Impact of Sea Level Rise on Landscape Ecology in the Greater Bay Area Under Global Warming Effect

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Abstract: In the context of escalating global climate change, sea level rise has emerged as a pressing global concern. This phenomenon exerts a profound influence not only on coastal landscapes and land use patterns, but also on biodiversity, ecosystem functions, and human life. As a vibrant and promising urban agglomeration in China and globally, the Guangdong-Hong Kong-Macao Greater Bay Area confronts particularly acute challenges and threats to its landscape patterns and biodiversity due to rising sea levels. The primary objective of this study is to scrutinize the implications of sea level rise on the landscape ecology of the Guangdong-Hong Kong-Macao Greater Bay Area amidst the backdrop of global warming, and to propose pertinent adaptive measures and management recommendations grounded in predictive analyses. The outcomes of this research will significantly contribute to the formulation of a strategic framework for managing sea level rise in the Greater Bay Area, providing policymakers with invaluable information and tools to safeguard the region's landscapes, biodiversity, and human communities in the midst of ongoing climate change.

1 INTRODUCTION

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report underscores the remarkable escalation in global surface temperatures and forecasts a continual augmentation in sea levels attributed to anthropogenic global warming. Notably, the real-world emissions of carbon dioxide (CO2) are anticipated to contribute significantly to substantial rises in sea levels towards the end of the century. When comparing the 2011-2020 average global surface temperature with the baseline period of 1850-1900, a significant increase of 1.1°C is observed, with further projections indicating a potential rise of 1-2°C. Concurrently, human-induced global warming is a major driver of glacier melting, thereby intensifying the upward trend in sea levels. Specifically, the IPCC predicts that by the century's end, real CO2 emissions will elevate sea levels by 32-76 cm, and by the middle of the next century, an intermediate estimate suggests an increase of 37-133 cm. Extensive research had identified the primary causes of sea-level rise since 1900 as the combined effects of thermal expansion of the ocean and enhanced ice-mass loss from Greenland (Frederikse et al, 2020, Anny & Gonéri, 2014). The direct consequences of this phenomenon encompass coastline erosion, flooding, salinization of water resources, habitat fragmentation, and numerous other detrimental impacts, significantly impacting coastal regions. Some studies have emphasized that the escalating sea levels will profoundly reshape the coastal landscape of the 21st century (Taherkhani et al, 2020). Researchers investigated North Carolina's largest coastal wildlife refuge reveals that alterations in land use patterns due to sea-level rise will further compromise wetland functions, wildlife habitats, and the global carbon cycle (Ury et al, 2021). It is estimated that approximately half of the world's cities with a population exceeding one million are situated in coastal zones, which are economically vibrant, densely populated, and play a pivotal role in advancing socio-economic development at the regional, national, and global levels (Lifang et al, 2014). The increasing levels of seas and oceans due to global warming pose a substantial threat to the daily lives of residents residing in coastal and low-lying areas. In this context, researchers has advanced adaptive measures to mitigate the potential impacts of sea-level rise (Nazarnia et al, 2020).

In recent decades, the coastline of the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) has exhibited dynamic and increasingly frequent alterations, primarily attributed to anthropogenic factors encompassing land reclamation, national

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policies, and urbanization processes. Against the backdrop of a rising sea level, the landscape ecology of the GBA is vulnerable to the combined pressures of human interventions and climate change (Hu et al, 2021). While previous studies have predominantly focused on the impacts of human activities, this paper adopts a natural perspective to scrutinize the influence of sea-level rise induced by global warming on the dynamic evolution of landscape patterns and the conservation of biodiversity within the GBA. The escalating vulnerability of the GBA to sea-level rise underscores the imperative for comprehensive research and proactive adaptation strategies.

By examining the natural drivers of landscape transformation and biodiversity decline, this study aims to provide profound insights into the ecological implications of sea-level rise in this region. Furthermore, it contributes to the formulation of targeted adaptation measures that prioritize the enhancement of ecosystem resilience and the conservation of biodiversity. By integrating the findings of this research with existing knowledge on human-induced landscape modifications, policymakers and stakeholders can devise holistic strategies that address both the direct and indirect consequences of sea-level rise. Ultimately, this interdisciplinary approach will bolster the sustainable development of the GBA in the face of ongoing climate change, fostering a harmonious balance between ecological integrity, socio-economic growth, and human well-being.

2 IMPACT OF SEA LEVEL RISE ON THE GREATER BAY AREA

The Guangdong-Hong Kong-Macao Greater Bay Area (GBA), spanning an area of 5.59 × 104 km² and situated in the southern region of China (111°21'E-114°53'E, 21°28'N-24°29'N), encompasses nine cities in Guangdong Province (Guangzhou, Shenzhen, Shantou, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, Zhaoqing) as well as the special administrative regions of Hong Kong and Macao. Characterized by a subtropical humid monsoon climate, the GBA boasts an average annual temperature ranging from 21.4 to 22.4°C and an average annual precipitation of 1800 mm. Geographically, the GBA enjoys exceptional advantages, surrounded by mountains on three sides and converged by three rivers, possessing a lengthy coastline, a robust port system, and an expansive maritime area. Despite occupying less than 1% of China's landmass and housing approximately 5% of its population, the GBA contributes a significant 11% to the country's total economic output, positioning it as one of the most open and dynamic regions in China. With a robust economic foundation and industrial prowess, the GBA serves as a crucial window and platform for China's economic development and international engagement.

2.1 Impact on Region Ecology Safety

The direct consequence of sea level rise on coastal regions is inundation and flood disasters. The Guangdong-Hong Kong-Macao Greater Bay Area (GBA), with its exceptionally extensive coastline and low-lying terrain surrounded by hills on three sides, is particularly vulnerable to slight fluctuations in sea level, which can lead to inundation of significant urban areas. For instance, an increase in sea level by merely 0.3m would bring the tidal level of the Pearl River estuary close to the astronomical high tide level, thereby impeding drainage and potentially causing flood disasters when coupled with heavy rainfall. Furthermore, sea level rise also reduces the return period of storm surges. Specifically, a 0.1m rise in sea level would decrease the return period of a once-in-200-year storm surge in Guangzhou to 145 years, while a 0.3m rise would further shorten it to 75 years (Yaodong et al, 2004). Research and simulations conducted that under a low sea level rise scenario of 0.3m, the inundation area is primarily concentrated around the Pearl River estuary (Lehua et al, 2022). Additionally, the central part of Zhuhai is also affected. Under a moderate scenario of 1.0m sea level rise, the inundated area of coastal regions encompassing Shenzhen, Dongguan, Guangzhou, Zhongshan, Zhuhai, and Jiangmen expands significantly. When sea levels rise to 1.6m, a high forecast scenario, the coastal plains of Guangzhou and Zhongshan, as well as most areas of Zhuhai, are inundated. Additionally, the inland regions along the rivers within the GBA also experience flooding due to sea level rise. On a broader scale, the inundated area within the entire GBA continues to expand with rising sea levels. Even relatively modest sea level rises pose a threat of inundation to most coastal cities. Significant sea level rises, however, will impact all 11 cities within the GBA to varying degrees. Concurrently, as the transitional zone between land and sea, the GBA's coastal areas serve as a crucial ecological buffer, supporting diverse ecosystems and providing vital ecological services. However, the impact of sea level rise on these ecosystems is

complex and multifaceted, necessitating further in-depth research and analysis.

2.2 Impact on Landscape

In the context of academic rigor, sea level rise is anticipated to induce substantial alterations in the proportional distribution of various landscape types, thereby augmenting the fragmentation, complexity, and heterogeneity of landscape patterns. The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) exemplifies a diversified landscape composition. Construction land, comprising urban areas and residential zones that harbor significant populations and resources, is predominantly concentrated in the central and coastal regions. Conversely, woodland, encompassing diverse forest types such as dense and open woodland, shrubs, and other wooded areas, is located in the higher elevations of the southwest and northern sections of the GBA. The phenomenon of sea level rise poses a considerable inundation threat to various landscape types within the GBA, particularly wetlands and construction land. As sea levels ascend, coastal environments like beaches and wetlands are prone to damage from wave and seawater erosion, leading to the recession of coastlines. Additionally, the rise in sea levels may inundate urban settlements and residential areas situated below the original coastline, jeopardizing agricultural lands (rice paddies, dry farmland), aquaculture ponds, and critical transportation infrastructure vital for sustaining human life. Moreover, the intensified storm surges and seawater erosion associated with sea level rise can contribute to land salinization, posing a threat to food security and the availability of freshwater resources. The destruction of these facilities not only disrupts the normal production and living conditions of humans but also threatens the stability and functionality of ecosystem services.

2.3 Impact on Biodiversity

Sea level rise represents a significant threat not only to various landscape types and thereby the normal life of humans, but also to the conservation of biodiversity within the Greater Bay Area. Coastal regions, as critical ecosystems bridging land and sea, offer invaluable resources for biological survival and reproduction, and play a pivotal role in maintaining the equilibrium of food chains and ecosystems. The unique ecological milieu of the Guangdong-Hong Kong-Macao Greater Bay Area serves as a habitat for numerous rare and endangered species, and furthermore, it constitutes an essential habitat and ecological corridor for migratory birds and animals. The escalation of sea levels, attributed to global warming, is anticipated to result in the erosion of biological habitats. Additionally, the fragmentation and heterogeneity of landscapes, stemming from alterations in land use types and functions, will further exacerbate this challenge. Organisms will thus be confronted with the dual predicament of habitat inundation and fragmentation, posing significant challenges to their survival.

The mangrove ecosystem, a distinctive coastal habitat, plays a pivotal role in safeguarding biodiversity and supplying diverse ecosystem services. Its robust root system efficiently filters pollutants and sediments from the aquatic environment, while its intricate root network and dense foliage withstand storm surges and waves, safeguarding the coast from erosion. Additionally, mangroves serve as significant carbon sinks within the global ecosystem, sequestering and storing vast quantities of carbon dioxide, thereby contributing significantly to the mitigation of global climate change. In the context of global warming and sea level rise, natural alterations in coastal regions not only jeopardize wildlife habitats but also adversely affect the global climate. Coastal erosion and flooding can destroy mangrove ecosystems, leading to the release of their stored carbon, thus amplifying climate change. The Guangdong-Hong Kong-Macao Greater Bay Area is particularly rich in mangrove resources, boasting natural protected areas such as the Futian Mangrove Reserve in Shenzhen and the Bay Mangrove Area in Jiangmen Town. Recent studies have revealed that with the rise in sea level, mangrove and tidal flat habitats in the Greater Bay Area are experiencing severe degradation (Wang et al, 2024). This phenomenon further compounds the threat to biodiversity conservation in the region, emphasizing the need for urgent conservation measures and policies to safeguard these crucial ecosystems.

3 SUGGESTIONS

3.1 Sustainable Urban Planning and Land Use Policies

To scientifically mitigate and manage the various changes and disasters stemming from sea level rise, a comprehensive understanding of the underlying evolutionary patterns of extreme weather disasters is paramount. Ensuring the continued functionality and services of ecosystems necessitates the adoption of

scientific planning and design methodologies. The impact of sea level rise is heterogeneous, varying across landscapes, land use types, altitudes, and regions. Therefore, tailored strategies are essential for addressing this challenge. For instance, it is advisable to avoid the construction of crucial infrastructure and urban expansion, such as residential areas, in vulnerable coastal zones. Elevating crucial facilities, strengthening physical defenses, and relocating them to inland areas when necessary are all viable options. A multifaceted approach combining these strategies is recommended. In the context of rising sea levels, the human living environment and biological habitats in coastal regions are bound to be affected in the future. Compared to a blind retreat strategy, extending into the sea represents a sustainable development path (Wenting et al, 2017). Currently, innovative practices such as "floating cities," "ecological floating islands," and "aquatic architecture" are being explored globally. These attempts may emerge as significant research focuses in the future, particularly in the context of climate change.

3.2 Strengthen Safety Monitoring and Risk Assessment

In the context of the inevitable rise in sea levels, it is crucial to enhance dynamic monitoring and management of coastlines. This involves conducting ecological security monitoring and risk assessments to establish a dynamic protection mechanism with effective response strategies. Management efforts should prioritize protection and manual intervention based on the varying impact gradients of sea level rise. Maximizing the disaster prevention and mitigation capabilities of existing engineering measures is imperative. This includes improving the capacity and mechanisms for responding to natural disasters, while fully leveraging the disaster prevention and mitigation potential of natural ecosystems. To strengthen coastline management, the construction of seawalls, artificial beaches, and artificial islands should be prioritized. Furthermore, appropriate protection and restoration measures should be implemented to mitigate the adverse impacts of storm surges and waves on coastal habitats.

3.3 Improve Ecosystem Resilience

Constructing resilient cities, bolstering the resilience and stability of ecosystems, regulating and sustaining the value of natural ecosystem service functions, and harnessing their role in diverse ecological environments are pivotal in addressing the risks and challenges posed by sea level rise. To enhance habitat stability and resilience, it is imperative to safeguard biodiversity through the establishment of green infrastructure such as constructed wetlands and intertidal protected areas. Additionally, the protection and restoration of mangrove ecosystems must be prioritized, with restrictions on logging and development activities, along with strengthened monitoring and law enforcement to ensure their effectiveness in protection and climate regulation. Based on local ecological conditions, green ecological corridors should be constructed to facilitate the migration and dispersal of wildlife, fostering gene flow and population exchange, ultimately enhancing biodiversity.

3.4 International Cooperation and Public Awareness

To effectively address the challenges posed by sea level rise and habitat erosion, it is crucial to elevate public awareness through educational and advocacy initiatives, thereby fostering public participation and cooperation. Concurrently, we must reinforce international exchanges, cooperation, and knowledge sharing to collectively confront the global warming and rising sea level challenges. This can be achieved through collaborative research efforts, technology transfer, and resource sharing mechanisms.

4 CONCLUSIONS

As global warming persists and its ramifications intensify, the rising sea level poses an increasingly grave threat to the urban centers within the Guangdong-Hong Kong-Macao Greater Bay Area. Yearly, these metropolitan landscapes are becoming increasingly vulnerable to a spectrum of extreme natural disasters, including typhoons, floods, and storm surges, which are exacerbated by the incessant rise in sea levels. The risks of inundation not only jeopardize the safety of inhabitants but also constitute a significant impediment to the ecological sustainability of these urban centers. Concurrently, the landscape patterns in this region are undergoing profound transformations, often culminating in the loss and fragmentation of habitats. This dual predicament of habitat loss and fragmentation significantly threatens biodiversity, thereby diminishing the resilience of local ecosystems and their capacity to adapt to environmental alterations.

The depletion of natural habitats disrupts the delicate equilibrium between species, adversely affecting the food chain and the overall stability of the ecosystem. Moreover, the degradation of ecosystem functions and services due to climate change further compounds this issue. In response to the pressing challenges posed by climate change, it is of utmost importance to implement adaptive measures that are comprehensive and multi-faceted.

The significance of the present study lies in its provision of a novel perspective and framework for comprehending, analyzing, and responding to the multifaceted challenges posed by climate change. Specifically, the findings contribute significantly to advancing our understanding of the vulnerabilities of urban ecosystems within the Guangdong-Hong Kong-Macao Greater Bay Area to rising sea levels, extreme weather events, and the associated threats to biodiversity. Furthermore, this research offers valuable insights into the development of targeted strategies for ecological protection and restoration, thereby fostering the sustainable development of the Greater Bay Area and beyond.

The current study presents the observations and prevailing trends pertaining to ecosystem vulnerability; however, it lacks a comprehensive analysis of the underlying mechanisms, intricate interactions between diverse factors, and the specific pathways that influence this vulnerability. Recognizing the complexity of climate change and its implications for ecosystem health, future research endeavors must embrace an interdisciplinary approach, integrating knowledge from diverse fields to effectively address this multifaceted challenge.

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