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Coastal Wetland Ecology: Tracking the Evolution Under the Intersection of Satellite Oceanography and Meteorology

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Abstract:

Coastal wetland ecosystems play a crucial role in the global ecological environment, and their evolution is influenced by various factors. This paper focuses on tracking the evolution of coastal wetland ecology under the combined action of satellite oceanography and meteorology. It elaborates on the impacts of related disciplines on the evolution of coastal wetland ecology, analyzes the methods of tracking the evolution of coastal wetland ecology using satellite oceanography and meteorological technologies, and discusses the trends and countermeasures of coastal wetland ecological evolution, aiming to provide a scientific basis for the protection and management of coastal wetland ecology.

Keywords:

Coastal wetland ecology
Satellite oceanography
Meteorology
Evolution tracking

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1. Introduction

As a transitional zone between terrestrial and marine ecosystems, coastal wetlands have unique ecological structures and functions. They not only serve as habitats for numerous rare species but also play a key role in regulating the climate, purifying water quality, and withstanding natural disasters. However, under the dual pressures of global climate change and human activities, coastal wetland ecosystems are facing serious threats, such as area shrinkage and ecological function degradation. The development of satellite oceanography and meteorology provides powerful technical support for tracking the evolution of coastal wetland ecology. Through satellite remote sensing and other means, large - scale, long - time - series observation data of coastal wetlands can be obtained. Combining with the theories and methods of meteorology, the evolution laws of coastal wetland ecology under the combined action of multiple factors can be deeply studied, which is of great significance for the protection and sustainable use of coastal wetlands.

2. Overview of the coastal wetland ecosystem

2.1. Definition and types of coastal wetlands

Coastal wetlands are located in the coastal areas connecting freshwater river systems and saltwater ocean systems. They are of great environmental significance, serving as a buffer zone between terrestrial and marine ecosystems. With complex physical and chemical properties, hydrological conditions, and morphological compositions, they are unique ecosystems with high ecological and economic value and potential value on Earth. They are also ecologically fragile and sensitive areas under the combined effects of global climate change and human activities [1]. Coastal wetlands encompass a variety of typical types. For example, muddy beaches, characterized by their fine silt sediments, provide habitats for special organisms. Intertidal salt marshes, with their water-salt environment under tidal action, nurture unique species. Mangroves, with their viviparity and salt-secreting characteristics, form an ecological barrier in the intertidal zone. Estuarine waters, where rivers and oceans meet, mix nutrients and support biodiversity. Estuarine deltas and sandbars are formed by the accumulation of river sediments and develop rich ecosystems over time. Coastal saltwater lakes, caused by seawater intrusion and salinization, nourish salt-tolerant organisms. Coastal freshwater lakes, replenished by terrestrial freshwater, provide habitats for freshwater organisms. Shallow seawater areas, with suitable light and water temperature, are breeding grounds for marine larvae and fishery resources.

2.2. Ecological functions of coastal wetlands

Coastal wetlands have significant ecological value. In terms of biological habitats, they create crucial living spaces for many organisms such as birds, fish, and shellfish. They not only provide suitable breeding grounds to ensure species reproduction but also create ideal habitats and foraging environments, maintaining the stability of biological communities. Regarding the carbon-sink function, their soils are rich in organic carbon. Through special ecological processes such as carbon sequestration by vegetation photosynthesis and the long-term burial of organic matter by soil microorganisms, they are integrated into the global carbon cycle, helping to mitigate climate change [2]. When it comes to the water purification function, coastal wetlands, through the coordinated efforts of physical sedimentation, chemical adsorption, and biological degradation, efficiently remove pollutants such as nitrogen and phosphorus from water bodies, laying a solid foundation for the healthy operation of the aquatic ecosystem. In addition, their vegetation communities and unique landforms form a natural defense line, which can effectively reduce the impact of storm surges and wave erosion, safeguarding the ecological security of coastal areas and the stability of human settlements.

3. The relationship between satellite oceanography and coastal wetland ecology

3.1. Application of satellite oceanography technology in coastal wetland monitoring

Satellite oceanography uses satellite remote-sensing technology to observe and study marine environmental elements. In coastal wetland monitoring, commonly used satellite remote-sensing data include optical remote-sensing data and microwave remote-sensing data. Optical remote-sensing data can obtain information such as the vegetation distribution and land-cover types of coastal wetlands. For example, the 10-m-resolution multispectral images of the “Sentinel - 2” satellite can be used to create remote-sensing maps of coastal wetlands, establish interpretation marks for multiple sub-categories of coastal wetlands, and classify and count them. Microwave remote-sensing data, not limited by weather and lighting conditions, can penetrate clouds and obtain information such as the terrain and soil moisture of coastal wetlands. For example, Synthetic Aperture Radar (SAR) can be used to monitor the changes in tidal flat topography and water-body distribution in coastal wetlands.

3.2. Contributions of satellite oceanography to the study of coastal wetland ecological evolution

Through satellite oceanography technology, the area changes and vegetation-cover changes of coastal wetlands can be monitored over long time - series. For example, by using satellite remote-sensing images to monitor the evolution of coastal wetlands in northeastern Italy from

1984 to 2016, it was found that the coastal wetlands outside the protected area decreased by 21.62%. It can also study the interrelationships between coastal wetlands and marine environmental elements, such as analyzing the impacts of sea-surface temperature, salinity, etc., on the growth and distribution of coastal wetland vegetation, providing data support for the study of the mechanisms of coastal wetlands ecological evolution [3].

4. The relationship between meteorology and coastal wetland ecology

4.1. Impacts of meteorological elements on coastal wetland ecology

Meteorological elements, including key variables such as temperature, precipitation, wind speed, and wind direction, have significant direct or indirect impacts on coastal wetland ecosystems. The dynamic temperature changes are crucial for the growth, development, and phenological regulation of coastal wetland vegetation. Its rise and fall affect key nodes such as vegetation sprouting and flowering. Extreme temperatures may also exceed the tolerance limits of organisms, leading to growth stagnation, reproductive failure, and a decline in population numbers. Precipitation, as the core hydrological supply, with its amount and frequency, reshapes the soil water-salt balance of wetlands, thereby driving the replacement of dominant vegetation species, the adjustment of functional-group structures, and the change of the ecological pattern. Wind speed and wind direction dominate the material and energy transfer in wetlands. When strong winds come, wetland vegetation is vulnerable to damage such as plant breakage and branch-leaf damage. It will also intensify soil erosion, resulting in substrate loss and impacting the stability of the ecosystem [4].

4.2. Impacts of climate change on coastal wetland ecology

Meteorological elements, including key variables such as temperature, precipitation, wind speed, and wind direction, have significant direct or indirect impacts on coastal wetland ecosystems. The dynamic changes in temperature are crucial for the growth, development, and phenological regulation of coastal wetland vegetation. Its rise and fall affect key nodes such as vegetation sprouting and flowering. Extreme temperatures may also exceed the tolerance limits of organisms, leading to growth stagnation, reproductive failure, and a decline in population numbers. Precipitation, as the core hydrological supply, with its amount and frequency, reshapes the soil water-salt balance of wetlands, thereby driving the replacement of dominant vegetation species, the adjustment of functional-group structures, and the change of the ecological pattern. Wind speed and wind direction dominate the material and energy transfer in wetlands. When strong winds come, wetland vegetation is vulnerable to damage such as plant breakage and branch-leaf damage. It will also intensify soil erosion, resulting in substrate loss and impacting the stability of the ecosystem.

5. Methods for tracking the evolution of coastal wetland ecology under the intersection of satellite oceanography and meteorology

5.1. Multi-source data fusion

Multi-source data fusion, a key link in exploring the evolution of coastal wetland ecology, aims to integrate the marine environmental data collected by satellite oceanography and the meteorological observation data in the field of meteorology. Specifically, with the help of precise spatio-temporal matching technology, the fine data such as sea-surface temperature and salinity obtained by satellite remote sensing are organically integrated with the key indicators such as temperature and precipitation monitored and recorded by ground-based meteorological stations for a long time, constructing a comprehensive data set covering multiple information [5]. This data set can break through the limitations of a single data source, comprehensively reflect the environmental background of the coastal wetland ecosystem, and provide a solid and comprehensive data foundation for the subsequent in-depth analysis of the internal mechanisms, driving factors, and dynamic processes of the evolution of coastal wetland ecology, effectively improving the accuracy and reliability of the research.

5.2. Model construction and simulation

Model construction and simulation play a core role in explaining the evolution process of coastal wetland ecology under the combined action of satellite oceanography and meteorology factors. By introducing advanced mathematical models and practical ecological models, researchers can quantitatively simulate the complex and changeable evolution trends of coastal wetland ecosystems. Take the coastal wetland ecosystem dynamics model as an example. This model sets marine environmental elements (such as seawater velocity, tidal dynamics, and marine nutrient-salt concentration), meteorological elements (including temperature fluctuations, precipitation patterns, and wind-speed and wind-direction changes), and wetland ecological elements (including vegetation coverage, species diversity, and soil physical and chemical properties) as key variables and incorporates them into a unified analysis framework. Based on this, with the powerful computing power of the model, it can accurately simulate the evolution trajectories of coastal wetland ecosystems under different climate scenarios and marine-environmental change scenarios, and prospectively predict the area change trends, vegetation-community succession dynamics, and potential transformation directions of ecological functions of coastal wetlands in the future, providing forward-looking guidance for scientific decision - making and ecological management.

5.3. Spatio-temporal analysis methods

Spatio-temporal analysis methods rely on the powerful technical platform of Geographic Information System (GIS) to conduct systematic and in-depth analysis of the collected multi-source data [6]. With the excellent spatial-analysis function modules of GIS, researchers can accurately analyze the distribution patterns, heterogeneity characteristics, and dynamic change trends over time of various elements within the coastal wetland ecosystem in the geographical space. By serially integrating the data obtained at different time nodes and combining long-time-series analysis techniques, the spatio-temporal differentiation laws and internal-correlation characteristics of the evolution of coastal wetland ecology can be comprehensively revealed. For example, in the study of the core area of the Yancheng National Rare Birds Nature Reserve, the GIS technology was used to deeply mine the long-time-series of spatio-temporal change information of three representative coastal wetland vegetation communities, *Spartina alterniflora*, *Suaeda salsa*, and *Phragmites australis*, from 1990 to 2022, accurately depicting the expansion and contraction of their distribution ranges, the optimization and reorganization of community structures, and the dynamic adjustment process of ecological niches, thus providing an intuitive and detailed basis for in-depth understanding of the response mechanisms of coastal wetland ecosystems to complex environmental changes [7].

6. Strategies for the protection and management of coastal wetland ecology

6.1. Strengthening monitoring and assessment

Fully utilize the cutting-edge technical means of satellite oceanography and meteorology to build a long-term and dynamically - monitored coastal wetland ecological monitoring network system. This system focuses on the key ecological elements of coastal wetlands, including area dynamic changes, vegetation-community structure and coverage dynamics, water-quality parameter fluctuations, and biodiversity abundance and composition. With the help of high-precision sensors and real-time data - transmission links, it can achieve all-round and real-time tracking and monitoring of the above-mentioned elements, ensuring that the evolution trend of the coastal wetland ecosystem can be accurately and timely grasped. At the same time, conduct comprehensive assessments of the coastal wetland ecosystem periodically. Using scientific and rigorous assessment indicator systems and quantitative analysis methods, deeply analyze the health status, functional integrity of the ecosystem, and its response mechanisms to internal and external interference factors, laying a solid scientific foundation for the subsequent formulation of precise and effective protection and management decisions.

6.2. Formulating scientific protection plans

Upholding the concept of scientific overall planning, comprehensively integrate the dynamic information of the marine environment revealed by satellite oceanography and the climate and meteorological change trends reflected by meteorology. Closely combine the unique ecological background characteristics and evolution trajectories of coastal wetlands to carefully draw a scientific, reasonable, and feasible coastal wetland protection plan [8]. In the process of plan formulation, clearly define targeted protection goals, accurately identify key protection areas such as ecological key areas and vulnerable areas, and delimit ecological protection red lines through rigorous scientific demonstration and legal procedures, building a solid ecological security barrier for coastal wetlands [9]. At the same time, taking into account the needs of regional economic development, with sustainable development as the orientation, carefully and rationally arrange the development and utilization activities of wetland resources, striving to achieve a virtuous interaction and coordinated progress between coastal wetland ecological protection and economic and social development, and realizing the organic unity of ecological, economic, and social benefits.

6.3. Ecological restoration and reconstruction

For coastal wetland ecosystems that have shown signs of degradation, implement comprehensive ecological restoration and reconstruction projects according to local conditions. For example, carefully implement the strategy of returning farmland to wetlands to restore the natural wetland habitat in an orderly manner. Carry out special vegetation-restoration actions. According to the structure and succession laws of the original vegetation community, select pioneer species and constructive species suitable for the local environment to gradually rebuild the vegetation community. Implement water-system connectivity projects to optimize the wetland hydrological cycle pattern and improve the connectivity and stability of the wetland ecosystem. While implementing restoration projects, strengthen the continuous monitoring and scientific assessment of the ecological restoration effectiveness of coastal wetlands. Build a dynamic feedback mechanism, and flexibly adjust the restoration technical routes and management strategies according to real-time monitoring data and assessment results, ensuring that the restoration projects can accurately meet the needs of the ecosystem and efficiently achieve the restoration and improvement of coastal wetland ecological functions [10].

7. Conclusion

The evolution of coastal wetland ecology is affected by satellite oceanography and meteorology, showing phenomena such as area reduction and function degradation. The process is explored through data fusion, model simulation, and spatio-temporal analysis. Future research needs to improve the accuracy and resolution of monitoring technologies, deepen interdisciplinary research to reveal the evolution mechanisms and strengthen international cooperation to support the sustainable development of coastal wetland ecosystems.

Disclosure statement

The author declares no conflict of interest.

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