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Editorial: Degradation, Ecological Restoration and Adaptive Management of Estuarine Wetlands under Intensifying Global Changes, Volume II

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Editorial on the Research Topic
Degradation, Ecological Restoration and Adaptive Management of Estuarine Wetlands under Intensifying Global Changes, Volume II

This editorial focuses on the specific Research Topic "*Degradation, ecological restoration, and adaptive management of estuarine wetlands under intensifying global change*." We offer an overview and conclusions on the state-of-the-art research aimed at addressing the challenges encountered by estuarine wetlands under multiple pressures.

Estuarine wetlands provide various critical ecosystem services, including providing habitats for organisms, preventing seawater intrusion, biodiversity conservation, and microclimate regulation, in addition to nutrient cycling and carbon sequestration. Estuaries host numerous mega-cities which are characterized by intense human activity. The associated human disturbance has altered the structure and function of estuarine ecosystems through land reclamation, pollution, overfishing, and altered flows.

Moreover, estuarine wetlands are facing increasing threats from the effects of global climate change, including more frequent tsunamis, rising sea levels, and large-scale biological invasions. These environmental stressors not only affect primary and secondary productivity, community composition, distribution, and biodiversity within estuaries but also disrupt natural ecohydrological and biogeochemical processes, ultimately leading to the disruption of ecosystem services.

Multiple pressures on estuarine wetlands

High-intensity human reclamation is a key driver of the large-area loss and degradation of estuarine wetlands. The reduction of natural coastlines and the increase in the proportion of artificial coastlines in China has been a major source of concern. High-intensity reclamation not only causes coastline hardening but also decreases offshore suspended sediment concentrations and aggravates natural coastline erosion (Li et al.). In addition, reclamation and the construction of dams affects tidal processes resulting in changes in key habitat factors such as salinity, moisture content and hydrological connectivity (Man et al.) in estuarine wetlands. Furthermore, considering estuarine wetlands are major carbon (C) pools (Li et al.), shifts in nutrient accumulation, salinity, and mineral factors in wetland sediments would affect the soil organic C (SOC) stability (Zhao et al.).

Fragmentation of plant patches caused by activities such as establishment of aquaculture ponds, ports, and farmland are some of the key pressures suffered by estuarine wetlands following reclamation (Zhang et al.), and they decrease the stability of estuarine wetland plant communities. Furthermore, in the wake of current extreme climate events, the risks of degradation and ecosystem collapse increase. The impacts of reclamation activities on wetland plants are observed over the entire life cycle of plants, including hindering seed diffusion, limiting plant seed germination, and causing the death of plant seedlings. Therefore, once plant communities are degraded, self restoration is difficult and permanent bare spots are likely to be established (Wang et al.). Strategies for the restoration of bare patches should be explored by coastal wetland managers.

Estuarine wetlands represent important breeding fields or wintering grounds for birds, such as along the East Asia-Australia Flyway (EAAF). However, the degradation of estuarine wetlands due to reclamation has led to the disappearance of suitable breeding grounds and habitats for birds and has placed numerous species at risk (Jordán et al.). Fish spawning grounds, feeding grounds, nursery grounds, and migration channels are hotspots for fish diversity conservation; however, comprehensive information on the shoreline morphology of remaining habitats and the relationships among habitat factors is still lacking, which hampers the targeted protection of key species (Xu et al.) and their habitats (Xu et al.; Zhou et al.).

Aquatic environment pollution in estuarine wetlands is another major stress factor. The concentrations of pollutants in estuaries are often higher than the local background values upstream due to the high intensity of human activities and complex hydrological processes in the estuaries (Yu et al.). The accumulation of pollutants such as heavy metals in estuarine wetland sediment and enrichment of animal and plant nutrients cause high ecological risks (Wang et al.).

As a highly open land–sea transition zone, estuarine wetlands are at high risk of invasion by alien species. Globally, most of the major estuaries, especially those with human development footprints, experience biological invasion. In China, *S. alterniflora* is the most invasive plant in estuarine wetlands. *S. alterniflora* is present in almost all estuaries in China from the southern tropical zone to the northern temperate zone. *S. alterniflora* has a strong capacity to expand following colonization in areas with high habitat invasibility and can expand outward through asexual reproduction (Yan et al.). In addition, *S. alterniflora* can establish along the tidal creek through seed dispersal. *S. alterniflora* invasion would influence the structure and function of wetland ecosystems considerably.

Biological adaptation to multiple pressures

In estuaries, the functional traits of wetland plants, including biomass, plant height, root–stem–leaf proportions, morphology, photosynthesis rate, nutrient contents, and functional enzyme activity, would adapt to the habitat conditions (Liu et al.). An increase in salinity in estuarine wetlands would reduce plant biomass (Mao et al.; Song et al.), in addition to plant investment in vegetative parts, while increasing their investment in reproductive parts to ensure the survival of their progeny (Wu et al.). Changes in plant functional traits can be employed as indicators of the degree of environmental stress (Wu et al.), in addition to plant adaptability to habitat change and the prediction of the evolution trends of plant community distribution and structure in future under environmental stress.

The effects of environmental stress on biological communities are also reflected in shifts in competitive relationships between species and in food chains. For example, interspecific relationships may shift from mutual competition to common resistance following an increase in environmental stress. In addition, changes in the distribution patterns and species compositions of plant–macroinvertebrates communities caused by environmental stress in estuarine wetlands (Li et al.) would directly affect foraging, concealment behavior of birds, and adaptability of birds to habitats (Lu et al.).

The effects of climate change and multiple pressures caused by high-intensity human activities on plant–soil relationships and root microbes are more subtle. Usually, plant–soil relationships are influenced by the morphological characteristics of the underground root system and the biochemical function of the root system (An et al.) With advancements in the development of underground ecological observation technologies, differences in the growth and development of plant roots and their capacity to absorb water and ions under different salinity and mineralization conditions have been observed in estuarine wetlands. Similarly, the allelopathy of plant roots and the secretion of allelochemicals in soil would change, in turn affecting soil physicochemical properties and affecting the responses of plant–soil interactions to external stress (Cui et al.). The bioturbation of soil or sediment by benthos, especially burrowing organisms such as crabs, would modify the sediment structure and cause the vertical migration of nutrients. Furthermore, crabs feed on plants, establishing plant –benthos–soil interactions (Xie et al.). Root microbes are more susceptible to environmental changes, and rhizosphere microbial community composition and functional diversity varies significantly across freshwater and saline water gradients (Ma et al.). Changes in microbial functional groups imply changes in organic matter mineralization and greenhouse gas emissions.

Ecological restoration to mitigate impacts

Estuarine wetland restoration projects are increasingly undertaken to mitigate the negative impacts of estuarine degradation. Such projects aim to re-establish various ecological attributes, including community structure (species diversity and habitat) and ecological processes (energy flow and nutrient cycling), which are associated with increased resilience and resistance of the estuarine ecosystems to abiotic and biotic stress factors. Increasingly adopted restoration practices, including wetland restoration (Li et al.) and efficient ecological management, improve the C storage capacity of wetlands and increase the blue C storage of estuarine wetlands.

Ecological restoration practices do not always yield satisfactory results, particularly in the wake of intensifying global change and socioeconomic change (Gibbons and Quijón). Ecologists, biologists, and environmental science researchers have been investigating effective solutions for application in the restoration of degraded estuarine wetland ecosystems globally. The concepts of "nature –based solutions," "adaptive management (Li et al.)," or "ecological networks" seem to offer great prospects and are currently being applied to estuarine ecosystem restoration based on risk and climate change adaptation and mitigation strategies.

New perspectives on monitoring wetlands restoration

Following the implementation of ecological restoration, assessing the results of these efforts will be crucial. Updating restoration techniques and adjusting restoration measures will be essential through thorough monitoring of the entire ecological restoration process. This requires a deep understanding of the ecosystem throughout the restoration process. The distribution patterns, community structures, and functional traits of animals and plants in estuarine wetlands are the products of long-term adaptation of animals and plants to the highly dynamic nature of estuaries and their oscillating environmental conditions (Sui et al.).

The interaction between freshwater and saline water associated with the interaction between runoff and tidal current in estuarine wetlands shapes estuarine wetland habitat characteristics. The interaction between runoff and tidal current is a dynamic equilibrium state, resulting in continuous fluctuation or periodic pulse that control estuarine wetland habitat factors. Plants that are most sensitive to changes in habitat factors usually exhibit hierarchical spatial self-organization under stress (Wang et al.). However, changes in habitat elements caused by multiple pressures, such as runoff, sediment change, and sea level rise, exceed the adaptive threshold of animals and plants, which transform multiple homeostasis states in biological communities and cause community degradation (Duan et al.).

In the face of high-intensity short-term pressures, such as storm surges and human reclamation activities, animal and plant communities will undoubtedly exhibit major responses (Fan et al.). Afterward, the animal and plant communities would recover, and when the stress intensity exceeds the resistance threshold of the animal and plant communities, artificial restoration strategies are required to reconstruct the community. Compared with artificial restoration, enhancing the adaptability and self-recovery capacity of biotic communities is a natural solution.

As the world enters the United Nations Decade on Ecosystem Restoration (2021–2030), countries and organizations globally are paying greater attention to innovative ecological restoration approaches that could facilitate the achievement of the full potential of such ecosystems in delivery of social and ecological value, and in turn, sustainable development. Therefore, it is essential to explore how anthropogenic disturbance and climate change are affecting estuarine wetlands and the latest restoration frameworks that can guide future practice toward conservation and restoration of the biodiversity of estuarine wetlands.

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Conflict of interest

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