

# Trade-offs between biodiversity and flood protection services of coastal salt marshes

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Coastal salt marshes provide a range of ecosystem services. However, their area is steadily diminishing as a result of human-made modifications to the coastal zone. The accelerated rise of sea level is another challenge to the self-generating capacity of coastal salt marshes. This is a subject of extensive research, leading to conservation and restoration strategies. The value of salt marshes as a natural sea defense is an area of growing interest as well. This article reviews salt-marsh restoration options described in the literature, including the idea of sediment nourishment on the scale of the estuary or lagoon as a whole. It then considers trade-offs between enhancement of salt marshes' flood protection service and the ecological quality of the ecosystem.

## Addresses

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## Introduction

Coastal salt marshes and adjacent mudflats form a dynamic gradient between land and sea and are the typical habitat of salt-tolerant vegetation [1]. They are common in many tidal-dominated temperate environments, like coastal lagoons and estuaries, and are often intensively used for human settlement and agriculture due to their location, flat surface and fertile soils [2]. Human activities in marsh ecosystems include exploitation of plant production, drainage and reclamation for agriculture and building, introduction of non-native species, construction of engineering works for shipping and flood protection, and resource extraction [3]. Yet such activities have led to pollution, degradation and erosion of up to half of the salt marshes worldwide [2]. Furthermore, salt marshes are threatened by

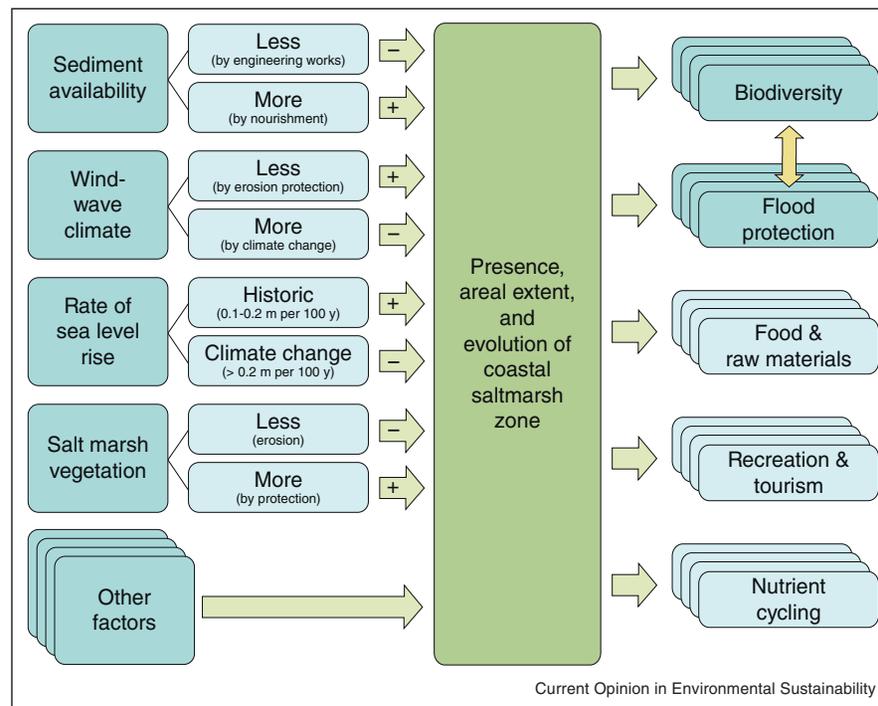
urbanization, economic development and the accelerated rise of sea level due to climate change [4].

For decades, considerable attention has been given to the biodiversity value of wetlands such as salt marshes. Conservation and development goals have been formalized in international policy and legislative frameworks, most of which focus on protecting the areal extent of salt marshes and the associated habitat (vegetation species abundance and diversity) alongside other ecological parameters such as bird and invertebrate populations. In consequence, salt marshes are the subject of a range of management and restoration strategies. Since the Millennium Ecosystem Assessment, however, emphasis has shifted to their value and services in relation to food and fiber production; regulation of nutrients, carbon and water levels; and recreation (see e.g. [2]). Major flooding disasters like Hurricane Katrina (2005) and Hurricane Sandy (2012) brought added focus to the value of salt marshes as natural flood defenses. Studies have demonstrated the buffering effect of salt marshes by calculating the damage avoided due to vegetated coastal zones; 60% of the variation in relative damages of 34 major US hurricanes could be explained by the presence of coastal wetlands [5]. Research has also shown that artificial embankments have lower construction and maintenance costs when combined with a natural foreshore (e.g. [6]).

Due to these new insights, several projects have been initiated worldwide to conserve, restore and (re)create salt-marsh zones. These did involve, for instance, erosion protection of salt-marsh edges; nourishment of existing salt marshes; development of new salt marshes; accretion works; management of marsh vegetation; and creation of space for salt-marsh development on formerly embanked areas [7]. Sediment nourishment on the larger scale of the estuary or lagoon is a more recent topic of research.

Questions, however, have been raised about the effectiveness of the flood defense service of natural coastal ecosystems during extreme storm conditions (see e.g. [8]), and there is growing appreciation of the biodiversity value of restored salt marshes (see e.g. [7,9]). This has led to several reviews and meta-analyses on the feasibility of using salt marshes to contribute to flood protection (e.g. [10,11]). Other studies have investigated the biodiversity value of salt marshes (e.g. [12]), seeking to identify knowledge gaps and make recommendations for marsh restoration (e.g. [9]).

Figure 1



The main controlling factors of salt-marsh formation (left) and the services provided by salt marshes (right).

We argue that any restoration project involves trade-offs between flood protection and biodiversity conservation. Nonetheless, opportunities for synergy can be found with the use of an integrated approach and collaboration between coastal engineers, coastal morphologists and ecologists with the shared ambition to utilize natural ecosystems and natural processes in a flood protection strategy. This paper describes first, the effectiveness of salt marshes in wave damping during extreme storm conditions, second, opportunities and constraints for improving the flood defense function of salt marshes, and third, synergies and trade-offs between the flood protection service and biodiversity. We start by describing the salt-marsh ecosystem. Figure 1 illustrates processes within the salt-marsh system and the services they provide.

### Salt marshes: the result of geomorphological, hydrodynamic and biological processes

Salt marshes occur high in the intertidal zone in sheltered conditions, rising up from the mean high water neap tide (MHWN) level landward, where the height, length and frequency of inundation by saline water decreases. The lower levels of the salt-marsh area support pioneer species. By trapping sediment, this vegetation contributes to accretion and development of creeks, rendering the environment suitable for the establishment of species that need more stable

sediment. Because of the positive feedback between salt-marsh vegetation and sedimentation, vegetation forms an important aspect of salt-marsh geomorphology [13].

In addition to the tidal regime, the main physical factors that control salt-marsh dynamics (vertical and lateral accretion and erosion) are sediment supply, the wind-wave dynamics and rising sea level [13]. Salt marshes adapt quickly to changes in their boundary conditions. With abundant sediment supply, a salt marsh can keep pace with sea level rise by accretion or moving landwards (if there is sufficient space to accommodate them). Similarly, a change in tidal currents or wave action may change the profile of the marsh, and with it, its areal extent.

The most floristically diverse part of the salt marsh is the zone that is regularly, but not daily, submerged. In zones that are only occasionally flooded, vegetation diversity decreases with ongoing succession. In a dynamic environment, the succession process is cyclic due to erosion and sedimentation. The inter-relation between physical and biological processes within marshes has long been a subject of study. With the availability of remote sensing data over the last 10–20 years, variations in vegetation and relevant physical properties have been explored as well [14].

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