International Journal of Marine Science, 2024, Vol.14, No.1, 21-28
http://www.aquapublisher.com/index.php/ijms

Review and Progress Open Access

The Potential Impact of Climate Change on the Diffusion of Plastic Waste in the Ocean

Jinni Wu [1], Lei Chen [2]
1 Cuixi Academy of Biotechnology, Zhuji, 311800, China
2 Zhuji Anhan Biotechnology Co., Ltd, zhuji, 311800, China
Corresponding author email: 2314548193@qq.com
International Journal of Marine Science, 2024, Vol.14, No.1, doi: 10.5376/ijms.2024.14.0004
Received: 07 Jan., 2024
Accepted: 18 Feb., 2024
Published: 10 Mar., 2024

Preferred citation for this article:
Wu J.N., and Chen L., 2024, The potential impact of climate change on the diffusion of plastic waste in the ocean, International Journal of Marine Science, 14(1): 21-28 (doi: 10.5376/ijms.2024.14.0004)

Abstract In recent years, global climate change and marine plastic pollution have become serious threats to the Earth's ecosystem and human society. Climate change has led to rising temperatures, rising sea levels, and an increase in extreme weather events, and the spread of plastic waste in the ocean has become a global problem, posing a threat to marine ecosystems and biodiversity. This study introduces the concept of climate change and focuses on exploring its direct impact on the marine environment, including factors such as rising seawater temperature, changes in ocean circulation, and acidification; discussed how climate change affects the distribution and decomposition of marine plastic waste. At the same time, this study delves into the potential impact of climate change on plastic waste in the ocean, from the negative impacts of climate change on marine ecosystems, including threats to biodiversity and disruptions to the food chain. Understanding this relationship is crucial for taking effective measures to reduce plastic pollution in the ocean. This not only provides a reliable basis for research on marine ecological environment, but also brings deeper insights into human health and sustainable development.
Keywords Climate change; Marine debris; Distribution mechanism; Plastic pollution hazards

The marine environment not only provides a sanctuary for biodiversity but also offers abundant resources and services to humanity. Today, global climate change is exerting widespread and profound impacts on the oceans, one of which is the proliferation and accumulation of plastic debris in the marine environment (Figure 1). Plastic pollution is a pervasive environmental issue that poses significant challenges to both marine ecosystems and human societies (Sun, 2021). Climate change is a pressing global issue that has garnered extensive attention. It leads to adverse effects such as global temperature rise, frequent occurrences of extreme weather events, and rising sea levels. However, there is limited discussion on the relationship between climate change and the spread of plastic debris in the oceans, and how climate change further exacerbates this issue.

Figure 1 Plastic waste in the ocean (Image source: http://k.sina.com.cn/article_1791371917_6ac62a8d01900s9d2.html)

Global warming has led to an increase in sea water temperature, posing a threat to marine ecosystems and biodiversity. The phenomenon of ocean acidification is also intensifying, affecting the survival of many marine organisms. Furthermore, climate change has altered ocean currents and ecological niches within marine ecosystems. All these factors may influence the dispersion and behavior of plastic debris, making it a critically observed issue. The presence of plastic debris has become a global environmental problem. Every year, millions of tons of plastic waste are discharged into the oceans, causing serious harm to marine organisms and ecosystems (Depledge et al., 2013). Plastic debris not only threatens the survival of marine life but may also enter the food chain, ultimately impacting humans. Of particular concern is that the dispersion and distribution patterns of plastic debris in the oceans may be influenced by climate change, yet this relationship has not been fully researched and understood.

This study will begin by reviewing the mutual relationship between climate change and the marine environment to better comprehend the impact of climate change on marine ecosystems. The authors will explore the distribution and dispersion patterns of plastic debris in the oceans, analyze the sources and mechanisms of plastic waste, and conduct a detailed investigation into how climate change affects plastic debris in the oceans. This includes the effects of temperature rise, ocean acidification, and changes in ocean currents, aiming to understand their impacts on biodiversity and ecosystem functionality. The objective of this review is to delve into the potential influences of climate change on the spread of plastic debris in the oceans, thereby enhancing our understanding of the interconnection between these two global issues. The findings of this research are expected to provide valuable insights into understanding the relationship between climate change and plastic debris in the oceans, offering useful references for protecting the marine environment and addressing the challenges posed by climate change.

1 Climate Change and the Marine Environment

1.1 Basic concepts of climate change

When referring to climate change, it generally denotes the long-term variations in the Earth's climate system, encompassing changes in various meteorological elements such as temperature, precipitation patterns, and wind directions. Climate change is the complex result of interactions between the natural world and human activities, with its impacts spanning globally and exerting profound effects on the Earth's environment, society, and economy (Li, 2019). The greenhouse effect is a natural phenomenon present in the Earth's atmosphere. Solar radiation passes through the atmosphere, reaching the Earth's surface, and a portion of the Earth's radiation is absorbed and re-radiated back to the surface by greenhouse gases in the atmosphere, such as carbon dioxide, methane, and water vapor. This process helps maintain the Earth's temperature within a range suitable for life. However, human activities, particularly widespread industrialization and the extensive use of fossil fuels, have led to the excessive emission of greenhouse gases into the atmosphere. This enhances the greenhouse effect, making it more intense and resulting in global warming.

Global warming is a primary manifestation of climate change, referring to the increase in the Earth's average temperature. Since the late 19th century, the Earth's temperature has been consistently rising, with this trend becoming more pronounced towards the end of the 20th century. Global warming has led to increased frequency and intensity of meteorological events such as heavy rainfall, hurricanes, droughts, and heatwaves. The melting of glaciers and Arctic ice caps, coupled with the thermal expansion of seawater (Figure 2), contributes to a rise in global sea levels, posing a threat to coastal areas. Global warming has resulted in the escalation of extreme weather events, including heavy rainfall, hurricanes, and droughts, with widespread impacts on ecosystems and socio-economic systems. Long-term observational data reveals trends in climate change, including rising temperatures, alterations in precipitation patterns, and the heightened occurrence of climate events.

Climate change has impacted the distribution of ecosystems, biodiversity, and the survival of species. It has led to the instability of water resources, including droughts and floods, posing a threat to crop yields and food security. Climate change may result in the expansion of the range of infectious diseases, increased risks of heat stress, and respiratory diseases. Naturally, it has widespread impacts on the economy, including reduced agricultural yields, increased disaster costs, and alterations in investment risks.

Figure 2 Glacier melting caused by global warming (Image source: https://www.nipic.com/show/18662533.html)

1.2 Direct impact of climate change on the ocean

Climate change has direct and far-reaching effects on the oceans, manifested not only in the rise of sea water temperature but also in various aspects such as ocean acidification and sea level rise. The emission of greenhouse gases results in an increase in Earth's temperature, and approximately 70% of this additional heat is absorbed into the oceans. This leads to an elevation in sea water temperature, affecting not only the surface waters but also deeper layers of the ocean. The warming of seawater has widespread implications for marine ecosystems.

The temperature rise has particularly pronounced effects on coral reef ecosystems. Elevated temperatures can induce corals to expel symbiotic algae, leading to coral bleaching, which poses a threat to the survival of many coral reef organisms. With the increase in sea water temperature, the distribution range of some marine organisms may expand, while others may be at risk. Changes in marine ecological niches and food chains may occur as elevated temperatures affect the survival and reproductive capabilities of different species, potentially disrupting the balance of ecosystems.

Climate change also results in ocean acidification, another significant direct impact. Carbon dioxide (CO_2) emissions, in addition to contributing to the greenhouse effect, dissolve in seawater, forming carbonic acid. This makes seawater more acidic, severely affecting marine organisms and ecosystems (Paul, 2018). Acidification poses a threat to the construction and maintenance of coral reefs. Most corals in coral reefs rely on calcification to form their hard skeletons, but acidification reduces the concentration of carbonate ions in seawater, making coral growth challenging and leading to coral reef degradation. Acidification makes it more difficult for them to form shells, thereby threatening the survival of these organisms.

2 Plastic Waste Distribution and Dispersion in the Ocean

2.1 Sources of plastic waste

Plastic waste originates from a diverse range of sources, including plastic bags, disposable cutlery, straws, plastic bottles, packaging cups, and boxes. These products are often used for short periods and then discarded, becoming common sources of plastic waste. Various goods, food items, and everyday products are typically packaged in plastic materials such as plastic bags, foam plastics, plastic sealing bags, cling film, and more. A significant amount of packaging waste comes from consumer product packaging. Plastic products include food and beverage containers, cosmetic bottles, detergent bottles, and the like. These plastic containers are usually discarded after use, contributing to plastic waste. Clothing, shoes, and household items made from synthetic fibers release tiny plastic fibers, which may enter water bodies through washing, becoming a source of marine plastic waste. In industrial manufacturing processes, plastic waste, rejected products, and defective items can generate substantial plastic waste if not properly managed, posing environmental issues. Large quantities of plastic packaging waste generated by commercial and industrial units, including transport packaging, trays, films, bags, and more. Improper waste disposal, accumulation of garbage, failure to recycle or inadequate recycling also contribute to the accumulation of plastic waste.

Fishing industry debris in the ocean (Figure 3), such as damaged fishing nets, gear, and discarded fishing equipment, also serves as a source of marine plastic waste (Heo et al., 2023). Plastic waste may enter the oceans from urban drainage systems, rivers, and streams, with wind and water currents transporting plastic from land to water bodies. Tourism and recreational activities can contribute to an increase in plastic waste on beaches and tourist spots, especially in areas lacking proper waste disposal facilities. These sources collectively contribute to the accumulation of plastic waste in the environment, negatively impacting ecosystems and human health. Reducing the generation of plastic waste and increasing awareness and action on recycling and sustainable disposal are crucial measures to address this issue.

Figure 3 Fishery waste in the ocean (Image source: https://www.huanbao-world.com/a/gufeichuli/74122.html)

2.2 Distribution patterns of plastic waste in the ocean

The distribution patterns of plastic waste in the ocean are complex and influenced by various factors, including ocean currents, wind direction, river discharges, population density, and fishing activities (Han et al., 2022). Nevertheless, there are some common distribution patterns and features, and multiple plastic waste belts exist in the global oceans. Among them, the most well-known are the "Great Pacific Garbage Patch" in the North Pacific Ocean and the "South Pacific Garbage Patch" in the South Pacific Ocean. These regions are typically located in the center of the oceans, accumulating a large amount of floating plastic waste, forming massive garbage islands. The formation of these garbage patches is influenced by ocean currents, as these currents gather plastic waste in certain areas. Plastic waste is also widely distributed in nearshore and coastal waters, originating from river discharges, waste discharge from coastal cities and ports, as well as fishing activities.

Wind and tides can also push plastic waste towards coastal areas, affecting beaches and ecosystems. In addition to floating on the water surface, a portion of plastic waste may settle on the seabed. This debris could impact benthic ecosystems, suffocating bottom-dwelling organisms and disrupting benthic habitats. Microplastics, extremely small plastic particles, have entered the marine food chain. Marine organisms such as fish, shellfish, and plankton may ingest these microplastics, transferring plastic waste up the food chain (Faisal et al., 2022), ultimately potentially affecting human health. Plastic waste is not only distributed on the surface of the ocean but can also accumulate in the deep sea. Research indicates that plastic fragments may sink to the deep ocean, posing potential impacts on deep-sea ecosystems (Figure 4).

In general, the distribution of plastic waste in the ocean is complex, presenting various patterns. This distribution is influenced by multiple factors such as weather, hydrology, geography, and human activities. The diverse distribution patterns underscore the urgency of reducing plastic pollution and protecting the marine environment.

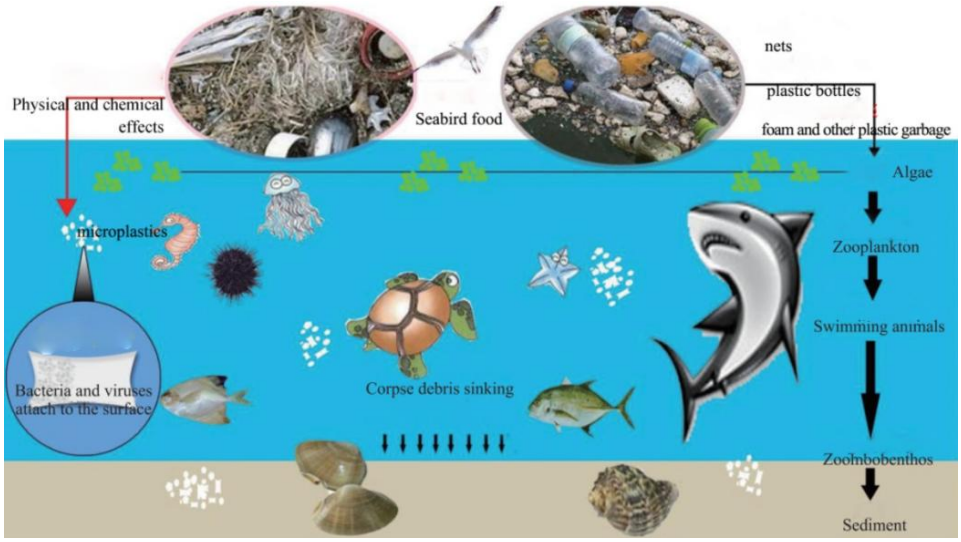

Figure 4 Distribution pattern of plastic waste in the ocean (Image source: http://society.yunnan.cn/system/2021/04/11/031386729.shtml)

2.3 Mechanisms of plastic waste dispersion

Ocean currents and wind play crucial roles in the dissemination of plastic waste in the ocean. Ocean currents transport plastic waste from one region to another, while wind can propel floating plastic debris to drift in specific directions. These natural forces result in the accumulation of plastic waste in the ocean, forming garbage patches, such as the "Great Blue Ocean Belt" in the North Pacific Ocean.

Rivers constitute one of the primary pathways for plastic waste entering the ocean. Plastic debris can be washed into the ocean from rivers, especially during floods and heavy rainfall. River discharges from coastal cities and industrial areas are significant sources of plastic waste entering the ocean, and human activities in coastal areas are also a source of plastic waste. Waste discharge from fisheries, tourism, coastal cities, and ports can lead to the accumulation of plastic waste in coastal waters. These areas are often hotspots for plastic waste, and the global issue of improper waste disposal and garbage accumulation exacerbates the problem of plastic waste on a global scale.

When waste is not properly handled, it may eventually find its way into rivers or the ocean. Shipping and maritime activities can lead to the accidental loss of plastic waste. At sea, plastic debris may fall off ships or cargo vessels, becoming part of marine litter. Some plastic waste may settle to the ocean floor, especially tiny plastic particles. These particles deposit into the habitats of benthic organisms and may potentially impact benthic ecosystems. Plastic waste can enter the food chain through bioaccumulation. Marine organisms such as fish, shellfish, and plankton may ingest plastic particles, transferring them to higher levels of the food chain.

3 Impact of Climate Change on Plastic Waste in the Ocean

3.1 Effect of temperature rise on plastic waste

The increase in temperature generally accelerates the decomposition rate of plastic waste, as higher temperatures expedite chemical reactions and physical processes, making plastic molecules more prone to breakdown. However, decomposition does not imply complete disappearance; instead, plastic is transformed into microplastic particles, potentially posing new challenges for ecosystems and organisms. With rising temperatures, chemicals present in plastic waste (such as phthalates and polybrominated diphenyl ethers) may be released into the surrounding environment, elevating the concentration of harmful substances in water bodies. Elevated temperatures can influence ocean currents, wind patterns, and marine circulation, thereby altering the distribution of plastic waste. Some studies suggest that climate change may make it easier for plastic waste to enter certain regions, such as the Arctic, posing new threats to local ecosystems (Figure 5). Certain organisms may find it easier to ingest plastic waste as their food sources are affected or mimicked by plastic debris. This could lead to more instances of bioaccumulation of plastic waste, affecting the food chain. The rise in temperature may cause an increase in sea

surface temperatures, potentially impacting the distribution and decomposition of plastic waste in the deep ocean. This has potential impacts on deep ecosystems, as deep organisms may have different interactions and adaptation strategies with plastic waste.

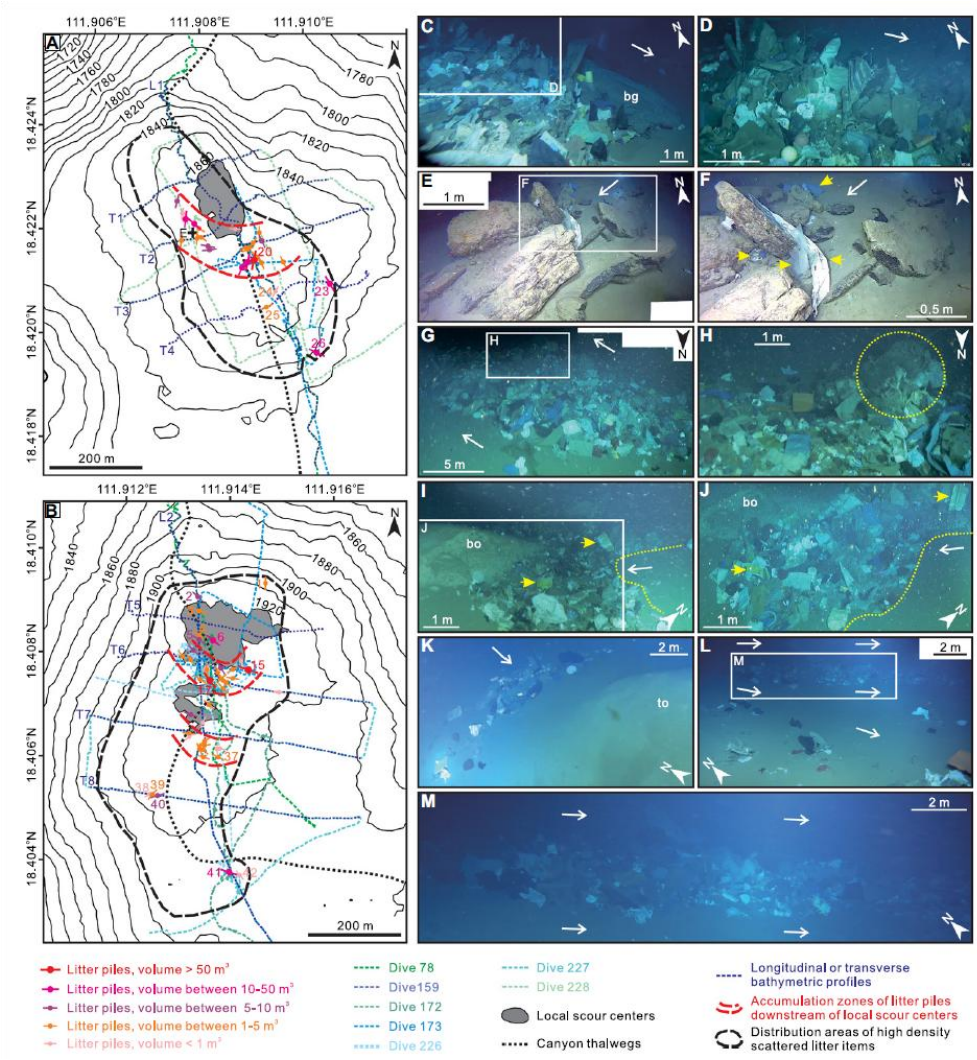

Figure 5 Distribution and transportation mechanism of plastic waste in the deep sea of the northern South China Sea (Image source: http://www.idsse.cas.cn/yjjz2015/2021/202102/t20210208_5890973.html)

The rise in temperature has brought about various complex effects on marine plastic waste, encompassing its decomposition, distribution, biological interactions, and environmental consequences. These impacts pose potential threats to marine ecosystems and organisms. Therefore, reducing greenhouse gas emissions to mitigate climate change, coupled with enhancing plastic waste management and cleanup measures, is a crucial step in safeguarding the marine environment.

3.2 Plastic waste's impact on marine life

Plastic waste has wide-ranging and severe impacts on marine life, which may be entangled or ingested by plastic waste, leading to physical injury or death. Plastic waste such as plastic bags, fishing nets, and various plastic fragments can wrap around body parts such as fins, mouth, and gills, causing injury, suffocation, or starvation. Many marine species mistakenly perceive plastic waste as food, directly affecting their health. For instance, sea turtles might ingest plastic bags, getting obstructed and unable to feed, resulting in malnutrition and stunted growth. Birds and whales may also ingest plastic fragments, negatively impacting their digestive systems and overall health (Carol, 2013). Chemical substances in plastic waste, such as phthalates and polyvinyl chloride

(PVC), can leach into the water, leading to an increase in toxic substance concentrations. This may cause toxic effects on marine organisms, damaging their reproductive capacity, immune systems, and overall survival capabilities.

Chemicals and microplastics in plastic waste may adsorb onto the surface or internal tissues of organisms, facilitating their transfer to higher levels of the food chain. This leads to the gradual accumulation of toxic substances, negatively impacting various levels of the food chain, including ultimate predators at the top of the food chain, such as whales and humans. Plastic waste can cause habitat destruction, including coral reefs, seagrass beds, and the habitats of benthic organisms, affecting the living conditions of benthic organisms and other marine life. Plastic waste may serve as a carrier for pathogens, as some organisms may linger on plastic waste for a period, potentially acting as vectors for disease transmission.

4 Sustainable Management and Strategies to Reduce Marine Plastic Pollution

Strategies to reduce marine plastic pollution encompass several measures. Establishing effective plastic waste recycling and reuse systems helps minimize the amount of garbage entering the oceans. Additionally, promoting biodegradable and alternative plastic products, such as biodegradable plastics and reusable containers, reduces the use of conventional plastics. Restricting or banning the use of single-use plastic products, such as straws, plastic bags, and disposable utensils, encourages the adoption of sustainable alternatives. Strengthening education and awareness initiatives reminds the public about the importance of the plastic waste issue, encouraging them to reduce plastic product usage, properly manage waste, and participate in cleanup activities. Improving waste management and disposal facilities ensures that garbage is adequately handled, preventing it from entering rivers and oceans.

International cooperation is also crucial, and countries can sign international agreements and collaborate on projects to address transboundary marine plastic pollution. Organizing and supporting cleanup activities can help remove plastic waste from the oceans. Scientific research and monitoring contribute to a better understanding of the scope and impact of the problem, supporting policies and management measures (Patra et al., 2023). Encourage improvements in product design and production standards to reduce the environmental impact of plastic products, including reducing the use of non degradable plastics and toxic substances. Finally, implementing economic incentive measures, such as tax policies and reward mechanisms, can encourage innovation and sustainable alternatives. These comprehensive measures require the collaborative efforts of governments, industries, non-governmental organizations, and the public to effectively reduce the extent of marine plastic pollution, safeguarding marine ecosystems and human health.

5 Summary and Outlook

This review explores the comprehensive impacts of climate change on the dispersion of plastic waste in the oceans. It discusses the concept of climate change, emphasizing its associations with global temperature rise, sea level elevation, and climate extreme events. This review also explores in detail the direct impact of climate change on the marine environment, including factors such as rising sea temperatures, changes in ocean circulation, and acidification. These influences alter the physical and chemical characteristics of the oceans, potentially affecting the distribution and decomposition of plastic waste. Furthermore, climate change negatively impacts marine ecosystems, disrupting food chains and biodiversity.

To gain a more comprehensive understanding of the effects of climate change on marine plastic waste, further research is needed to investigate its specific impacts on the decomposition rate and distribution patterns of plastic waste, especially in deep-sea environments. Conduct in-depth research on how climate change affects the interaction between marine organisms and plastic waste, including the ingestion behaviors and toxic effects of organisms. Lastly, cross-border collaboration and international research are essential directions for future studies, as climate change and plastic waste are global issues that require collective efforts to address.

To mitigate the impact of climate change on plastic waste in the oceans, the international community should take stronger climate action to reduce greenhouse gas emissions, controlling the speed and magnitude of climate

change (Somai, 2019). Governments worldwide should implement measures to restrict the use of single-use plastic products, promote biodegradable and sustainable alternatives. Education and awareness-raising are also crucial to increase public awareness of the plastic waste issue and encourage sustainable lifestyles. Additionally, investments in plastic recycling and cleanup technologies are needed to reduce plastic waste entering the oceans. The international community should enhance cooperation to collectively address marine plastic pollution, including cross-border cleanup initiatives and collaborative research projects.

Acknowledgments

I would like to extend special thanks to Ms. Jin Lingfei for her meticulous review during the editing process of this paper.

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