Study on the Impact of Offshore Pollution on Carbon Sinks in the South China Sea - Based on Data from Offshore Cities in the South China Sea

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Abstract: This study aims to explore the impacts of offshore pollution in the South China Sea on the carbon sink function, focusing on the environmental context of coastal cities in Guangdong Province and their carbon sink ecosystem response mechanisms. The study shows that the current offshore areas of the South China Sea have a wide range of pollutants, mainly from industrial activities, agricultural practices and urban sewage discharges, and the continuous accumulation of these pollutants poses a significant threat to the marine ecosystem, leading to a significant weakening of the carbon sink function. By analysing empirical data from coastal cities in Guangdong Province, it was found that the structure and function of phytoplankton communities were disturbed by pollution, which in turn affected the process of atmosphere-ocean carbon exchange. Changes in carbon fluxes in sediments reflected the vulnerability of ecosystems such as coastal wetlands and mangrove forests under the pressure of carrying pollution. We further applied statistical analysis and model construction methods to systematically process the data samples to verify the negative effects of pollution on carbon sinks. The conclusions of this study call for the strengthening of regional environmental protection *strategy* and public environmental awareness, and the promotion of ecosystem restoration and protection to maintain the ecological security of the South China Sea and the sustainability of its carbon sinks.

Keywords: South China Sea; Carbon Sinks; Pollution; Guangdong Province; Heavy Metals; Eutrophication

1. Overview of Pollution and Carbon Sinks in the South China Sea

1.1 Analysis of the Current Status of Offshore Pollution in the South China Sea

In recent years, the status of pollution in the offshore areas of the South China Sea has become increasingly serious, especially in the coastal cities of Guangdong Province. The current research data reveal some key trends and changes that reflect the deterioration of water quality in the sea area and its impact on the environment and ecosystem. Based on the analyses of the data obtained from the researches and experiments conducted, we can systematically examine the current pollution status of the offshore of the South China Sea from multiple dimensions.

In terms of water quality type, it shows that the proportion of poor category 4 seawater quality increases from 3.97% in 2015 to 6.2% in 2022 [1]. This significant increase suggests that the trend of deteriorating water quality offshore in the South China Sea should not be ignored, especially with regard to the potential impact on carbon sinks. The increase in water quality of Class IV is usually associated with high concentrations of certain pollutants, such as nitrogen, phosphorus and heavy metals, etc. Exceeding the standard concentrations of these pollutants may inhibit the normal functioning of marine ecosystems and lead to a decline in the diversity of marine organisms.

In terms of the proportion of area with good water quality, the data pointed out that the proportion was 88 per cent in 2015, increased slightly to 89.7 per cent in 2020, but then declined sharply to 71.8 per cent in 2022 [2]. This change may be closely related to the increase in economic activities in coastal cities, industrial emissions, insufficient capacity for their own municipal waste treatment, and the frequency of marine pollution accidents. In 2022, the proportion of Class II water quality was 17.9%, and the proportion of Class III water quality was 2%, and these data indicate that although water quality was once good, the subsequent decline reflects a threat to ecosystem health and an increase in the decay of carbon sink functions [3].

Turning to the analysis of pollution sources and frequency of occurrence, the cities adjacent to the South China Sea have increased the risk of marine pollution due to rapid industrialisation and urbanisation. The main sources of pollution can be attributed to industrial wastewater discharge, agricultural runoff, and urban sewage. Among them, industrial wastewater discharge is particularly noteworthy because it carries a wide variety of pollutants and generally high concentrations, which directly leads to seawater eutrophication and exacerbates seawater acidification, thus leading to overpopulation of marine organisms, especially certain seaweeds and zooplankton, and the formation of the so-called ‘water bloom’ phenomenon.

With the gradual deterioration of the marine environment, the ecosystem will be affected not only by water quality itself. The deterioration of water quality may lead to the loss or fragmentation of marine habitats, which in turn affects the migration and reproduction patterns of marine organisms. For example, marine organisms with high economic value, such as shrimps and crabs, will face increasingly severe survival challenges, ultimately affecting fishery resources and the livelihoods of fishermen.

In further analysing the direct and indirect impacts of these pollutants on the surrounding environment, we should place special emphasis on the weakening of the carbon sink function. Marine carbon sinks absorb and store carbon dioxide in a responsible manner, and deteriorating water quality directly affects this absorption capacity. Increased pollutants lead to the inhibition of photosynthesis, which reduces the biomass of marine plants such as seagrasses and krill, which are the very organisms that are responsible for carbon fixation in the sea.

The current state of pollution and its dynamics in the coastal waters of the South China Sea is a complex system involving multiple factors such as deterioration of water quality, diversification of pollutant species, and decline of ecosystem service functions. Through in-depth analyses of the data, we are not only able to clearly identify the sources and impacts of pollution, but also provide a scientific basis for subsequent policy formulation and governance measures, with a view to re-establishing the ecological balance and sustainable development of the South China Sea.

1.2 Concept and Importance of Carbon Sinks

Carbon sinks are natural or artificial systems capable of absorbing and storing carbon dioxide (CO_2), and their basic functions are reflected in carbon fixation and greenhouse gas emission reduction. Carbon sinks regulate atmospheric CO_2 concentrations through the synthesis and decomposition of carbon compounds through different biogeochemical processes, such as photosynthesis and respiration. Specifically, sinks include not only forest and marine ecosystems, but also a wide range of ecosystems such as peatlands, soils and planted vegetation, where the carbon storage capacity of these ecosystems is an important factor in combating global climate change.

Carbon Sequestration is the process of converting atmospheric carbon dioxide into a solid or liquid form, and can occur in plants, marine plankton and mineral deposits. For example, forests fix carbon dioxide through photosynthesis and convert it to organic matter, while enhancing soil carbon storage as they grow. This conversion mechanism not only mitigates the threat of greenhouse gases to global temperature rise, but also provides a habitat for biodiversity and thus ecosystem sustainability.

Carbon sinks play a vital role in ecosystems, particularly in the maintenance of biodiversity, the conservation of water resources and the enhancement of soil quality. By absorbing and storing atmospheric carbon dioxide, carbon sinks not only slow down the rate of global warming, but also provide important support for the maintenance of biodiversity. Studies have shown that healthy ecosystems tend to support higher species richness, and carbon sinks, as key components of ecosystems, create suitable habitats that contribute to population diversity and stability. For example, coastal wetlands are important carbon sinks that not only absorb large amounts of carbon dioxide through their rich vegetation, but also provide habitats for a wide variety of waterbirds and other organisms, demonstrating their ecological value in maintaining biodiversity.

Carbon sinks also play a significant role in water conservation. Studies have shown that an increase in vegetation cover can effectively reduce soil erosion and enhance the soil's ability to retain water [4]. This effect is particularly obvious in the coastal areas of the South China Sea. By promoting the proliferation of soil organic matter, carbon sinks not only enhance the soil's ability to retain water, but also promote the healthy functioning of the water cycle, providing a stable water source for the surrounding areas. A healthy water system enhances drought resistance and helps to provide the surrounding ecosystems with the water they need in times of drought, thus further guaranteeing ecological stability.

2. Basic Situation of Coastal Cities in Guangdong Province

2.1 Geographical Location and Socio-Economic Context

Guangdong Province is located in the southern coastal region of China, and its unique geographical location and excellent natural resources have given it a significant role in the country's economic development. Specifically, the coastal cities of Guangdong Province, especially the Pearl River Delta region, are blessed with topographical conditions. The region's long and intricate coastline forms a rich ‘wetland ecosystem’, which not only provides a habitat for biodiversity, but also plays an important role in the formation and maintenance of carbon sinks.

In terms of climate, Guangdong Province has a humid subtropical climate with an average annual temperature between 18 and 22 degrees Celsius and abundant rainfall, providing a suitable environment for plant growth and carbon storage. Rich in marine resources, the marine biodiversity is particularly remarkable globally, covering a wide range of species and quantities that provide a solid foundation for ecological balance and the stability of the carbon cycle.

2.2 Environmental Protection Policies and Measures

Under the current background of rapid social and economic development, environmental protection has gradually become the focus of public attention, and the enhancement of citizens' environmental awareness is particularly important in this process. Based on the method of ‘social survey and questionnaire analysis’, the study shows that citizens' awareness of environmental protection directly affects their participation and satisfaction, and ultimately feeds back into the formulation and implementation of local environmental policies. Taking coastal cities in Guangdong Province as an example, due to their rich natural resources and important ecological status, it is crucial to raise citizens' awareness of environmental protection.

Widespread publicity on environmental protection is an important factor in raising citizens' environmental awareness. Through activities centred on ‘environmental knowledge dissemination’, local governments combined with ‘Participatory Education’ to further deepen citizens' understanding of ecological and environmental issues, especially “Carbon Sink Protection” [5]. This expanded understanding not only enhances the public's sense of environmental responsibility, but also promotes practical action on environmental protection within the community.

2.3 Ecosystem Types and Their Characteristics

As an important ecological resource, coastal wetland ecosystems have multiple ecological functions and significant environmental values. According to the Wetland Ecosystem Assessment Methodology (Wetland Ecosystem Assessment Methodology), coastal wetlands mainly show their unique roles in biodiversity conservation, carbon storage and water purification [6]. Coastal wetlands are not only important habitats for a wide range of waterbirds and other organisms, but also provide suitable living environments and reproduction space for specific populations. For example, certain migratory bird species will rely on the abundant food resources and safe havens provided by this ecosystem, proving its key role in maintaining biodiversity. The ability of coastal wetlands to store carbon should not be overlooked. Through long-term monitoring of wetland soils and water bodies, it can be found that the growth and sedimentation of wetland plants have a significant effect in absorbing and sequestering carbon dioxide (CO_2). In a study in a coastal city in Guangdong Province, the carbon sink capacity of wetland ecosystems was quantified as storing about 2.5 tonnes of CO_2 per hectare per year, which provides a strong support and scientific basis for climate change mitigation [7]. By applying advanced remote sensing technology and ground monitoring data, the carbon storage capacity of wetland ecosystems under different vegetation types and water level changes can be further analysed to reveal its dynamic change characteristics.

As an important coastal ecological structure, mangrove ecosystems have unique ecological functions, including but not limited to carbon sequestration, water purification, habitat provision and prevention of coastal erosion. According to the Ecological Restoration Assessment Framework, when analysing the protection and restoration of mangrove forests, their ecological functions should be combined with the existing environmental pressures, and the current state of their protection and the need for future restoration should be explored in depth.

The ecological characteristics of mangrove forests make them important carbon sinks, and data show that mangrove forests are able to absorb more than 250 tonnes of CO_2 per hectare per year per hectare, which is a significant advantage over other terrestrial ecosystems [8]. However, mangrove ecosystems in coastal cities of Guangdong Province have faced intensified environmental pressures in recent years, especially the impacts of rapid expansion of urbanisation, industrial pollution and climate change on the ecosystems. Therefore, understanding the importance of mangrove forests in ecological restoration is not only needed to save this critical ecosystem, but is also a fundamental condition for achieving the goal of carbon neutrality.

In Guangdong Province, most of the mangrove protection projects in recent years have focused on the establishment of nature reserves and the implementation of ecological compensation mechanisms. In Zhuhai, for example, through a comprehensive assessment of the mangrove area, nearly 500 mu of mangrove ecological restoration projects have been successfully implemented, which have not only contributed positively to the ecological diversity, but also effectively reduced water pollution in the Pearl River Estuary. According to the monitoring data, the nitrogen and phosphorus concentrations in the water bodies in the mangrove restoration area decreased by about 30 percent compared with the non-restored area, which demonstrates the potential of mangrove forests to be applied in water quality improvement.

3. Mechanisms of Offshore Pollution Impacts on Carbon Sinks in the South China Sea

3.1 Types and Sources of Pollutants

Industrial activities are one of the major sources of offshore pollution in the South China Sea, and the many pollutants emitted have far-reaching impacts on the marine environment. In this section, it is firstly necessary to clarify that the main pollutants generated by industrial activities include heavy metals, persistent organic pollutants (POPs), nitrogen oxides (NOx), sulphur oxides (SOx), and volatile organic compounds [9]. These pollutants are emitted from a variety of sources, including the petrochemical industry, metal smelting, power production, and paper and chemical manufacturing.

For example, wastewater discharges from the petrochemical industry are often rich in carcinogenic substances such as benzene, benzo and pyrene, which are persistent organic pollutants that not only pose a threat to human health, but also have a serious impact on the living environment of marine organisms. Studies have shown that the presence of high concentrations of these pollutants can inhibit the growth of marine microalgae, which in turn affects their photosynthetic carbon fixation [10]. On the other hand, heavy metals such as cadmium (Cd), lead (Pb) and mercury (Hg) produced by metal smelting can gradually accumulate in marine organisms through deposition and food chain transmission, destabilising the ecosystem.

As an important ecological asset in China, the offshore region of the South China Sea carries rich biodiversity and the carbon sink function it provides [11]. However, along with the rapid economic development of coastal cities in recent years, especially the acceleration of industrialisation and urbanisation, the ecological environment of the South China Sea has suffered from unprecedented pollution pressure, which further affects the effectiveness of the carbon sink capacity in the region. Therefore, an in-depth exploration of the impact of offshore pollution on carbon sinks in the South China Sea, together with actual empirical data from coastal cities in Guangdong Province, will be of great theoretical and practical significance for the formulation of relevant policies [12].

It is necessary to start from the types of pollutants and analyse their specific sources and impacts on the carbon sink function. For example, the release of organic pollutants and heavy metals from industrial activities can not only directly change the physicochemical properties of water bodies, but also indirectly inhibit the growth of phytoplankton in the water bodies, which in turn disrupts the food chain and the carbon fixation process on which it depends. Studies have shown that industrial emissions of heavy metals such as lead and cadmium can reduce the diversity of phytoplankton communities, which in turn affects their photosynthetic capacity, thus impairing the overall carbon sink effect.

The impact of agricultural practices on the ecosystem cannot be ignored. The heavy use of chemical fertilisers and pesticides, especially in watershed surface source pollution (non-point source pollution), not only reduces the biological activity of the soil, but also enters the South China Sea through erosion and runoff, resulting in the eutrophication of the water body, which further triggers algal bloom [13]. This phenomenon not only causes water quality deterioration, but also inhibits the growth of other aquatic organisms due to toxic algal bloom, which ultimately leads to the decline of carbon sink capacity.

The inadequacy of the current status of urban domestic wastewater treatment has also significantly affected the ecological health of the South China Sea. Despite increased government investment in wastewater treatment facilities in recent years, many coastal cities are still struggling to meet the growing demand for discharges. The direct discharge of wastewater without effective treatment may lead to a decrease in dissolved oxygen levels, which in turn affects the survival rate of marine organisms and the carbon fixation function it brings. Therefore, enhancing the capacity of wastewater treatment and improving the quality of water bodies are, to a certain extent, crucial for maintaining the function of carbon sinks.

On this basis, by deeply analysing the response mechanism of the offshore ecosystem of the South China Sea to these pollution factors, we can find that pollution not only purely affects the survival of various types of organisms, but also exacerbates the loss of the carbon sink performance by altering the carbon flux (carbon flux) in the bottom sediments. The study shows that the pollution-induced decomposition rate of organic carbon in sediments is accelerated, which affects the structural characteristics of benthic ecosystems, and ultimately creates a vicious cycle.

By systematically analysing the multi-dimensional impact mechanism of offshore pollution on carbon sinks in the South China Sea, combined with empirical data from coastal cities in Guangdong Province, it will provide an important theoretical basis and data support for the subsequent studies, which will help to better understand and cope with the potential threat of ecological pollution on carbon sinks, and provide a scientific basis for decision-makers to formulate corresponding environmental protection policies, so as to effectively maintain and enhance the carbon sink capacity of the South China Sea while ensuring the economic development. The South China Sea's carbon sink capacity can be effectively maintained and enhanced while ensuring economic development.

The current status of urban sewage treatment is one of the most important aspects in the study of the impact of offshore pollution on carbon sinks in the South China Sea [14]. With the rapid economic development, the industrialisation and urbanisation of coastal cities in Guangdong Province have accelerated, and the discharge of domestic sewage has increased significantly. However, the construction and operation of sewage treatment facilities often lag behind, which leads to a large amount of untreated or incompletely treated sewage being discharged directly into the ocean, with negative impacts on the marine ecosystem.

At present, although the sewage treatment rate of coastal cities in Guangdong Province has increased, there are still problems such as regional differences and ageing facilities. According to the latest statistics, the sewage treatment capacity of these cities is not yet fully up to standard. Especially during peak sewage discharge hours, the treatment facilities may not be able to fully cope with the situation, resulting in deterioration of water quality and thus affecting the capacity of carbon sinks. In order to comprehensively assess the impact of wastewater treatment on carbon sinks, we can analyse it by establishing a mathematical model between wastewater treatment efficiency and carbon sink capacity [15].

Let the efficient rate of sewage treatment be E, the sewage discharge be Q, and the carbon sink capacity be C. We can use the following formula to express the relationship between the two. The specific content is shown in Formula (1).

$$C = \mathrm{k}(E * Q) \tag{1}$$

Where k is a constant that represents the coefficient of influence of unit sewage treatment efficiency on carbon sink capacity. Through this formula, we can quantify the contribution of the improvement of sewage treatment to the carbon sink capacity, and then provide a scientific basis for the formulation of relevant policies.

From the above analysis, it can be seen that the impact of offshore pollution on the carbon sink function in the South China Sea is multidimensional, as shown in Table 1.

Table 1. Multi-Dimensional Analysis of the Impact of Offshore Pollution in the South China Sea on Carbon Sink Functions

Source of pollution	Type of pollutant	Mechanism of impact	Level of impact
Industrial activities	Organic pollutants	Alter the physico-chemical properties of water bodies and inhibit the growth of phytoplankton	High
	Heavy metals (lead, cadmium)	Reduces phytoplankton diversity and impairs photosynthesis	
	Other pollutants	Impacts on the food chain, disrupting carbon fixation processes	
Agricultural practices	Fertilisers	cause eutrophication of water bodies	Medium
	Pesticides	Causes algal blooms and inhibits aquatic organisms	
Municipal sewage	Affects dissolved oxygen in water	Untreated wastewater bodies, biological survival reducing	Medium
	Inadequate wastewater treatment	capacity Impacts carbon fixation	
Benthic sediments	Organic carbon	Accelerates decomposition rate and affects benthic ecosystems	High

3.2 Manifestations of a Weakened Carbon Sink Function

In exploring the manifestations of offshore pollution in the South China Sea on the weakening of the carbon sink function, it is important to first consider the response mechanisms of marine ecosystems to pollution. The marine ecosystem is a highly complex and interconnected biophysical system containing multiple biological communities and trophic levels, which play a crucial role in the carbon cycle. Inputs of pollutants can have multiple impacts on the survival, reproduction and functioning of these communities, leading to a weakening of the carbon sink function.

Primary producers in marine ecosystems, such as microalgae and seagrasses, absorb carbon dioxide through photosynthesis and convert it into organic matter, which is a major component of the marine carbon sink. However, the accumulation of pollutants such as heavy metals, nutrients (e.g., nitrogen and phosphorus), and organic contaminants not only directly affects the growth rate and biodiversity of these organisms, but may also lead to eutrophication of the water column, which in turn triggers algal blooms. Such blooms not only reduce the depth of light penetration, but also lead to oxygen depletion during post-decomposition, creating so-called ‘dead zones’ that further limit carbon fixation and storage capacity.

Ecosystem response modelling provides a quantitative assessment methodology to better understand the long-term impacts of pollution on marine ecosystems. For example, through dynamic system modelling, it is possible to predict changes in the biomass of primary producers and their impact on carbon fixation rates at specific pollutant concentrations. Studies have shown that when the pollutant concentration reaches a certain threshold, the marine primary productivity and carbon sink absorption capacity will decrease significantly, which in the long term not only affects the stability of local ecosystems, but also may weaken the contribution of the entire South China Sea ecosystem to the global carbon cycle.

In the offshore region of the South China Sea, urban domestic sewage, as a significant pollutant, and the complexity of its types and sources directly affect the structure and functional performance of phytoplankton communities. With the acceleration of urbanisation, the concentration of nutrients such as nitrogen (N) and phosphorus (P) contained in domestic sewage has been increasing year by year, and these pollutants have been discharged into the ocean in large quantities through rivers and outfalls, resulting in the eutrophication of the surface waters. Under eutrophication conditions, the structure of phytoplankton communities often undergoes significant changes, and the explosive reproduction of certain dominant species, such as cyanobacteria, replaces the original diversified communities and forms a homogenised ecosystem. This community change caused by urban domestic sewage not only reduces the biodiversity of phytoplankton, but also significantly affects its growth, reproduction and its role in the carbon sink process [16].

In recent years, the increasing pollution problem offshore in the South China Sea, especially the discharge of urban domestic sewage, poses a significant threat to the coastal ecosystem. In this context, the change of carbon flux (carbon flux) in sediments has become an important part of ecological research, especially the mechanism of its influence on the carbon sink function [17]. Urban domestic wastewater mainly comes from residents' daily life, industrial activities and agricultural runoff, and its complex composition includes nitrogen (N), phosphorus (P), and organic matter, etc. The deposition of these pollutants and their decomposition processes have a profound effect on the storage and release of carbon in sediments.

Regarding the change of carbon flux in sediments, along with the increase of pollutant concentration, the redox state of sediments (redox state) will change significantly. It has been shown that when the redox state decreases, the activity of anaerobic microorganisms (anaerobic microorganisms) in the sediments is enhanced, which promotes the decomposition of organic matter and leads to an increase in the release of carbon. This process can be accurately measured by sediment carbon flux monitoring tools, thus revealing the bi-directional regulation of the carbon cycle in sediments. It is also worth mentioning that changes in carbon fluxes from sediments are often closely related to biological exchange processes, especially changes in microbial community structure, which may lead to an increase in the rate of carbon release and a decrease in the carbon sink function of the ecosystem.

4. Analyses Based on Water Quality Monitoring Data of Near-Shore Sea Areas in Guangdong Province

The situation of Guangdong's offshore monitoring outlets is shown in Figure 1.

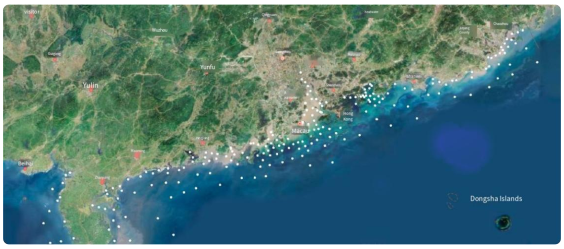

Figure 1. Distribution of Offshore Monitoring Network Points in Guangdong Province

According to the water quality monitoring data for 2020 to 2023 published on the official website of the Guangdong Provincial Department of Ecology and Environment, it is possible to monitor whether the indicators of pH, inorganic nitrogen (mg/L), reactive phosphate (mg/L), petroleum products (mg/L), dissolved oxygen (mg/L) and chemical oxygen demand (mg/L) in the near-shore waters have exceeded the standards. The monitoring data for the third period of 2023 was collated and the results are shown in Table 2.

5. Conclusions and Recommendations of the Study

The impact of offshore pollution in the South China Sea on the functioning of carbon sinks is a complex and multidimensional ecological issue involving interactions between multiple sources of pollution and ecosystems. By analysing the major pollutants such as heavy metals, nutrient salts, plastic particles and organic pollutants, it is possible to identify their respective sources and far-reaching impacts on the marine ecosystem, especially in the coastal cities of Guangdong Province, where the accelerated process of industrialisation and urbanisation has significantly exacerbated the extent of pollution. The enrichment of heavy metals has led to threats to the food chain in marine organisms, while the input of nutrient salts has triggered the phenomenon of eutrophication, resulting in ecological imbalance and the reduction of biodiversity. These pollutants not only directly affect the survival and reproduction of marine organisms, but also further weaken the capacity of the South China Sea as a carbon sink. Meanwhile, the application of marine ecosystem response modelling provides us with a quantitative.

Table 2. Phase III Monitoring Results of Near-Shore Water Quality in Guangdong Province in 2023

municipalities	Monitoring time	Main water quality indicators	Major exceedance items	Water quality category
Guangzhou	October 17, 2023	PH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate, pH, dissolved oxygen	poor category 4
Shenzhen	October 16-21, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate	Category I to IV
Zhuhai	October 13-29, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate	Category I to IV
Shantou	October 28-November 3, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	inorganic nitrogen	
Zhanjiang	October 13 to November 4, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate	
Jiangmen	October 25-November 1, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	inorganic nitrogen	
Huizhou	October 21-23, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)		Category I to IV
Shanwei	October 24-26, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)		Category I to IV
Yangjiang	October 11-26, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	inorganic nitrogen	Category I to IV
Dongguan	October 17-16, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate, pH, dissolved oxygen	poor category 4
Zhongshan	October 16, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate, pH	poor category 4
Chaozhou	November 3, 2023	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)	Inorganic nitrogen, reactive phosphate	Category I to IV
Jieyang	October 27-28, 2023, November 02	pH, Inorganic Nitrogen, Reactive Phosphate, Petroleum, Dissolved Oxygen, Chemical Oxygen Demand (COD)		Category I to IV

analysis of the impacts of pollution on primary producers and phytoplankton communities, and by observing their growth and reproduction trends and their roles in the carbon sink process, we have learned that the different manifestations of pollution ultimately lead to a significant reduction in carbon fixation capacity. The impacts of agricultural practices and urban sewage are also not negligible. Excessive application of nitrogen and phosphorus as well as the discharge of untreated domestic sewage exacerbate the eutrophication of the water body and directly affect the community structure of phytoplankton. Changes in carbon fluxes in the sediments throughout the cycle were also significantly affected, especially under the change of redox state, where the decomposition of organic matter promoted the release of carbon, which drastically reduced the carbon storage capacity of the sediments. Therefore, future research should focus on the systematic analysis and management of different pollution types, and the development of a series of effective ecological protection and restoration policies through enhancing sewage treatment capacity, improving agricultural practices, and raising public awareness of environmental protection, in order to safeguard the ecological health and sustainable development of the South China Sea region. At the same time, the implementation of policies needs to rely on scientific data support and statistical analyses, adopt appropriate statistical tools, and deeply understand the interaction mechanism between pollution and carbon sinks through systematic long-term monitoring and assessment. Through multifaceted research and practice, the South China Sea and its neighbouring ecosystems are expected to achieve significant results in improving environmental quality, enhancing carbon sink capacity and maintaining ecological balance, providing a positive response to global climate change.

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