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Ecosystem-based adaptation for improving coastal planning for sea-level rise: A systematic review for mangrove coasts

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ABSTRACT

This paper systematically reviews and synthesizes peer-reviewed, English-language scientific publications ($n=212$) to identify relevant research about how **E**cosystem-**B**ased **A**daptation (EBA) is integrated with coastal planning. **P**referred **R**eporting **I**tems for **S**ystematic reviews and **M**eta-**A**nalysis (PRISMA) methodology is applied in this study. Attention was given to studies concerning human-environment interactions as opposed to physical or biological climate change issues alone because the coastal planning and EBA approach addresses the management of human actions in nature. The literature references include the issue of climate change (77%); however, limited evidence of EBA in coastal areas are reported (18%), and it is evident that the issues have become relevant in the scientific literature published in recent years. Broad texts demonstrate that SLR is one of the major long-term impacts (68%), and all of these papers recognize the most affected ecosystems in the tropics would be mangroves. EBA is an emerging option that can offset anticipated ecosystem losses and improve coastal planning to cope with SLR because it provides benefits beyond climate change stressors. There is a need to synthesize a road map for incorporation of mangrove regulations into local planning instruments and for building capacity for their implementation. Application of PRISMA in marine science will enhance future reviews, facilitate the systematic search and adequately document any theme, and also be useful in determining research gaps or information needs.

1. Introduction

Change is a natural attribute of marine and coastal ecosystems that are responding and adapting to climate variability, as well as human activity. However, accelerated changes and impacts in coastal areas are expected over the coming decades due to sea-level rise (SLR). Sea levels are projected to rise by at least 0.6 m by the end of the century, with the consequent growth of coastal flooding affecting more than 100 million people per year [1]. Mangroves forests are usually the focus of concerns about the disappearance of coastal areas [2], and SLR is a substantial cause of recent and predicted future reductions in the area and health of mangroves [3–12]. Biogeographic distribution of mangroves is generally confined to the tropical and subtropical regions, with the largest percentage of mangroves found in tropical areas between 10°N and 10°S latitude. The total area of mangroves in the year 2000 was estimated as 137,760 km^2 (13.750.898 ha), accounting for 0.7% of total tropical forests of the world, though only 6.9% are protected (less than the 10% CDB target by 2012) [13]. Predictions suggest that 30–40% of coastal wetlands [1] and 100% of mangrove forests [14] could be lost in the next 100 years if the present rate of loss continues [13]. As a consequence, important ecosystem services provided by mangrove forests will be diminished or lost [14], which could be catastrophic in developing countries where economies and livelihoods depend largely on the capacity of these ecosystems to provide services to sectors and society, especially fishery productivity [15]. The full implications of mangrove loss are not fully appreciated, although studies reveal that mangroves are under pressure [11,13]. In addition, other forces, such as population density growth or migrations, disorderly urbanization, absence of governance, over-exploitation of resources, and other human interventions, will amplify the effects of existing ‘natural’ stressors such as biophysical changes [16].

Within on-going climate change negotiations at the international level, the need for adaptation is now recognized [15,17–19] because human induced climate change is happening faster than originally expected, and faster than most ecosystems have previously experienced [20]. It is believed that more rapid climate change will lead to more problematic adaptation [1,17,21]. Management strategies incorporating the impacts of climate change on

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coastal systems is recognized as crucial [22]. The Ecosystem-based Adaptation (EBA) concept has emerged recently in the worldwide climate change sphere at the United Nations Framework Convention on Climate Change (UNFCCC) [15], but the need for and role of EBA has been poorly recognized [15,23].

Effective EBA inclusion in coastal planning is urgent in the face of SLR and in the presence of current information gaps, and the evidence for EBA effectiveness needs to be strengthened [24]. Any environmental planning needs scientific research conducted in close coordination and cooperation because underestimated aspects cause management weakness [25]. Structured climate change planning needs to consider not only how ecosystems will be affected by climate but also how humans are going to be affected and what adaptation options may be implemented. The future of the ocean depends on successful, immediate implementation of a comprehensive governance framework that moves away from a sectorial approach to an integrated management approach [26]. Investigating, evaluating and protecting marine and coastal ecosystems, such as mangroves and their provisioning, regulating, cultural and supporting services, play an important role not only in safeguarding the livelihoods of coastal communities and the public and private investments in front of climate change but also in improving coastal planning to SLR through designing approaches to EBA.

This study concentrates efforts on literature analysis in a systematic way, focusing on tropical ecosystem-based adaptation (mangroves) in front of SLR and coastal planning. The first section defines a conceptual frame and gives a general description of the issues arising from the implications of SLR for mangrove forests in relation to management of coasts. The next section describes in detail the PRIMA methodological approach involving the suitability of the methodology for marine science, and the main advantages are listed. The third section systematically reviews and synthesizes the scientific literature to identify, select, and appraise relevant research about how EBA is conducted in coastal planning for SLR, using mangrove forests as a key ecosystem. Finally, the last section discusses and analyzes EBA and its implication on coastal planning ahead of SLR to determine research gaps in understanding and concludes with identifying future research needs.

Issues arising from the implications of sea level rise for mangrove forests in relation to management of coasts are described in Table 1.

2. What is ecosystem-based adaptation in the coastal planning arena?

With the purpose of establishing a common language, it is important to understand and differentiate some terms that are related with EBA and coastal planning: *Resilience* is the ability to recover from disturbance to some more or less persistent state [12] or the magnitude that can be absorbed before a system changes to a radically different state and the capacity to self-organize [30,31]. *Adaptive management* concerns the unpredictable interactions between humans and ecosystems that evolve together – it is the science of explaining how social and natural systems learn through experimentation [32]. *Climate Change Adaptation* involves changes in social–ecological systems (human-environmental interactions) in response to present and expected impacts of climate change in the context of interacting non-climatic changes [33]. *Management* is “a process of governance”, in which *Planning* plays an operational role (day to day) [34]. *Ecosystem-based Management* (EBM) for the oceans has been defined in a consensus statement as ‘an integrated approach to management that considers the entire ecosystem, including humans’. EBM considers the cumulative impacts of different sectors [7] and recognizes explicitly the ecosystem itself. EBM is gradually growing in developing nations, which is evidence that EBA recognition is still emerging as a preparation for SLR impacts in tropical areas even though the climate change literature makes obvious the role of coastal ecosystems such as mangroves in the presence of sea level changes.

Whereas most coastal populations located in tropical areas depend on natural resources and marine and coastal ecosystems services, the capacity of ecosystems to provide services is under pressure not only from climate variability and change but also from non-climate stressors, but coastal planning is almost absent in the tropics. In this scenario, EBA is an alternative for improving coastal planning for SLR in the tropics, considering the extensive natural ecosystems that are still healthy. From scientists, more evidence is needed on the role of ecosystems in reducing the vulnerability of societies; from local communities, traditional knowledge is crucial for improving scientific phenomena understanding; and from policy-makers, multi-sectorial and cross scale approaches are needed for mainstreaming EBA into policies [15]. EBA in front of SLR must involve responses to all of them.

Table 1
Implications of sea level rise for mangrove forests in relation to management of coasts.

Sea-level rise effects in relation to management of coasts (adapted from Nicholls, [35])	Implications for Mangrove
Sediment erosion and backwater effect (flooding from rivers)	Mangrove resistance depends on sediment surface [11]
Inundation/flooding from the sea (surge effect)	Flooding tolerance due to mangrove's morphology and physiology is the basis of the most valued ecosystem services provided for coast protection by this forest [27]. Mangroves sustain coastal systems stability for millennia [11]
Fluctuations in water table that impeded drainage	Connectivity between mangroves and adjacent systems which enhances the potential of exchange across boundaries increases their vulnerability to human and natural disturbances [12]. Reduced flows and lowering of groundwater levels has been shown to result in lowered mangrove surface elevations; if these combine with rises in sea level, loss of mangroves in lower areas becomes more likely [29].
Saltwater intrusion in surface waters and groundwater	Mangroves display a high level of trait plasticity in response to salinity [27], however if the limits are exceeded significant losses for coastal protection are expected
Changes on biota and forest structure and composition	Responses of mangrove to sea-levels rise depends on reactions of individual plants, and some evidence exists on modification of leaf, root and growth (biomass) structure in response to increasing flooding [28]. Given that SLR decimate the role of mangroves as nurseries for economically important fisheries. Invasive or not native species might arrive.
Combination of effects listed above	Health of mangroves depends on natural biotic and physical components interactions, although the resilience of the mangrove ecosystem is high, a combination of stressors threatening their goods and services