture, pollution
South America	Land conversion to agri/aquaculture
West and Central Africa	Development (urban), degradation, land conversion to agriculture, oil/gas extraction, pollution
East Africa	Clearing, degradation, land conversion to agri/aquaculture, overharvesting, pollution, sedimentation
Middle East	Degradation, development (coastal, tourism, urban), land reclamation, poor planning, oil spills, overharvesting, sedimentation
South Asia	Disease (top-dying), erosion, encroachment, land conversion to agri/aquaculture, reduced freshwater flow, plantations, poor planning, storms
South-East Asia	Land conversion to agri/aquaculture, development (coastal, urban), disease, industrial overharvesting, overfishing, gas extraction, poor planning and enforcement, pollution, sedimentation
East Asia	Development (coastal), land conversion to agri/aquaculture, overharvesting, pollution, unsustainable timber harvested
Australasia	Development (coastal, urban), land reclamation, oil spills, pollutants (agricultural), storms
Pacific Ocean	Development (coastal, tourism, urban), overharvesting, overfishing, pollution, sedimentation (from mining)

Like all estuarine ecosystems, mangrove forest structure, function, and stability are greatly influenced by hydrological, salinity, and sediment delivery regimes, and these abiotic factors are often modulated by estuarine freshwater inputs. So, it is imperative to ensure the minimum freshwater inputs and hydrological regimes that are needed to sustain mangrove ecosystems for future generations (Osland *et al*., 2018). 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 such that they allow long shore sediment transport to coastal areas. In cases of sediment starvation, it may be necessary to artificially enhance sediment retention and supply through the placement of permeable dams to trap sediment, or 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. 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 like mangroves due to higher supply of fluvial sediments, nutrients, lower exposure to sulphates and reduced salinity. On the contrary, decrease in precipitation and increases in evaporation are also observed in some places leading to increased soil salinity and reduced productivity.

So, predicting the changes in future rainfall patterns will be useful to make precautionary measures necessary to maintain the hydrological connectivity of mangroves. In addition, mangroves are closely interconnected to adjacent ecosystems, both seawards (coral reefs and seagrass beds) and landwards (flooded wood- and grasslands, including salt marshes and tidal freshwater forests, adjacent mudflats and intertidal flats, salt flats, salt pans, salinas, salt barrens, apicuns, tannes and coastal sabkhas). Hence, the legislative definition of mangroves should be changed to "mangroves as an integrated system", as suggested by Borges *et al.* (2017), in order to maintain the link between mangroves and adjacent ecosystems, which will facilitate ecosystem service-provisioning by mangroves. Historical evidences and recent phylogeographic studies revealed that mangroves witnessed contraction and expansion with respect to changes in sea level during the Pleistocene period. So, it is suggested here to include 50-100m as the "No Development Zone" along the periphery of mangroves irrespective of size of the mangrove area, because small patches also provide significant ecological services (Curnick *et al*., 2019), to freeze the developmental activities in the vicinity of mangroves, and to maintain the interconnection between adjacent ecosystems and hydrological connectivity and to preserve the natural corridors.

Various landscapes and land use forms in the "No Development Zone" should be assessed in detail to formulate the effective guidelines to regulate the already existing developments activities. In addition, the rivers - the roots for stability of coastal wetlands – must 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. Overall, a strong policy framework, effective implementation and long-term monitoring are required to protect the existing mangroves from climate change and environmental pollution, generated from upstream man-made activities.

Stop ineffective rehabilitation/restoration

Salt marshes, mud flats and intertidal flats are the natural corridors of mangroves for dealing with sea level rise. Yet, in terms of restoration (the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed) and rehabilitation (reparation of ecosystem processes, productivity and services), mangroves are often planted on these natural corridors with the aim of increasing the mangrove coverage without understanding or even taking into account habitat characteristics and coastal dynamics (Sharma *et al*., 2017; López-Portillo *et al.*, 2017). Erftemeijer and Lewis (1999) have commented that planting of mangroves on mudflats represents habitat conversion rather than habitat restoration, and have strongly cautioned against the ecological wisdom of opting for such strategies. Recently Lee *et al.* (2019) also commented that despite the short-term increases in area, practice of large-scale monogeneric planting aimed at reversing mangrove losses could not offset for the continual destruction of established forests. Further, most of the restoration and rehabilitation efforts are focused on establishing forest cover often for timber value and coastal protection without directly considering further on biodiversity components, such as tree or structural diversity (Lewis, 2000; Ellison, 2000). Thus, most rehabilitation/restoration efforts thus far ended as failure.

A recent estimate has identified an area of 8,120 km^2 suitable for global mangrove restoration (Tables 1 and 5). Of which, 6,630 km^2 are highly restorable. In addition, 1,389 km^2 of degraded mangrove areas are identified suitable for restoration (Worthington and Spalding, 2019). "Community based rehabilitation" or "Community based ecological mangrove rehabilitation" is a successful approach for mangrove restoration/rehabilitation (Selvam *et al*., 2003; Datta *et al*., 2012; MacKenzie *et al*., 2019), which emphasizes the use of local ecological knowledge to substitute for baseline information gaps (e.g., detailed reference site topography and hydrology). The successful cases of community based restoration/ rehabilitation are evident at Pichavaram, India (Selvam *et al*., 2003), Pred Nai village in Trat province, Thailand (On-prom, 2014), Banacon Island in Bohol Province, Phillipines (Phulhin *et al*., 2017), Volta estuary catchment area of Ghana (Aheto *et al.*, 2016), and Tanakeke Island of South Sulawesi Province, Indonesia (Brown *et al*., 2014). The restoration success is also evident at 93 sites, based on an assessment of 166 documented restoration efforts in 24 countries (Worthington and Spalding, 2019).

Table 4. Major legislative arrangements for mangrove protection in selected countries of South and South East Asia

Country	Main governing body	Legislative measure
India	Ministry of Environment and Forest and Climate Change	Indian Forest Act of 1927; Wildlife (Protection) Act, 1972; Water Prevention and Control of Pollution Act, 1974; Forest Conservation Act, 1980; Environmental Protection Act of 1986; National Forest Policy, 1988; Environmental Impact Assessment Notification (EIA) of 1994; Coastal Aquaculture Authority Act, 2005; Wetland (Conservation and Management) Rules 2017; Coastal Regulation Zone (CRZ) Notification, 2018; National wetland management Programme (NWMP); National Lake Conservation Plan (NLCP); National River Conservation Plan (NRCP).
Pakistan	Provincial Forest Departments	Forest Act, 1927; National Action Plan on Environment.
Bangladesh	Ministry of Environment and Forest	Forest Act, 1927; Forest Policy, 1994; Environmental Regulations, 1997; Coastal Zone Policy, 2005;
Myanmar	Ministry of Forests	Forest Act, 1995; Forest Policy, 1995
Thailand	Royal Forestry Department and Ministry of Natural Resources and Environment	National Forest Reserves Act, 1964; Community Forestry Bill, 2007; Land Development Act, 1983; Enhancement and Conservation of National Environment Quality Act, 1992.
Vietnam	Ministry of Natural Resources and Environment and Ministry of Agricultural and Rural Development	Forest Protection and Development Law, 2004; Land Law, 1993; Environment Protection Law, 1994; Decree 25.
Malaysia	Department of Forestry (Provincial Government)	National Forestry Act, 1984; 9th Malaysian Plan (2006–2010); Environment Quality Act, 1974; Merchant Shipping (Oil Pollution) Act of 1994.
Indonesia	Ministry of Forestry	Presidential Decree 32 (1990)/Law no.5 (1990); Law no. 27 (2008); Law no. 32 (2009); Decree no. H.1/4/2/18/1975.
Philippines	Department of Environment and Natural Resource	Republic Act 7586 (1992); Republic Act 8371 (1997); Republic Act 8550 (1998); Coastal Zone Management Plan, 1997; Presidential Decree no. 979 (1976); DENR A.O. 76 (1987).

(Source : DasGupta and Shaw, 2013)

However, functionality of restored/rehabilitated areas are rarely monitored to fully ascertain mangrove restoration success 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 most projects are short in duration (<3 years) and do not devote funding for adequate maintenance and monitoring periods (Roderstein *et al*., 2014). Thus, long-term sustainable financial support is crucial for successful community-based restoration/rehabilitation. Median costs of mangrove restoration is around US$3000 per hectare (Bayraktarov *et al*., 2016), however where large-scale engineering to restore hydrology, combined with high staffing costs leads to projects costing over US$100,000 per hectare (Worthington and Spalding, 2019). So, mangrove restoration/rehabilitation is expensive for many developing nations' especially South East Asian countries. Thus, investments in large-scale planting must be the last option. Rehabilitation of abandoned aquaculture areas should be directed to hydrological correction (Lewis *et al*., 2016) to facilitate natural recruitment of mangroves and also improving soil fertility.

Table 5. Restorable areas and degraded areas for mangroves of selected countries

Country	Restorable area (km^2)	Proportion of original mangrove areas restorable	Extent of highly restorable mangrove areas (km^2)	Area of degraded mangrove areas (km^2)
Australia	336	3.3%	314	54
Bangladesh	138	3.2%	129	1
Belize	65	12.9%	64	3
Brazil	491	4.2%	476	58
Colombia	216	8.6%	51	15
Cuba	160	4.5%	74	68
Ecuador	107	6.7%	26	1
Ghana	22	9.6%	22	2
Honduras	70	12.2%	69	3
India	152	4.1%	126	12
Indonesia	1,866	6.4%	1,616	419
Malaysia	168	3.4%	157	63
Mexico	1,455	12.8%	993	33
Mozambique	259	8.0%	258	40
Myanmar	436	7.9%	431	295
Nicaragua	104	10.6%	99	16
Nigeria	110	1.7%	105	0
Papua New Guinea	135	2.7%	126	4
Philippines	156	5.4%	129	14
Sri Lanka	29	12.1%	24	1
Thailand	175	6.9%	78	8
United States	227	10.5%	204	2
Venezuela	120	4.1%	109	12
Vietnam	174	9.6%	149	43

(Source Worthington and Spalding, 2019)

Distinct priorities to distinct areas

Structure and functions of mangroves as well their ecological response against changing livelihood dependency of local communities are more of site specific. So, site-wise priorities will be useful for better policy making. Legislative measures often do not offer strict protection of all mangroves areas and are not strictly enforced. Further, societal acceptance for strict and complete protective measures is low, as stakeholders and users often depend on use of resources for their livelihood and well-being. Still, the mangrove areas under strict protection witness reduced degradation and increasing service-provisioning. However, a high dependency on mangroves by local communities in many countries raises a conflict of interest. The solution to this resides in assigning distinct priorities specific to areas by spatial conservation prioritization such as those implemented in the Marxan (Ball *et al.*, 2009) or Zonation (Moilanen *et al.*, 2005) frameworks, where both ecological values (such as biodiversity) of the system and their use by human societies (related to the ecosystem processes and services) can simultaneously be accounted for.

Recently, Helfer and Zimmer (2018) have outlined the spatial prioritization and planning of mangrove conservation on functional biodiversity and service-relevant ecosystem processes. The data often used for spatial prioritization are spatial distribution of species and/or ecosystem services (e.g., Chan *et al.*, 2006; Leathwick *et al.*, 2008). Although country-wise species compositions of mangroves are known from comprehensive reviews and databases, detailed spatial distribution of mangroves remains unknown in many countries. Thus, efforts should be taken to assess the site-specific spatial distribution of mangroves. Additional data on distribution of threats to biodiversity or service-provisioning, connectivity of mangroves and adjacent coastal, marine and terrestrial ecosystems can also be profitably used in spatial conservation planning (Helfer and Zimmer, 2018).

By this approach, mangrove areas can be categorised broadly into areas with highest versus low human impacts through considering both the degree of existing threats from land-use and/or environmental change and the dependency of local community on the respective ecosystem. For such an approach, demarcation of mangrove habitats and adjacent land-use is imperative. The potential of remote sensing in mapping of mangroves and assessing the different landscapes and land-use patterns, along with chemical and genetic high-throughput techniques put forward by Helfer and Zimmer (2018), cannot be overestimated for identifying potential threats (developmental activities) and natural corridors in the vicinity of mangroves. Areas with still healthy but delicate mangroves need to be protected strictly, whereas healthy areas with predicted high tolerance and/or resilience to human impacts can be used in sustainable ways, considering livelihood activities of adjacent communities. Both developmental activities and sustainable use needs to be assessed, legally regularized and subjected to strict monitoring. Based on the available data, many subsistence-driven activities of local communities (except for excessive wood-extraction) do not cause drastic change in mangroves, whereas increased developmental activities affect mangroves.

Species-specific research/restoration

The primary factor that distinguishes wetlands like mangroves from other landforms or water bodies is the characteristic vegetation of aquatic plants, adapted to the unique hydric soil. The foundation species of the vegetation modify the abiotic conditions that are stressful to organisms thereby providing the primary habitat to support entire ecological communities. Mangrove trees are keystone species and their responses to climate change processes are expected to be greatly influenced by plant-mediated processes. Recently, the need of better understanding of foundation species of coastal wetlands is a matter of necessity (Osland *et al.*, 2019) for effective adaptive marine conservation planning, along with 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).

So, there is clearly a need for more site-specific and species-specific research to better understand the mangrove responses to rising sea levels, changing temperature and precipitation regimes and growing developmental activities. Thus, understanding the species composition of mangroves, the spatial distribution of mangrove species and habitat suitability will help avoiding species loss and designing species-specific conservation efforts with the aim of sustainably providing ecosystem services. Sarker *et al.* (2016) showcased the usefulness of habitat suitability models with detailed information on species-specific habitat requirements to identify suitable habitats of threatened mangrove species and in guiding habitat restoration, protection, and replanting projects. This will be explicitly useful for species-specific spatial conservation measures for threatened species.

Long-term monitoring for early implementation of ecosystem design

Mangroves naturally have the potential to withstand certain degree of biotic and abiotic stressors. Thus, anthropogenic or climate change-impacts are often gradual in mangroves and they vary among mangrove stands, based on the degree of stress. Long-term monitoring of changes in hydrological and ecological status of mangroves will be useful to take effective measures, e.g., the implementation of Ecosystem Design, to prevent the complete loss of plant community structure and ecological functioning (Lewis *et al*., 2016). Monitoring the full range of intertidal and deltaic dynamics over large areas was challenging, but new advances in remote sensing technologies enable us to measure and monitor processes that are affecting the coastal environment on large spatial scales (Murray *et al.*, 2019).

Streamline future research for site-specific information

Conservation and policy making should start with right data. However, the lack of enough data is still a major impeding factor for successful mangrove conservation. Despite considerable work on the floristics and ecology of mangroves, they remain underexplored for forest structure, faunal diversity, genetic diversity, physico-chemical properties of sediments, microbial diversity, ecosystem services and their economic values and, all of which are prerequisites for an effective implementation of EBM. Since all these components are highly variable among mangrove forests, site-specific information is precious.

As mangroves are highly dynamic, having witnessed drastic changes in the past and experiencing ongoing climate consequences, additional information is to be considered in policy-making with regard to the connectivity of mangroves and adjacent coastal, marine and terrestrial ecosystems, recent changes in the distribution, species composition and/or health status, the distribution of threats to biodiversity or service-provisioning and possible impact of climate change. To transform the current conservation measures of mangroves into effective EMB-based measures, a multi-disciplinary approach to critically revisit the available information and make efforts to fill knowledge gaps for better policy making is warranted.

CONCLUSION

Human activities significantly altered the land (75%) and ocean areas (66%; Tollefson, 2019) and man-made demand on the living resources now exceeds its capacity to regenerate by 30% (WWF, 2008). Particularly, wetland ecosystems are among the most harmed, with nearly 50% loss since 1900 (Li *et al*., 2018). In case of the mangroves, habitat destruction for agricultural and aquaculture practices remains the major threat. Ecosystem destruction will reduce the products and services that people can draw from the environment in future. So without limiting the human activities, the rate of mangrove degradation will continue to increase. In addition, the interactive effect of global change is expected to cause impulsive ecological consequences (Harris *et al*., 2018; Sippo et al., 2018). While some interactions between global change drivers can lead to mangrove mortality and loss, others can lead to mangrove expansion at the expense of other ecosystems (Osland *et al.*, 2018). Hence, preserving the ecological health of existing mangroves is a need of the hour. Massive rehabilitation/restoration efforts with huge financial support and manpower did not reverse global mangrove loss as wells as the sustainability, whereas legislative protection, despite the poor enforcement, has prevented certain level of the habitat conversion thereby supporting the natural regeneration. Thus, restructuring of legislative framework, strict enforcement and monitoring should be prioritized for better protection of ecological health of existing mangroves. Since structure and functions of mangroves 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 the mangroves rather than converting them to other uses (Lee *et al*. 2019). The conservation value of mangroves can also be improved through flagship, charismatic and globally threatened macrofauna like Royal Bengal Tigers in Sundarbans, proboscis monkey in Borneo, and sail fin lizards in Philippines mangroves.

Acknowledgements : The first author acknowledges the Science and Engineering Research Board (SERB), DST, New Delhi for funding under National Post-Doctoral Fellowship scheme to carry out the work.

REFERENCES

Addison, P. F. E., Flander, L. B. and Cook, C. N. (2015) Are we missing the boat? Current uses of long-term biological monitoring data in the evaluation and management of marine protected areas. *Journal of Environmental Management* 149 : 148–156.

Agoramoorthy, G., Chena, F. and Hsu, M. J. (2007) Threat of heavy metal pollution in halophytic and mangrove plants of Tamil Nadu, India. *Environmental Pollution* 155 : 320–326.

Aheto, D. W., Kankam, S., Okyere, I., Mensah, E., Osman, A., Jonah, F. E., Mensah, J. C. (2016). Community-based mangrove forest management: Implications for local livelihoods and coastal resource conservation along the Volta estuary catchment area of Ghana. *Ocean and Coastal Management* 127 : 43-54.

Almeida, L. T. D., Olimpio, J. L. S., Pantalena, A. F., Almeida, B. S. D. and Soares, M. D. O. (2016). Evaluating ten years of management effectiveness in a mangrove protected area. *Ocean and Coastal Management* 125 : 29–37.

Alongi, D. M. (2002) Present state and future of the world's mangrove forests. *Environmental Conservation* 29(3) : 331–349.

Amir, A. A. (2018) Mitigate risk for Malaysia's mangroves. *Science* 359(6382) : 1342-1343.

Ashbridge, E., Lucas, R., Ticehurst, C. and Bunting, P. (2016). Mangrove response to environmental change in Australia's Gulf of Carpentaria. *Ecology and Evolution* 6 : 3523–3539.

Atwood, T. B., Connolly, R. M., Almahasheer, H., Carnell, P. E., Duarte, C. M., Lewis, C. J. E., Irigoien, X., Kelleway J. J., Lavery, P. S., Macreadie, P. I., Serrano, O., Sanders C. J., Santos, I., Steven, A. D. L., Lovelock, C. E. (2017). Global patterns in mangrove soil carbon stocks and losses. *Nature Climate Change* 7 : 523–528.

Bala Krishna Prasad, M. (2012) Nutrient stoichiometry and eutrophication in Indian Mangroves. *Environmental Earth Sciences* 67 : 293–299.

Ball, I. R., Possingham, H. P. and Watts, M. (2009) Marxan and relatives: software for spatial conservation prioritisation. In: Moilanen, A., Wilson, K. A., Possingham, H. P. (eds) *Spatial conservation prioritization: quantitative methods and computational tools*. Oxford University Press, Oxford, pp 185–195.

Begam, M. M., Sutradhar, T., Chowdhury, R., Mukherjee, C., Basak, S. K. and Ray, K. (2017). Native salt-tolerant grass species for habitat restoration, their acclimation and contribution to improving edaphic conditions: a study from a degraded mangrove in the Indian Sundarbans. *Hydrobiologia.* doi:10.1007/s10750-017-3320-2.

Bennett, N. A. and Dearden, P. (2014). From measuring outcomes to providing inputs: governance, management, and local development for more effective marine protected areas. *Marine Policy* 50 : 96–110.

Bhattacharya, B., Sarkar, S. K. and Mukherjee, N. (2003) Organochlorine pesticide residues in sediments of a tropical mangrove estuary, India: implications for monitoring. *Environment International* 29 : 587–592.

Binks, R. M., Byrne, M., McMahon, K., Pitt, G., Murray, K. and Evans, R. D. (2018). Habitat discontinuities form strong barriers to gene flow among mangrove populations, despite the capacity for long-distance dispersal. *Diversity and Distributions*. doi:10.1111/ddi.12851.

Borges, R., Ferreira, A. C. and Lacerda, L. D. (2017) Systematic Planning and Ecosystem-Based Management as Strategies to Reconcile Mangrove Conservation with Resource Use. *Frontiers in Marine Science* 4 : 353. doi: 10.3389/fmars.2017.00353.

Bosire, J. O., Dahdouh-Guebas, F., Walton, M., Crona, B. I., Lewis, R. R., Field, C. and Koedam, N. (2008). Functionality of restored mangroves: a review. *Aquatic Botany* 89(2) : 251–259.

Brown, B, Fadilla R, Nurdin Y, Soulsby I, Ahmad R (2014b) Community based ecological mangrove rehabilitation (CBEMR) in Indonesia. *SAPIENS* 7: 53–64.

Brown, B., Yuniati, W., Ahmad, R. and Soulsby, I. (2014a). Observations of natural recruitment and human attempts at mangrove rehabilitation after seismic (tsunami and earthquake) events in Simulue Island and Singkil Lagoon, Acheh, Indonesia. In Santiago-Fandino V, Kontar YA, Kaneda Y (eds), Post-Tsunami Hazard Reconstruction and Restoration. Springer, New York: 311–327.

Bryan-Brown, D. N., Connolly, R. M., Richards, D. R., Adame, F., Friess, D. A. and Brown, C. J. (2020). Global trends in mangrove forest fragmentation. *Scientific Reports* 10 : 7117. doi: 10.1038/s41598-020-63880-1.

Bunt, J. S. (1996). Mangrove zonation: an examination of data from seventeen riverine estuaries in tropical Australia. *Annals of Botany* 78 : 333–341.

Bunt, J. S. (1999). Overlap in mangrove species zonal patterns: some methods of analysis. *Mangroves and Salt Marshes* 3 :155–164.

Bunt, J. S. and Bunt, E. D. (1999). Complexity and variety of zonal pattern in the mangroves of the Hinchinbrook area, Northeastern Australia. *Mangroves and Salt Marshes* 3 : 165–176.

Bunt, J. S. and Stieglitz, T. (1999) Indicators of mangrove zonality: the Normanby river, N.E. Australia. *Mangroves and Salt Marshes* 3 : 177–184.

Bunt, J. S., Williams, W. T., Hunter, J. F. and Clay, H. J. (1991). Mangrove sequencing: analysis of zonation in a complete river system. *Marine Ecology Progress Series* 72 : 289–294.

Bunting, P., Rosenqvist, A., Lucas, R. M., Rebelo, L. M., Hilarides, L., Thomas, N., Hardy, A., Itoh, T., Shimada, M. and Finlayson, C. M. (2018) The Global Mangrove Watch-A New 2010 Global Baseline of Mangrove Extent. *Remote Sensing* 10: 1669. doi: 10.3390/rs10101669.

Castellanos-Galindo GA, Klunger LC, Tompkins P (2017) Panama's impotent mangrove laws. *Science* 355 (6328): 918-919.

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C. and Daily, G. C. (2006). Conservation Planning for Ecosystem Services. *PLoS Biology* 4(11): e379. https://doi.org/10.1371/journal.pbio.0040379.

Chapman, V. J. (1975). Mangrove biogeography. In: Walsh GE, Snedaker SC, Teas H (eds.) *Proceedings of International Symposium on Biology and Management of Mangroves.* Gainesville, FL: Institute of Food and Agricultural Sciences, University of Florida, pp. 3-22.

Chowdhury, R., Favas, P. J. C., Jonathan, M. P., Venkatachalam, P., Raja, P. and Sarkar, S. K. (2017a). Bioremoval of trace metals from rhizosediment by mangrove plants in Indian Sundarban wetland. *Marine Pollution Bulletin* 124 : 1078–1088.

Chowdhury, R. R., Uchida, E., Chen, L., Osorio, V. and Yoder, L. (2017b). Anthropogenic Drivers of Mangrove Loss: Geographic Patterns and Implications for Livelihoods. In Rivera-Monroy, V. H., et al. (eds.), *Mangrove Ecosystems: A Global Biogeographic Perspective*, Chapter 9, pp. 275–300.
Clarke, P. and Jupiter, S. (2010). Principles and Practice of Ecosystem-Based Management: A Guide for Conservation Practitioners in the Tropical Western Pacific. *Wildlife Conservation Society.* Suva, Fiji.
Cowan, J. H., Rice, J. C., Walters, C. J., Hilborn, R., Essington, T. E., Day, J. W. and Boswell, K. M., 2012. Challenges for implementing an ecosystem approach to fisheries management. *Marine and Coastal Fisheries* 4 : 496–510.
Crain, C. M., Halpern, B. S., Beck, M. W. and Kappel, C. V. (2009). Understanding and managing human threats to the coastal marine environment. *Conservation Biology* 1162 : 39–62.
Curnick, D. J., Pettorelli, N., Amir, A. A., Balke, T., Barbier, E. B., Crooks, S., Dahdouh-Guebas, F., Duncan, C., Endsor, C., Friess, D. A., Quarto, A., Zimmer, M., Lee, S. Y. (2019). The value of small mangrove patches. *Science* 363 (6424) : 239.
Dale, P. E. R., Knight, J. M. and Dwyer, P. G. (2014). Mangrove rehabilitation: a review focusing on ecological and institutional issues. *Wetland Ecology and Management* 22 : 587–604.
DasGupta, R. and Shaw, R. (2013). Cumulative Impacts of Human Interventions and Climate Change on Mangrove Ecosystems of South and Southeast Asia: An Overview. *Journal of Ecosystems.* Article ID 379429, 15 pages, doi.org/10.1155/2013/379429.
Datta, D., Chattopadhyay, R. N. and Guha, P. (2012). Community based mangrove management: a review on status and sustainability. *Journal of Environmental Management*. 107 : 84-95.
Dharmawan, B., Bocher, M. and Krott, M. (2016). The failure of the mangrove conservation plan in Indonesia: Weak research and an ignorance of grassroots politics. *Ocean and Coastal Management* 130 : 250–259.
Doyle, T. W., Smith III, T. J. and Robblee, M. B. (1995). Wind damage effects of Hurricane Andrew on mangrove communities along the southwest coast of Florida, USA. *Journal of Coastal Research* 21 : 159–168.
Duke, N. C., Ball, M. C. and Ellison, J. C. (1998). Factors influencing biodiversity and distributional gradients in mangroves. *Global Ecology and Biogeography* 7(1) : 27–47.
Duke, N. C., Kovacs, J. M., Griffith, A., Preece, L., Hill, D. J., van Oosterzee, P., Mackenzie, J., Morning, H. S. and Burrows, D. (2017). Large-scale dieback of mangroves in Australia's Gulf of Carpentaria: a severe ecosystem response, coincidental with an unusually extreme weather event. *Marine and Freshwater Research.* doi:10.1071/MF16322.
Duke, N. C., Meynecke, J. O., Dittmann, S., Ellison, A. M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K. C., Field, C. D., Koedam, N., Lee, S. Y., Marchand, C., Nordhaus, I., Dahdouh-Guebas, F. (2007). *A world without mangroves? Science* 317(5834) : 41–42.
Eizaguirre, C. and Baltazar-Soares, M. (2014). Evolutionary conservation—evaluating the adaptive potential of species. *Evolutionary Applications* 7 : 963–967.
Ellison, A. M. (2000). Mangrove restoration: do we know enough? *Restoration Ecology* 8 : 219–229.
Ellison, A. M., Bank, M. S., Clinton, B. D., Colburn, E. A., Elliott, K., Ford, C. R., Foster, D. R., Kloeppel, B. D., Knoepp, J. D., Lovett, G. M., Mohan, J., Orwig, D. A., Rodenhouse, N. L., Sobczak, W. V., Stinson, K. A., Stone, J. K., Swan, C. M., Thompson, J., Holle, B. V., Webster, J. R. (2005). Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and Environment* 3 : 479–486.
Ellison, A. M., Mukherjee, B. B. and Karim, A. (2001). Testing patterns of zonation in mangroves: scale dependence and environmental correlates in the Sundarbans of Bangladesh. *Journal of Ecology* 88 : 813–824.
Ellison, A. M., Felson, A. J., Friess, D. A. (2020) Mangrove Rehabilitation and Restoration as Experimental Adaptive Management. *Frontiers in Marine Sciences* 7: 327. doi: 10.3389/fmars.2020.00327.
Erftemeijer, P. L. A. and Lewis, R. R. (1999). Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion? In: Ecotone, VIIIth Seminar, Enhancing Coastal Ecosystem Restoration for the 21st Century, Ranong and Phuket, May 1999, pp. 1–11.
Eriksson, H., Adhuri, D. S., Adrianto, L., Andrew, N. L., Apriliani, T., Daw, T., et al. (2016) An ecosystem approach to small-scale fisheries through participatory diagnosis in four tropical countries. *Global Environmental Change Human and Policy Dimensions* 36: 56–66. doi: 10.1016/j.gloenvcha.2015.11.005

Eslami-Andargoli, L., Dale, P., Sipe, N. and Chaseling, J. (2009). Mangrove expansion and rainfall patterns in Moreton Bay, Southeast Queensland, Australia. *Estuarine, Coastal and Shelf Science* 85 : 292-298.

Ezcurra, E., Barrios, E., Ezcurra, P., Ezcurra, A., Vanderplank, S., Vidal, O., Villanueva-Almanza, L., Aburto-Oropeza, O. (2019). A natural experiment reveals the impact of hydroelectric dams on the estuaries of tropical rivers. *Science Advances* 5 : eaau9875.

Faridah-Hanum, I., Yusoff, F. M., Fitrianto, A., Ainuddin, N. A., Gandaseca, S., Zaiton, S., Norizah, K., Nurhidayu, S., Roslan, M. K., Hakeem, K. R., Shamsuddin, I., Adnan, I., Awang-Noor, A. G., Balqis, A. R. S., Rhyma, P. P., Siti Aminah, I., Hilaluddin, F., Fatin, R., Harun, N.Z.N. (2019). Development of a comprehensive mangrove quality index (MQI) in Matang Mangrove: Assessing mangrove ecosystem health. *Ecological Indicators* 102 : 103–117.

Feller, I. C., Friess, D. A., Krauss, K. W. and Lewis III, R. R. (2017) The state of the world's mangroves in the 21st century under climate change. *Hydrobiologia* 803: 1–12.

Fleischman, F. (2016). Understanding India's forest bureaucracy: a review. *Regional Environmental Change* 16 (Suppl 1) : S153–S165.

Friess, D. A., Thompson, B. S., Brown, B., Amir, A. A., Cameron, C., Koldewey, H. J., Sasmito, S. D., Sidik, F. (2016). Policy challenges and approaches for the conservation of mangrove forests in Southeast Asia. *Conservation Biology* 30 : 933–49.

Friess, D. A., Yando, E. S., Abuchahla, G., M, Adams, J. B., Cannicci, S., Canty, S. W. J., Cavanaugh, K. C., Connolly, R. M., Cormier, N., Dahdouh-Guebas, F., Diele, K., Feller, I. C., Fratini, S., Jennerjahn, T. C., Lee, S. Y., Ogurcak, D. E., Ouyang, X., Rogers, K., Rowntree, J. K., Sharma, S., Sloey, T. M., Wee, A. K. S. (2020). Mangroves give cause for conservation optimism, for now. *Current Biology* 30(4) : R153-R154.

Giri, C., Ochieng, E., Tieszin, L. L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N. C. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography* 20 : 154–159.

Glick, P. and Stein, B. A. (2010). Scanning the conservation horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington DC.

Guo, Z., Guo, W., Wu, H., Fang, X., Ng, W. L., Shi, X., Liu, Y., Huang, Z., Li, W., Gan, L., He, S., Zhong, C., Jian, S., Gong, X., Shi, S., Huang, Y. (2017). Differing phylogeographic patterns within the Indo-West Pacific mangrove genus Xylocarpus (Meliaceae). *Journal of Biogeography.* doi: 10.1111/jbi.13151.

Guo, Z., Huang, Y. J., Chen, Y., Duke, N. C., Zhong, C. and Shi, S. (2016). Genetic discontinuities in a dominant mangrove *Rhizophora apiculata* (Rhizophoraceae) in the Indo-Malesian region. *Journal of Biogeography* 43(9) : 1856–1868.

Guo, Z., Li, X., He, Z., Yang, Y., Wang, W., Zhong, C., Greenberg, A. J., Wu C. -I., Duke, N. C., Shi, S. (2018). Extremely low genetic diversity across mangrove taxa reflects past sea level changes and hints at poor future responses. *Global Change Biology* 24:1741–1748.

Hamilton, S. E. and Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest covers for the 21st century (CGMFC-21). *Global Ecology and Biogeography* 25(6) : 729–738.

Harris, R. M. B., Beaumont, L. J., Vance, T. R., Tozer, C. R., Remenyi, T. A., Perkins-Kirkpatrick, S. E., Mitchell, P. J., Nicotra, A. B., McGregor, S., Andrew, N. R., Letnic, M., Kearney, M. R., Wernberg, T., Hutley, L. B., Chambers, L. E., Fletcher, M.-S., Keatley, M. R., Woodward, C. A., Williamson, G., Duke, N. C., Bowman, D. M. J. S. (2018). Biological responses to the press and pulse of climate trends and extreme events. *Nature Climate Change* 8 : 579–587.

Helfer, V. and Zimmer, M. (2018). High-Throughput Techniques As Support for Knowledge-Based Spatial Conservation Prioritization in Mangrove Ecosystems. In *Threats to Mangrove Forests*, Makowski, C. and Finkl, C. W. (eds.), pp. 539-554.

Hoffmann, A. A. and Sgro, C. M. (2011) Climate change and evolutionary adaptation. *Nature* 470 : 479–485.

Howard, R. J., Day, R. H., Krauss, K. W., From, A. S., Allain, L. and Cormier, N. (2017). Hydrologic in a dynamic subtropical mangrove-to-marsh ecotone. *Restoration Ecology* 25 : 471–482.

Huxham, M., Dencer-Brown, A., Diele, K., Kathiresan, K., Nagelkaerken, I. and Wanjiru, C. (2017). Mangroves and People: Local Ecosystem Services in a changing Climate. Chapter 8. In: *Mangrove Ecosystems – A Global Biogeographic Perspective,* (V.H. Rivera-Monroy et al. eds.), Springer International Publishing AG, pp. 1245-274.

IPCC (2014) Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 1454 pp.
Islam, M. M., Sunny, A. R., Hossain, M. M. and Friess, D. A. (2018) Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. *Singapore Journal of Tropical Geography* 39 : 244–265.
IUCN and UNEP-WCMC (2019) www.protectedplanet.net.
Kathiresan, K. (2002) Why are mangroves degrading? *Current Science* 83 :1246–1249.
Kathiresan, K., Balasubramanian, R. and Sitrangoboopathy, N. (2020) Control of a dangerous pest on mangrove seedlings by organic fertilizer. *Indian Forester* 146(2) : 185-186.
Krauss, K. W., McKee, K. L., Lovelock, C. E., Cahoon, D. R., Saintilan, N., Reef, R. and Chen, L. (2014). How mangrove forests adjust to rising sea level. *New Phytologist* 202 : 19–34.
Lavieren, H. V., Spalding, M., Alongi, D. M., Kainuma, M., Clüsener-Godt, M. and Adeel, Z. (2012). *Securing the Future of Mangroves.* United Nations University Institute for Water, Environment and Health, Canada. pp.52.
Leathwick, J., Moilanen, A., Francis, M., Elith, J., Taylor, P., Julian, K., Hastie, T. and Duffy, C. (2008). Novel methods for the design and evaluation of marine protected areas in offshore waters. *Conservation Letters* 1 : 91–102.
Lee, S. Y., Hamilton, S., Barbier, E. B., Primavera, J. and Lewis III, R. R. (2019). Better restoration policies are needed to conserve mangrove ecosystems. *Nature Ecology and Evolution* 3 : 870–872.
Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., McKee, K., Bosire, J. O., Cannicci, S., Diele, K., Fromard, F., Koedam, N., Marchand, C., Mendelssohn, I., Mukherjee, N., Record, S. (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biogeography* 23 : 726–743.
Leverington, F., Lemos Costa, K., Pavese, H., Lisle, A. and Hockings, M. (2010). A global analysis of protected area management effectiveness. *Environmental Management* 46 : 685–698.
Lewis, R. R. (2000). Ecologically based goal setting in mangrove forest and tidal marsh restoration. *Ecological Engineering* 15 : 191–198.
Lewis, R. R. and Brown, B. (2014). Version 3. Mangrove Action Project Indonesia, Blue Forests, Canadian International Development Agency, and OXFAM. 275 p.
Lewis, R. R., Hodgson, A. B. and Mauseth, G. S. (2005). Project facilitates the natural reseeding of mangrove forests (Florida). *Ecological Restoration* 23 : 276–277.
Lewis, R. R., Milbrandt, E. C., Brown, B., Krauss, K. W., Rovai, A. S., Beever, J. W. and Flynn, L. L. (2016). Stress in mangrove forests: early detection and pre-emptive rehabilitation are essential for future successful worldwide mangrove forest management. *Marine Pollution Bulletin* 109 : 764–771.
Lewis, R. R., Brown, B. M., and Flynn, L. L. (2019). "Methods and criteria for successful mangrove forest rehabilitation," In Coastal Wetlands: An Integrated Ecosystem Approach, 2nd Edn, eds G. M. E. Perillo, E. Wolanski, D. R. Cahoon, and C. S. Hopkinson (Amsterdam: Elsevier), 863–887. doi: 10.1016/B978-0-444-63893-9.00024-1.
Li, X., Bellerby, R., Craft, C. and Widney, S. E. (2018). Coastal wetland loss, consequences, and challenges for restoration. *Anthropocene Coasts* 1 : 1-15.
Lira-Medeiros, C. F., Parisod, C., Fernandes, R. A., Mata, C. S., Cardoso, M. A., Ferreira, P. C. G. (2010). Epigenetic variation in mangrove plants occurring in contrasting natural environment. *PLoS ONE* 5: e10326.
Long, R. D., Charles, A. and Stephenson, R. L. (2015). Key principles of marine ecosystem-based management. *Marine Policy* 57: 53-60.
López-Portillo, J., Lewis, R. R., Saenger, P., Rovai, A., Koedam, N., Dahdouh-Guebas, F., Agraz-Hernández, C. and Rivera-Monroy, V. H. (2017). Mangrove forest restoration and rehabilitation. In: Rivera-Monroy, V. H., Lee, S. Y., Kristensen, E. and Twilley, R. R. (Eds.), *Mangrove Ecosystems: A Global Biogeographic Perspective*. Springer, New York, New York, USA, pp. 301–345.
Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., Rogers, K., Saunders, M. L., Sidik, F., Swales, A., Saintilan, N., Thuyen, A. X. and Triet, T. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature* 526 : 559–563.
Lovelock, C. E., Feller, I. C., Reef, R., Hickey, S. and Ball, M. C. (2017) Mangrove dieback during fluctuating sea levels. *Scientific Reports* 7 : 1680.

Ludt, W. B. and Rocha, L. A. (2014). Shifting seas: the impacts of Pleistocene sea-level fluctuations on the evolution of tropical marine taxa. *Journal of Biogeography* 42(1) : 25–38.
Lyu, H., He, Z., Wu, C-I. and Shi, S. (2018) Convergent adaptive evolution in marginal environments: unloading transposable elements as a common strategy among mangrove genomes. New *Phytologist* 217 : 428– 438.
Mace, G. M. (2014). Whose conservation? Changes in the perception and goals of nature conservation require a solid scientific basis. *Science* 345 : 1558–1559.
MacKenzie, R. A., Jayd, K., Pham, H. T. and Sharma, S. (2019) Community-Based Management of Mangrove Forests in Southeast Asia. In *Societal Dimensions of Environmental Science* (pp. 151-173). CRC Press.
Magris RA, Pressey RL, Weeks R, Ban NC (2014) Integrating connectivity and climate change into marine conservation planning. *Biological Conservation* 170: 207–221.
Maguire, T. L., Saenger, P., Baverstock, P. and Henry, R. (2000). Microsatellite analysis of genetic structure in the mangrove species *Avicennia marina* (Forsk.) Vierh. (Avicenniaceae). *Molecular Ecology* 9 : 1853–1862.
Mazón, M., Aguirre, N., Echeverría, C., Aronson, J. (2019). Monitoring attributes for ecological restoration in Latin America and the Caribbean region. *Restoration Ecology* 27: 992–999. doi: 10.1111/rec.12986
McLeod, E., Salm, R., Green, A. and Almany, J. (2009). Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and Environment* 7 : 362–370.
Moilanen, A., Franco, A. M. A., Early, R., Fox, R., Wintle, B. and Thomas, C. D. (2005). Prioritising multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proceedings of Royal Society of London-B Biological Science* 272:1885–1891.
Murray, N. L., Phinn, S. R., DeWitt, M., Ferrari, R., Johnston, R., Lyons, M. B., Clinton, N., Thau, D. and Fuller, R. A. (2019). The global distribution and trajectory of tidal flats. *Nature* 565 : 22-225.
On-prom, S. (2014). Community-Based Mangrove Forest Management in Thailand: Key Lesson Learned for Environmental Risk Management. In *Sustainable Living with Environmental Risks*, Kaneko, N., Yoshiura, S., Kobayashi, M. (eds) Springer, Tokyo. pp. 87-96. doi:10.1007/978-4-431-54804-1_8.
Osland, M. J., Feher, L. C., López-Portillo, J., Day, R. H., Daniel, O., Suman, D. O., Menéndez, J. M. G. and Rivera-Monroy, V. H. (2018). Mangrove forests in a rapidly changing world: Global change impacts and conservation opportunities along the Gulf of Mexico coast. *Estuarine, Coastal and Shelf Science* 214 : 120–140.
Osland, M. J., Grace, J. B., Guntenspergen, G. R., Thome, K. M., Carr, J. A. and Feher, L. C. (2019). Climatic Controls on the Distribution of Foundation Plant Species in Coastal Wetlands of the Conterminous United States: Knowledge Gaps and Emerging Research Needs. *Estuaries and Coast*: https://doi.org/10.1007/s12237-019-00640-z.
Osorio, J. A., Wingfield, M. J. and Roux, J. (2016). A review of factors associated with decline and death of mangroves, with particular reference to fungal pathogens. *South African Journal of Botany* 103 : 295–301.
Perez, A., Libardoni, B. G. and Sanders, C. J. (2018). Factors influencing organic carbon accumulation in mangrove ecosystems. *Biologiocal Letters* 14 : 20180237.
Polidoro, B. A., Carpente, K. E., Collins, L., Duke, N. C., Ellison, A. M., Ellision, J. C., Farnsworth, E. J., Fernando, E. S., Kathiresan, K., Koedam, N. E., Livingstone, S. R., Miyagi, T., Moore, G. E., Vien Ngoc Nam, Ong, J. E., Primavera, J. H., Salmo, S. G., Sanciangco, J. C., Sukardjo, S., Wang, Y., Yong, J. W. H. (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE* 5: 1 – 10.
Pulhin, J. M., Gevana, D. T. and Pulhin, F. B. (2017). Community-Based Mangrove Management in the Philippines: Experience and Challenges in the Context of Changing Climate, chapter 16. In R. DasGupta and R. Shaw (eds.), *Participatory Mangrove Management in a Changing Climate, Disaster Risk Reduction*, pp 247-262. DOI 10.1007/978-4-431-56481-2_16.
Remani, K. N., Jayakumar, P. and Jalaja, T. K. (2010). Environmental problem and management aspects of Vembanad Kol wetlands in south west coast of India. *Nature, Environment and Pollution Technology* 9 (2) : 247–254.
Rey, J. R., Carlson, D. B. and Brockmeyer, R. E. (2012). Coastal wetland management in Florida: environmental concerns and human health. *Wetlands Ecology and Management* 20 : 197–211.

Rilov, G., Mazaris, A. D., Stelzenmuller, V., Helmuth, B., Wahl, M., Guy-Haim, T., Mieszkowska, N., Ledoux, J. B., Katsanevakis, S. (2019). Adaptive marine conservation planning in the face of climate change: What can we learn from physiological, ecological and genetic studies? *Global Ecology and Conservation* 17 : e00566.
Roderstein, M., Perdomo, L., Villamil, C., Hauffe, T. and Schnetter, M. L. (2014). Long-term vegetation changes in a tropical coastal lagoon system after interventions in the hydrological conditions. *Aquatic Botany* 113 : 19–31.
Romañacha, S. S., DeAngelis, D. L., Koh, H. L., Li, Y., Teh, S. Y., Barizan, R. S.R. and Zhai, L. (2018). Conservation and restoration of mangroves: Global status, perspectives, and prognosis. *Ocean and Coastal Management* 154 : 72–82.
Rotich, B., Mwangi, E. and Lawry, S. (2016). *Where Land Meets the Sea: A Global Review of the Governance and Tenure Dimensions of Coastal Mangrove Forests.* Bogor; Washington, DC: CIFOR and USAID Tenure and Global Climate Change Program.
Rovai, A. S., Twilley, R. R., Castaneda-Moya, E., Riul, P., Cifuentes-Jara, M., Manrow-Villalobos, M., Horta, P. A., Simonassi, J. C., Fonseca, A. L., Pagliosa, P. R. (2018). Global controls on carbon storage in mangrove soils. *Nature Climate Change* 8 : 534-538.
Roy, S. D. and Krishnan, P. (2005). Mangrove stands of Andamans vis-à-vis tsunami. *Current Science* 89 : 1800–1804.
Saintilan, N., Wilson, N. C., Rogers, K., Rajkaran, A. and Krauss, K. W. (2014). Mangrove expansion and salt marsh decline at mangrove poleward limits. *Global Change Biology* 20 : 147–157.
Sarker, S. K., Reeve, R., Thompson, J., Paul, N. K. and Matthiopoulos, J. (2016). Are we failing to protect threatened mangroves in the Sundarbans world heritage ecosystem? *Scientific Reports* 6 : 21234. https://doi.org/10.1038/srep21234.
Schmiegelow, J. M. M. and Gianesella, S. M. F. (2014). Absence of zonation in a mangrove forest in Southeastern Brazil. *Brazilian Journal of Oceanography* 62(2) :117–131.
Selvam, V., Ravichandran, K. K., Gnanappazham, L. and Navamuniyammal, M. (2003). Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data. *Current Science* 85 :794–798.
Sharma, S., Nadaoka, K., Nakaoka, M., Uy, W. H., MacKenzie, R. A., Friess, D. A. and Fortes, M. D. (2017). Growth performance and structure of a mangrove afforestation project on a former seagrass bed, Mindanao Island, Philippines. *Hydrobiologia* 803(1) : 359-371.
Singh, H. S. (2003). Marine protected areas in India: coastal wetland conservation. *Indian Forester* 129(11) : 1313–1321.
Sippo, J. Z., Lovelock, C. E., Santos, I. R., Sanders, C. J., Maher, D. T. (2018). Mangrove mortality in a changing climate: An overview. *Estuarine, Coastal and Shelf Science*. doi: https://doi.org/10.1016/j.ecss.2018.10.011
Snedaker, S. C. (1982). Mangrove species zonation: why? In: Sen DN, Rajpurohit KS (eds). *Contributions to the ecology of halophytes*. The Hague: Dr. W. Junk (Tasks for vegetation science, 2), pp. 111-125.
Stubbs, B. J. and Saenger, P. (2002). The application of forestry principles to the design, execution and evaluation of mangrove restoration projects. *Bois et Forêts des Tropiques* 56 : 5–21.
Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A. and Simard, M. (2017). Distribution and drivers of global mangrove forest change, 1996–2010. *PLoS ONE* 12(6): e0179302. doi:10.1371/journal.pone.0179302.
Tollefson, J. (2019) One million species face extinction. *Nature* 569 : 171.
Trombulak, S. C., Omland, K. S., Robinson, J. A., Lusk, J. J., Fleischner, T. I., Brown, G. and Domroese, M. (2004) Principles of Conservation Biology: Recommended Guidelines for Conservation Literacy from the Education Committee of the Society for Conservation Biology. *Conservation Biology* 18 (5) : 1180–1190.
Twilley, R. R., Rovai, R. A. and Riul, P. (2018). Coastal morphology explains global blue carbon distributions. *Frontiers in Ecology and Environment*. doi:10.1002/fee.1937.
Vane, C. H., Harrison, I., Kim, A. W., Moss-Hayes, V., Vickers, B. P. and Hong, K, (2009). Organic and metal contamination in surface mangrove sediments in South China. *Marine Pollution Bulletin* 58 :134–144.
Ward, R. D., Friess, D. A., Day, R. H. and MacKenzie, R. A. (2016). Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosystem Health and Sustainability* 2: e012111.

Wee, A. K. S., Mori, G. M., Lira, C. F., Núñez-Farfán, J., Takayama, K., Faulks, L., Shi, S., Tsuda, Y., Suyama, Y., Yamamoto, T., Iwasaki, T., Nagano, Y., Wang, Z., Watanabe, S., Kajita, T. (2018) The integration and application of genomic information in mangrove conservation. *Conservation Biology* 33 : 206–209.

Woodroffe, C. D., Rogers, K., McKee, K. L., Lovelock, C. E., Mendelssohn, I. A. and Saintilan, N. (2016) Mangrove sedimentation and response to relative sea-level rise. *Annual Review of Marine Science* 8 : 243–266.

Worldwide Fund for Nature (WWF) (2008) Living Planet Report 2008. (Accessed 14 September 2016). http://assets.panda.org/downloads/living_planet_report_2008.pdf.

Worthington, T. and Spalding, M. (2019) *Mangrove restoration potential: A global map highlighting a critical opportunity.* 34pp.

Yang, Y., Duke, N. C., Peng, F., Li, J., Yang, S., Zhong, C., Zhou, R. and Shi, S. (2016). Ancient Geographical Barriers Drive Differentiation among Sonneratia caseolaris Populations and Recent Divergence from S. lanceolata. *Frontiers in Plant Science* 7 :1618. doi: 10.3389/fpls.2016.01618

Yang, Y., Li, J., Yang, S., Li, X., Fang, L., Zhong, C., Duke, N. C., Zhou, R. and Shi, S. (2017). Effects of pleistocene sea-level fluctuations on mangrove population dynamics: A lesson from *Sonneratia alba*. B*MC Evolutionary Biology* 17 : 22.

Zimmer, M. (2018) Ecosystem Design: When Mangrove Ecology Meets Human Needs. In *Threats to Mangrove Forests*, Makowski, C. and Finkl, C. W. (eds.), pp.367-376.