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A review on impact of typhoons and hurricanes on coastal wetland ecosystems

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ABSTRACT

Tropical storms (typhoons and hurricanes) are an important form of natural disturbance in coastal wetland ecosystems in tropical and temperate regions. The impacts of a tropical storm on coastal wetland ecosystems are diverse and complex, and their influence on the structure, process, and function of coastal wetland ecosystems and landscape changes has been studied extensively. This paper reviews the effects of typhoons and hurricanes on coastal wetland plants and animals, carbon and nitrogen cycles, water quality, sediments, wetland landscape changes, and recovery. Direct and indirect impacts of typhoons and hurricanes are analyzed mainly from their paths and characteristics, and the response of coastal wetland ecosystems. Typhoons and hurricanes cause damage to mangroves, including the loss of foliage, broken trunks, and even uprooting. The damage varies based on the tree species, stand structure, location, and intensity of the typhoon, or hurricane. Typhoons and hurricanes also affect large aquatic plants and phytoplankton, such as seagrass and algae, including their community structure and species richness. The numbers of coastal wetland animals and their species diversity decrease because of the damage and change of habitat following a disturbance. However, some coastal wetland animals in the disturbance-prone ecosystems demonstrate adaptability to the disturbance, such as high dispersal ability, to cope with partial or total loss of local populations and habitats. Saltwater intrusion induced by tropical storm causes obvious impacts on the production and emission of CH_4 and CO_2. The short- and long-term changes of wetland water quality are influenced by the concomitant heavy rains. Storm surges transport sandy and muddy littoral and shallow offshore sediments hundreds to thousands of meters inland, and represent an important pathway for sediment delivery into the interior of coastal marshes. Sediment transported by hurricanes is one of the important sources of coastal wetland sediment deposition. Their volume, physical properties (bulk density and grain size), and the material they contain vary with the different distances to the shoreline and the storm path. Typhoons and hurricanes cause coastal erosion by induced storm surges and the decrease of wetland area, and changes to wetland morphology and elevation. These acute effects may reduce the future ability of coastal wetlands to protect landward areas from the impacts of storms by dampening wave energy, distancing the mainland from the open water, and potentially reducing the storm surge height. The long-term impacts and recovery of damaged coastal wetlands depend on the intensity and frequency of typhoons and hurricanes. The recovery speeds of tidal creeks and vegetated wetlands are different, as are those of the different tree species. During the recovery process, plant and animal communities interact with each other. Finally, our review clarifies the current knowledge gap in this research, and helps give direction for future research that is still needed.

1. Introduction

Tropical storms, including typhoons and hurricanes, are the most extreme weather events affecting coastal wetland ecosystems and the adjacent marine area, and the concomitant heavy rains can cause damage to areas hundreds of kilometers from the storm center [1]. The global typhoon activity characteristics are changing; however, whether this change has a direct correlation with global warming is unclear [2]. According to a series of prediction models, with an increase of the tropical sea-surface temperature in the future, the tropical cyclone will become more intense, leading to greater wind speeds and more rainfall [3]. The destructiveness of typhoons and hurricanes is extensive and has the potential to intensify; therefore, the impacts of typhoons and hurricanes have always been the focus of research in meteorology, physical geography, ecology, and the study of natural disasters.

The impacts of tropical storms on coastal wetland ecosystems in tropical and temperate regions are diverse, including direct impacts (such as gales, rough seas, and storm surges), and indirect impacts induced by the tropical storm (such as large-scale heavy rains and floods) [4]. In addition, the relationship between the tropical storm and the accompanying disasters, as well as the complexity of the coastal wetland

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ecosystem itself, lead to a complex impact of the tropical storm on the coastal wetland ecosystem. Furthermore, because of the uncertainty of the formation of the tropical storm and its path, and the challenge of the working conditions in estuarine wetlands (in particular, field sampling under bad weather conditions), it is more difficult to investigate the impacts of tropical storms on estuarine and coastal wetland ecosystems [1]. The impacts of a tropical storm on coastal wetland plants, especially on mangroves and their recovery, on the wetland water quality, and sediment attracted early attention [5,6]. In recent years, research has also gradually been carried out on the impacts of a tropical storm on coastal wetland animals, and wetland landscape changes [7,8]. At present, the related research results are mainly from countries and regions severely affected by tropical storms, such as North America and Japan [9–11], with less work from China [12,13].

In this article, we summarize the research progress on the impacts of typhoons and hurricanes on coastal wetland plants and animals, the carbon and nitrogen cycles, water quality, sediments, wetland landscape changes, and recovery, to provide ideas and assistance to research on the impacts of typhoons on coastal wetland ecosystems and mechanisms in China.

2. Impacts of tropical storm on coastal wetland plants

Typhoons and hurricanes can affect wetland plants in several ways, including physical removal of vegetation and prolonged water-logging [9]. The gale force winds associated with typhoons and hurricanes often cause direct damage to coastal wetland vegetation, including destroying the foliage and trunks of mangroves, and flattening the many large emergent aquatic plants by violent storms and waves. The prolonged water-logging caused by typhoons and hurricanes forms an anaerobic environment, inhibiting the extension of plant roots [14], and making the shallow-rooted marsh more susceptible to physical removal [15]. The storm surge triggered by typhoons and hurricanes can cause plants to be uprooted and the residual sediment on the surface of the mangrove wetland, after the storm tide ebbs, can lead to the death of mangrove plants [5]. The saltwater intrusion that accompanies a storm tide can lead to the salinization of wetland soil and cause toxicity, and even the extinction, of sensitive plant species [16].

The direct damage on mangrove plants varies with the tree species, stand structure, location, and the intensity of the typhoon (or hurricane). Work by Kauffman and Cole [11] showed that the mortality rate of Micronesia mangrove, caused by the gale associated with Typhoon Sudal (force 3–4), ranged from 6% to 32%, and 80%–95% of the standing trees survived, suggesting that mangroves can maintain the structural integrity of a forest under the impact of typhoons of this intensity. The mortality rate of the community dominated by *Rhizophora apiculata* was the highest, while that of the community dominated by *Sonneratia alba* was the lowest. The mortality rate at leeward sites was only 3%–8%, while it exceeded 27% on the windward side. Aung et al. [17] found that the mortality rate among Rhizophoraceae group affected by Cyclone Nargis was more than 90%, while it was less than 20% for other non-Rhizophoraceae group species. Research by Ramsey et al. [18] showed that the damage to *Taxodium distichum* by Hurricane Katrina in the coastal forest wetlands was limited to foliage loss. Conversely, with successively decreasing hurricane wind speed from south to north, the damage to bottomland hardwoods ranged from broken trunks to partial foliage loss. The severity of damage to the coastal wetland forest by the hurricane is directly related to stand structure.

Tropical storms also affect coastal wetland phytoplankton. Seaweed demonstrates certain adaptability to the changes of salinity and tidal waves caused by hurricanes, often only showing individual physical changes after the disturbance [19]. Storms can promote outbreaks of dominant algal species with increased runoff providing ideal conditions for algal growth [20]. However, the study by Filippino et al. [21] found that after a storm surge, the composition, nutrient concentration, and absorption efficiency changed for the phytoplankton community in James River. Storms scour the algae community, destroying the coupling relationship between primary productivity and chlorophyll biomass, suppressing the outbreak of algal blooms to a certain extent. The combined action of tropical storms and increasing eutrophication processes in coastal wetlands makes the manifestations of the influence on phytoplankton communities more complex. However, the comprehensive consideration of the combined action of both of these factors on the phytoplankton community helps to better understand the response of the coastal wetland phytoplankton against the background of global change.

Tropical storms can change the community structure and species richness of plants. Hurricanes can directly cause temporary reduction in populations of coastal wetland species, although these species usually recover rapidly [22]. Hurricane Katrina caused the sediment in the Louisiana coastal oligohaline wetlands to dramatically increase, the enhanced elevation led to variations in the coverage and richness of *Spartina patens* and *Schoenoplectus americanus* swamp vegetation, and significant increases in the coverage and richness of *S. patens*. This indicated that hurricane disturbance and resultant changes in the abiotic environment, especially swamp surface elevation, can lead to changes of dominant species in the coastal wetland plant community [9]. Based on an in-situ control simulation experiment, Tate and Battaglia [16] found that the comprehensive effect of storm surges and seaweed accumulation can change the community structure of coastal wetland plants. Storm surges caused reduced coverage of most species, and for the foliage to wither and fall. Seaweed accumulation caused extensive death of undergrowth vegetation and a decline in the richness of community species. The impacts of storm surges and seaweed accumulation were greater on the community structure of savanna and forest wetlands far away from the offshore, while the offshore oligohaline swamp with slightly higher soil salinity had greater adaptability and plasticity to the influence of storm surges.

3. Impacts of tropical storm on coastal wetland animals

Tropical storms destroy the habitat of wetland animals and change the habitat distribution, leading to changes in animal populations. A study by Schmidt et al. [7] showed that the suitable wetland patches for *Sylvilagus palustris hefneri* had a high loss rate within six months after a hurricane, and a relatively low 2-year recovery rate, suggesting that hurricanes cause severe damage to the habitat of the species. The repetition rate of *S. palustris hefneri* had a positive correlation with the size and number of available patches around the affected area. The research of Convertino et al. [23] showed that extreme storms can cause a reduction in breeding *Charadrius alexandrinus nivosus* population and its breeding range because the spatial and temporal variations of the storm may affect nest abundance. Balthis et al. [24] and Engle et al. [25] found that tropical storms result in changes to the physicochemical properties of coastal wetland water bodies, leading to significant reduction in the populations of some benthic animal species and variations in the dominant species composition. The authors suggested that these effects were likely caused by hurricane-related scouring, decreased dissolved oxygen (DO) concentration and salinity changes. The strong winds and storm surge caused by tropical storms will affect the migration of, for example, fish and crab. The estivo-autumnal tropical storms promote the spread of *Micropogonias undulatus* pre-larva in Chesapeake Bay, resulting in an increased escrod population of *M. undulatus* crowd in winter and the following summer [26]. *Callinectes sapidus* usually lay eggs in the coastal waters of Chesapeake Bay, which can be transported back to the Gulf by the action of winds blowing north and west, and by tides where tropical storms play a supplementary or limiting role [27].

Conversely, other wetland animals have certain adaptability and their habitats are not severely damaged by tropical storms. The habitat change caused by tropical storms is not beyond the survival tolerance range of the animals, which is a reflection of gradually evolved genetics and characteristics of coastal wetland animals adapting to the