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Adaptation or Extinction: Survival Strategies of Marine Organisms under the Pressure of Climate Change

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Abstract With the increasing impact of global climate change on the marine environment, marine organisms are facing unprecedented survival challenges. This study aims to explore the adaptation strategies of marine organisms under the pressure of climate change, analyze the importance of these strategies in maintaining biodiversity and ecosystem service functions, and discuss the role and responsibility of humans in promoting this adaptation process. This study comprehensively analyzes the impact of factors such as rising sea surface temperature, rising sea level, ocean acidification, and extreme climate events on marine life, summarizes the main challenges faced by marine life, and reveals that marine life responds to environmental changes through various mechanisms such as species migration, physiological adjustments, and reproductive strategies. This study emphasizes the urgency of maintaining the health and diversity of marine ecosystems in the context of global climate change, providing a scientific basis for developing effective marine conservation strategies.

Keywords Marine life; Climate change; Adaptation strategies; Biodiversity; Marine conservation

Currently, climate change has become an urgent challenge facing the world, and its current status and trends indicate that the seriousness of the problem is only increasing. Climate change is mainly manifested by the continued rise in the global average temperature, the increase in the frequency and intensity of extreme weather events, rising sea levels, and the accelerated melting of glaciers and ice caps. Scientific research shows that since the industrial revolution, the average temperature of the earth has increased by about 1 °C, and this warming trend has shown signs of accelerating in recent decades (Jones, 2023). This change is mainly due to increased concentrations of greenhouse gases (such as carbon dioxide , methane and nitrous oxide) caused by human activities.

As one of the largest life support systems on Earth, marine ecosystems are facing unprecedented challenges. These challenges stem from the superimposed effects of multiple human activities and global climate change, which have had a profound impact on the biodiversity, ecological balance and ecological services provided by the ocean. Rising sea temperatures caused by climate change are one of the major threats to marine ecosystems. Rising sea temperatures have led to frequent coral bleaching, which not only affects the survival of thousands of species of organisms in coral reef ecosystems, but also destroys the natural protective barrier function provided by coral reefs to coastal areas. The increase in seawater acidity due to the increase in carbon dioxide in the atmosphere is affecting the calcification process of marine organisms, including corals, shells, and certain plankton, threatening the foundation of the entire marine food chain (Sun et al., 2023).

Faced with these challenges, the resilience of marine ecosystems is being severely tested. The loss of marine biodiversity and the degradation of ecological functions not only affect the health and stability of the ocean itself, but also affect the well-being of human society, including food security, economic development, and cultural value. Therefore, strengthening the protection and management of marine ecosystems, reducing anthropogenic pressure, and coping with the impacts of climate change are of great significance to maintaining global ecological balance and promoting sustainable development.

This study integrates existing scientific research to explore the diverse adaptation strategies of marine organisms in the face of climate change stress, evaluates the effectiveness of these strategies, and discusses human roles and responsibilities in promoting adaptive management of marine ecosystems. Through this work, we hope to provide new insights and directions for global ocean conservation efforts and promote long-term sustainable management and protection of marine ecosystems.

1 The Impact of Climate Change on the Marine Environment

1.1 Phenomena and consequences of rising sea temperatures

The rise in sea temperature is one of the most significant phenomena under global climate change. The reason is mainly attributed to the continuous increase in the concentration of greenhouse gases in the atmosphere, which leads to an increase in solar radiation absorbed by the earth's surface, thereby causing an increase in the global average temperature. As the largest heat absorber on the earth's surface, the ocean bears the main burden of the increase in heat caused by excess greenhouse gases, resulting in a general rise in seawater temperatures. This phenomenon is not only limited to surface water bodies, but also affects the deep sea, changing the thermal structure and circulation pattern of the ocean (Dewitte et al., 2021).

The consequences of rising sea temperatures are manifold, and it has a profound impact on marine ecosystems. Coral reefs, as hotspots of marine biodiversity, are very sensitive to temperature. Rising sea temperatures have led to large-scale coral bleaching, which in turn affects many marine species that rely on coral reef ecosystems. Rising temperatures have also affected the distribution of marine species, with many species beginning to migrate to cooler waters, including commercial fishing stocks, which has had an impact on global fishery resources.

Rising sea temperatures also affect the global climate system, particularly the exchange of energy between the ocean and the atmosphere. Heated oceans release more water vapor into the atmosphere, increasing the intensity of the global water cycle and leading to an increase in extreme weather events such as heat waves, droughts and heavy rainfall. This not only affects human society and natural ecosystems, but also puts pressure on ocean edge ecological environments such as estuaries and beach ecosystems.

1.2 Impact of sea level rise on coastal ecosystems

Sea level rise is one of the most devastating consequences of global climate change, with profound effects on coastal ecosystems. As global temperatures rise, polar ice caps and mountain glaciers melt faster, and ocean water expands as temperatures rise, driving continued sea level rise. This phenomenon not only threatens the safety and economic activities of coastal human communities, but also has serious negative impacts on natural ecosystems.

Ecosystems such as coastal wetlands and mangroves are extremely important for maintaining biodiversity and providing ecological services, but they are facing habitat loss caused by rising sea levels. With seawater erosion and saltwater intrusion, the species composition and productivity of these ecosystems are changing, causing endemic biological populations to be threatened and ecosystem functions to decline. Mangroves, in particular, are not only important habitats for many fish and wildlife, but also effectively absorb carbon dioxide and slow down climate change. However, rising sea levels limit their ability to expand inland because human activities have occupied potential migration zones (Wang, 2021).

Rising sea levels also lead to increased coastal erosion and the retreat of beaches and coastlines, which not only affects the structure and function of coastal ecosystems, but also destroys important natural protective barriers, making coastal areas more vulnerable to storms and tsunamis. Rising sea levels are also changing groundwater systems in coastal areas, with saltwater intrusion threatening freshwater resources and further exacerbating the vulnerability of coastal communities and ecosystems.

1.3 Ocean acidification and its impact on the calcification process of marine organisms

Ocean acidification is a process in which a large amount of carbon dioxide (CO_2) in the atmosphere increases, dissolves into seawater and forms carbonic acid, leading to a decrease in the pH value of seawater and affecting the chemical equilibrium state of the ocean (Li et al., 2020). This phenomenon has become increasingly severe in

the past few decades, with profound impacts on marine ecosystems, especially those that rely on calcification processes. Calcification is a crucial process for many marine organisms, including corals, shellfish, certain plankton, and algae, to construct shells or skeletons, which are mainly composed of calcium carbonate.

As ocean acidification increases, the concentration of carbonate ions available for biological calcification in seawater decreases, which directly affects the ability of organisms to build and maintain their calcium carbonate structures. For coral reefs, acidified water slows the growth of coral skeletons, reducing their structural integrity and ability to withstand external stresses. Not only does this reduce the biodiversity habitat that coral reefs provide, it also reduces their role in coastal protection, such as mitigating storm-induced erosion and wave action.

Shellfish and certain plankton are also severely affected by ocean acidification. The calcification process becomes more difficult for these organisms, affecting their survival, growth and reproduction. Especially for plankton at the bottom of the marine food web, calcification barriers will affect the energy flow and material circulation of the entire marine ecosystem because they are the basis of the food chain of many marine organisms.

The impacts of ocean acidification on marine life are not limited to calcification processes. Changes in pH may also affect physiological functions of organisms, such as respiration, sensory orientation, and reproductive capabilities, thereby further affecting population health and biodiversity.

2 Key Challenges Facing Marine Life

2.1 Decline in biodiversity

The decline in biodiversity of marine ecosystems is a growing global problem that poses a huge threat to the marine environment and other biological populations. The decline in marine biodiversity not only reduces biological species, but also damages the structure and function of marine ecosystems, affecting the ecological services they provide, such as carbon cycle, oxygen production and food web stability.

Habitat change and loss is one of the main causes of global biodiversity decline, with a particularly serious impact on marine ecosystems. Marine life's habitats, including coral reefs, mangroves, seagrass beds, coastal wetlands and deep-sea environments, are affected to varying degrees by human activities and climate change. These habitats provide food, shelter and breeding grounds for marine life and are key to maintaining marine ecological balance and biodiversity.

The impact of climate change on marine ecosystems is also a key factor in the decline of biodiversity. Rising ocean temperatures, ocean acidification, and sea level rise have put tremendous pressure on the living environment of marine organisms (Giddens et al., 2022). These changes not only affect the physiology and reproduction of organisms, but also change species distribution and migration patterns, further exacerbating the loss of biodiversity (Figure 1).

Pollution is also an important reason for the decline of marine biodiversity. Plastic pollution, heavy metals and chemical contamination have toxic effects on marine life, affecting their health and ability to reproduce. In particular, the widespread presence of plastic particles has become a persistent threat to marine ecosystems.

The emergence of invasive species has also put pressure on marine native species to compete and replace them, changing the structure of local biological communities and further threatening biodiversity. The introduction of these alien species is often caused by human activities, such as through ships' ballast water or marine aquaculture activities.

2.2 Changes in food webs

Changes in food webs reflect complex adjustments to species relationships and energy flows within ecosystems, and such changes are particularly significant in the context of global climate change. Climate change is altering the food web structure of many ecosystems indirectly or directly by affecting environmental factors such as temperature, precipitation patterns, and ocean chemistry. These changes not only affect individual species, but also affect the interactions between species and the functions of the entire ecosystem (Tan et al., 2022).

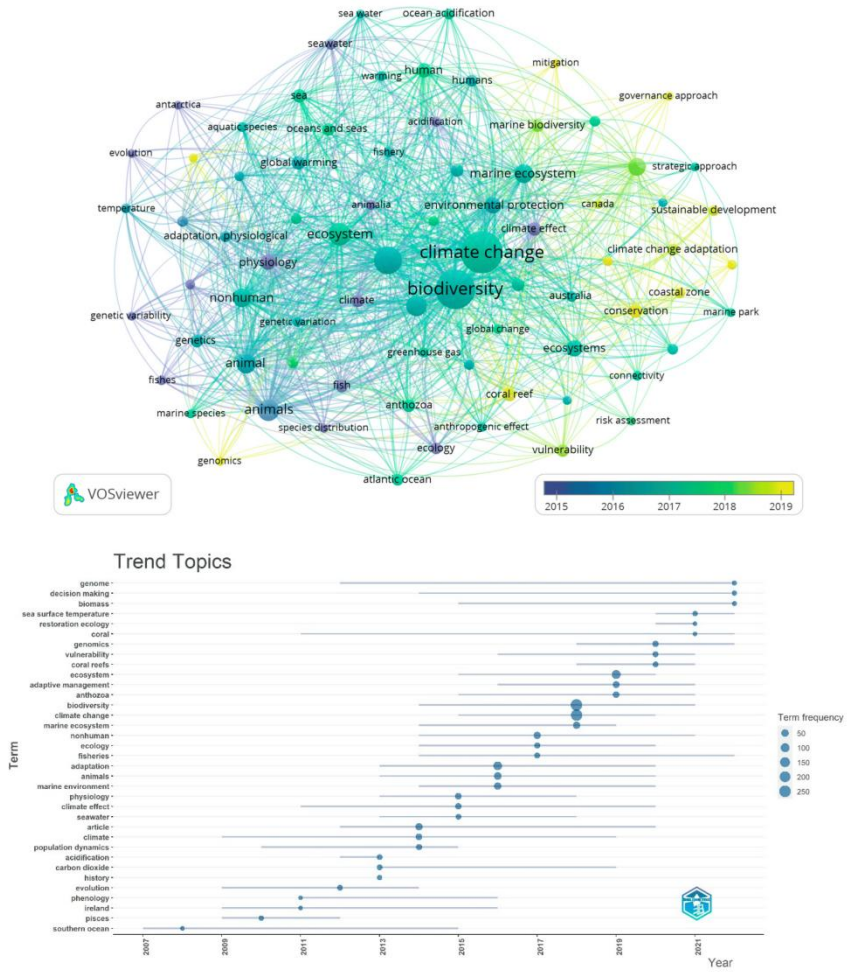

Figure 1 Trend in marine biodiversity and climate change (Dube, 2024)

Changes in the marine environment caused by climate change, such as rising sea temperatures and ocean acidification, affect the productivity of marine plankton, which is the basis of the marine food web. When basic productivity is affected, the entire food web will be affected by chain reactions, including affecting the distribution, abundance, and survival of advanced predators such as fish, seabirds, and marine mammals.

Climate change also affects the geographical distribution of species, forcing some species to migrate to new habitats in search of suitable living conditions. Such migrations not only alter the composition of native food webs, but may also introduce new predators or competitors that disrupt existing interspecies interactions and balances. For example, the migration of some predatory fish species from temperate regions to polar regions may pose a threat to native species that they would not otherwise encounter.

Extreme weather events exacerbated by climate change, such as heat waves, droughts and floods, are also having severe impacts on food webs. These extreme events can not only directly cause species death, but can also indirectly affect the structure and function of food webs by changing habitat conditions and the amount of available resources. For example, extreme precipitation events may cause changes in nutrient concentrations in rivers and lakes, affecting the growth and reproduction of aquatic organisms, thereby affecting the food web structure of the entire aquatic ecosystem.

2.3 Need for adjustment of breeding and migration patterns

As global climate change increasingly impacts ecosystems, many species are having to adjust their breeding and migration patterns to adapt to these changes. These adjustments are inevitable choices that organisms make when facing changes in habitat, changes in food resources, and changes in climatic conditions in order to survive and

reproduce. The need to adjust reproduction and migration patterns reflects the ability of organisms to respond to environmental changes, and also reveals the profound impact of ecosystem changes on species life cycles.

Changes in seasonal weather patterns caused by climate change, such as earlier springs and longer winters, are affecting the breeding times of many species. For example, some birds and insects have begun to breed earlier to ensure that their young are born during a period when food resources are most abundant, thereby increasing survival rates. However, this adjustment of breeding time cannot be successfully achieved by all species, especially those species that have strict requirements for specific environmental conditions. They may not be able to find the right breeding time, resulting in a decrease in reproductive success rate (Zhang, 2023).

Climate change also affects the migration patterns of species. Many animals, especially birds and marine mammals, rely on specific migration routes and habitats for seasonal migrations. As climate conditions and habitat characteristics change, these species have to adjust their migration routes and even find new habitats. This adjustment not only requires species to have the ability to quickly adapt to environmental changes, but may also face unknown challenges in the new environment, such as insufficient food resources, new predators and competitors, and habitat destruction.

The impact of environmental changes on breeding grounds is also an important aspect of the need to adjust breeding and migration patterns. For species that rely on specific breeding grounds, such as sea turtles and certain fish species, rising sea levels and habitat destruction due to climate change directly threaten their reproductive success. This forces species to find new breeding grounds, but suitable breeding grounds may become increasingly scarce, further increasing the survival challenges they face.

3 Adaptation Strategies of Marine Organisms

3.1 Species migration and habitat selection

In the context of coping with global climate change, marine organisms maintain their survival and reproduction through a variety of adaptation strategies, among which species migration and habitat selection are one of their important means of adaptation. This is not only a strategy for species to adapt to environmental changes, but also reflects the complexity of interactions and dependencies between ecosystems (Pandori and Sorte, 2019; Li et al., 2022).

Species migration refers to the movement of marine organisms to more suitable areas in order to escape adverse environmental conditions, such as excessively high water temperatures or unsuitable salinity. As global sea temperatures rise, many fish and marine mammals have begun migrating to the polar regions or deeper waters in search of cooler waters. For example, Atlantic cod, whose distribution range is moving northward to adapt to colder water environments due to rising sea temperatures.

Habitat selection involves marine organisms choosing the most suitable location for survival based on changes in environmental conditions. This includes not only physical conditions such as temperature and salinity, but also ecological factors such as the availability of food resources, the presence of predators, and conspecific competition. For example, sea turtles choose to lay their eggs on warm beaches because the temperature of the beach affects the sex ratio and hatching success of sea turtle hatchlings. As global temperatures rise, some sea turtle populations are beginning to seek sandy beaches farther north as nesting grounds in search of more favorable temperature conditions.

As sea levels rise and coastlines change, organisms in some coastal habitats, such as mangroves and salt marshes, are also facing habitat selection pressures. These biological populations need to adapt to changes in their habitats and find new suitable locations to maintain their survival and reproduction.

3.2 Physiological adaptation mechanism

The physiological adaptation mechanism is a series of internal adjustments made by organisms to environmental changes, in order to maintain the normal progress of their life activities and the survival and reproduction of

populations. These mechanisms cover multi-level responses from molecules to cells, from organs to the entire organism, enabling organisms to maintain the stability and adaptability of their physiological functions in the face of environmental factors such as temperature changes, water pressure, salinity changes, and oxygen concentration changes.

In terms of temperature adaptation, organisms adapt to different temperature conditions by changing their metabolic rate, protein expression, and the fluidity of their cell membranes. For example, polar fish adapt to extremely low temperature environments. Many fish living in Antarctic waters, such as Antarctic icefish, contain a special antifreeze protein that prevents their body fluids from freezing when they are below freezing. Antifreeze proteins allow these fish to survive in extremely cold waters without freezing to death by lowering the freezing point of body fluids.

Water stress is another common environmental challenge, especially for terrestrial plants and some terrestrial animals. Facing drought conditions, plants adapt by closing stomata to reduce water evaporation, increasing the water absorption capacity of roots, and accumulating osmotic adjustment substances such as proline to maintain intracellular water. Animals may reduce water loss by changing behavioral patterns, such as choosing a cool place to rest, or by physiological adjustments such as increasing the kidney's ability to reabsorb water.

Eels display amazing physiological adaptability when it comes to salinity regulation. Eels need to migrate between freshwater and saltwater environments during their life cycle. In order to adapt to this environmental change, eels are able to adjust the osmotic pressure in their bodies and maintain the balance of salt and water in their bodies by changing the function of their kidneys and adjusting the activity of ion transport proteins in their bodies.

Changes in oxygen concentration also require organisms to have corresponding physiological adaptation mechanisms. For example, animals at high altitudes may have higher hemoglobin affinity or more red blood cells to increase the efficiency of oxygen carrying and utilization in low-oxygen environments. Aquatic animals adapt to water environments with lower oxygen content by improving their respiratory organs, such as increasing the surface area of their gills.

3.3 Adjustment of breeding strategies

Facing the challenges posed by climate change, marine organisms adapt to new environmental conditions by adjusting their reproductive strategies to ensure that their offspring can survive in the changing environment. These adjustments are manifested in reproductive time, breeding location, and reproductive behavior, demonstrating the flexible response of organisms to environmental changes during the evolution process.

As global temperatures rise and seasonal rhythms in ecosystems change, many marine birds adjust their breeding seasons to ensure that chicks hatch during times when food resources are most abundant. For example, black-footed albatrosses begin their breeding season earlier due to rising ocean temperatures to adapt to changes in food availability.

Another example is the Atlantic herring, a fish that has also shown adaptation to environmental changes during reproduction. Research has found that Atlantic herring adjust their spawning locations and depths according to changes in ocean temperatures to find the most suitable temperature conditions for the growth of young fish. This behavioral adaptation strategy not only helps to improve reproductive success, but also ensures that juvenile fish can obtain sufficient food resources during the critical growth stage (Arevalo et al., 2021).

4 Human Intervention and Protection Measures

4.1 Establishment and management of marine protected areas

The establishment and management of marine protected areas is an important aspect of global marine conservation efforts, aiming to protect and restore the health, diversity and productivity of marine ecosystems. By restricting or prohibiting certain activities within designated areas, marine protected areas provide a relatively less

disturbed environment for marine life, helping to protect threatened species and ecosystems such as coral reefs, mangroves, seagrass beds and Deep sea environment (Kelly and Griffiths, 2021).

The establishment of marine protected areas is usually based on scientific research and ecological data and involves consultations with a wide range of stakeholders, including governments, scientific research institutions, conservation organizations, fisheries departments and local communities. When selecting areas for protection, factors to consider include the richness of biodiversity, the presence of endemic species, the importance of the ecosystem, and the level of threats faced. The process of establishing a marine protected area also involves formulating a management plan to determine protection objectives, management measures and monitoring and evaluation mechanisms.

Managing marine protected areas is a complex process that requires effective legal and policy support, as well as adequate financial and human resources. Management measures may include restrictions or prohibitions on fishing, anchoring, tourism, and other activities that may cause damage to the ecosystem. In addition, effective management also requires regular monitoring of ecological conditions in protected areas, assessing the effectiveness of conservation measures, and adjusting management strategies as needed.

Community participation is one of the key factors in the successful management of marine protected areas. By raising local community awareness and engagement, not only can the effectiveness of conservation measures be enhanced, but economic and social well-being benefits can also be achieved for local communities, such as through sustainable tourism and fisheries practices. In addition, international cooperation is also crucial for the effective management of transboundary marine protected areas, as marine ecosystems and species migration are not restricted by national borders.

4.2 Climate change mitigation measures

Climate change mitigation measures refer to a series of strategies and actions taken to reduce greenhouse gas emissions and enhance carbon sink capabilities, with the purpose of slowing down the speed and magnitude of changes in the global climate system. These measures cover many fields such as energy production and consumption, transportation, industry, agriculture, forest management and waste treatment, aiming to achieve economic and social development while reducing environmental impact.

The energy transition is one of the key measures to mitigate climate change. This includes improving energy efficiency, reducing reliance on fossil fuels and increasing the use of renewable energy sources such as solar, wind, hydro and geothermal energy. By optimizing the energy structure and improving energy use efficiency, emissions of greenhouse gases such as carbon dioxide can be significantly reduced.

Reforms in the transportation sector are also important measures to mitigate climate change. Promoting low-carbon transportation modes, such as electric vehicles, public transportation systems and non-motorized travel, can reduce greenhouse gas emissions in the transportation sector. In addition, encouraging green travel and establishing more efficient logistics and transportation networks can also help reduce the carbon footprint.

In the industrial sector, greenhouse gas emissions during industrial production can be reduced by adopting clean and efficient production technologies, improving process flows, and utilizing measures such as waste heat and waste recycling. At the same time, developing a circular economy and improving resource utilization efficiency and recycling rates are also important climate change mitigation strategies.

In terms of agriculture and forest management, through the implementation of sustainable agricultural practices and forest protection and restoration projects, the carbon sequestration capacity of the land can be enhanced while protecting biodiversity. This includes reducing overgrazing, avoiding deforestation and degradation, and implementing measures such as reforestation and wetland restoration.

Raising public awareness and promoting international cooperation are important ways to achieve climate change mitigation goals. Increase public awareness and participation in climate change issues through education and

publicity. At the global level, strengthening international cooperation and jointly formulating and implementing emission reduction goals and strategies is the key to meeting the challenges of global climate change (Ottersen et al., 2022).

4.3 Biodiversity protection and ecological restoration

Biodiversity protection and ecological restoration are the two core directions of current environmental protection work, aiming to protect the diversity of life on earth and restore damaged ecosystems. These efforts are critical to maintaining ecological balance, protecting natural resources, combating climate change, and safeguarding human well-being.

Biodiversity conservation focuses on protecting and managing natural resources to avoid species extinction and ecosystem degradation. Establishing and expanding protected area networks is a fundamental strategy for protecting biodiversity. By delineating national parks, nature reserves and biosphere reserves, we provide safe habitats for wild animals and plants and protect them from interference by human activities. Implement species conservation plans, especially for endangered and threatened species, to increase their populations through measures such as artificial breeding, habitat restoration, and reintroduction into the wild. Protecting biodiversity also requires strengthening international cooperation, especially the protection of transboundary species and ecosystems, and jointly addressing the challenge of biodiversity loss through the signing of international agreements and the implementation of regional protection projects.

Ecological restoration refers to the process of restoring degraded, damaged or lost ecosystems through human intervention. The goal of ecological restoration is to restore the structure and function of the ecosystem and enhance its self-sustainability. This includes restoring damaged ecosystems through afforestation, wetland restoration, degraded land management and water purification. Ecological restoration work emphasizes the use of native species for restoration to maintain the originality and integrity of the ecosystem. Ecological restoration also emphasizes community participation and multi-stakeholder cooperation to ensure the socio-economic sustainability of restoration work.

There is a close connection between biodiversity conservation and ecological restoration. Ecological restoration work helps to enhance the biodiversity of damaged ecosystems, and rich biodiversity is the basis for ensuring the health and function of ecosystems. In the face of global environmental changes and the impact of human activities on the natural environment, adopting effective biodiversity protection strategies and ecological restoration measures is of great significance to maintaining the stability of the earth's life support system, promoting ecological sustainable development, and ensuring long-term human well-being.

5 Summary and Outlook

As global climate change increasingly impacts the marine environment, marine life is forced to adopt various adaptation strategies to cope with these challenges. These adaptation strategies reflect the response of organisms to environmental changes during the evolution process, including species migration, physiological adaptation, changes in reproductive strategies, and behavioral adaptation. Through these mechanisms, marine organisms try to maintain their ability to survive and reproduce, and find new ways to survive in an ever-changing environment. Species migration manifests itself as the movement of marine organisms to cooler waters or deeper seas in order to find a more suitable living environment; physiological adaptation involves the adjustment of the internal functions of organisms, such as changing the body's salt concentration regulation mechanism to adapt to changes in salinity; reproductive strategies Changes include adjusting breeding time and location to adapt to changes in environmental conditions; behavioral adaptation may be reflected in changes in foraging habits, habitat selection, and social behavior patterns.

In this context, human beings' role and responsibility in marine protection become particularly important. As intelligent creatures on earth, humans not only enjoy the benefits brought by marine resources, but also bear the major responsibility of protecting the marine environment. This includes reducing greenhouse gas emissions to mitigate the impacts of climate change on the ocean, establishing and managing marine protected areas to protect

critical marine ecosystems and species, implementing sustainable marine resource management strategies, and enhancing scientific research on marine ecosystems, and Increase public awareness and participation in the importance of marine protection.

As for future research directions, it is necessary to further enhance our understanding of the mechanisms by which marine ecosystems respond to climate change, especially the long-term effects of biological adaptation strategies and potential ecological feedbacks. Strengthening interdisciplinary research and combining research results in the fields of marine science, climate change science, and socioeconomics can provide scientific basis for formulating more effective marine protection policies and management strategies. At the same time, the use of new technologies and methods, such as remote sensing monitoring, bioinformatics and artificial intelligence, will bring new perspectives and tools to marine biodiversity protection and climate change adaptation research (Wu et al., 2023).

Facing the challenges of climate change to the marine environment, human society needs to take positive actions to strengthen marine protection and ecological restoration. Through continued scientific research and international cooperation, as well as increased public awareness and decision-making support from policymakers, we are expected to achieve sustainable management and protection of marine ecosystems and safeguard the future of our blue home, the Earth.

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