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Research progress on the impact of Suaeda salsa on carbon cycling in coastal wetland ecosystems

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Abstract. With the deepening global warming crisis, studying the potential carbon sequestration capacity of coastal ecosystems is of significant importance for achieving carbon neutrality goals. This paper employs a literature review method to summarize recent relevant literature on the involvement of Suaeda salsa in carbon cycling, as well as the impacts of climate warming and human activities on its growth and carbon sequestration capacity. The research finds that Suaeda salsa exhibits good carbon sequestration capabilities, with climate warming and increased salinity promoting its growth, while the impact of different growth stages on carbon sequestration is minimal, making it superior to other halophytes. However, human activities have led to the widespread loss of Suaeda salsa. In the future, Suaeda salsa may become the dominant vegetation in some coastal wetland areas and play a significant role in carbon fixation and salinization improvement.

Keywords: Suaeda salsa, coastal wetlands, carbon cycling, carbon sequestration, climate warming

1. Introduction

Wetlands constitute one of the four major terrestrial ecosystems, characterized by diverse ecological systems with significant spatiotemporal variability. Coastal wetlands, situated at the interface of terrestrial and marine ecosystems, primarily consist of coastal salt marshes and mangroves [1]. According to a report from the China Geological Survey, coastal wetlands are estimated to sequester approximately 0.22 Gg C per square kilometer annually. Compared to terrestrial ecosystems, coastal wetlands exhibit greater efficiency in absorbing CO_2 from the atmosphere and storing it stably, thus possessing stronger carbon sequestration capabilities. As per the 2020 China Land Change Survey, coastal wetlands cover approximately 10.04% of the total wetland area, with coastal tidal flats spanning an area of up to 1.5097 million hectares. However, the total area of coastal wetlands has decreased by 46.30% due to the compounded effects of climate warming and human activities. Therefore, more effective conservation measures are still required.

Table 1. Coastal Wetland Areas Surveyed by the China Geological Survey

Types of coastal wetlands	Shallow marine areas	mangrove forests	coastal tidal flats
Area (ten thousand hectares)	411.68	2.71	150.97
Percentage of total wetland area(%)	7.31	0.05	2.68

Suaeda salsa, also known as winged sea-blite, belongs to the Chenopodiaceae family and the Suaeda genus(Suaeda Forsk.exScop). It is an annual herbaceous true halophyte [2]. Often found in saline-alkaline soils, it is a primary vegetation in salt marshes, particularly dominant on beaches and lake shores (Sun et al., 2018). It holds significant value in blue carbon sequestration in marine environments, biodiversity conservation, and possesses certain socio-economic value due to its vibrant colors and nutritional content. However, according to calculations by the Hongyan Yin team, the area of Suaeda salsa in coastal regions of the Bohai Sea has drastically reduced by 92.63%. Therefore, urgent and scientifically sound conservation measures are imperative before further destruction occurs [3].

Since the Industrial Revolution, intensified human activities have disrupted the balance of carbon cycling in ecosystems, leading to a continual increase in atmospheric carbon dioxide levels. In recent years, the average concentration of CO_2 has been steadily rising. According to statistics from the World Meteorological Organization (WMO), the global average concentration of CO_2 in 2022 surpassed pre-industrial levels by 50% for the first time and continues to rise. With the current trend of increasing CO_2 concentrations, more extreme weather events, including ocean warming, heatwaves, and rising sea levels, may occur.

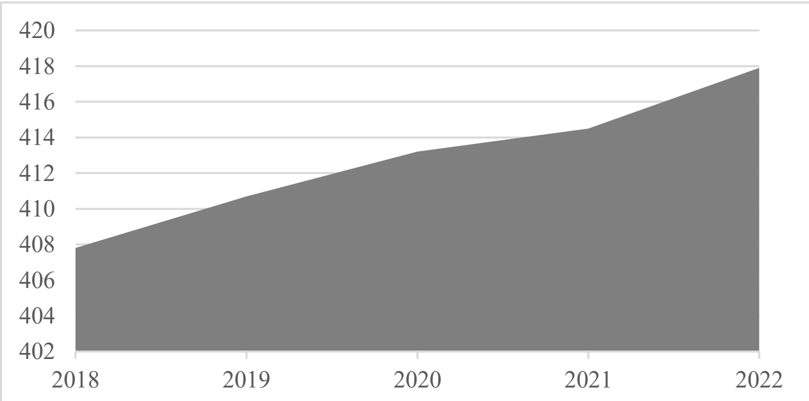

Figure 1. Global Average CO_2 Concentrations (ppm) from 2019 to 2022

The deepening crisis of climate warming demands that we explore more effective mitigation measures. Blue carbon, one of the hot topics in carbon sequestration research in recent years, utilizes ecosystem vegetation to sequester carbon and is considered one of the important means to mitigate the rise in carbon dioxide levels. Wetland ecosystems, characterized by high primary productivity, are integral components of the global carbon cycle [4]. This paper will focus on how Suaeda salsa participates in coastal carbon cycling. By utilizing existing data, we aim to understand the carbon sequestration capacity of Suaeda salsa, predict its future growth trends, and propose feasible strategies for the restoration of coastal wetland ecosystems and soil remediation under the dual pressures of climate change and human activities.

2. Ecological Characteristics of Suaeda salsa

Suaeda salsa prefer to grow in specific saline-alkaline habitats, such as coastlines, salt lakes, surrounding areas of inland reservoirs, and salinized land. They are mainly distributed in the eastern coastal regions of northern China, including the Liaohe River Delta, the Yellow River Delta, and the estuaries of the Huaihe River and the Haihe River. Suaeda salsa, a perennial herbaceous halophyte, possesses a robust root system and its leaves are short-linear or strap-shaped. Although individual plants are small, they often form large-scale plant communities.

Suaeda salsa exhibits excellent salt stress response mechanisms through fleshy leaf structures, intracellular ion compartmentalization, and synthesis of osmotic regulatory substances [5]. These characteristics enable Suaeda salsa to be one of the first pioneer species to colonize bare coastal land, participating as primary producers in major carbon cycling processes [6]. Studies conducted in the

Yellow River Delta, a well-known coastal wetland in China, have shown that the total carbon sequestration amount and capacity of Suaeda salsa communities are significantly higher than those of other salt marsh vegetation, such as Tamarix chinensis and Phragmites australis [7]. According to surveys conducted in Wulei Island Bay, the carbon sequestration capacity of Suaeda salsa is 1123.95 g/m2, which is 227.5% higher than the average carbon sequestration capacity of 494 g/m2 for terrestrial vegetation in China [8].

Table 2. Carbon Sequestration Capacity and Carbon Storage of Salt Marsh Vegetation in the Yellow River Delta [7]

Wetland vegetation types	Carbon Sequestration Capacity /(kg·m—2·a—1)		Carbon Storage/(kg·m—2)	
	Range	Average	Range	Average
Tamarixchinensis	0.16~0.18	0.17	0.50~0.69	0.59
Nitrariatangutorum	0.11~0.15	0.13	0.24~0.38	0.31
Suaedasalsa	0.29~0.34	0.32	0.29~0.34	0.32

3. Impact of Suaeda salsa on Carbon Cycling in Coastal Wetlands

The carbon cycling in coastal wetlands mainly consists of three components: carbon input, storage, and output. In recent years, carbon sequestration capacity has become a primary indicator of carbon cycling. Suaeda salsa directly influences carbon cycling through both plant carbon sequestration and root-soil carbon sequestration, and it also indirectly affects the carbon sequestration capacity of rhizosphere microorganisms. Additionally, Suaeda salsa possesses land remediation functions, which contribute to maintaining ecological stability, thereby protecting carbon storage and cycling.

3.1. Plant Carbon Sequestration

Similar to all autotrophic plants, the aboveground parts of Suaeda salsa can absorb carbon dioxide from the atmosphere and store it in the form of biomass through photosynthesis. As Suaeda salsa continues to grow, the accumulation of organic carbon in the form of sugars increases mainly in the leaf vascular tissues, where photosynthesis predominantly occurs [9]. The carbon sequestration capacity of Suaeda salsa remains relatively stable across various growth stages, and it even increases during the aging phase [8]. Salinity variations in coastal areas are the primary factors affecting photosynthesis. Due to intensified evaporation caused by climate warming and rising sea levels in recent years, salinity in coastal wetlands continues to increase. The main salt ions contributing to this increase are chloride and sodium ions. Therefore, simulated experiments using NaCl as a variable were conducted to study the effects of salinity on the light reaction and carbon assimilation rate of Suaeda salsa. It was found that there is a positive correlation between NaCl concentration and the light efficiency and carbon assimilation rate of Suaeda salsa. This may be due to the increase in Rubisco activity and chlorophyll content [10].

3.2. Soil Carbon Sequestration

When plants age or die, their litter enters the soil and, along with residual roots, is decomposed by soil microorganisms into more stable soil organic matter that can be stored long-term. The DNDC (Denitrification-Decomposition) model can simulate carbon cycling in ecosystems by calculating denitrification and organic matter decomposition processes [11]. Soil microbial communities are the foundation of soil ecological functions, capable of sequestering carbon from plant litter into the soil. The decomposition rate of Suaeda salsa litter primarily depends on the types and quantities of soil microbial communities. The dominant microbial community in Suaeda salsa root-soil differs significantly from that in bare soil, with bacterial communities being dominant and exhibiting greater diversity than actinomycetes [12]. This is because bacteria have a higher adaptability to alkaline environments and are more likely to thrive and become dominant in high-pH coastal wetlands [13]. The decomposition of Suaeda salsa litter is influenced by various factors. Firstly, the decomposition time of litter is closely related to hydrological conditions. Experiments conducted by Wang Wenfang's team concluded that the organic carbon content exhibits a trend of initially decreasing, then increasing, and then decreasing again with decomposition time. The relationship between litter mass residual rate and decomposition rate with environmental factors such as salinity and flooding frequency is not particularly strong [14]. Additionally, seasons also have a significant impact on litter decomposition. The different temperatures and fluctuations in temperature directly affect the rate of soil microbial mineralization and decomposition [15].

The interaction between Suaeda salsa and soil microorganisms can be viewed as a positive cycle. Suaeda salsa improves soil texture, providing a habitat for microorganisms, increasing the types and quantities of microbial communities, and providing favorable support for the rich development of rhizosphere bacterial community diversity. The enhancement of microbial diversity directly affects the release of soil metabolic products, providing more nutrients for plants like Suaeda salsa and increasing the sequestration of organic carbon [16]. In this cycle, plants continuously fix carbon dioxide and store it in the soil, constituting a part of the large carbon cycle in coastal wetlands.

4. Factors Influencing the Participation of Suaeda salsa in Coastal Wetland Carbon Cycling

With the dual impacts of global climate warming and human activities, such as rising temperatures, rising sea levels, and increasing urbanization, the habitat of coastal wetlands has been altered, leading to widespread shrinkage and degradation of coastal wetlands.

4.1. Impact of Global Climate Warming

According to reports from the Intergovernmental Panel on Climate Change (IPCC), global temperatures have risen by approximately 1.1°C compared to pre-industrial levels. Analysis of data obtained from warming simulations in wetland ecosystems conducted in the Yellow River Delta indicates significant changes in community structure due to increased temperatures. The rise in temperature has led to an increase in salinity, resulting in the replacement of hydrophytic plants by more salt-tolerant halophytes. Previously dominant communities in the Yellow River Delta, primarily composed of reeds, have gradually transitioned back to communities dominated by Suaeda salsa [17].

Climate warming also brings about extreme weather events, with flooding being the primary impact in coastal wetlands. Experiments have shown that carbon cycling exhibits slower rates after extreme flooding events [2]. Flooding triggered by heavy rainfall, for example, can lead to a reduced rate of carbon dioxide absorption through photosynthesis in Suaeda salsa and increased gas emissions through respiration. This is due to decreased root function caused by soil hypoxia, which induces stomatal closure in plants and affects plant growth. Moreover, hypoxic conditions can result in root rot and microbial death [18-19].

4.2. Impact of Human Activities

Since the onset of the industrial era, urbanization has continued to deepen, leading to the occupation of large areas of wetland ecosystems for agricultural development, industrial construction, and other human activities, directly or indirectly encroaching upon the habitat of Suaeda salsa. Natural hydrological conditions have also been altered due to infrastructure development such as water conservancy projects and road construction, as well as wetland water pollution from industrial wastewater. These infrastructures can disrupt water circulation and affect the hydrodynamic conditions necessary for the growth of Suaeda salsa. The introduction of invasive species due to human activities, such as the common occurrence of Spartina alterniflora, has led to the proliferation of these species, occupying the habitat of native plants and destabilizing ecosystems. According to statistics from the past three decades, China's coastal tidal wetlands have shown an overall decrease, with a total area reduction of 42.98%, including a decrease in bare tidal flats of 46.30%, with many areas where Suaeda salsa grows being converted into other land use types or reverting to bare land [5].

However, human activities do not only bring negative impacts to Suaeda salsa. Previous studies have shown that nitrogen content is a major limiting factor for photosynthesis in Suaeda salsa[9]. Therefore, artificial nitrogen addition may contribute to the growth of Suaeda salsa and increase the soil organic carbon sequestration in wetlands, becoming one of the ways to increase the carbon cycling rate of Suaeda salsa. Additionally, due to the attractive appearance of Suaeda salsa (red in May-June and purple-red in August-September) and its edible value, there is a trend of artificial cultivation.

5. Conclusion

This study investigated the mechanisms of Suaeda salsa's impact on carbon cycling in coastal wetland systems, aiming to understand the relationship between Suaeda salsa's characteristics and carbon cycling, analyze the potential changes brought about by various disturbances, and evaluate its carbon sequestration capacity as well as the impacts of climate warming and human activities on the growth and carbon sequestration capacity of Suaeda salsa. Based on comprehensive literature review, it was found that Suaeda salsa is a common halophytic plant in coastal wetlands in eastern China, including the Yellow River and northward regions. It stores carbon dioxide through photosynthesis and ultimately sequesters it in the soil as litter or utilizes it by microorganisms. Suaeda salsa exhibits relatively high carbon sequestration capacity among common halophytes, and moderate warming and increased salinity promote its photosynthesis and growth, allowing it to dominate in ecosystem succession. However, extensive losses have occurred due to human activities. This indicates that Suaeda salsa is more adaptable to global climate warming and has significant carbon sequestration potential, but attention is required. It provides insights for further in-depth research and application of blue carbon. The interaction between Suaeda salsa and root-associated microorganisms remains understudied, and data on the amount of carbon stored in the soil or utilized by root-associated microorganisms are lacking, indicating that the carbon cycling of Suaeda salsa has not been fully studied.

Studying Suaeda salsa as a representative species helps better understand the role of coastal salt-tolerant vegetation in the global carbon cycle, guiding better protection and restoration of coastal ecosystems. Suaeda salsa's participation in the carbon cycling of ecosystems is directly related to its ability to improve saline-alkali land characteristics, and its nutritional and ornamental value suggests it may become a widely planted vegetation in coastal areas in the future.

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