International Journal of Marine Science, 2024, Vol.14, No.2, 102-110
http://www.aquapublisher.com/index.php/ijms

Resaearch Article Open Access

Rising Tides: Long term Impact of Sea Level Rise on Marine Ecosystems

Yujie Chen ✉, Rudi Mai
Hainan Institute of Tropical Agricultural Resources, South China Sea Biological Research Center, Sanya, 572025, China
✉ Corresponding author email: 1768126628@qq.com

International Journal of Marine Science, 2024, Vol.14, No.2, doi: 10.5376/ijms.2024.14.0013
Received: 19 Feb., 2024
Accepted: 01 Apr., 2024
Published: 25 Apr., 2024

Preferred citation for this article:
Chen Y.J., and Mai R.D., 2024, Rising tides: long term impact of sea level rise on marine ecosystems, International Journal of Marine Science, 14(2): 102-110 (doi: 10.5376/ijms.2024.14.0013)

Abstract With the intensification of global climate change, rising sea levels have become an urgent environmental issue, having profound impacts on marine ecosystems. Rising sea levels lead to ecosystem degradation, decreased biodiversity, and shrinking habitats, further threatening the survival and reproduction of marine life. The aim of this study is to systematically evaluate the impact of sea level rise on marine ecosystems, explore its potential impacts on marine biodiversity and human society, and discuss possible adaptation and mitigation measures. By adopting a comprehensive analysis method, this study provides a detailed analysis of the causes and impact mechanisms of sea level rise, as well as the response and adaptability of ecosystems. This study emphasizes the importance of strengthening monitoring, research, and evaluation of the impact of sea level rise at the global and regional levels, in order to better develop effective adaptation and mitigation measures and mitigate the negative effects of sea level rise.

Keywords Sea level; Marine ecosystem; Biodiversity; Climate change; Adaptation strategy

Over the past few decades, global climate change has become a reality that cannot be ignored, and one of the most striking phenomena is the continued rise of sea levels. According to the report of the International Climate Change Expert Group, the global mean sea level has risen by about 2 cm since the end of the 20th century, and this rising trend is continuing at an accelerating rate (Wang et al., 2023). Sea level rise is largely blamed on global warming, which causes glaciers and ice caps to melt, and seawater to expand thermally due to rising temperatures. These changes are not only direct evidence of changes in the earth's climate system, but also herald unprecedented challenges to marine ecosystems and human society.

Marine ecosystems, as the largest living systems on Earth, are critical to maintaining Earth's biodiversity and providing ecosystem services. However, rapid sea level rise is having a profound impact on these ecosystems. From the intertidal zone to the deep ocean, from coral reefs to polar ice caps, rising sea levels are causing a series of chain reactions such as habitat loss, saltwater intrusion into freshwater systems, and ocean acidification. These changes not only threaten the survival of marine organisms, but also affect their distribution, reproduction, and migration patterns, further leading to a reduction in biodiversity and ecosystem service functions (Ullah, 2024).

Human research on sea level rise and its impact on marine ecosystems is of extremely important significance. This can help us better understand the specific impact of climate change on the marine environment, thereby providing scientific basis for biodiversity protection and marine resource management. In-depth research on the impacts of sea level rise can provide important information for developing mitigation and adaptation strategies to mitigate the negative impacts of climate change on marine ecosystems and human society. This research will also promote interdisciplinary collaboration, integrating knowledge and technologies from multiple fields such as climate science, oceanography, ecology and socioeconomics to provide comprehensive solutions to the challenges of global environmental change.

Sea level rise is not only a global environmental problem but also a complex socioeconomic challenge. This study aims to comprehensively analyze the current status and trends of sea level rise, explore its long-term impact on marine ecosystems, and assess the potential impact of these changes on human society. Through this research, we

hope to provide more scientific and reasonable suggestions and strategies for ocean management and protection under global climate change, and provide reference and guidance for future policy formulation and environmental governance.

1 Causes of Sea Level Rise

1.1 Rising global temperatures and melting polar ice caps

Rising global temperatures are a major challenge facing the world today. It directly leads to the accelerated melting of polar ice caps, a phenomenon that has had a profound impact on the earth's natural environment and human society. With the emission of large amounts of greenhouse gases, especially CO_2, the average temperature of the earth continues to rise. This increase in temperature not only affects the Earth's climate patterns, but also causes the polar regions, especially the ice caps in the Arctic and Antarctic, to melt at an unprecedented rate (Wei et al., 2023).

The melting of polar ice caps contributes significantly to global sea level rise. As ice sheets gradually merge into the ocean, global sea levels rise year by year, threatening the ecosystems and human settlements in coastal areas. Rising sea levels have led to more frequent coastal flooding, eroding coastlines, destroying habitats, affecting fishery resources, and also increasing the risk of storm surges, posing a threat to coastal cities (Figure 1).

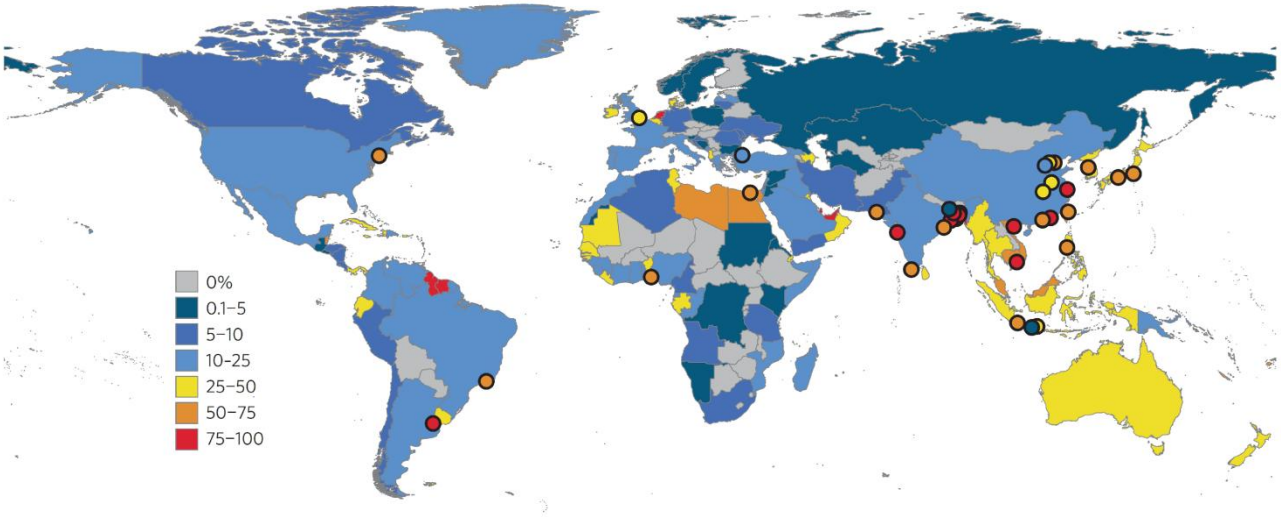

Figure 1 The areas affected by Sea level rise and the percentage of the population that are at risk (Elneel et al., 2024)

Melting polar ice caps also affect the global climate system. Ice and snow have high reflectivity and can reflect most solar radiation, but when the ice caps melt and expose darker seawater or land, these areas will absorb more solar energy, exacerbating the regional and global greenhouse effect. The melting of the Arctic ice caps also affects the global ocean circulation system, because the injection of fresh water changes the salinity and density of seawater, which in turn may affect global climate patterns and weather systems.

1.2 The physical process of thermal expansion and contraction of sea water

Thermal expansion and contraction of seawater is a basic physical process, which describes the phenomenon that the volume of seawater changes with temperature changes. This process plays a key role in Earth's climate system and sea level changes. When the temperature of seawater rises, the movement of water molecules accelerates, causing the average distance between molecules to increase, which in turn causes the volume of seawater to expand. This is the so-called "thermal expansion" phenomenon. On the contrary, when the temperature of seawater decreases, the movement of water molecules slows down, the average distance between molecules decreases, and the volume of seawater shrinks accordingly. This is the "cold shrinkage" phenomenon (Su et al., 2024).

This process has important consequences for sea level rise on a global scale. As global temperatures continue to rise, the oceans absorb large amounts of heat, causing seawater temperatures to rise and seawater volumes to

expand. In fact, one of the main causes of sea level rise over the past few decades is the thermal expansion of seawater. This effect is particularly obvious in surface seawater, which is directly heated by solar radiation and is more sensitive to temperature changes.

It is worth noting that the thermal expansion and contraction effects of seawater do not occur uniformly. Due to the uneven distribution of ocean temperature and salinity and the influence of deep ocean circulation, the degree of thermal expansion and contraction of seawater in different sea areas varies. Seawater reaches its maximum density near 4 °C, so the thermal expansion and contraction behavior of water near this temperature is different from that at other temperatures.

1.3 Human activities

The factors causing sea level rise due to human activities are multifaceted and complex. Their impacts are both direct and indirect, involving global warming, melting of glaciers and ice caps, thermal expansion and contraction of seawater, and groundwater and reservoir management. Together, these activities have driven significant sea level rise over the past century, with profound consequences for coastal communities, ecosystems, and the global climate.

Global climate warming is the core factor causing sea level rise caused by human activities. With the acceleration of the industrialization process, large amounts of greenhouse gases, especially CO_2, CH_4 and N_2O, are emitted into the atmosphere, enhancing the greenhouse effect of the atmosphere and causing the global average temperature to rise. This rise in temperatures directly accelerates the melting of glaciers around the world, as well as the Greenland and Antarctic ice sheets. As these bodies of ice enter the ocean, they not only increase the total volume of seawater, but also push up global sea levels.

Human activities also indirectly affect sea level rise in other ways. For example, over-exploitation of groundwater and redirection of natural water bodies, such as through the construction of large dams and reservoirs, increase the amount of water flowing to the ocean, thereby affecting sea levels. Urbanization and the development of coastal areas have also changed the natural drainage system of the land surface and accelerated the rate of land runoff entering the ocean (Zheng et al., 2022).

2 Impact of Sea Level Rise on Marine Ecosystems

2.1 Changes and loss of coastal ecosystems

Coastal ecosystems, including mangroves, salt marshes, coral reefs, seagrass beds, etc., are among the ecosystems on earth with the richest biodiversity and the highest ecological service value. They provide habitat, breeding grounds and food sources for many species, and also provide important ecological services to human society, such as coastline protection, carbon sequestration, water quality purification and support for economic activities. However, due to the impact of human activities and the intensification of global climate change, coastal ecosystems are experiencing unprecedented changes and losses, which poses a serious threat to biodiversity, ecological balance, and human well-being.

Human activities are the main cause of change and loss of coastal ecosystems. Land use changes caused by urbanization and industrial development, reclamation, port and dock construction in coastal areas, etc. have directly destroyed the natural state of coastal ecosystems (Chen et al., 2023a). Agricultural expansion, overfishing and pollution (including plastic pollution, chemicals and heavy metal pollution) further exacerbate the degradation of coastal ecosystems. The introduction of invasive species also destroys the local ecological balance and affects the structure and function of the original biological community.

Global climate change, particularly rising sea levels, increased ocean temperatures and ocean acidification, poses a major threat to coastal ecosystems. Rising sea levels have restricted the growth space of mangroves and salt marshes, affecting their growth and reproduction; rising ocean temperatures have led to widespread bleaching of coral reefs, threatening the health of coral reef ecosystems; ocean acidification has affected the calcification process of many marine organisms, thus affecting its survival and development.

Changes and losses in coastal ecosystems not only reduce biodiversity, but also weaken the ecological services provided by the ecosystem, such as reducing the natural protection capacity of the coastline, exacerbating coastal erosion and flood risks, affecting fishery resources, and reducing carbon storage. capabilities, thus exacerbating the negative impacts of climate change. The degradation of coastal ecosystems also directly affects the livelihoods and economic development of human communities that depend on these ecosystems.

2.2 Loss of biodiversity

The loss of biodiversity is a severe environmental crisis currently facing the world, which refers to the reduction of biological species on the earth and the reduction of ecosystem functions. This phenomenon not only threatens the complexity and richness of life on earth, but also poses a huge challenge to human living environment and future development. Biodiversity loss is mainly caused by human activities, including habitat destruction and fragmentation, overexploitation of natural resources, pollution, climate change, and invasive species.

Habitat destruction and fragmentation are the main causes of biodiversity loss. As population grows and economic activities expand, large amounts of natural areas are converted into farmland, cities, industrial areas, and roads, resulting in native ecosystems being destroyed or fragmented into smaller fragments. This change has seriously affected the living space of species, making it difficult for many species to maintain their populations, eventually leading to species reduction or even extinction (Henriques et al., 2024).

Overexploitation of natural resources, such as overfishing, hunting and logging, is also an important cause of biodiversity loss. These activities not only directly reduce the numbers of specific species, but also disrupt the balance of the ecosystem and affect the interactions and dependencies between species.

Pollution, including air, water and soil pollution, negatively affects biodiversity by changing environmental conditions. Pollutants such as heavy metals, plastic particles and chemical pesticides can poison wildlife and affect their growth, development and reproduction.

Climate change, especially the rise in global temperatures and the increase in extreme weather events, is changing the living environment of living things. These changes force species to migrate, change their living habits, or face survival pressure, further exacerbating the loss of biodiversity.

The introduction of invasive species is another factor contributing to biodiversity loss. Exotic species may pose competitive pressure on native species, predation or spread of diseases, and damage the structure and function of native ecosystems.

2.3 Impact of fishing industry and marine resources

The fishing industry is one of the world's most important sources of food, providing nutrition and employment for billions of people. However, with population growth and advancements in fishing technology, overfishing has become one of the major factors causing significant impacts on marine resources. Overfishing has not only led to a sharp decline in some fish stocks, even to the point of extinction, it has also destroyed the balance of the marine ecosystem and has had a long-term impact on biodiversity.

Overfishing has directly led to the decline of many commercially valuable fish stocks. For example, the Atlantic cod population has declined significantly due to long-term overfishing, which has seriously affected the related fishing industry. When the number of a species declines to a certain level, not only the fishing industry is affected, but the role of the species in the ecosystem will also change, possibly leading to changes in the structure of the food web.

The impact of the fishing industry on marine ecosystems is also reflected in non-selective fishing during fishing, that is, the "by-catch" problem. Many fishing techniques, such as bottom trawling, not only capture target fish species, but also capture a large number of non-target species, including fish, turtles, seabirds and mammals. These non-target species are often discarded, causing huge losses. It wastes resources and destroys the ecological balance of the ocean.

Some fishing methods cause physical damage to seafloor ecosystems, particularly bottom trawling. Bottom trawls drag across the seafloor, destroying important seafloor habitats such as coral reefs and seagrass beds, affecting the structure and function of these ecosystems and reducing the breeding and habitat of marine life.

3 Impact of Rising Sea Levels on Human Society

3.1 Increased flood risk in coastal areas

The increased risk of flooding in coastal areas has become one of the most immediate and serious problems in the consequences of global warming and sea level rise. As the earth's surface temperature continues to rise, the accelerated melting of polar ice caps and mountain glaciers, and the intensification of thermal expansion of seawater, have led to rising global sea levels. This series of interconnected natural processes, coupled with the impact of human activities, exposes coastal areas to unprecedented flood threats.

Rising sea levels directly lead to an increased risk of flooding in low-lying coastal areas. As seawater intrudes, original flood protection measures become inadequate, leaving these areas more vulnerable to tidal and storm surge impacts. Especially when encountering tropical storms, hurricanes or other extreme weather events, rising sea levels make storm surges more destructive, leading to more severe flooding.

The increased frequency and intensity of extreme climate events is also an important factor in increasing flood risk in coastal areas. Changing weather patterns due to global warming are increasing the likelihood of extreme precipitation events, meaning coastal areas may experience more frequent and intense rainstorms, causing flooding. In addition, heavy rainfall combined with rising sea levels increases the likelihood of river flooding, further exacerbating flood risks.

Human activities, especially overdevelopment of coastal areas, exacerbate flood risks. During the process of urbanization, natural wetlands and other water-absorbent surfaces are replaced by impermeable materials such as concrete and asphalt, which reduces the ground's ability to absorb rainfall and increases runoff. At the same time, infrastructure construction in coastal areas often fails to fully consider the risks posed by climate change and sea level rise, resulting in insufficient flood prevention capabilities.

3.2 Coastal erosion and land loss

Coastal erosion and land loss are major environmental problems facing many coastal areas around the world. They directly threaten the lives of coastal communities, the integrity of ecosystems, and the sustainability of economic development. Coastal erosion is a natural process, but due to the impact of human activities and the intensification of global climate change, this process has been significantly accelerated in many areas.

The causes of coastal erosion can be divided into two categories: natural factors and human factors. Natural factors include wind, waves, tides, and rising sea levels. These forces continue to shape the coastline, transport sand, and change the coastal landscape. Among them, storm surges and strong wind waves are the main natural factors that cause rapid erosion, especially during tropical storms or hurricanes. Anthropogenic factors mainly include overdevelopment of coastal areas, construction of hard breakwaters, and changes in river runoff. These activities change the natural sediment cycle and flow patterns and intensify the erosion process.

Coastal erosion has a range of impacts on coastal areas. The most direct impact is the loss of land, especially in low-lying coastal areas. The land is gradually eroded by seawater, leading to the loss of ecological habitats and affecting local biodiversity. For human communities, coastal erosion can lead to the loss of housing, infrastructure and farmland, threatening human safety and economic well-being. Coastal erosion will also lead to increased costs for coastal protection projects, such as the need to strengthen or rebuild breakwaters and seawalls (Tierolf et al., 2024).

3.3 Threats to coastal infrastructure and residential areas

As global climate change intensifies and sea levels rise, coastal infrastructure and residential areas face unprecedented threats. These threats not only come from direct physical damage, such as floods and erosion, but

also include a series of chain reactions caused by it, such as the salinization of freshwater resources, the loss of ecosystem services, and the upheaval of socioeconomic structures. These impacts together constitute a comprehensive threat to coastal infrastructure and residential areas, and effective measures are urgently needed to deal with them.

Increased flood risks caused by rising sea levels and an increase in extreme weather events directly threaten the safety of coastal infrastructure. Transportation networks, water and drainage systems, power supply and communication infrastructure may all be damaged by flooding, affecting their normal operations. Especially for some low-lying coastal cities and small island countries, the long-term flood threat brought by rising sea levels poses a fundamental challenge to their survival and development.

Coastal erosion poses a long-term physical threat to residential areas and infrastructure. As the coastline recedes, residential areas and infrastructure that were originally located in safe areas are gradually exposed to the direct impact of wind waves and erosion. The loss of land and houses causes residents to have to relocate, and communities face the risk of falling apart (Abu et al., 2024).

Saltwater intrusion is also a serious problem, especially for coastal areas that rely on groundwater freshwater resources. As sea levels rise, seawater pushes inland, causing salinization of underground freshwater layers, affecting the quality of drinking water and agricultural irrigation, thus posing a threat to residents' quality of life and regional food security.

4 Strategies and Measures to Deal with Sea Level Rise

4.1 Coastal protection and restoration measures

Coastal protection and restoration measures are a series of strategies and activities that address issues such as coastal erosion, sea level rise and extreme climate events, aiming to protect and restore the natural environment and socio-economic activities in coastal areas. These measures not only help mitigate the effects of natural disasters but also enhance the health and biodiversity of coastal ecosystems, providing long-term ecological, social and economic well-being for local communities.

Hard protective measures, such as seawalls, breakwaters and cofferdams, are traditional methods of coastal protection. These structures protect coastal areas from erosion and flooding by physically isolating them from the direct impact of seawater and waves. However, hard protection measures are often costly and can have negative impacts on marine ecosystems, such as blocking the natural flow of sediment and migratory pathways of marine life.

Soft protective measures and ecological engineering methods have received increasing attention in recent years. These methods include beach nourishment, artificial dune construction, mangrove and wetland restoration, etc., aiming to reduce coastal erosion and enhance biodiversity by restoring and enhancing the natural protective functions of coastal ecosystems. For example, mangroves not only effectively mitigate the impact of storm surges, but also provide rich biological habitats and promote carbon sequestration.

Integrated Coastal Zone Management (ICZM) is an interdisciplinary and multi departmental collaborative approach that achieves the goal of sustainable development in coastal areas by considering natural, social, economic, and cultural factors in a coordinated manner. ICZM emphasizes the development of science based management plans, covering various aspects from land use planning, resource management, risk mitigation, and community participation (Chen et al., 2023b).

Coastal protection and restoration measures need to comprehensively consider environmental, technical, economic and social factors and adopt diversified strategies and methods. Through scientific planning and rational management, we can not only effectively respond to the challenges posed by coastal erosion and sea level rise, but also ensure the health of coastal ecosystems and the long-term well-being of communities.

4.2 Global efforts to mitigate climate change

Global efforts to mitigate climate change are a comprehensive action plan involving multi-country cooperation and cross-sector coordination, aiming to reduce greenhouse gas emissions and limit the increase in global average temperatures to avoid the most serious impacts of climate change. These efforts revolve around the three core directions of emission reduction, adaptation and international cooperation, including but not limited to formulating and implementing international agreements, promoting the development of clean energy technologies, implementing carbon pricing mechanisms and strengthening climate adaptation capabilities.

International agreements and commitments are the cornerstone of global efforts to mitigate climate change. The United Nations Audiovisual Library of International Law, its Kyoto Protocol and The Paris Agreement are the main platforms and tools for the international community to address climate change. In particular, the Paris Agreement aims to control the global average temperature increase well below 2 °C and strive to limit it to 1.5 °C. Each country formulates nationally determined contributions (NDCs) based on its own national conditions and promises to increase emissions reduction efforts (Jiang and Liu, 2023).

Promoting the development of clean energy and low-carbon technologies is key to slowing the rise in temperatures. This includes the widespread use of renewable energy sources such as solar, wind, hydropower and geothermal energy, as well as improving energy efficiency, developing electric vehicles and green buildings. Many countries and regions have made significant progress in this regard, with the cost of renewable energy falling, making it an increasingly affordable option.

Implementing carbon pricing mechanisms, such as carbon taxes and carbon trading markets, is an effective economic means to incentivize emission reductions. By pricing carbon emissions, businesses and individuals can be encouraged to reduce greenhouse gas emissions and invest in clean energy and low-carbon technologies. There are multiple carbon trading systems in operation around the world, which have promoted the effective reduction of carbon emissions.

Strengthening climate resilience is also part of the global effort. This means improving the resilience and adaptability of social, economic and ecological systems to the impacts of climate change, including improving water management, establishing more flexible agricultural systems, protecting and restoring ecosystems, and strengthening disaster risk management.

Global efforts to mitigate climate change require close cooperation among countries, the firm determination of policymakers, the innovative spirit of enterprises and broad public participation. Despite the many challenges, through joint efforts, the global community is expected to transition to a low-carbon, sustainable future and mitigate the effects of climate change.

4.3 Adaptive management and future planning

Adaptive management and future planning are key strategies to combat sea level rise and its long-term impacts on marine ecosystems. This methodology focuses on flexibility and learning to better understand and respond to the uncertainties and risks posed by climate change.

Adaptive management emphasizes the adoption of dynamic and iterative methods in management practice, and continuously adjusts management strategies based on new data and information. This approach allows decision-makers to respond to changes in a systematic way, ensuring that management measures can adapt to environmental changes and new scientific understanding through real-time monitoring, evaluation and feedback mechanisms. For example, in coastal protection projects, adaptive management may involve regularly evaluating the effectiveness of breakwaters and tidal gates and adjusting design and operations based on actual sea level rise (Palme et al., 2024).

Future planning involves taking a forward-thinking and long-term perspective and developing future-oriented strategies to mitigate risks and capitalize on possible opportunities. This includes the use of climate models and

prediction tools to assess future environmental conditions and the potential impacts of these conditions on marine ecosystems and human society (Khan et al., 2024). Future planning enables decision-makers to consider different climate change scenarios and develop flexible adaptation strategies for possible future conditions, such as planning sustainable coastal urban development that takes into account the impacts of future sea level rise.

Effective implementation of adaptive management and future planning requires interdisciplinary collaboration and the participation of multiple stakeholders, including scientists, policymakers, community leaders and the private sector. By sharing knowledge, experience and resources, vulnerabilities can be better identified, adaptation measures developed and implemented, and society's resilience to future changes promoted.

The development of policy and legal frameworks is critical to support adaptive management and future planning. This includes developing flexible policies that can adapt to new scientific discoveries and technological advances, and establishing incentives to encourage actions to mitigate and adapt to climate change.

5 Summary and Outlook

Sea level rise is one of the direct consequences of climate change, which has profound long-term effects on Earth's marine ecosystems. These impacts are not limited to coastline erosion and frequent flooding, but have a deeper impact on marine life habitats, biodiversity and marine ecological balance. As sea levels continue to rise, we are witnessing changes in ecosystem function, shifts in species distributions, and habitat loss. These changes pose a direct threat to fisheries, tourism and the livelihoods of coastal communities, while also exacerbating global biodiversity loss.

Future research directions should focus on several key areas. Monitoring and prediction of sea level rise rates and patterns need to be enhanced to more accurately assess its potential impacts on marine and coastal ecosystems (Santos et al., 2024). Conduct in-depth research on the most affected ecosystems and species, particularly those highly sensitive to climate change such as coral reefs, mangroves and estuarine wetlands. It is critical to explore and evaluate different adaptive management strategies to determine how to best protect threatened ecosystems and communities.

In terms of policy development, findings from scientific research should be used to develop policies at national and international levels aimed at mitigating the effects of climate change and increasing the adaptive capacity of coastal communities. This includes developing shoreline management and protection strategies, restoring damaged ecosystems, establishing sea level rise monitoring networks and increasing public awareness and understanding of the impacts of climate change.

Sea level rise is a complex global problem that poses long-term challenges to both marine ecosystems and human society. Through in-depth research on sea level rise and its long-term impacts, we will not only be able to better protect and manage marine ecosystems, but also contribute to maintaining the earth's biodiversity and promoting sustainable development. Future research and policy formulation need to fully consider the complexity and urgency of these challenges and take scientific, reasonable and forward-looking measures to ensure that the earth can continue to provide support and shelter for all life.

References

Abu M., Heath S.C., Adger W.N., Codjoe S.N.A., Butler C., and Quinn T., 2024, Social consequences of planned relocation in response to sea level rise: impacts on anxiety, well-being, and perceived safety, Sci Rep., 14(1): 3461.
https://doi.org/10.1038/s41598-024-53277-9

Chen C.X., Fang Y., and Liu J.Y., 2023, Vulnerability assessment of urban landscape systems under risk of sea level rise superimposed with storm surge:a case study of Guangzhou, Huazhong Nongye Daxue Xuebao (Journal of Huazhong Agricultural University), 42(4): 53-63.

Chen C.X., Fang Y., Yan Q.Q., and Liu J.Y., 2023, Multi-scenario simulation assessment of land-use pattern vulnerability and coping strategies in response to sea level rise, Zhongguo Yuanlin (Chinese Landscape Architecture), 39(3): 27-33.

Elneel L., Zitouni M.S., Mukhtar H., Galli P., and Al-Ahmad H., 2024, Exploring key aspects of sea level rise and their implications: an overview, Water, 16(3): 388.
https://doi.org/10.3390/w16030388

Henriques R.J., de Oliveira F.S., Schaefer C.E.G.R., Lopes P.R.C., Senra E.O., Lourenço V.R., and Francelino M.R., 2024, Impacts of anthropocene sea-level rise on people, environments, and archaeological sites in Marajó Island, Brazilian Amazonia, J. S. Am. Earth. Sci., 136: 104836. https://doi.org/10.1016/j.jsames.2024.104836

Jiang X.Y., and Liu J.Y., 2023, Legal issues for state practices of protecting physical coasts in response to sea level rise and their implications, Zhongguo Ruankexue (China Soft Science), 4: 1-10.

Khan A.R., Razak M.S.B.A., Yusuf B.B., Shafri H.Z.B.M., and Mohamad N.B., 2024, Future prediction of coastal recession using convolutional neural network, Estuar. Coast. Shelf S., 299: 108667. https://doi.org/10.1016/j.ecss.2024.108667

Palmer M.D., and Weeks J.H., 2024, The need for multi-century projections of sea level rise, Earth's Future, 12(2): 1-4. https://doi.org/10.1029/2023EF004403

Santos C.A.G., do Nascimento G.R., Freitas L.M.T., Batista L.V., Zerouali B., Mishra M., and da Silva R.M., 2024, Coastal evolution and future projections in Conde County, Brazil: A multi-decadal assessment via remote sensing and sea-level rise scenarios, Sci. Total Environ., 915: 169829. https://doi.org/10.1016/j.scitotenv.2023.169829

Su J., Mayer B., Chen X.P., and Pohlmann T., 2024, The impact of mean sea level rise on the oceanic water exchange of a back-reef lagoon, Reg. Stud. Mar. Sci., 71: 103400. https://doi.org/10.1016/j.rsma.2024.103400

Tierolf L., Haer T., Athanasiou P., Luijendijk A.P., Botzen W.J.W., and Aerts J.C.J.H., 2024, Coastal adaptation and migration dynamics under future shoreline changes, Sci. Total Environ., 917: 170239. https://doi.org/10.1016/j.scitotenv.2024.170239

Ullah M.S., 2024, Sea-level rise and sustainable shore protection strategies in the low-lying delta: A case study of Bangladesh, Reg. Stud. Mar. Sci., 71: 103424. https://doi.org/10.1016/j.rsma.2024.103424

Wang H., Quan M.Y., Xu W.Q., Xiang W.X., Li W.S., and Jiang Y.X., 2023, Sea level rise projection in China's coastal and offshore areas, Haiyang Xuebao (Acta Oceanologica Sinica), 45(8): 1-10.

Wei W., Tao Y., Wang D.M., Wang X.X., and Zhu C.W., 2023, Effects of atmospheric CO_2 concentration rising and sea level rising on belowground biomass of plants in tidal wetlands, Turang (Soils), 55(1): 147-152.

Zheng K.Y., Gao C., Zheng X.X., Yi L.A.L., Tan L.S., and Huang Y.M., 2022, Research progresses in relative sea-level rise in China's coastal regions, Ningbo Daxue Xuebao (Jounal Of Ningbo University), 35(2): 113-120.