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Contents

1 Introduction

With the rapid development of social economy and the urbanization process of coastal areas, offshore ecosystems are also facing increasing pressure brought by various pollution problems. Marine environmental resources and biodiversity are being threatened by the increasingly serious discharge of sewage, garbage, oil spill and industrial waste into the sea. For a long time, humans have used the oceans to dispose of wastes, including organic matter, nutrients, chemicals, litter, etc., in part based on an erroneous belief that the seas and global ocean have the capacity of absorbing and recycling all those contaminants. In addition, oil tanker accidents, radioactive waste water emissions and other human activities have impacted the oceans, producing increasing risks both for the environment and human health. To date, the results of these activities have informed recommended management approaches, and reduced the effects of some contaminants (e.g., metals, TBTs, microbial) (Borja et al., 2020). The major topics have been oil spills, pollution (including anthropogenic chemicals and microbial wastes), and eutrophication. However, in recent years, there has been a dramatic increase in research on macro-, micro- and nano-plastics and other forms of marine litter.

More and more attention has been paid to the pollution from land and sea. To be sure, there are significant regional differences in the collection and management of wastewater and solid waste (UNEP, 2016). By 2015, the world had produced 8.3 billion tons of new plastics and 6.3 billion tons of plastic waste. Among them, 9% of plastic waste is recycled, 12% is burned, and 79% is piled up in landfills or abandoned in the natural environment. Based on current production and waste management trends, it is estimated that 12 billion tons of plastic waste will enter the landfill or natural environment by 2050 (Geyer et al., 2017). It is estimated that the total amount of large and micro plastic waste floating in the open ocean is 5.25 trillion, and the weight is 269,000 tons (Eriksen et al., 2014). Globally, more than 80% of wastewater is directly discharged without treatment (over 95% in some developing countries) (WWAP, 2017). Long term solutions such as governance system improvement, institutional change and behavior change at different levels will support the transition to circular economy and sustainable ocean. In addition, climate change is resulting in ocean warming, acidification, changes in circulation, dissolved oxygen concentrations and water cycle amplification. As a result, the transfer of nutrients associated with primary productivity from surface waters to the deep sea is declining. In the meantime, rising sea levels not only erode the coasts, but also further exacerbate seawater intrusion and salinization in coastal areas. All above pressures have impacts on marine ecosystem and biodiversity, such as changes in the distribution pattern of marine species, seasonal behaviors and interactions between species. Climate change and ocean acidification might also have joint impacts on species and ecosystems with local changes (pollution, eutrophication, etc.).

With the continuous acceleration of economic and social development in coastal areas, the increase of resource utilization scale and the change of ecological environment governance, China's marine environment quality has experienced a process from overall good to overall deterioration, and then gradually improved since the reform and opening up 40 years ago. At the beginning of reform and opening up, the development and utilization of marine resources in China is still in its infancy, and the quality of marine ecological environment is good as a whole. From the 1990s to 2012, the intensity of marine development has been increasing. The coastal economy has entered a development mode of resource competition, low utilization efficiency and similar main industries. The marine ecological environment quality has deteriorated comprehensively. At the end of the 20th century, about 32600 km^2 of the sea area under China's jurisdiction has been seriously polluted, reaching a peak of about 67900 km^2 in 2012. Since the 18th National Congress of the Communist Party of China, with the continuous advancement of the construction of ecological civilization, the pollution control and ecological restoration in coastal areas have been strengthened, and the marine ecological environment quality has stepped into an improvement period. The seriously polluted area of China's coastal waters has shown a significant downward trend. By 2020, the seriously polluted area has dropped to 30070 km^2.

The fourteenth Five Year Plan period is the first five years to start the new journey of building a socialist modern country in an all-round way. China's development is still in an important period of strategic opportunities. On September 22, 2020, Chinese President Xi Jinping solemnly declared at the seventy-fifth General Assembly debate that China will enhance China's independent contribution and adopt more effective policies and measures. CO_2 emissions will reach the peak by 2030, and strive to achieve carbon neutralization by 2060. This important declaration provides direction guidance for China's response to climate change and green and low-carbon development. Achieving carbon neutrality has become an important task for China to deal with climate change in the future. To be sure, healthy and sustainable oceans are crucial to maintaining a prosperous society and achieving a carbon neutral strategy. While innovation is required to improve many specific technologies and practices, four of the ocean-based climate action areas are ready to be implemented today (ocean-based renewable energy; ocean-based transport; coastal and marine ecosystems; the ocean-based food system). The fifth, carbon storage in the seabed, has significant theoretical potential to divert carbon from the atmosphere. The ocean provides great potential for China's economic and social development. China's president Xi Jinping has stressed the importance of marine environment many times: during the visit to Africa in July 2018, he pointed out that the blue economy should be included in the agenda of Africa's social and economic transformation in 2063, and China takes the lead in promoting friendly maritime cooperation and providing Africa with the support it needs to develop its blue land. During his state visit to Portugal, President Xi Jinping mentioned that the two countries need to promote the development of blue economy through promoting maritime cooperation in signed articles published in local mainstream newspapers. Strengthen the blue partnership between China and other coastal countries, promote cooperation in marine research, marine development and protection, port logistics and other fields, jointly develop the blue economy, make better use of the ocean and benefit future generations; In April 2019, during the 70th anniversary of the founding of the Chinese people's Liberation Army Navy , the important concept of the community of maritime destiny was put forward. The concept of the community of maritime destiny is the enrichment and development of the concept of the community of human destiny and the specific practice of the concept of the community of human destiny in the maritime field, It is another "China's wisdom" and "China's plan" that China has contributed to global governance, especially in the field of global ocean governance. It will vigorously promote the development and progress of the world and benefit the people of all countries.

The marine pollution task of "global marine governance and ecological civilization" policy research project (2020-2021) aims to promote the prevention and control of marine plastic pollution, nutrient management and control, and mercury pollution, and promote the healthy development of marine ecosystem. The objectives are as follows:

- Analyze the pollution sources of marine plastic debris from the whole chain of plastic industry, and optimize the prevention and control policies and measures of marine plastic pollution;
- Taking the Bohai Sea as an example, the changes of nutrient distribution were analyzed, and countermeasures and suggestions were put forward for the coastal nutrient management and control;
- To carry out the research on the prevention and control of mercury pollution in coastal waters, so as to provide the basis for the marine field to evaluate the implementation effect of Minamata convention.

The research includes three sections:

1) To compare and analyze the policies and measures related to solid waste management and plastic pollution prevention and control in China and the European Union, analyze the source of marine plastic debris from the whole chain of production design, consumption and use, solid waste disposal and other plastic industries, evaluate the pollution prevention and control effect of marine plastic debris, and optimize the estimation of China's plastic waste flux into the sea.

2) To investigate the changes of nutrient distribution in the Bohai Sea under the combined effects of excessive terrestrial nutrient input / reduction, climate change, water and sediment regulation of the Yellow River, and analyze the coupling effect of coastal chemical elements and ecological environment through the temporal and spatial evolution of bottom layer anoxia and chlorophyll distribution, and compare and analyze the regulation of human activities and climate change on nutrient cycle in the Bohai Sea and the Baltic Sea, The countermeasures and suggestions on the management and control of nutrients in coastal waters were put forward.

3)To sort out the monitoring, investigation and research data of mercury in seawater, sediments and organisms, and conduct comparative analysis with EU, etc., so as to assess the mercury pollution in China's coastal waters, analyze the mercury import and migration process in the marine environment, and provide basic information for the marine field to assess the effectiveness of the implementation of the Minamata convention.

2 Eutrophication and mitigation actions in the China coastal sea

2.1 Overview of coastal eutrophication

Hypoxia usually happens in coastal seas due to abundant nutrients and organic matter input and water stratification, such as St. Lawrence estuary, Baltic Sea, Gulf of Mexico, Arabian Sea, Changjiang (Yangtze River) estuary, and Zhujiang (Pearl River) estuary (Chen et al., 2014; Dai et al., 2006; Gilbert et al., 2005; Li et al., 2002; Rabouille et al., 2008; Turner et al., 2005; Wang et al., 2012; Zhang et al., 2010; Zhu et al., 2011). Hypoxia is closely related to eutrophication (such as sewage discharge and agriculture activities), can affect composition of benthic community and nutrients cycle (Cooley et al., 2009; Jäntti and Hietanen, 2012; Song et al., 2021). Moreover, greenhouse gases emission to the air are affected (Naqvi et al., 2010). In generally, hypoxic water has low pH, and eutrophication can strengthen acidification in coastal sea (Cai et al., 2011), thus affect the calcification rate of marine organisms, the food web composition, marine fishery (Cooley et al., 2009; Feely et al., 2004; Shaw et al., 2012), and nutrients cycle (Eichner et al., 2017; Hutchins et al., 2009). In short, eutrophication and hypoxia can affect ecosystem health, service and output. This study takes Bohai and Baltic Sea as examples, addresses nutrient dynamics and main factors, evolution of eutrohpication and its ecological effects. Combined with the prevention and control policies of eutrophication in the research area and global, this study puts forward countermeasures and suggestions on the governance and management of nutrients in China coastal sea.

2.2 Distribution patterns of nutrient and control mechanisms in coastal sea

2.2.1 Bohai Sea

Anthropogenic activities have considerably perturbed the watersheds of Chinese seas, in particular the Bohai Sea. Therefore, prominent effects on the coastal ecosystem have been observed in the Bohai Sea. The Bohai Sea is a semi-enclosed shallow water body of the northwestern Pacific Ocean, connected to the Yellow Sea through the narrow Bohai Strait. It has a surface area of 77,000 km^2, average depth of 18 m. A number of rivers empty into the Bohai Sea with a total annual water discharge of $68.5 \times 10^9\ m^3$, in which the Huanghe discharge represents more than 75% of the total freshwater discharge. The Huanghe water has long residence time in the Bohai Sea with an average of 1.2 year and is related to water exchange in the Bohai Strait (Liu et al., 2012b), thus has a far-reaching influence on ecological environment of the Bohai Sea.

2.2.1.1 Nutrients distribution patterns

Nutrient concentrations generally decreased from the coastal areas to the central part of the Bohai Sea and had significant seasonal variations. Nutrients showed stratification in summer with higher values at near-bottom layers than those in the surface and were vertically mixed well in winter. Based on observations during 1978-2016, nitrate and DIN concentrations in the Bohai Sea continuously increased from 1990 and rapidly increased after 2002, nitrite and ammonium concentrations slightly increased in summer, and fluctuated in winter. The proportions of nitrate in DIN gradually increased, the proportions of ammonium and nitrate in DIN decreased. Dissolved silicate concentration decreased from 1978 to 1987 and increased after. Annual average phosphate concentration generally exhibited a decreasing trend, the phosphate level generally decreased in summer and slightly and undulately increased in winter. In generally, nutrient concentrations were lower in summer than in winter. N/P increased, Si/N decreased, and Si/P showed an overall slight increasing trend. The nutrient limitation was changing from nitrogen limitation to phosphorus limitation and silicon limitation (Wang et al., 2019a).

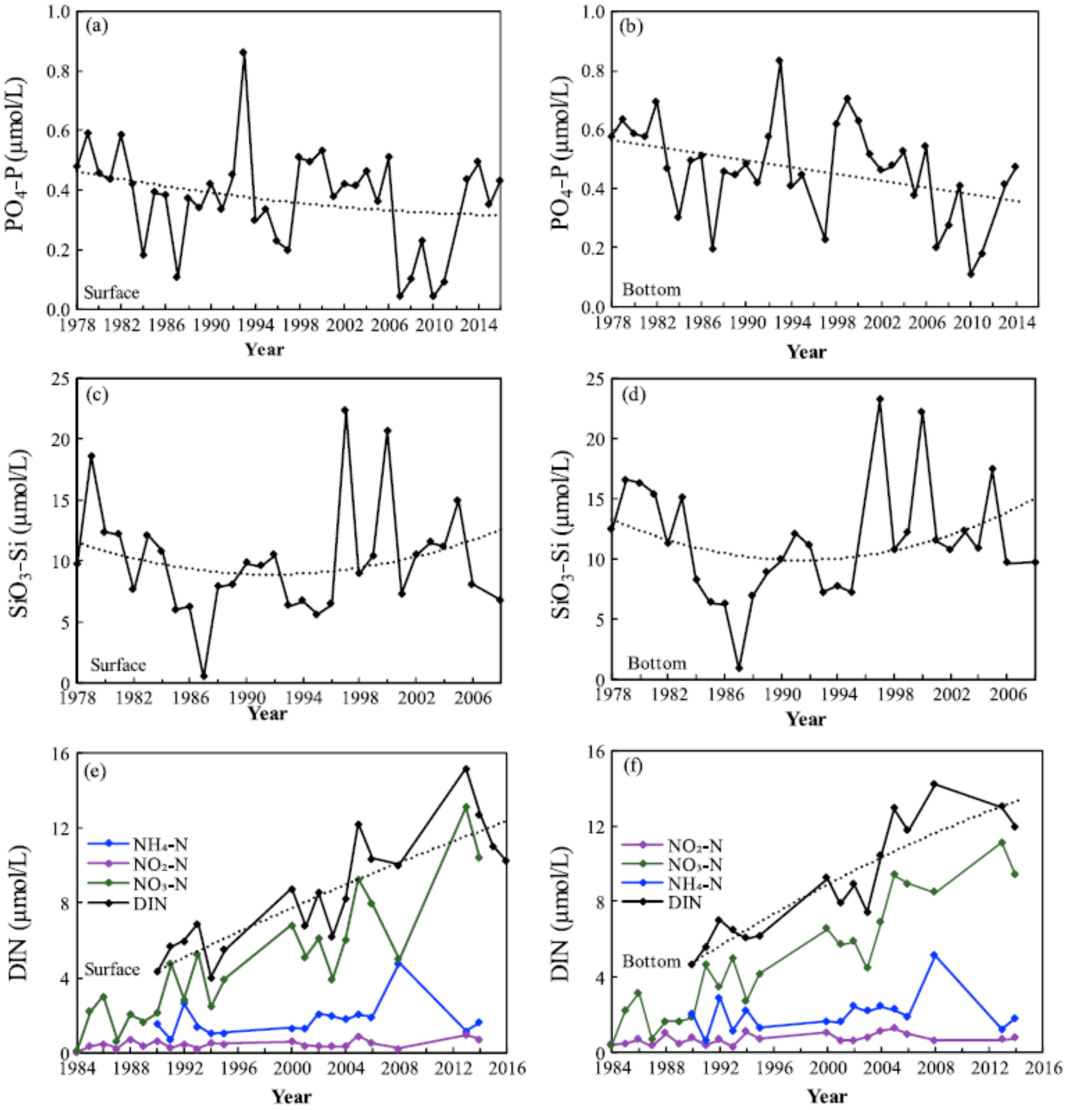

Figure 2.1 Annual average nutrient concentrations in Bohai Sea during 1978-2016 (Wang et al., 2019a)

2.2.2.2 Major nutrient sources and control factors

2.2.2.2.1 Riverine input

Obviously, the seasonal patterns of both water discharge and sediment load have been changed by the water and sediment regulation scheme (WSRS), leading to high monthly water discharge advancing to as much as two months prior to the normal high flow season. The seasonal patterns of nutrient transports from the Huanghe to the Bohai Sea have shifted accordingly and nutrient imbalance was aggravated (Li et al., 2017; Liu et al., 2012a; Liu, 2015; Ran et al., 2013). Moreover, the distribution of Huanghe diluted freshwater discharge in the Bohai Sea was closed related to the river discharge, abrupt changes in river discharge led to more Huanghe diluted freshwater discharge spread in Laizhou Bay during the water regulation event (Wang et al., 2011), and decreased salinity in Laizhou bay (Mao et al., 2008). and in particular that residence time of the Huanghe water was long in the Bohai Sea, thus the WSRS has a far-reaching influence on the ecological environment of the Bohai Sea (Liu et al., 2012b).

In the lower reach of Huanghe, nutrient levels are characterized by high concentrations of nitrate and low phosphate, $Si(OH)_4$ also has high concentration which largely originated from mechanical denudation, chemical weathering, and a much higher evaporation over precipitation rate (Liu et al., 2009, 2012). Concentrations of nutrients had seasonal variations, with dissolved nitrogen being higher in the dry season than in the flood season, phosphate showing stable levels, and dissolved silicate being higher in the flood season than in the dry season. Thus, nutrients composition has high ratios of N/P and Si/P, and low ratio of Si/N.

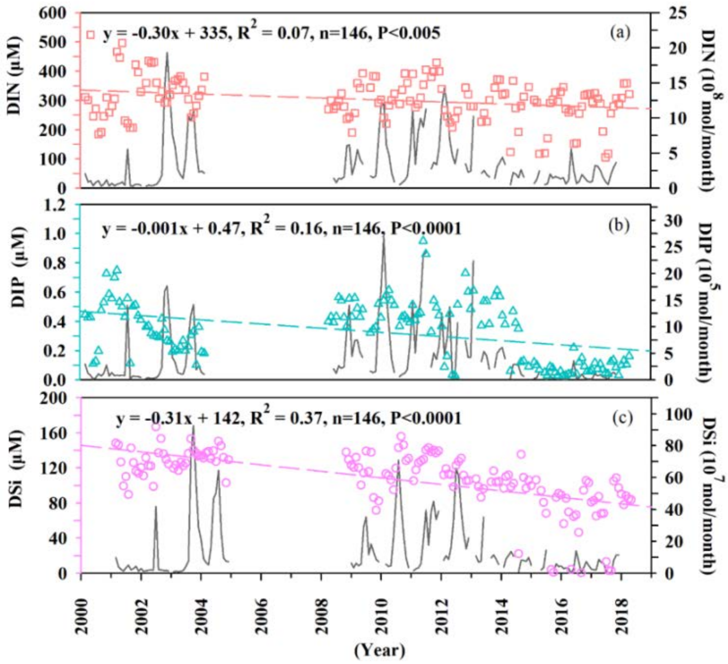

Figure 2.2 Monthly concentrations (color data points) and fluxes (black lines) of dissolved nutrients in the lower Huanghe from 2001 to 2018 (Wu et al., 2021)

Affected by the economy development and intensified human activities, the changes in ecological environment of the Huanghe is too fast to catch up with. During 2001-2018, nutrient concentrations showed decreasing trends and dissolved organic phosphorus concentrations increased since 2009, reaching up to 95% of the total dissolved phosphorus (Figure 2.2). Extremely low nutrient concentrations were firstly observed since 2014 in response to the retention effect of large reservoirs, which significantly reduced the downstream water discharge and sediment load and increased phytoplankton assimilation (Wu et al., 2021). Main nutrient sources are quantified, with fertilizer loss, sewage effluents, and runoff accounting for 33–40%, 79-85%, and 34-62% of the total DIN, DIP, and DSi fluxes, respectively (Figure 2.3). Strictly controling the amount of fertilizer and improving the application methods, enhancing sewage treatment technology and vigorously promoting "green travel" might reduce nutrients emptied into the Huanghe based on the main source of nutrients (Wu et al., 2021).

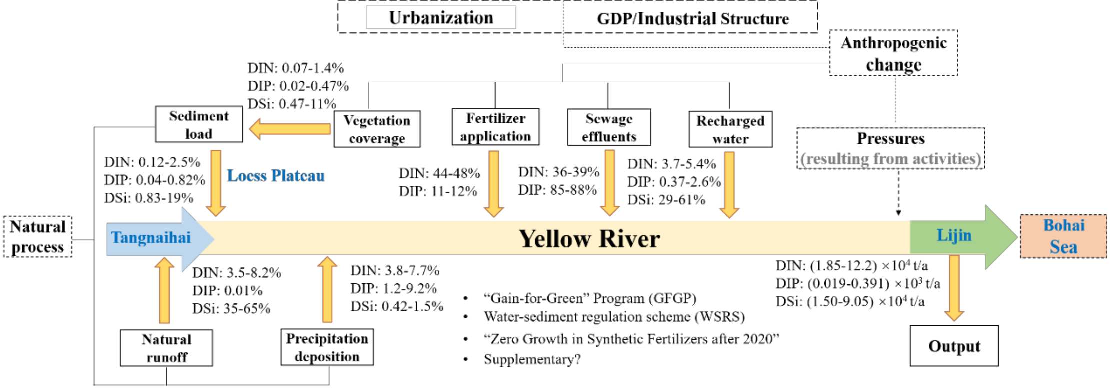

Figure 2.3 Relative contributions of various sources toward nutrient fluxes to the Huanghe (Wu et al., 2021)

2.2.2.2.2 Other sources

Based on pore water profiles of nutrients and diagenetic equations, benthic nutrient fluxes were estimated which has strong coupling with water column and plays an important role in nutrient cycle. Sediment in the Bohai Sea represented a source for ammonium, phosphate and dissolved silicate, while it was a sink for nitrite and nitrate in summer. Benthic nutrient fluxes were 2-3 times higher than the riverine input with the regeneration rate of phosphate being slower relative to DIN and dissolved silicate. The release of dissolved silicate and phosphate from sediments might mitigate the decrease of dissolved silicate and phosphate due to the reduction of freshwater discharge (Liu et al., 2011).

There are limited published and/or open data on atmospheric nutrients deposition for the Bohai Sea and need further studies. Observations in the Qinhuangdao coast indicated that the soluble nitrogen and phosphorus concentrations in aerosols and depositions were higher in winter than in summer (Yu et al., 2020). Nitrogen transport flux delivered by atmospheric deposition was comparable to terrigenous input (including riverine input and sewage outlets) (China council for international cooperation on environment and development annual policy report, 2020; Zhang et al., 2004). Moreover, although submarine groundwater discharge (SGD) had large uncertainties, nutrient fluxes transported via SGD to the Bohai Sea were higher than those from the riverine input and atmospheric deposition (Liu et al., 2017; Wang et al., 2019b). The pollution of large-scale mariculture is widely concerned globally. Nutrients input to the Bohai Sea through marine aquaculture (including feeding and non-feeding marine culture) contributed <5% of total N and P fluxes by industrial wastewater and domestic sewage (Cui et al., 2005).

2.2.2 Baltic Sea

Similar to the Bohai Sea, the Baltic Sea is a semi-closed marginal sea, which only connects with the North Sea and the Atlantic Ocean through narrow channels, e.g. Skagerrak Strait. The Baltic Sea covers an area of about 420,000 km2, with an average water depth of 51 m. The area where the water depth is less than 30 m accounts for about one third of the sea area, and the deepest point of the Baltic Sea is located in Baltic Proper, with a water depth of about 459 m (Andersen et al., 2015). The residence time of seawater in different areas of the Baltic Sea is different. For example, the residence time of seawater in Kattegat and Danish Straits is 1 to 3 months (Gustafsson, 2000), while that in Gulf of Finland is about 1 year (Andrejev et al., 2004). In general, the residence time of the entire system is more than 30 years (Stigebrandt and Gustafsson, 2003), so the Baltic Sea is prone to eutrophication. The Baltic Proper has a relatively deep permanent halocline (70-80 m) and a shallower seasonal thermocline, with the existence of permanent hypoxia (Andersen et al., 2015). There is no permanent halocline in the Bothnian Sea and Bothnian Bay located in the northern Baltic Sea, and water bodies often mix vertically (Mälkki and Tamsalu, 1985).

2.2.3.1 Distribution patterns of nutrients

The average concentrations of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) in the surface layer (0-10 m) of each sub open seas in winter from 2011 to 2016, and the average concentrations of DSi in winter for decades (some data include spring) (Table 2.1) were sorted out. In general, DIN and DIP concentrations in the eastern Baltic Sea including Gulf of Finland and Gulf of Riga were relatively high. DIN and DIP concentrations in the northern Baltic Sea, including Aland Sea, Bothnian Sea, the Quark and Bothnian Bay, were at a moderate or low level. The concentrations of DIN and DIP in the western Baltic Sea, including Kattegat, Great Belt, the Sound and Kiel Bay, were at a moderate or high level. The DIP concentration in the central basin, including Eastern Gotland basin, Western Gotland basin and northern Baltic proper, was at a moderate level, while DIN concentration was relatively low. The DIP concentrations of Bay of Mecklenburg, Bornholm basin and Gdansk basin were at a moderate or high level. The DIN concentrations of Bornholm basin was on the high side, while that in Mecklenburg, and Gdansk basin were on the low side.

Table 2.1 DIN, DIP and DSI concentrations in each sub open seas in winter (μmol/L)

Sub open seas	DIN	DIP	DSi *
Kattegat	5.90	0.54	8.76
Great Belt	6.45	0.65	
The Sound	5.99	0.64	
Kiel Bay	5.91	0.64	17.64
Bay of Mecklenburg	6.35	0.70	15.51
Arkona Basin	3.97	0.62	12.38
Gdansk Basin	4.60	0.52	

Bornholm Basin	9.33	0.66	13.43
Eastern Gotland Basin	3.55	0.57	
Western Gotland Basin	3.27	0.67	14.26
Northern Baltic Proper	4.93	0.64	
Gulf of Riga	10.42	1.04	11.60
Gulf of Finland	8.59	0.96	14.78
Åland Sea	3.88	0.45	14.47
Bothnian Sea	3.82	0.34	
The Quark	4.78	0.24	
Bothnian Bay	6.50	0.06	27.66

* Note: The DSi data of Kiel Bay and Bay of Mecklenburg are the average DSi concentration before algal blooms from January to May in 1980-2011 (Norbert et al., 2013). The DSi concentration in the other sub open seas are the volume weighted average values from from 1980 to 2000 in winter (Papush et al., 2009). The DSi data of Bornholm Basin and Eastern Gotland Basin, Western Gotland Basin and Northern Baltic Proper are the volume weighted average values above the halocline.

DIN concentrations in the sub open seas of the Baltic Sea showed an upward trend until the early 1990s. After that, DIN concentration in each sub open seas almost stopped increasing and maintained at a high level, with a significant decrease in most of the sub open seas (HELCOM, 2018a).

The observation of DIP in some sub open seas can be traced back to the 1960s. The DIP concentration in most sub open seas increased significantly from 1960 to 1970s, and then remained at a high level. There was no obvious trend in DIP concentration in most sub open seas. However, the DIP concentration in Åland Sea continued to increase from 1990 to 2016, and that in the Bothnian Sea, Gulf of Riga, Gdansk Basin and Northern Baltic Prope had also increased significantly during 2011 to 2016.

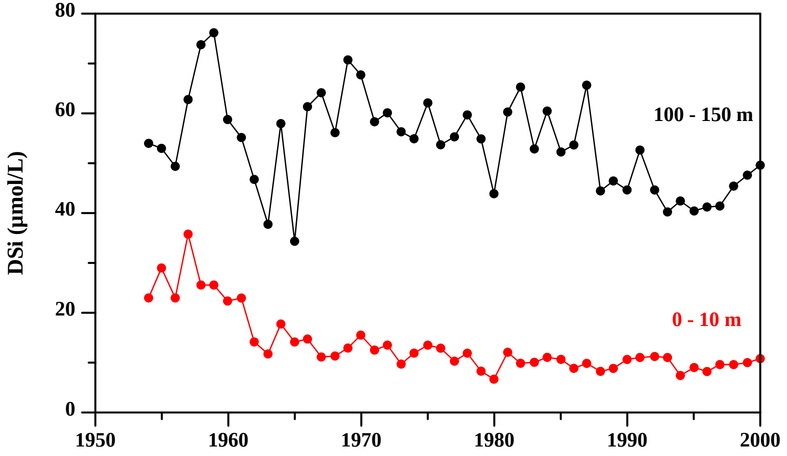

Figure 2.4 Variation of DSi concentration over time in Baltic Sea Basin (Source: Conley et al., 2008)

As shown in Figure 2.4, DSi concentrations in the surface layer (0-10 m) and deep layer (100-150 m) of the Baltic Sea basin have been on a downward trend since 1950s (Sandén et al., 1991; Suikkanen et al., 2007; Conley et al., 2008; Hanninen et al., 2020), especially from 1950s to 1960s. Conley et al. (2008) estimated that the DSi concentration of Baltic Proper at the beginning of last century was 2.6 times higher than that at the beginning of this century. However, some studies have pointed out that the trend of DSi concentration leveled off since the 1990s (Norbert et al., 2013; Papush and Danielsson, 2005). The research of Fleming-Lehtinen et al. (2008) showed that DSi concentrations in northern Baltic Proper, Gulf of Finland and Bothnian Sea decreased by 30% to 50% from the beginning of 1970s to the end of 1990s, and then increased by 20% to 40%.

2.2.3.2 Inputs of nutrients

The Baltic Sea is one of the sea areas with the most serious environmental pollution in the world, and eutrophication has appeared since 1960s (HELCOM, 2007a). It was not until the early 1980s, however, that eutrophication was first identified as a large-scale stress of the Baltic sea, and part of the factor of eutrophication was attributed to the inputs of nutrients by human activities (HELCOM, 1987; HELCOM, 2009). It was also at this point that the inputs of nitrogen and phosphorus reaches the maximum value (Figure 2.5). The Helsinki Commission decided to reduce the inputs of nutrients by 50% (HELCOM, 1988) and identified the protection of the Baltic Sea from eutrophication as one of the goals of the Baltic Sea Action Plan (HELCOM, 2007b).

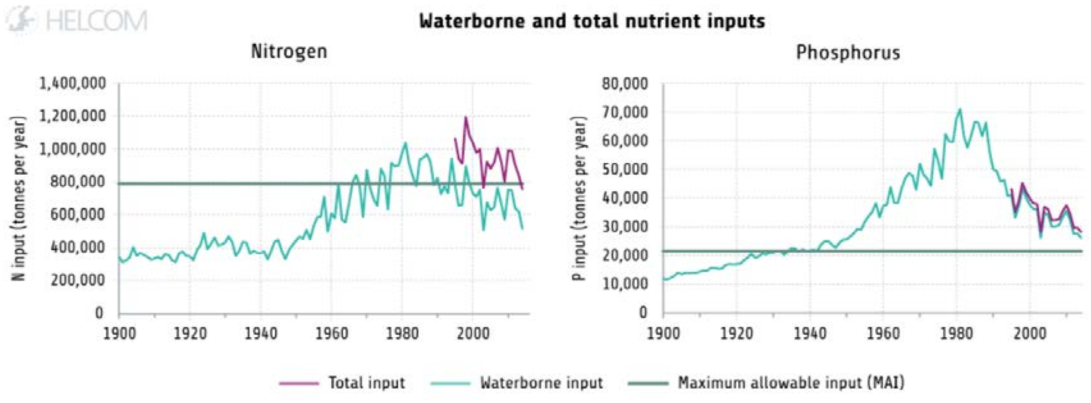

Figure 2.5 Changes of nitrogen and phosphorus inputs over time and maximum allowable inputs to the Baltic Sea from 1990 to 2014 (Source from HELCOM, 2018a, data from HELCOM, 2015, Gustafsson et al., 2012 and Savchuk et al., 2012).

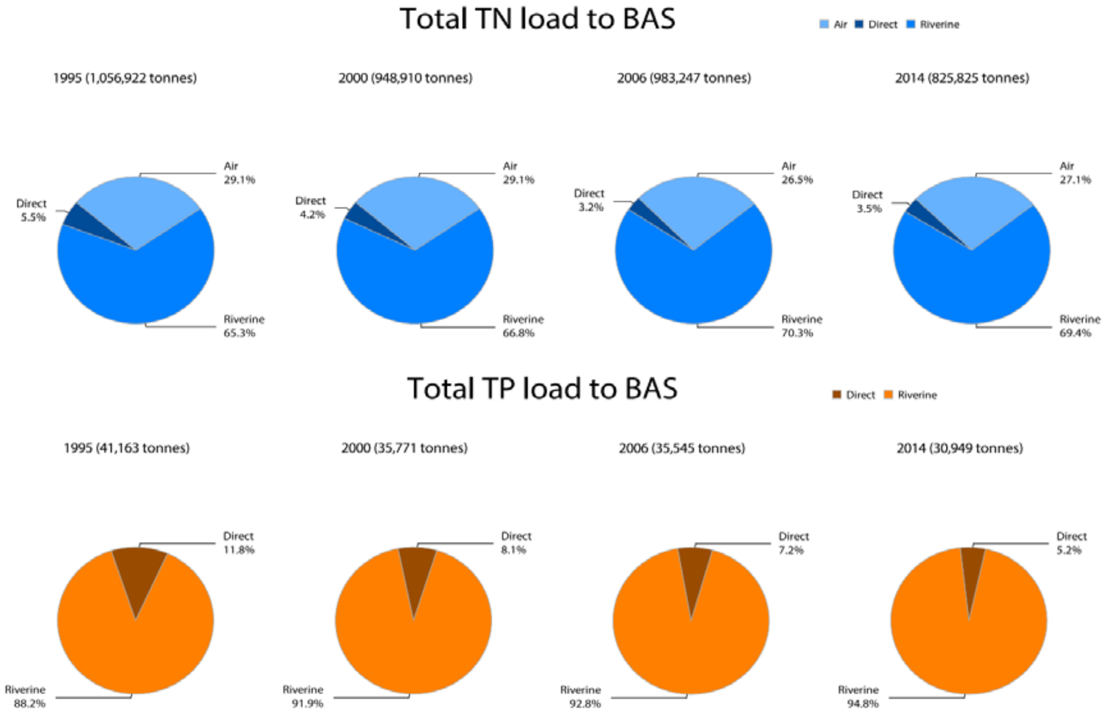

Figure 2.6 The proportion of sources of TN and TP load to the Baltic Sea from 1995 to 2014 (HELCOM, 2018b).

The total nitrogen (TN) input to the Baltic Sea included water input and atmospheric input, where the water input was a combination of river input and direct point sources input (industrial, municipal and aquaculture wastewater directly discharged into the sea in coastal areas). The total phosphorus (TP) input to the Baltic Sea mainly came from river inputs and direct point sources input (HELCOM, 2018b). As shown in Figure 2.6, river input was the largest source of TN and TP, accounting for 70.3% and 94.8% respectively. Atmospheric input related to transportation, industrial activities and agricultural combustion processes accounted for about 27.1% of TN input. Direct point sources accounted for 3.5% and 5.2% of TN and TP input, respectively. From the perspective of the proportion of nutrients from various sources from 1995 to 2014 (Figure 2.6), the proportion of TN and TP input from rivers was increasing, while the proportion of TN input from atmosphere was slightly decreasing. The proportion of TN and TP input from direct point sources was also decreasing; especially the proportion of TP input was decreasing by nearly 6%.

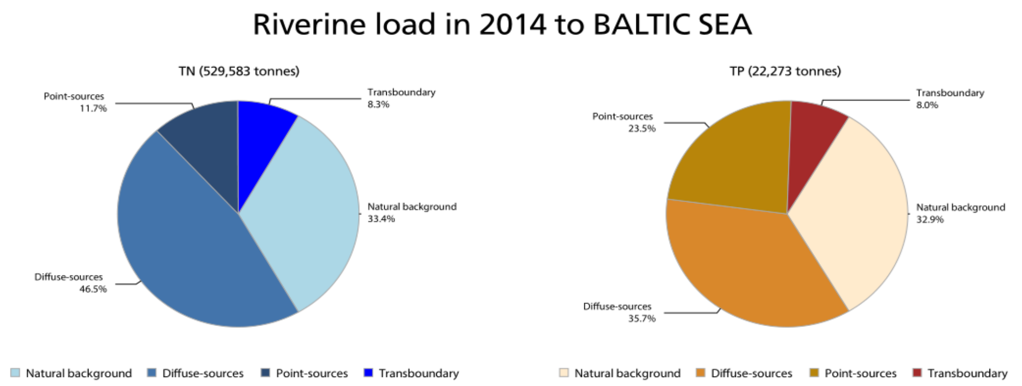

Figure 2.7 Proportion of sources of TN and TP imported into the Baltic Sea via rivers in 2014 (HELCOM, 2018b)

River input was mainly affected by natural and anthropogenic sources, among which anthropogenic sources included diffuse sources and point sources. In addition to natural and anthropogenic sources, some of the nutrients in the river came from non-HELCOM countries (mainly Belarus) in the upper reaches of the river, which were separately defined as trans-boundary input (HELCOM, 2018b). One third of TN and TP came from natural sources. The diffuse sources affected by agricultural activities were the largest source of TN and TP input, accounting for 46.5% and 35.7% respectively. The point sources dominated by municipal wastewater treatment plants accounted for 12% and 24% of TN and TP input respectively, and the proportion of trans-boundary nutrients was less than 10% (Figure 2.7).

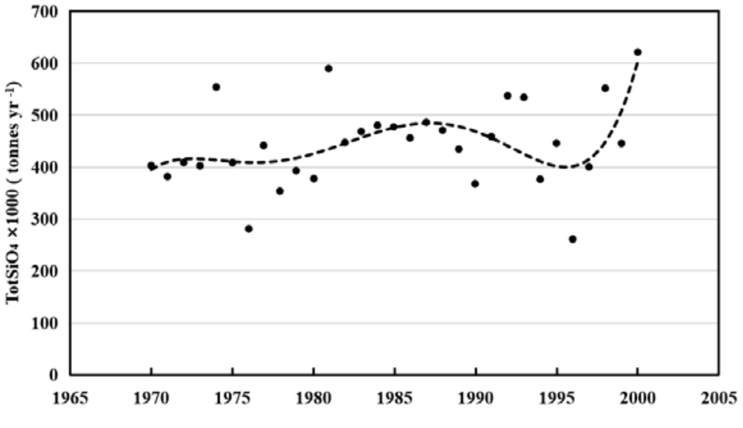

Figure 2.8 Total amount of silicate imported into the Baltic Sea by rivers over time (Data source: Hnninen et al., 2020)

Generally speaking, the inputs of nitrogen and phosphorus to the Baltic Sea has decreased in recent decades. Between the reference period (1997-2003) and 2017, the input of nitrogen and phosphorus decreased by 14% and 24% in the entire Baltic Sea. Nitrogen inputs were reduced by 0%-24% and phosphorus by 6.4%-51% in most sub open sea area, but phosphorus input was increased by 4% in the Gulf of Riga (HELCOM, 2019). From 1995 to 2017, the nitrogen input from atmospheric to the entire Baltic Sea decreased by 33%, while the waterborne nitrogen input and waterborne phosphorus input decreased by 11% and 31% respectively. The atmospheric nitrogen input to each sub open sea areas decreased by 29% to 33%, and the waterborne nitrogen input and waterborne phosphorus input to most sub open sea areas decreased to varying degrees.

In 2017, the inputs of waterborne nitrogen (758,675 tonnes per year) to the Baltic Sea water was equivalent to that in the 1960s, while the inputs of waterborne phosphorus (28,002 tonnes per year) to the Baltic Sea water returned to the level in the 1950s. However, The annual nitrogen (986,555 tonnes per year) and phosphorus (tonnes per year) inputs to the Baltic Sea were still approximately 24.5% and 38.6% higher than the maximum allowable nitrogen (792,209 tonnes per year) and maximum allowable phosphorus (21,716 tonnes per year), respectively.

River input was the main way for providing dissolved silicate (DSi) to coastal water. In the last century, due to the influence of lakes and reservoirs, the amount of silicates imported from rivers to the Baltic Sea may have decreased by 30% to 40% (Humborg et al., 2008). However, some studies have pointed out that the total amount of silicate transported to the Baltic Sea by river have not changed significantly during 1970 to 1990 (Rahm et al., 1996), and even showed a slow increase in the late 1990s (Figure 2.8).

2.2.3 Comparison analysis of nutrients in the Bohai Sea and Baltic Sea

In order to reduce the impact of seasonal variation, we represented the interannual variation by comparing the surface nutrient levels in winter in the Bohai Sea and each sub open seas of the Baltic Sea. The DIN concentration in the Bohai Sea was very low before the 1990s, and then began to increase significantly in recent years, with the average annual DIN concentration ranging from 13.7 µmol/L to 21.32 µmol/L since 2010. In the past three decades, the average DIP concentration in the Bohai Sea maintained at 0.5~0.9 µmol/L and kept a fluctuating trend. DIP concentration was very low (< 0.2 µmol/L) only in some years due to human activities or climate change (Wang et al., 2019a). Since 1978, the DSi concentration in the Bohai Sea showed a trend of decreasing first and then increasing (Xin et al., 2019). The published data showed that DSi concentration ranged from 5.5 to 17.7 µmol/L from 2000 to 2006, with the average value of ~13 µmol/L (Wang et al., 2019a).

The concentrations of DIN and DIP in most of the sub open seas of Baltic Sea increased significantly before the 1990s. After that, with the implementation of some management measures, the DIN concentration in most sub open seas and the DIP concentration in a few sub open seas decreased. Since 2010s, the average annual DIN concentration ranged from 3.27 µmol/L to 10.42 µmol/L, and the average annual DIP concentration ranged from 0.06 µmol/L to 1.04 µmol/L. The DSi concentration in the Baltic Sea has been decreasing continuously since the beginning of the last century, and has been fluctuating since the 1990s. The annual average DSi concentration in several sub open seas ranged from 8.76 to 27.66 µmol/L.

In terms of concentration levels, the average DIN concentration in the Bohai Sea was higher than the peak average DIN concentration in most sub open seas of Baltic Sea. The average DIP concentration was closer, while the average DSi concentration in the Bohai Sea was equivalent to the intermediate level of the sub-sea areas of the Baltic Sea. Relatively higher DIN concentrations, close DIP concentrations, and intermediate DSi concentrations in Bohai Sea resulted in higher N/P ratios and lower Si/N ratios in the Bohai Sea than that in Baltic Sea. Benefited from the efforts of HELCOM in controlling nutrient input, the input of TN into the Baltic Sea decreased significantly, resulting in the decrease of DIN concentration in most sub open seas of Baltic Sea. Although relevant measures have been taken to protect the Bohai Sea in China in recent decades, previous studies have shown that the total DIN input into the Bohai Sea through rivers has not decreased significantly in recent years and maintained at a high level (Xin et al., 2019). In addition, the amount of agricultural fertilizer, municipal sewage discharge and aquaculture area in the Bohai Rim region have been increasing (Wang et al., 2019a), which indirectly indicated that the total amount of nitrogen input into the Bohai Sea through these channels has not been effectively controlled. Therefore, effective control of nitrogen input in Bohai is the key to improving eutrophication in Bohai.

2.3 Ecological responses to coastal eutrophication

2.3.1 Bohai Sea

2.3.1.1 Eutrophication impacts on ecosystem

Salinity in the Bohai has increased by 2.0 in the second half of the 20th century, mainly related to a sharp decrease in the Huanghe runoff and the effects of climate change and the intrusions of the North Yellow Sea water (Lin et al., 2001; Mao et al., 2008). The WSRS has led to that high monthly average water discharge, sediment load and nutrient transports advance to as early as 2 months earlier than before the event, such that the surface Chl-a exhibited two peaks in spring and autumn until 2002, but has exhibited only one peak in spring-summer since 2002 (Ding et al., 2020). Along with changes in physicochemical environment, the composition pattern of the phytoplankton community changed dramatically during 1959 – 2015, in which diatoms accounted for 65.3%~99.8% of phytoplankton abundances and phytoplankton transitioned from diatom-dominated communities to communities co-dominated by diatoms and dinoflagellates (Luan et al., 2018; Zhang et al., 2004). In last century, centric diatoms such as *Chaetoceros spp*. and *Coscinodiscus spp*. dominated in the communities, while *Paralia sulcata*, *Thalassionema* spp., and dinoflagellates such as *Noctiluca scintillans* and *Tripos spp*. gradually became predominant in this century (Luan et al., 2018).

There have been pronounced degradation responses of ecosystems due to the environmental changes occurring in the Bohai Sea, such as decreases in standing stock and production of phytoplankton, economic living resources, indices of recruitment for Penaeid prawn, and the succession of diatoms to dinoflagellates and changes in the fish community structure and species diversity (Ning et al., 2010). Zooplankton is the primary food source for many economic fish species, therefore, zooplankton determines the replenishment mechanism of economic fish species to a great extent. The biomass of zooplankton increased by about 70% from the beginning of the 1990s to the beginning of the 2010s (Xin et al., 2019), and the species of zooplankton adults showed significant decreases in the same period (Bi and Sun, 2000; Wang et al., 2002; Xu et al., 2016). Notably, outbreaks of jellyfish blooms appeared more frequently in the BS since the 21st century (Ge and He, 2004; Dong et al., 2010; Wu et al., 2017). It not only causes a lot of economic losses, but also threatens human health.

Along with eutrophication caused by human activities, the diversity of benthos has been significantly decreased. In generally, the dominant benthos species have been changed, with larger echinoderms and molluscs in the early years and transforming into small polychaetes and crustaceans in recent years (Liu et al., 2014). Such as in Laizhou Bay, the dominant species of benthos were bivalves *Musculista senhousia* and echinoderm *Echinocardium cordatum* in the 1980s (Sun and Liu, 1991), became small *Alvenius ojianus* and *Yokoyamaia argentata* in the 1990s (Han et al., 2003), and were *Nitidotellina minuta* in the 21^{st} century (Zhou et a., 2010).

During 1959-2010, there were rapid shifts in fish community structure, the abundance of dominant species changed, and the diversity of fish species and species number density decreased. From the 1950s to the 1990s, the dominant fish species changed, with large-sized, high-valued species (e.g., Small Yellow Croaker *Larimichthys polyactis and Largehead Hairtail Trichiurus lepturus*) being replaced by small-sized, low-valued species (e.g., *Japanese Anchovy Engraulis japonicus and Hairfin Anchovy Setipinna taty*). From the 1990s to 2015, the Small Yellow Croaker and some of the small sized species (*Hairfin Anchovy and Dotted Gizzard Shad Konosirus punctatus*) have become the dominant species. The food web became simple, with species from relatively low trophic levels controlling the energy flow within the fishery ecosystem (Shan et al., 2016).

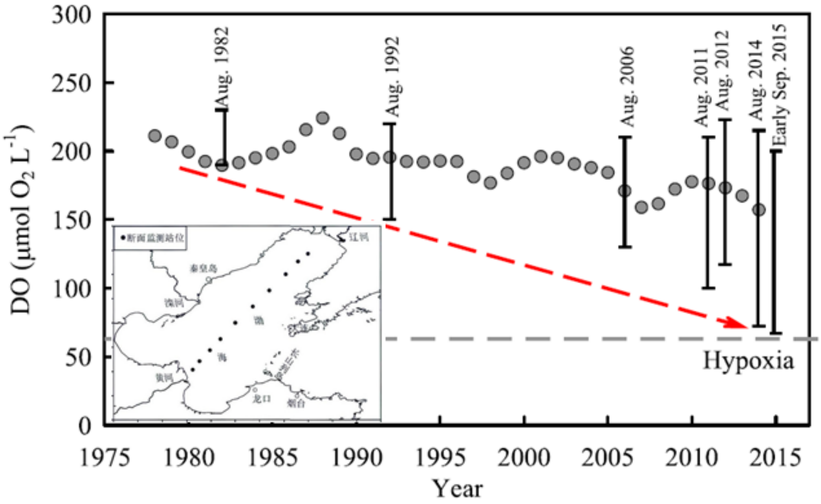

Figure 2.9 DO concentration changes in Bohai Sea, modified from Zhai et al. (2019).

2.3.1.2 Hypoxia

The bottom DO in the Bohai Sea has been gradually decreasing since 1978 (Figure 2.9). Prior to 2000, the bottom DO in the Bohai Sea remained high, with concentrations above about 6 and 5 mg/L in 1982 and 1992, respectively. In the summer of 2006, the minimum bottom DO in the central northwest offshore Bohai Sea will be about 4 mg/L. Thereafter the bottom DO is further reduced, the minimum values of bottom DO were ~3 and 2 mg/L in 2011 and 2015, respectively (Zhai et al., 2019). In terms of seasonal distribution, DO concentrations in the Bohai Sea are at a high level (~10 mg/L) in April and gradually decrease, reaching a minimum in summer, showing a seasonal hypoxia process (Song et al., 2020).

The bottom DO concentration in the Bohai Sea has been decreasing since 2000, and in the 2010's a low-oxygen zone (<3 mg/L) was formed covering an area of more than 4000 km^2. In recent years, the seasonal low-oxygen process in the Bohai Sea has developed rapidly, the low-oxygen zone has expanded from the southeast of Qinhuangdao, the northwest of the Huanghe Estuary, to the east of the Huanghe Estuary and the Laizhou Bay. Moreover, some of the sea areas are already close to hypoxia conditions. In general, the Bohai Sea hypoxia zone is still at a preliminary stage of development, and relevant studies are still scarce, especially for ecosystem impacts. According to statistics, the hypoxia disaster in 2013 in the northern Shandong Peninsula (including the Bohai Sea and Yellow Sea) led to the death of a large area of aquatic organisms, with more than 80,000 mu of marine pasture affected, including direct economic losses of 450 million yuan for seafood such as sea cucumber, sea snails, Japanese sea crab and shellfish, and incalculable ecological losses (Zhai et al., 2020b).

2.3.2 Baltic Sea

2.3.2.1 Eutrophication impacts on ecosystem

The comprehensive assessment of eutrophication in the Baltic Sea from 2011 to 2016 shows that 97% of the sea areas were still affected by eutrophication in varying degrees, although the eutrophication in the Baltic Sea has improved. The nutrient level in the evaluation was the furthest from Good Environment Status (GES), meaning that it had the greatest impact on the comprehensive assessment results (HELCOM, 2018a). Nutrient levels directly affected all aspects of the Marine ecosystem.

The massive inputs of N and P promoted the algae growth. From 1970s to 1990s, chlorophyll a (Chl-a) concentration in most areas of the Baltic Sea increased significantly in summer, followed by little change and remained at a high level (HELCOM, 2018e). Green tide caused by cyanobacteria blooms was a natural phenomenon in the Baltic Sea (Bianchi et al., 2000), which has been observed as early as 1900s (Hallfors et al., 2013). Green tide has been prevalent since 1960s in the Baltic Proper and the Gulf of Finland (Finni et al., 2001; Poutanen and Nikkila, 2001). However, satellite data from Kahru and Elmgren (2014) shown that the area of green tides in the Baltic Sea in summer has continued to increase since the 1970s (Figure 2.10), although it decreased from the end of 1980s to the beginning of 1990s. In addition, due to the change in nutrient structure, the structure of phytoplankton also changed greatly. For example, the diatom/dinoflagellate index in Eastern Gotland Basin decreased significantly from the 1980s to the 1990s, and then increased after 2000 (HELCOM, 2018f).

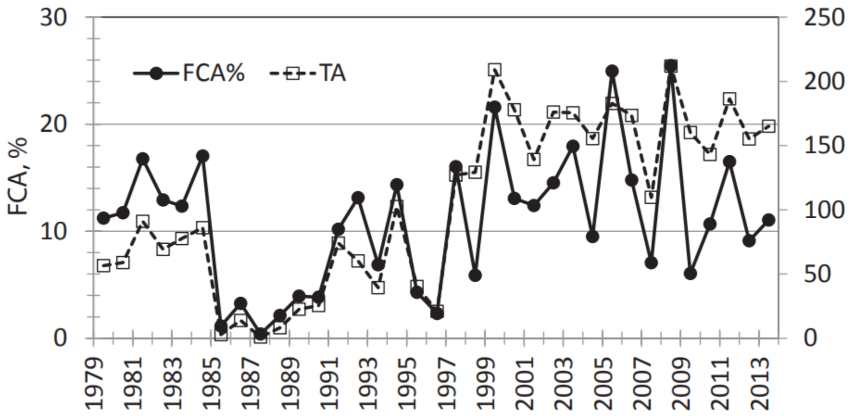

Figure 2.10 Mean fraction of cyanobacteria accumulations (FCA %) and total accumulated area

affected (TA) in the entire Baltic Sea between 1979 and 2013 based on satellite detection (Source: Kahru and Elmgren, 2014)

The massive growth of algae intensifies the eutrophication of the water, and the increase in the intensity and frequency of algal blooms usually leads to the decrease in the transparency of the water and the increase in the sinking organic matter. Long-term studies have shown that the transparency of water bodies in most sub open seas of Baltic Sea has been fluctuating or deteriorating continuously in recent decades (HELCOM, 2018g), especially in the northeastern sub open sea areas (Fleming-Lehtinen and Laamanen, 2012). Only a few sub open seas have seen improvements in transparency. The Baltic Sea Basin itself had poor water exchange capacity due to the deeper halocline and shallower thermocline. Moreover, due to the degradation of a large number of sinking organic matter by microorganisms, a large amount of oxygen would be consumed, which aggravated the hypoxia phenomenon when there was a permanent hypoxia area. These biochemical environment changes reduced the habitat quality in coastal areas, and further restricted and affected the growth of aquatic organisms such as macroalgae, macroplants, zooplankton and soft-bottomed fauna. For example, the abundance and average size of zooplankton decreased from 1970s to 2010s (HELCOM, 2018h). This chain reaction could affect the entire food web in the Baltic Sea and further affect the social service functions of the marine ecosystem. According to the research of Ahtiainen et al. (2014), the total annual loss of the Baltic Sea region due to the impact of eutrophication was 3.8 to 4.4 billion Euros.

In recent decades, with the efforts of HELCOM, the inputs of TN and TP have decreased significantly, and there have also been some positive developments in eutrophication.. For example, DIN concentrations has decreased in most areas of the Baltic Sea, while water transparency and Chl-a concentration have decreased in parts of the western Baltic Sea. In addition, the intensity of algal blooms in spring from 2000 to 2014 was reduced due to the reduction of some nutrient concentration (Groetsch et al., 2016). However, the reduction of nutrient inputs to the Baltic Sea is difficult to see the corresponding improvement of eutrophication in a short period of time. That is, the response has a lag.

2.3.2.2 Hypoxia

2.3.2.2.1 Development and status of hypoxia zone

According to the sedimentary record, there were three prolonged hypoxia processes in the Baltic Sea during the Holocene (Figure 2.16), cal. 8000-4000 yr BP, cal. 2000-800 yr BP, and after 1900 AD (Zillén et al., 2008; Zillén and Conley, 2010), respectively. The first hypoxia phase (cal. 8000-4000 yr BP) occurred during the Holocene Megathermal (HTM), a period characterized by a hot, dry climate in north-western Europe, therefore low freshwater input. In addition, sea level rise during this period led to increased seawater intrusion, resulting in higher salinity and increased stratification, which limited the venting of bottom waters. At the same time, increased productivity in warmer climates led to increased levels of oxygen-consuming organic matter. The combination of these factors is the main reason for the occurrence of hypoxia (Zillén et al., 2008). The second hypoxia process (cal. 2000-800 yr BP) coincided with the Medieval Warm Period. In addition, population growth and large-scale land exploitation during this period led to a significant increase in nutrient inputs, which exacerbated the Baltic Sea hypoxia process. The third hypoxia process (after 1900) is closely linked to human activity, with the dramatic increase in population numbers, agricultural production, drainage ditches and deforestation along the Baltic Sea following the industrial revolution in Europe in 1850, which led to a large input of nutrients and thus triggered the hypoxia process. In general, the first hypoxia process in the Baltic Sea was mainly caused by natural processes, the second hypoxia process played an important role by both natural and anthropogenic processes, and the third hypoxia process was closely related to human activities (Zillén et al., 2008; Zillén and Conley, 2010; Carstensen et al., 2014a).

The development of hypoxia processes in the Baltic Sea over the last 100 years has been unprecedented, with the hypoxia area growing rapidly from about 5000 km^2 to more than 80 000 km^2 , an increase of more than 10 times, making the Baltic Sea the largest offshore hypoxia area in the world (Carstensen et al., 2014a; Hansson et al., 2019). According to data from the central Baltic Sea (Figure 2.17a), the area of the hypoxia zone was less than 20,000 km^2 before 1950 and increased rapidly to more than 50,000 km^2 by 1970's; In the period 1973-1993 (the stagnation period), the Baltic Sea experienced a decrease of about 10 m in salinity due to increased freshwater input and increased latitudinal wind speed, and the stratification intensity decreased, so that the hypoxia process was alleviated to some extent, the area of hypoxia zone in 1993 was about the same as that in 1930's. Thereafter, the area of the hypoxia zone increased rapidly, and from 1999 onwards, a steady-state transition occurred in the Baltic Sea hypoxia zone, with both the area and volume of the hypoxia and anaerobic zones continuing to increase, reaching 70,000 km^2 by 2010 (Carstensen et al., 2014a; Carstensen and Conley, 2019). The most severe hypoxia processes occurred in 2018, with ~33% and ~24% of the total area of the hypoxia and anaerobic zones at the base of the Baltic Proper. Many new hypoxia and anaerobic zones were added during the year, such as the Gulf of Gdansk, Hanö Bight and Bornholm Basin. The large-scale hypoxia processes that occurred in 2018 were mainly due to the hot and windless spring and summer, which stimulated primary productivity and intensified the oxygen-consuming processes of bottom organic matter remineralization and decomposition (Hansson et al., 2019).

2.3.2.2.2 Influencing factors of hypoxia in the Baltic Sea

The process of hypoxia in the Baltic Sea is influenced by multiple effects of physical processes, climate change and anthropogenic processes, in recent times, excessive nutrient input due to anthropogenic activities is the main factor contributing to hypoxia in the Baltic Sea (Carstensen et al., 2014b; Meier et al., 2019).

By the 1980s, anthropogenic inputs of nitrogen and phosphorus to the Baltic Sea had increased fourfold and eightfold respectively (Larsson et al., 1985). Excessive nutrient inputs lead to frequent algal blooms, which provide large amounts of oxygen-consuming organic matter to the bottom waters, and the intense oxygen consumption by microorganisms disrupts the balance between oxygen replenishment (physical process) and depletion (oxidation of organic matter), leading to hypoxia occurrence (Carstensen et al., 2014a). Over the past 100 years, increased nutrient input due to human activities has been the main cause of hypoxia in the Baltic Sea (Meier et al., 2019).

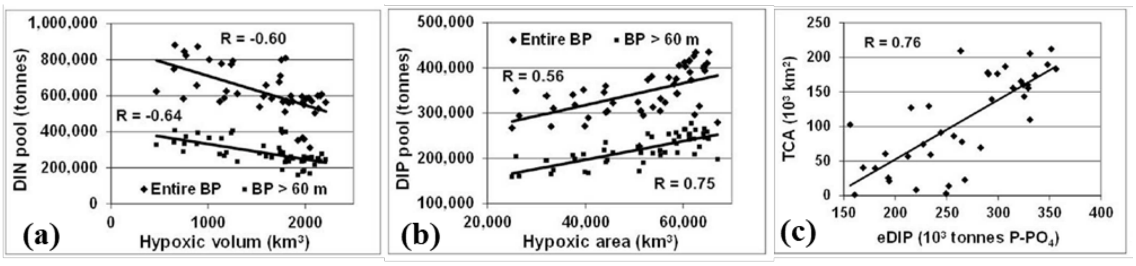

Figure 2.11 Hypoxia and nutrient relationships in the full water column, deep water (>60 m) in the Baltic Proper (Savchuk, 2018). a, Relationship between DIN and volume of hypoxia zone (km3); b, Relationship between DIP and area of hypoxia zone (km2)); c, Relationship between area of cyanobacteria aggregation and excess inorganic phosphorus (eDIP = DIP - DIN/16)

The distribution of hypoxia zones in the Baltic Sea showed an opposite correlation with the distribution of nitrogen and phosphorus (Figure 2.11), with the size of hypoxia zones showing a negative correlation with DIN and a positive correlation with DIP, therefore a negative correlation with the ratio of DIN to DIP (DIN/DIP). Overall, changes in the size of the Baltic Sea hypoxia zone lagged by 2 years compared to changes in DIN/DIP (Savchuk, 2018). The coupling between oxygen depletion processes and nitrogen and phosphorus biogeochemical processes in the Baltic Sea determines the above-mentioned distributional relationships (Vahtera et al., 2007). In spring, nitrogen input causes an increase in primary production, leading to the occurrence of algal blooms. Most of the algal bloom organic matter settles to the bottom and decomposes to consume oxygen, exacerbating the hypoxia (oxygen-free) process, and the release of phosphate from the sediment is exacerbated by the hypoxia and oxygen-free conditions. In summer, this phosphate reaches the surface layer through upwelling, reducing the nitrogen to phosphorus ratio in the water column. In addition, hypoxia conditions cause denitrification to remove nitrogen from the water, leading to a further reduction in the nitrogen to phosphorus ratio, and these nitrogen-limited conditions favour the growth of nitrogen-fixing cyanobacteria in large numbers and the occurrence of algal blooms, which can affect an area of up to 200,000 km^2 (Kahru and Elmgren, 2014). Cyanobacterial blooms add further nitrogen nutrients to the water column, leading to the development of phytoplankton blooms that further exacerbate hypoxia. It can be seen that endogenous phosphate-induced cyanobacterial blooms play an important role in the process of hypoxia in the Baltic Sea (Figure

2.11c), and that a 'vicious circle' of nitrogen, phosphorus and oxygen biogeochemical processes inhibits recovery from eutrophication (Vahtera et al., 2007), leading to a 'self-sustaining' eutrophic state in the Baltic Sea (Savchuk, 2018).

2.3.2.3 Summary

Overall, hypoxia has had a serious negative impact on the Baltic Sea ecosystem, including a reduction in fisheries resources, weakened nutrient removal and an intensification of the algal bloom process. In the case of marine life, for example, fish trapped in hypoxia waters occur almost every year near the Denmark Strait. For example, in August 2018, hypoxia in Ekenföld Bay led to the death of a large number of fish; in addition, the process of hypoxia has already led to the loss of 3 million tons of zoobenthos in the Baltic Sea, with a severe hypoxia event in 2002 alone leading to the extinction of approximately 300,000 tons of zoobenthos , a weight equivalent to the weight of the Danish population. The death of benthic organisms increases bottom oxygen consumption and exacerbates hypoxia (Carstensen and Conley, 2019).

The area of the anoxic zone in the Baltic Sea increased from about 5000 km^2 (1.3% of the Baltic Sea) to more than 60,000 km^2 (16% of the Baltic Sea) in 1993-2016, partly due to the low frequency and short duration of reoxidation of anoxic water bodies in the past 20 years. Overall, the nutrient mitigation policy has a positive effect on mitigating the trend of increased anoxia in the Baltic Sea. Without any measures taken in 2007, the nutrient input continues to increase, and in 2100, the area of the anoxic zone in the Baltic Sea will reach about 90,000 km^2. If nutrient discharge remains at the original level, the area of anoxic zone will reach about 80,000 km^2.Oxygen deficiency areas are expected to drop to about 50,000 km^2 by 2100 due to the implementation of the Baltic Action Plan (Conley, 2012).

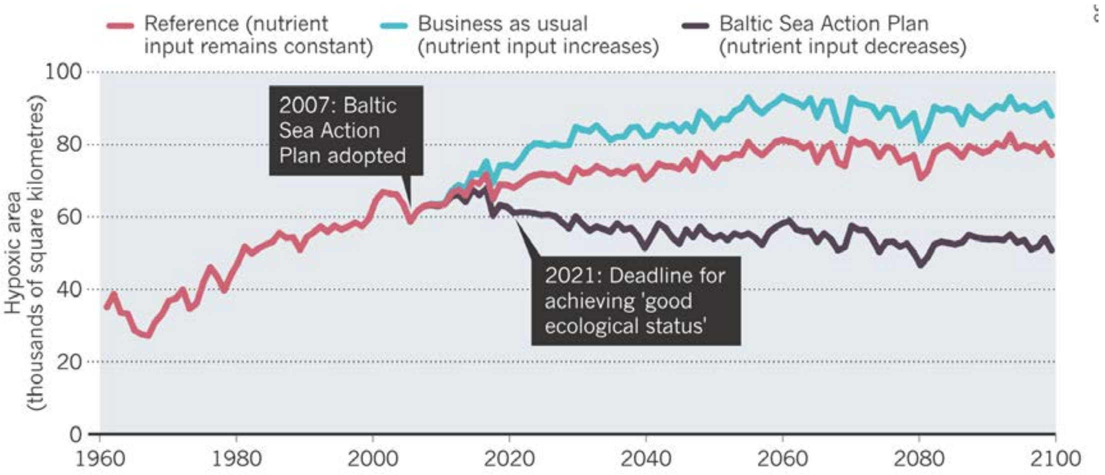

Figure 2.12 Schematic diagram of the trends in the hypoxia zone for the three states predicted by the model (Conley, 2012). (Red line shows continued increase in nutrient input, green line shows no change in nutrient input, black line shows decrease in nutrient input)

2.4 Mitigation actions on coastal eutrophication

2.4.1 Baltic Sea

Due to the large number of Baltic coastal countries, their management and governance work is facing severe challenges. Through a number of international regulatory agencies and treaties, the Baltic coastal countries began to implement environmental governance in the 1970s. At present, the Baltic Sea is one of the most comprehensively managed waters in the world. The governance of the Baltic Sea is a multi-level control system, including global conventions (such as the Convention on biological diversity), regional conventions and organizations (such as the Helsinki Convention), the European Union, relevant national and local authorities, non-governmental organizations and the public society.

In 1974, the Baltic States acceded to the Convention for the Protection of the Baltic Marine Environment, known as the Helsinki Convention, which was also the first regional marine convention in the world. The Helsinki Committee (HELCOM) comprises ten States parties (organizations), including Denmark, Sweden, Finland, Germany, Poland, Lithuania, Latvia, Estonia, the Russian Federation and the European Union. The Head of Delegation of the Environment Ministers of the States Parties is responsible for the development and implementation of HELCOM-related measures. HELCOM compiles source data and formulates non-binding recommendations for emission reduction targets. Reduction targets are binding when passed by national legislators. Eutrophication control is an important part of comprehensive management of the Baltic Sea. In 1988, HELCOM set a target of reducing the amount of nitrogen and phosphorus discharged into the Baltic Sea by 1995 to 50% of that in 1985. Although this target was ultimately not met, much progress has been made in reducing nutrient emissions in the Baltic Sea, especially in the area of point source pollution control. Between 1985 and 1995, countries and regions concerned adopted measures such as strengthening sewage treatment. Therefore, the input load of point source nitrogen and phosphorus to sea is reduced by 50-70%.

In 2007, HELCOM launched the Baltic action plan (BSAP), which incorporates up-to-date scientific knowledge and innovative approaches to management into the enforcement of management policy and promotes the construction of target oriented multilateral cooperation models for Baltic coastal countries. The overall goal of this ambitious program is to achieve the attainment of a good ecological situation in the Baltic Sea, with corresponding ecological indicators including: the achievement of natural state levels of nutrient concentration, algal blooms, and dissolved oxygen, improvement of water quality, and animals and plants exhibiting a natural state distribution. Reduction of nutrient emissions into the Baltic Sea is an important part of the Baltic Action Plan. As a result, HELCOM has developed a detailed nutrient mitigation plan. Two important components of the plan are as follows: First, to determine the maximum allowable input of nutrients; Second, the required emission reduction targets are shared equally among all Baltic countries, which have taken steps to reduce nutrient emissions. Based on the comprehensive analysis of monitoring data and numerical model results, HELCOM determined the maximum allowable input amounts of nitrogen and phosphorus. Taking the average input level of nutrients during 1997-2003 (reference period) as a reference, the emission reduction targets of nitrogen and phosphorus are 135,000 and 15,250 t/a respectively, corresponding to nitrogen and phosphorus. The reduction ratios of phosphorus are 18% and 42% respectively. At the time point, action will be taken to reduce nutrient input from water and atmosphere to achieve nutrient emission reduction targets by 2016;By 2021, the Baltic Sea will be ecologically and environmentally sound. Although the above reduction targets are based on existing knowledge, they are temporary and will be refined and adjusted by HELCOM based on dynamic updates of monitoring data and model results (HELCOM, 2007b).

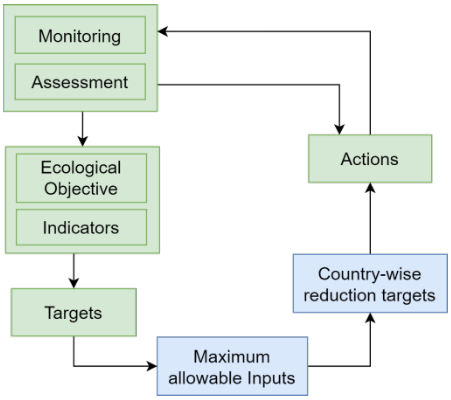

Figure 2.13 Schematic diagram of adaptive management measures

Adaptation management is one of the important working principles of HELCOM. From 2008 to 2013, HELCOM dynamically updated and improved the nutrient emission reduction plan. Its main work includes scientific assessment of the ecological objectives of nutrient; complete the development numerical model and calculate the maximum input of nutrient operation; compile updated and improved data sets from water and atmosphere to Baltic pollutants and normalize the data to eliminate the effects of weather conditions on interannual variations; develop new software to calculate emission reduction targets for each country; revise the allocation principle. In the 2007 Baltic Action Plan, transparency was used as an indicator of good environmental conditions associated with eutrophication to calculate the maximum allowable input of nutrients. In order to improve the reliability of eutrophication assessment, four eutrophication indices including winter DIP concentration, winter DIN concentration, summer chlorophyll concentration and oxygen loss/concentration were added in 2013.At the same time, the target of reducing nitrogen and phosphorus emission was adjusted to 118,134 and 15,177 tons/year respectively, and the corresponding proportion of reducing nitrogen and phosphorus emission was 13% and 41% (HELCOM, 2013).

The European Union attaches great importance to the issue of eutrophication in the offshore waters. Several regional seas conventions contain the contents of mitigating coastal eutrophication. At the same time, a series of EU directives have been formulated to address the issue of eutrophication. For example, the Urban Sewage Treatment Directive was formulated in 1991 to protect the environment from the negative effects of urban and certain industrial wastewater discharges. The Nitrate Directive was adopted in 1991 to prevent agricultural sources from polluting ground and surface water by promoting scientific and rational methods. The Water Framework Directive was adopted in 2000 with the aim of achieving good environmental conditions in all water bodies of EU member states, including seawater within a mile of offshore waters, by 2015; The Marine Strategy Framework Directive, adopted in 2008, aims to achieve and maintain good environmental conditions in European waters by 2020.

With the efforts of various countries along the Baltic Sea, positive results have been achieved in reducing nutrient emissions. In 2008-2010, nitrogen and phosphorus inputs decreased by 9% and 10% respectively from 1997 to 2003 (HELCOM, 2015); In 2015, nitrogen and phosphorus inputs decreased by 12 and 25% respectively from 1997 to 2003. Total input of nitrogen and phosphorus in the Baltic Sea decreased by 20% and 27% respectively compared with 1995.Nitrogen input in the Bothnian Sea, the Gulf of Finland and the Gulf of Bosnia has been significantly reduced since 2003, 2004 and 2006, respectively. For phosphorus input, the Kattegat region has declined significantly since 1995; the Baltic Sea, the Gulf of Bosnia, the Bosnian Sea and the Danish Channel decreased significantly in 1995-2011, 1995-2002, 1995-2002 and 1995-1999, respectively. The reduction of phosphorus input to the Gulf of Finland has been achieved, but phosphorus input in the Gulf of Riga has been increasing up to 2007 and has not recently seen a significant reduction (HELCOM, 2018b). Overall, the Baltic Sea reversed the growth trend in nutrient input earlier than areas such as the Black Sea and Great Barrier Reefs due to proper controls.

HELCOM and the European Union have successfully promoted measures such as systematic monitoring, data sharing, raising public awareness and numerical models covering the entire watershed in the process of eutrophication control in the Baltic Sea, which have well supported the formulation of emission reduction targets and Baltic Action Plans. The Baltic Sea has gained many advanced experiences in eutrophication control, including: (1) strengthening policy formulation and effective implementation of cross-regional and cross-government policies; (2) improving the management of eutrophication. Early monitoring of long time series is very important for identifying and understanding problems, formulating and implementing management policies; (3) Solve easy-to-handle problems first, which can usually lead to significant improvement in environmental conditions, for example, reducing and controlling point source pollution first; (4) Global and regional changes increasingly threaten initial gains, requiring the revision of appropriate management measures; (5) Inclusive governance measures based on stakeholder and cross-sectoral collaboration are important to governance.

With the deepening of eutrophication treatment, the reduction of nutrient emission in the Baltic Sea has entered deep water area and is facing challenges, including: 1) long response period of ecosystem to nutrient emission reduction. As nutrients are stored in sediments, nutrients in ecosystems can exist for decades or even centuries. In particular, the release of phosphorus from sediments will continue for decades after the reduction of emissions. Secondly, phosphorus release in anoxic areas stimulated the increase of nitrogen fixation by cyanobacteria, which counteracted the effect of nutrient emission reduction; 2) Cross-sectoral policy conflicts affect the implementation of emission reduction measures. Substantial progress has been made in reducing nutrient emissions through relatively simple measures. However, further nutrient emission reduction in the Baltic Sea will face higher costs. For example, EU agricultural policy still subsidizes intensive agriculture, which contradicts EU environmental directives and puts great pressure on reducing emissions from agricultural sources. Currently, two-thirds of non-point source nutrient inputs come from agricultural sources, and emission reduction results of agricultural sources have not been significant since 1980. 3) Climate change makes governance more difficult. Even if the nutrient mitigation target is met, it may be counteracted by processes such as increased freshwater runoff, increased nutrient re-mineralization and enhanced stratification resulting from ocean warming, which may also lead to the continued expansion of the hypoxia zone in the Baltic Sea.

2.4.2 Bohai Sea

In China, nutrients are usually controlled and treated as pollutants. At present, there is no special plan or treatment action for Bohai eutrophication. Starting from the 10th five year plan, the main action plans related to the eutrophication control in the Bohai Sea include the Bohai blue sea action plan, the Bohai environmental protection master plan (2008-2020), and the Bohai comprehensive control action plan.

During the 10th Five Year Plan period, in accordance with the overall arrangement of the state's environmental protection work, the local governments of three provinces and one city around the Bohai Sea and the relevant state departments carried out environmental protection work in the Bohai Sea in various aspects in accordance with the "Bohai blue sea action plan", "the Tenth Five Year Plan for the prevention and control of water pollution in the Liao River Basin" and "the Tenth Five Year Plan for the prevention and control of water pollution in the Hai River Basin" approved by the State Council, And achieved certain progress and results. However, although there is no obvious deterioration of water quality in the Bohai Sea, the situation is still not optimistic. From the perspective of pollutant indicators, although most of the water quality indicators meet the class II sea water quality standards, inorganic nitrogen, active phosphate and petroleum are over standard in varying degrees. The area of inorganic nitrogen polluted sea area continued to rise, from 3700 km^2 in 2003 to 6300 km^2 in 2005. Total phosphorus and nitrogen mainly come from agricultural non-point source pollution.

During the 11th Five-Year Plan, the State issued the Overall Plan for the Bohai Sea Environmental Protection (2008-2020), which put forward specific requirements for nutrients to enter the sea and reduce their emissions (Table 2.2), such as total nitrogen to be controlled at 125,000 tons/year and 100,000 tons/year in 2012 and 2020 respectively. Total phosphorus entering the sea in 2012 and 2020 shall be controlled at 9,000 tons/year and 7,000 tons/year respectively. The plan put forward the linkage of non-point source control and prevention, and established the land pollution source control and comprehensive treatment system. Emphasize comprehensive management of secondary watershed and agricultural non-point source control to effectively solve the difficult problem of continuous increase of nitrogen and phosphorus pollutants in the Bohai Sea. The main measures to promote the reduction of nutrient emission include: Firstly, focus on controlling rural non-point sources in offshore land areas. Construction of clean planting, clean breeding and demonstration projects for rural cleanliness to reduce nitrogen and phosphorus pollutants from non-point sources of agriculture and effectively solve pollution problems caused by pesticides, fertilizer application, livestock and poultry breeding, rural domestic sewage and garbage and unreasonable use of straw; Secondly, we will continue to reduce the total discharge of industrial pollution sources. Eliminate production projects that do not conform to the national industrial policies, are backward in technology, are heavily polluted and cannot meet the standards steadily. Strengthen industrial structure adjustment, implement clean production, develop recycling economy and effectively control new industrial point source pollution. Further reduce industrial pollutant discharge in 13 coastal cities of the Bohai Sea. Thirdly, improve the operation efficiency of urban sewage treatment facilities. To comprehensively improve the operation efficiency and treatment level of existing urban sewage treatment plants, improve the coverage of auxiliary pipe network of sewage treatment plants, and improve the auxiliary pipe network of existing and existing sewage treatment plants. Great attention is paid to sludge treatment and disposal and resource utilization.

Table 2.2 Total nutrient control and abatement targets

Indicator	2005	2012	2020
Ammonia discharge to the sea (10,000 tons/year)	11	9	6
Total nitrogen discharge to the sea (10,000 tons/year)	14.95	12.5	10
Total phosphorus discharge to the sea (10,000 tons/year)	1.05	0.9	0.7
Ammonia nitrogen reduction in 13 cities (10,000	6	Decrease by ≥	Total discharge up to

tons/year)		10%	limit
Total nitrogen reduction in 13 cities (10,000 tons/year)	7.8	Decrease by ≥ 10%	Total discharge up to limit
Total phosphorus reduction in 13 cities (10,000 tons/year)	0.54	Decrease by ≥ 10%	Total discharge up to limit

Note: Reference is made to the General Plan for Environmental Protection in the Bohai Sea (2008-2020).

In 2018, the Ministry of Ecology, the State Development and Reform Commission and the Ministry of Natural Resources jointly issued the Bohai Sea Comprehensive Management Struggle Action Plan, aiming at ensuring that the Bohai Sea ecological environment will not deteriorate anymore and that three-year comprehensive management will be effective through scientific planning and multiple measures. One of the key tasks of the action plan is land source pollution control action, among which many measures contribute to alleviating eutrophication in the Bohai Sea, including: 1) pollution control of rivers entering the sea. Strengthen comprehensive management of state-controlled inbound rivers and other inbound rivers inflowing into the Bohai Sea to reduce the amount of pollutants such as total nitrogen inflowing into the sea; 2) Rectification of pollution sources discharging directly to the sea. Enhance the capacity of sewage (waste) water treatment, ensure the operation effectiveness and stability of sewage (waste) water treatment facilities, and urge industrial direct discharge of pollution sources to meet the discharge standards comprehensively and stably; 3) Prevention and control of agricultural and rural pollution. Relying on the Action Plan Against the Agricultural and Rural Pollution, provincial governments are taken as key areas to carry out scientific and rational use of pesticide fertilizers, pollution control of livestock and poultry breeding, utilization of agricultural waste as resources, treatment of rural domestic sewage, collection, transfer and disposal of rural domestic waste, etc. 4) Prevention and control of urban domestic pollution. Relying on the Action Plan for Abatement of Urban Black and Odour Water Bodies, the coastal cities will be taken as the key areas to speed up the completion of short boards of urban environmental infrastructure construction, implement the requirements of sponge city construction, effectively reduce non-point source pollution in cities, carry out the treatment of urban sewage with "improving quality and efficiency" and the collection and treatment of rainwater at the beginning of the city; (5) Total control of discharge of water pollutants. To implement total nitrogen control, coastal cities shall promote the treatment of fixed pollution sources in key nitrogen-related industries in accordance with the requirements of prevention and control of total nitrogen pollution from fixed pollution sources.

2.5 Recommendations on Eutrophication Prevention and Control

(I) Formulating the national special program for comprehensive prevention and control of eutrophication

To formulate a special national action plan for comprehensive prevention and control of eutrophication, formulate targets and action plans for nitrogen and phosphorus reduction at the national level, and establish a long-term mechanism for eutrophication control and prevention. At the same time, in combination with other national ecological environment protection and treatment projects, increase the synergy between different special actions.

(II) Strengthen the supporting role of scientific research and business monitoring

Through strengthening scientific research (especially understanding nutrients sources, migration and transformation processes of different forms nutrients, biogeochemical cycle, the effects of climate change on eutrophication, hypoxia, etc.), it can provide scientific basis for formulating comprehensive eutrophication control policy. Provide basic support for eutrophication control measures and effectiveness evaluation by carrying out long-term business monitoring.

(III) Promoting synergies among departments

To legislate laws and regulations to regulate the discharge of nutrients and discuss the integration of comprehensive eutrophication treatment policy into policies of various departments, coordinate relevant departments such as agriculture, industry, urban construction and coastal local governments in fulfilling their responsibilities, and promote cross-sectoral, multi-disciplinary and multi-party participation in the reduction of nitrogen and phosphorus pollution loads. Take areas with severe nutrient pollution as pilots to carry out comprehensive management of nutrient, and gradually extend it to the entire Bohai Sea.

3 Ecological Environmental Problems and Policies of Marine Plastic Debris and Microplastics

3.1 Overview of marine plastic debris and microplastics

3.1.1 The origin of the problem of marine plastic debris and microplastics

Since plastics were widely produced and utilized in the 1950s, they have made an inestimable contribution to the development of human society, affecting all aspects of modern life. As the four modern basic materials alongside steel, cement and wood, plastics play an increasingly important role in advanced manufacturing, aerospace, deep-sea exploration, and medical equipment. However, of the more than 9 billion tons of plastic products produced globally, more than half (>5.3 billion tons) are discarded as garbage. At this stage, the annual global plastic production is nearly 360 million tons, but less than 10% is recycled, and a large amount of plastic waste is continuously produced. Due to its relatively difficulty to degrade in the natural environment, it has a significant impact on the global ecological environment. Plastic debris has spread all over the earth, such as in Easter Island at a distance of 3,600 kilometers from the land, the North and South pole regions and glaciers (Obbard et al., 2014; Peeken et al., 2018; La Daana et al., 2020), the Himalayas, the seabed with the depth of 2000 meter, and at the bottom of the Mariana trench (Van Cauwenberghe et al., 2013; Woodall et al., 2014; Peng et al., 2020). Plastic waste entering the ocean will not only entangle or be ingested by organisms, but also be a carrier of persistent organic pollutants and harmful microorganisms in the environment. This makes it a potential risk to marine ecosystems and even human health. As a result, it draws increasing global attentions.

Marine plastic pollution has become a problem almost along with the large-scale production and application of plastics. As early as 1972, American scientists reported plastic pollution in the coastal waters of New England and the Sargasso Sea (Carpenter and Smith, 1972). In 1996, the Great Pacific Garbage Patch was discovered and caused a certain degree of attentions from the international community. In 2004, British scholars discovered the existence of plastics in their accumulated seawater samples for many years, and most of the plastic particles in the samples need to be observed with a microscope. Therefore, plastics of this type of size are defined as "microplastics". In 2008, international experts in related fields organized a seminar and they defined the upper size limit of microplastics as 5 mm. Plastics of this size may be more easily eaten by marine organisms, but they cannot cause entanglement hazards similar to those caused by large plastic debris (Arthur et al., 2008).

After 2010, marine plastics and microplastics pollution began to raise widespread attention from the international community, and a series of research and control measures were rapidly carried out. In 2010, the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) held an international workshop on micro-plastic particles as a vector in transporting persistent, biocummulating and toxic substances in the oceans in Paris, marking the official start of marine microplastics research prelude.

Since 2011, the United Nations Environment Programme (UNEP) has included marine plastic debris in the three major environmental themes of the "*UNEP Year book 2011*", and began to pay attention to the pollution of marine plastic debris, especially marine microplastics. Since 2014, UNEP has proposed that marine plastic and microplastic pollution need urgent attention, research and response in five consecutive United Nations Environment Assembly sessions. At the G20 summit in June 2019, countries agreed on the "Blue Ocean Vision" in the "*Osaka Declaration*", promising to achieve zero discharge of marine plastic debris by 2050. In addition, the "*United Nations Decade for Promoting the Sustainable Development of Marine Science*" (2021-2030) has made marine plastic pollution one of the priority issues to be solved.

3.1.2 Characteristics of marine plastic debris and microplastics

The characteristics of marine plastic debris and microplastics can be divided into two parts: physical characteristics and chemical characteristics. The physical characteristics include its shape, size, density, color and other information, while the chemical characteristics include its chemical composition, additives, and so on. Although there are still some controversies, with the deepening of research, the current scientific community has basically reached a consensus on the characterization of plastic debris, especially microplastics. In 2019, GESAMP released

“Guidelines for the monitoring and assessment of plastic litter in the ocean“, which defined the characteristics of plastic debris in detail.

According to the size, plastic debris can be divided into the following categories:

Table 3.1 Plastics debris in the environment are classified by size

Term	Size
Megaplastic	> 1 m
Macroplastic	> 25 mm
Mesoplastic	5-25 mm
Microplastic	< 5 mm
Nanoplastic	< 100 nm

The color and shape of marine plastic debris are subjectively judged by people. The colors of microplastics are diverse, and the shapes often included line (fibre, filament, strand), fragment (granule, flake), film (sheet), foam (EPS, PUR), pellet (resin bead, mermaids’ tears), etc.

Chemical properties mainly refer to the material of plastic waste, that is, the chemical composition. Most marine plastic debris can be divided into thermoplastic and thermoset plastic. Thermoplastics can be repeatedly heated to soften and cool to harden. Representative materials include: polystyrene (PS), polypropylene (PP), polyethylene (PE), polyamide (PA), polycarbonate (PC), polyvinyl chloride (PVC), etc. Thermosetting materials are irreversible after heating and forming, such as polyurethane (PU), phenolic resin (PF), epoxy resin (EP), etc. Approximately 15% of synthetic compounds are fibers, such as polyester (PES) and acrylic (acrylic). In addition, additives are added to improve the performance of plastics during the production process. Commonly used are flame retardants, ultraviolet stabilizers, antioxidants, plasticizers, and pigments. The materials and properties of different plastics often determine their use, density and other information. For specific common uses and densities of each type of plastic, see Appendix 3.1.

Microplastics are divided into primary and secondary particles. Primary microplastics are industrially produced as such, which pass through sewage treatment plants or directly into the natural environment. Secondary microplastics result from large plastic waste via degradation processes such as UV light and physical abrasion.

3.2 Distribution, source and fate of marine plastic debris and microplastic

3.2.1 Distribution of marine plastic debris and microplastic

Plastic debris in the ocean accounts for 80% of all discarded solid waste (UNEP, 2016). Marine plastic debris and microplastics have been detected in various environments in the global oceans (Figure 3.2). In view of the current prevalence and seriousness of plastic pollution, some scholars call the current period "Plasticene" (Reed et al., 2018).

Eriksen et al. (2014) and Sebille et al. (2015) estimated based on models that there are around 15-51 trillion plastics debris floating in the ocean, weighing about 93-26.8 million tons. The plastics in the ocean are transported and converged in accumulation zones in the subtropical gyres, mainly concentrated in the ocean gyres of the North Atlantic and South Atlantic, North Pacific and South Pacific, and Indian Ocean (Eriksen et al., 2014). Floating plastic garbage forms the famous "Pacific Garbage Patch" in the subtropical circulation of the North Pacific.

It was found that the average size of plastic debris in the ocean tends to be miniaturized, and the quantity of microplastics continues to increase (Barnes et al., 2009). Isobe et al. (2019) studied the long-term changes of the abundance for microplastics in the Pacific Ocean from 1957 to 2066 with a combination of numerical simulation and transoceanic surveys, and concluded that the weight of microplastics near the marine subtropical convergence zone will increase by about two times compared with the current status.

According to EU statistics, without further mitigation actions, the abundance of plastic debris in the ocean will increase to 100-250 million tons by 2025 (Global Environment Outlook 6, UN Environment, 2019).

3.2.2 Sources and pathway of marine plastic debris and microplastics

Marine plastic debris mainly comes from land sources and sea sources (Andrady, 2011; Coe et al., 1997) (Figure 3.3). These plastic wastes may be produced during the entire life cycle of plastics. The GESAMP estimated that land-based plastic debris accounts for 80% of the total marine debris, of which 60%-95% are plastic debris. Among them, the land-based source of plastic waste includes landfills, industrial sewage outlets, sewage treatment plants, coastal recreational area, agricultural plastic sheeting, shipping, and riverine input, atmospheric deposition through runoff and wind (Liffmann and Boogaerts, 1997; Sundt et al., 2014). Sea-based source input includes plastic waste discharged into the sea from activities such as fishing, aquaculture, and shipping (Lebreton et al., 2017). Marine plastic pollution from land-based sources accounts for about 80% (Allsopp et al., 2006), and the remaining 20% of plastic pollution is based on the ocean. Half of the latter comes from fishing boat operations, such as abandoned fishing nets, fishing lines, and boats. Floating plastic debris has increased exponentially in the Pacific Garbage Patch, and at least 46% is fishing nets (Lebreton et al., 2017). Abandoned, lost or otherwise discarded fishing gear (ALDFG) is an important part of marine plastic pollution related to fisheries. It is estimated that every year 29% of fishing lines are lost, 8.6% of trap fishing gears are lost, and 5.7% of fishing nets are lost (Richardson et al., 2019). In the evaluation of fishing nets, it is found that the risk of gillnet loss is the highest, and the risk of seine and middle trawl is the lowest. Gillnets are easily entangled with marine life (Huntington, 2016).

Coasts and rivers are important ways for plastic waste to enter the sea. Jambeck et al. (2015) estimated the poorly managed plastic waste imported into the ocean by the population within 50 kilometers of the coast of 192 countries for the first time, and estimated that the global flux of plastic waste into the sea in 2010 was 4.8-12.7 million tons. Lebreton et al. (2017) further established a model based on the above research results to estimate the flux of plastic waste discharged from rivers around the world. They believed that there were about 1.15~2.41 million tons of plastic waste from rivers into the ocean every year. Based on the models they built, in their following research and related websites continue to update and revise the data of global river plastic flux into the sea. Lebreton et al. (2018) estimated the plastic in the Great Pacific Garbage Patch. It is estimated that at least 0.79 million metric tons (0.45 - 1.29 million tons) of marine plastic would float in an area of 1.6 million square kilometers.

These studies were mostly based on model methods, and there is still a lack of sufficient field scientific observation data correction, and the results obtained remains controversial. In 2014, Chinese scientists carried out preliminary research on it, and further estimated the amount of the plastic waste into the sea in China. By establishing a material flow model based on a large amount of measured detailed data to estimate the amount of plastic waste into the sea in China, the result was far lower than the previous estimation by Jambeck et al. (2015) (Bai et al. 2018). Zhao et al. (2019) used in situ data to estimate the flux of microplastics in the Yangtze River Estuary into the sea, and estimated that the annual plastic waste transported into the sea by the Yangtze River was much lower than the 333,000 tons estimated by Lebreton et al. (2017). Mai et al. (2019) calculated the Pearl River estuary's eight outlets in each season based on the field measured data and established a model using HDI index to estimate the flux of plastic waste into the sea from global rivers. They found that the abundance of microplastics in the Pearl River is at a moderate level among the global rivers (Mai et al., 2020), which proves the overestimation of China's plastic waste into the sea in the early studies of foreign scholars. Meijer et al. (2021) studied the source and sink of plastics through field measurement and modeling. The model showed that more than 1000 rivers account for 80% of global riverine plastic emissions into the ocean, and the pollution of urban small rivers was the most serious. In this research, at the national level, the countries with the largest amount of plastics entering the sea are the Philippines, India, Malaysia and China. Among them, 9% of the total waste plastics enter the sea in Malaysia and 0.6% in China.

In terms of microplastics pollution, primary microplastic is an important source of marine microplastics. Some studies believe that the global average annual plastic waste flux into the sea is 1.5 million tons, and studies have shown that only 2% of virgin microplastics come from microbeads added in cosmetics and personal care products (Boucher and Friot, 2017). There are several ways of loss and release of primary microplastics worldwide: tires abrasion, synthetic textiles, marine coatings, road markings, personal care products, plastic microbeads, and urban dust (see Appendix 3.2). The release of secondary microplastics mainly comes from improper management of plastic waste. Secondary microplastics are broken into fragments due to physical and biochemical effects and enter the marine environment. With the continuous decomposition of large plastics, the content of secondary microplastics will gradually increase.

3.2.3 Fate of marine plastic debris and microplastic

From 1950 to 2019, global plastic production continued to grow rapidly (Figure 3.4). Since the start of large-scale production in 1950s, it was estimated that 8300 million metric tons (Mt) as of virgin plastics have been produced to 2015. As of 2015, approximately 6300 Mt of plastic waste had been generated, around 9% of which had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment (Geyer et al., 2017). Today, the annual output of plastics has exceeded 300 million tons and is expected to exceed 1.5 billion tons by 2050 (Ryan, 2015).If current production and waste management trends continue, roughly 12,000 Mt of plastic waste will be in landfills or in the natural environment by 2050 (Geyer et al., 2017). The recent research shows that in the absence of any policy measures, the amount of improperly managed plastic waste will increase from 91 million tons in 2016 to 239 million tons in 2040; the amount of plastic waste generated in the next 20 years will double. The amount of plastic waste leaking into the ocean will increase nearly three times, and the total amount of plastic debris in the ocean will increase more than four times (The Pew Charitable Trusts, 2020, Figure 3.1).

The fate of marine plastic debris and microplastic is still undergoing research. Plastic debris will be subjected to different forces in the marine environment and degrade at different rates. Large plastic debris is broken into small plastic fragments under the forces of water current, wind, and light. The degradation rate of microplastics is affected by compositions and environmental conditions, ranging from several years to hundreds of years. There may be a large amount of plastic debris remaining in the ocean, which is difficult to degrade. Marine plastic debris may float or sink in the water column, and eventually accumulate in the deep sea or tidal flat (Geyer et al., 2017; Woodall et al., 2014), and may occur in the food chain (Seltenrich, 2015).

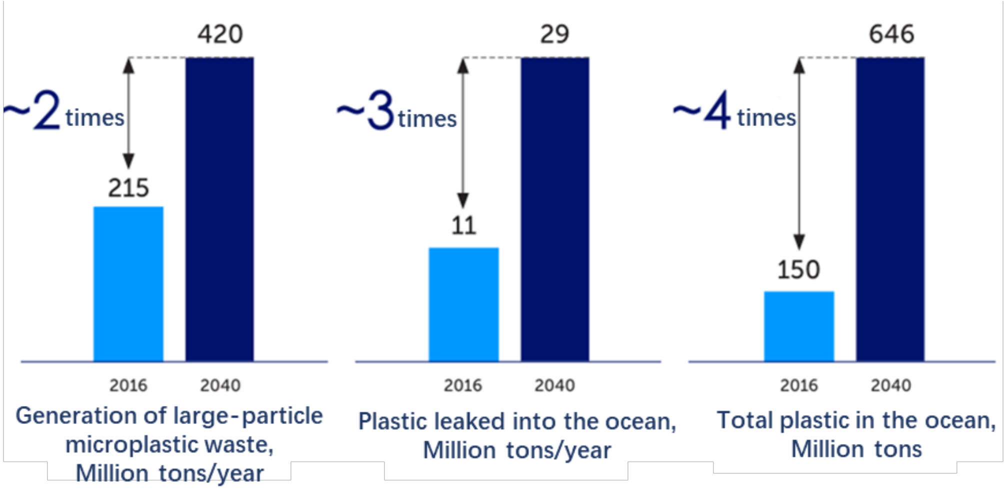

Figure 3.1 The amount of plastic waste entering the sea under the scenario of no measures (The Pew Charitable Trusts, 2020)

3.3 Current measures to reduce marine plastic debris and microplastics

The primary reason of marine plastic pollution is the low level of solid waste management caused by insufficient solid waste disposal infrastructure, deficient management system and lack of corresponding management policies, laws and regulations. In order to reduce the generation of marine debris, it is necessary to ensure that no solid waste leaks into the environment during the harmless treatment process of solid waste generation, collection, transfer, incineration, sanitary landfill, and etc., and to eliminate improper disposal methods such as open landfill. Through the implementation of "garbage classification" and other policies, make sure more recyclable waste plastic into the solid waste treatment system and be recycled. Building a "plastic circular economy" is also an effective way to prevent and control plastic waste from entering the sea at the source.

3.3.1 International actions to address marine plastic debris and microplastics

Back in the middle of the 20th century, the marine environmental problems caused by marine debris have attracted international attentions. Legal conventions related to marine waste management have been implemented as early as the 1950s, such as *the Convention of the International Maritime Organization* (1948). Others include *the London Convention* (1972), *the International Convention for the Prevention of Pollution from Ships* (1973), *the United Nations Convention on the Law of the Sea* (1982), *the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal* (1989), *the United Nations Convention on Biological Diversity* (1992), *FAO's Code of Conduct for Responsible Fisheries* (1995), *UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities* (GPA, 1995), *1996 Protocol* (1996), *Stockholm Convention on Persistent Organic Pollutants* (2001), and *Strategic Guidelines for International Chemicals Management* (SAICM, 2006). The pollution of marine debris, especially marine plastics debris, was highly concerned. In May 2019, *Amendment to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal* was endorsed, several new categories of waste plastics are added to regulate their cross-border transportation and harmless treatment.

3.3.2 Governance addressing marine plastic debris in EU and China

3.3.2.1 EU

The European Union (EU) is the first organization concerned about marine plastic pollution. In recent years, the EU has issued a series of plastic pollution prevention and control policies. In 2015, the European Commission put forward the circular economy action plan (CEAP) and then adopted the new CEAP in 2020. The CEAP aims to promote the transition from linear economy to circular economy in Europe and realize the reuse of wastes. Plastics are listed as priority materials under the circular economy. The plan proposes 54 actions to achieve a "closed loop" in the product life cycle through sustainable consumption, production and sound waste management, including greater recycling and reuse, and the establishment of a market for secondary raw materials. In 2018, the European Union issued the *Circular Economy Package*, including the plastic strategy, chemical waste management, port receiving waste management, key raw material management policies and the monitoring system of circular economy progress. In terms of market products, it is required to cover the whole life cycle of products, implement the *3R* (reuse, repair and remanufacturing) *principle*, and ensure the long-term and multiple use of resources in the economic chain; establish extended producer responsibility system to make sustainable products the mainstream. In the *plastic strategy*, the plan defines four priority areas: improving the quality of the plastic recycling and economic efficiency, reducing the amount of plastic waste and randomly discarded plastic waste, promoting investment and innovation under the circular economy, leading the global action, proposing to establish a closed-loop recycling system, reducing the environmental impact of plastic waste. We should reduce the cross-border transfer of original plastics and plastic waste, improve the treatment facilities and recycling process of plastic waste, adopt the extended producer responsibility system or plastic tax to reduce the use of plastics, and establish a closed-loop plastic recycling system. The plan requires that all plastic packages on the EU market can be reused or recycled by 2030. Meanwhile, rubber tire friction dust, textile and paint are listed as plastics to be treated, which are important microplastic sources. Overall, the strategy aims to tackle plastic pollution at its sources such as avoiding leakage of plastics to the environment, reducing the emission of microplastics from products, litter from single-use plastic products, fishing activities and aquaculture. This will help to reduce the amount of plastic waste ending up in the seas and coasts.

At the same time, the EU has adopted a series of goals: 10 million tons of recycled plastics will be used in new products by 2025, the recycling rate of plastic packaging waste will reach 55% by 2030, and plastic beverage bottles will contain at least 30% recycled plastics by 2030.

Specific EU policies focus on seven aspects including 1) Plastic Bags; 2) Single-use plastics; 3) Plastic waste shipments; 4) Packaging waste; 5) Microplastics; 6) Bio-based, biodegradable and compostable plastics; and 7) Global action on plastics. Ultra-thin lightweight plastic bags are easy to tear and difficult to recycle, which is an important object of plastic pollution control. *The Sixth Amendment to the Directive on Packaging and Packaging Waste (Plastic Bags Directive (EU) 2015/720)* requires member states to consume no more than 90 light plastic bags per person per year by the end of 2019 and no more than 40 by the end of 2025. Among them, light plastic bags are defined as plastic bags with a thickness of less than 0.05 mm (plastic bags with a thickness of 0.025 mm were prohibited in China since 2008). In 2019, Directive on single-use plastic products (SUPs) came into force with measures of tackling the 10 single-use plastic items to reduce marine litter from single use plastics. By 2021, it will ban the market circulation of ten kinds of plastic products with substitutes, including disposable plastic tableware (forks, knives, spoons and chopsticks), disposable plastic plates, plastic straws, plastic cotton swabs, plastic balloon sticks, photodegradable plastics and foam polystyrene cups. Second, new standards should be set for the identification of plastics that are not included in the list. For example, the label of wet wipes should indicate the content of plastics and its impact on the environment. Third, the use of extended producer responsibility system, the provisions of plastic waste recycling costs borne by manufacturers. Fourth, the recovery rate of plastic bottles will be increased to 90% by 2029, and the content of recycled plastic in plastic bottles will reach 25% and 30% respectively by 2025 and 2030. At the 14th Conference of the Parties of the Basel Convention in 2019, the decision was taken on the EU-introduced rules on the shipments of plastic waste. These new rules entered into force from 1 January 2021 through *Delegated Regulation (EU) 2020/2174 amending the EU Waste Shipment Regulation*. They ban the export of plastic waste from the EU to non-OECD countries, except for clean plastic waste sent for recycling. Depending on the type (hazardous, non-hazardous or requiring special consideration) and destination (intra-EU, OECD, non-OECD) of plastic waste, different procedures apply to import and export. EU rules (*Packaging Directive (94/62/EC)*) on packaging and packaging waste including design and waste management have been revised and amended several times. The Directive also sets the specific targets of 50 and 55% for recycling of plastic by 2025 and 2030, respectively. On May 31, 2021, the Committee adopted the guidelines on single-use plastic products, as well as the implementation decision on reporting on fishing gear, and plans to take effect the ban on certain disposable plastic products on July 3, 2021. In the process of promoting the policy, although it has caused some social disputes, it is still steadily implemented. In the EU, every year about 145000 tons of microplastics are estimated to be intentionally added to a range of products including fertilisers, plant protection products, cosmetics, household and industrial detergents, cleaning products, paints and products used in the oil and gas industry. the European Commission has started work to restrict the use of microplastics that are intentionally added in products through the Registration, Evaluation, Authorisation and Restriction of Chemicals regulation (REACH). In 2019, European Chemical Agency (ECHA) proposed a wide-ranging restriction on microplastics in products to avoid or reduce their release to the environment. This proposal is expected to prevent the release of 500 000 tonnes of microplastics over 20 years. Additionally, several EU Member States have enacted or proposed national bans on intentional uses of microbeads in cosmetics that are rinsed off after use, where the microplastics are used as abrasive and polishing agents. Regarding unintentional release of microplastics, options were considered including labelling, minimum requirements for product design and durability, methods to assess quantities and pathways of microplastics in the environment, funding for targeted research and innovation. Over alternative plastics e.g. bio-based, biodegradable and compostable plastics, there is currently no EU regulation. The European Commission proposed a policy framework on the sourcing, labelling and use of bio-based plastics, and the use of biodegradable and compostable plastics. Plastic pollution is a global problem that needs efforts worldwide. The EU is trying for a global agreement on plastics that addresses plastic pollution throughout the entire plastics lifecycle, in order to minimise the mismanagement of plastics and prevent plastic wastes from entering the environment.

The *EU Marine Strategy Framework Directive (MSFD,* Directive 2008/56/EC*)* was issued in 2008 to set targets for countries in the region to prevent and control marine pollution. The Commission adopted in 2020 a **report on the first implementation cycle of the MSFD in which** plastic litter is considered as one of the predominant pressures and coordinated monitoring methodologies at national, regional and EU levels are proposed. It is envisioned that the implementation of the MSFD lead to better understanding of the plastic litter impact on wildlife, supporting the development and implementation of the EU plastic strategy and contributing to the CEAP.

The application of EPR in plastics is mentioned in Article 8 of the Waste Framework Directive 2008/98, and is encouraged in the Packaging and Packaging Waste Directive (PPWD, 2006/66/EC). The practical application is mainly reflected in the collection of landfill and incineration tax, prohibition of the disposal of certain products or materials, collection of packaging tax and pay-per-use plans. Different countries levy taxes on plastic bags according to different standards. As early as 1991, Germany passed a law to tax the plastic bags sold by retail stores, then most retail stores charge 5 or 10 cents for each plastic bag. Germany increased the tax on disposable plastic bags in 2016, and the consumption of plastic bags in 2018 decreased by 64% compared with that in 2015. In 1994, Denmark taxed plastic bag manufacturers according to the weight of plastic bags, and allowed retailers to charge for plastic bags. After that, the use of plastic bags in Denmark decreased by 60%. Since 2020, the ban on plastic parts of France Energy Transition for Green Growth has been officially implemented, and France has become the first country in the world to ban the use of disposable plastic tableware. Italy has imposed a ban on plastics since 2011 and imposed a 45-Euro tax on the use of plastics per kilogram since 2021. At present, starch-based biodegradable plastics are the main alternative.

3.3.2.2 China

The prevention and treatment of plastic waste in China has been through a long process (Table 3.2). China is one of the earlier countries to issue "plastic ban order" (*Emergency Notice on Immediately Stopping the Production of Disposable Foam Plastic Tableware*, 2001) and "plastic restriction order" (*Notice of the General Office of the State Council on Restricting the Production, Sales and Use of Plastic Shopping Bags*, 2007).

China has been active in cleaning up the blue ocean. On the one hand, in accordance with the requirements of relevant laws and regulations and international conventions, we have continuously improved the prevention and control mechanism of plastic pollution, actively promoted the management and control of land-based waste, established an environmental supervision system for the whole process of solid waste collection, transportation and disposal, vigorously promoted the waste classification, and improved the recycling rate of plastic products by reducing the use of plastic products. Efforts should be made to reduce marine pollution from the source. On the other hand, we should continue to promote the construction of ecological civilization, and reduce the amount of plastic waste into the sea through the construction of beautiful villages, the implementation of the river head system and the lake head system. China will intensify publicity and education on marine environmental protection, popularize the knowledge of plastic and microplastic pollution prevention and control, effectively raise citizens' awareness of marine environmental protection, and constantly involve more enterprises, social organizations and the general public in marine ecological and environmental protection.

Specifically, in terms of laws and policies, although there is no law to directly control marine garbage in China, the state has formulated a series of regulations, policies and measures for the prevention and control of plastic garbage pollution for a long time, and constantly supplemented and revised them, such as: *Regulations of the People's Republic of China on the Control of Pollution Damage to Marine Environment by Land-based Pollutants* (1990), *Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste* (1995), *Technical Specification for Pollution Control of Waste Plastics Recovery and Recycling* (2007), *Law of the People's Republic of China on Promoting Circular Economy* (2009), *Cleaner Production Promotion Law of the People's Republic of China* (2012), *Environmental Protection Law of the People's Republic of China* (2014), *Law of the People's Republic of China on Marine Environmental Protection* (revised in 2017), *Law of the People's Republic of China on the Prevention and Control of Water Pollution* (revised in 2017), *Regulations of the People's Republic of China on the Management of Marine Dumping* (revised in 2017), *Implementation Plan for Banning the Import and Export of Solid Waste* (2017), etc. The regulations and regulations on solid waste management such as the catalogue of imported waste management have been revised and improved for many times. In recent years, the state has also successively issued environmental protection policies such as *The Action Plan for Prevention and Treatment of Water Pollution* (2015), *The Action Plan for Prevention and Treatment of Soil Pollution* (2016), River Chief System (2016). Some coastal cities have also carried out the pilot work of "Bay Chief System" (2017) to prevent garbage from directly entering the river or randomly stacking at the edge of the water body, and strengthen the garbage treatment of the water body and its shoreline. Timely remove the garbage and floating objects in the water body and properly handle them. All these have played a positive role in the reduction of plastic waste and the control of plastic waste into the sea. Since the promulgation of the "River Chief System", various cities have actively promoted the implementation of this policy. The relevant financial support, implementation plans, leading groups, governance measures and work reports are recorded in detail on a number of government open websites of provincial, district, county and township government affairs. Taking Fujian Province as an example, during the 13th Five-Year Plan period, 87 urban polluted odorous water bodies, 257 small watersheds and 10059 sewage outlets were renovated, provincial river and lake health assessment standards were formulated, and the blue book on river and lake health was issued to assess 179 rivers and 21 large reservoirs in the Province, of which the river basin area is more than 2 million square kilometers, The healthy rates of rivers and reservoirs are 88.9% and 90%, respectively. In the past two years, more scholars have studied the reasonable assessment methods for water bodies under this system, as well as the advantages and disadvantages of the policy.

On December, 2016, General Secretary Xi Jinping made an important directive on the "vigorously promote garbage classification system" at the 14th meeting of the central financial and economic leading group, calling for Beijing, Shanghai and other cities to "keep pace with the international level and take the lead in establishing a compulsory classification system for city garbage" to set an example for the whole country. In 2017, the *Report of the 19th National Congress of the Communist Party of China* clearly put forward that solid waste and garbage disposal should be included.

In 2018, the Ministry of Ecological Environment adopted the action plan for 2018-2020 on comprehensively implementing the implementation plan for the reform of solid waste import management system by banning the entry of foreign waste, which effectively controlled an important source of marine plastic debris in China. At the same time, since 2018, the Ministry of ecological environment has continuously carried out actions such as the *Waste Removal Action of the Yangtze River Economic Belt* and *the Action Plan for Comprehensive Treatment of the Bohai Sea*, and carried out comprehensive treatment of the garbage in the rivers and coastal waters of the Yangtze River and the Bohai Sea, so as to reduce the plastic garbage into the sea from the source. In the same year, *the Action plan for Tackling Key Problems of Agricultural and Rural Pollution Control* was issued to strengthen the prevention and control of rural production and domestic waste pollution, and pilot the extended producer responsibility system of "who produces, who recycles". It is required that by 2020, the national agricultural film recovery rate will reach 80%, basically realizing the full coverage of rural domestic waste disposal system.

In September 2015, the Ministry of Transport issued the "*Implementation Plan of Special Action on Pollution Prevention and Control Between Ships and Ports (2015-2020)*", which requires that the transfer and disposal facilities of domestic waste and other pollutants between ships and ports and between port cities be well connected, so as to improve the receiving and disposal capacity. In March 2018, the MSA issued a notice on the implementation of *International Convention for the Prevention of Pollution from Ships the 2016 Amendment V*, prohibiting ships from discharging harmful wastes such as plastics into the sea. In 2019, ten ministries and commissions, including the Ministry of Agriculture and Rural Areas, issued the "*Opinions on Promoting the Green Development of Aquaculture Industry*", proposing to dismantle the illegal cage purse seine aquaculture facilities in accordance with the law. It is proposed to strengthen the treatment of aquaculture waste, promote new material environmental protection floating ball, and strive to control white pollution. These policies and regulations effectively strengthen the control of marine plastic debris in China. Strengthen the recovery and standardize the recovery and disposal of waste fishing nets and fishing gear.

The *Implementation Plan of Extended Producer Responsibility System* issued by China in 2016 is a system innovation exploration based on the national conditions and the current development stage. It requires the construction of credit collection system of extended producer responsibility, the formulation of evaluation management methods and policy guidelines, the increase of scientific research support, and the acceleration of the establishment of renewable products and raw materials promotion. In 2017, the leading action for circular development was issued, and it was proposed that the output rate of main resources will increase by 15% in 2020 compared with 2015, and the recycling utilization rate of main wastes will reach about 54.6%.

In January 2019, the General Office of the State Council issued *the Work Plan for the Pilot Project of "waste-free city" Construction*. On April 30, 2019, the Ministry of Ecological Environment announced the construction pilot of 11 waste-free cities including Shenzhen.

Furthermore, the Ministry of Housing and Urban Rural Development has actively promoted the promotion of urban waste and formulated a list of 46 key cities in China, including Beijing. Since 2019, domestic waste classification work will be started in cities at prefecture level and above in China. Meanwhile, efforts will be made to strengthen the treatment of rural domestic waste, so as to achieve the treatment of about 90% of rural domestic waste. On June 3, 2019, General Secretary Xi Jinping made important instructions on garbage sorting work, emphasizing "cultivating good habits of garbage sorting, making efforts to improve the living environment, and contributing to the sustainable development of green development". On July 1, 2019, Shanghai municipal domestic waste management regulations were formally implemented, and the compulsory domestic waste classification action was first implemented. In the process of implementation, the law enforcement inspection team conducted "full coverage" covert visits to 16 districts in this city. According to the data of Shanghai Municipal Bureau of Green City Appearance, by November 2020, the domestic waste classification system has been basically completed, and zero landfill of primary domestic waste is basically realized in 2020. The total amount of dry waste incineration and wet waste resource utilization has increased from 10250 tons per day in 2018 to 26095 tons per day in 2020. So far, the overall effect has far exceeded expectations.

In September 2019, the 10th meeting of the communist party of China comprehensively deepen reform commission particularly put forward new requirements to plastic pollution, coping with plastic pollution, firmly establish a new development concept, orderly prohibited or restricted from part of the plastic products production, sale and use, actively promote recycled recycling biodegradable alternative products, increase the supply of green products, standardize the recycling and utilization of plastic waste, establish and improve the management system of all links, and effectively control plastic pollution in an orderly manner. It also shows the country's determination to tackle plastic pollution.

On October 30, 2019, the National Development and Reform Commission officially issued *Industrial Structure Adjustment Guidance Catalogue (2019 edition)*, it is clear that the daily chemical products containing plastic microbeads will be banned from production by December 31, 2020, and banned from sale by December 31, 2022.

On January 19, 2020, the National Development and Reform Commission and Ministry of Ecology and Environment issued the *Opinions on Further Strengthening Plastic Pollution Treatment*, prohibited or restricted from part of the plastic products production, sale and use, application alternatives and patterns (such as plastic products, biodegradable plastic bags and biodegradable plastic sheeting, etc.), to reduce the plastic products from the source. The guideline stipulates that China will take the lead in banning or restricting the production, sale and use of some plastic products in some regions and areas by 2020. China will strengthen the control of plastic pollution in accordance with the idea of "banning one batch, replacing one batch and standardizing one batch". Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Guangxi, among the 11 coastal provinces, autonomous regions and municipalities directly under the central government, have issued provincial-level implementation plans, while Tianjin, Shanghai and Hainan have solicited public opinions on the plans. In July 2020, the National Development and Reform Commission, Ministry of Ecology and Environment and so on nine ministries jointly issued *Notice about Promoting Plastic Pollution Control Work*, which specified the period of prohibition. A new plastic pollution clean-up campaign across China's provinces, municipalities and ministries has begun, which will greatly accelerate the reduction of plastic waste in the country.

In March 2021, the Fourth Session of the 13th National People's Congress voted to adopt the *14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of Vision Goals for 2035* (the "14th Five-Year Plan"), adhere to land and sea co-ordination, harmony between people and sea, win-win cooperation, and continue to consolidate and enhance the protection of the marine ecological environment and safeguard the sustainability of the ecological environment. The "14th Five-Year Plan" will control pollutants into the sea from land more strictly and more widely, and the implementation and assessment of plastic waste into the sea will inevitably be more precise.

In addition to policies, China has actively participated in international intergovernmental organizations, bilateral and multilateral activities to prevent and control marine plastic debris. China joined two UN regional sea action plans including the Coordinating Body on the Seas of East Asia (COBSEA) and the Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific Region (NOWPAP), actively promote and sign under the framework of TEMM trilateral Marine garbage cooperation, the East Asia Summit declaration on combating plastic waste in the ocean, ASEAN+3 of the Association of Southeast Asian Nations Marine Waste Cooperation Initiative, *China-Canada Joint Statement on Dealing with Marine Waste and Plastic*, etc. It is expected to effectively promote regional marine environmental protection through exchanges and cooperation in academic research, capacity building, information sharing and public participation.

With the help of these policies, the recycling rate of waste plastics in China has increased in the past few years and is at a high level in the global recycling and treatment of waste plastics. The whole life cycle of waste plastic products in China consists of the stages of raw material extraction, processing and forming, storage and circulation, use, disposal and recycling. In the global trade of waste plastics import and export, China has been playing the role of importer and recycler of waste plastics for a long time.

After China's ban on the import of waste plastics, EU exports of waste plastics dropped by 39% in 2018 compared with that in 2016 (PlasticEurope, 2019), some southeast asian countries adjusted their plastic import policies mainly because of China's ban on the import of waste plastics (Liang et al., 2020), mainly due to China's ban.

China is gradually promoting the application of degradable plastics, setting standards for the production of disposable degradable plastic bags, and promoting the development of the degradable plastics industry. In response to the problems in local work, the state is working on a unified standard for degradable plastics, formulating an unified label for degradable plastics, and promoting the promotion and application of sustainable plastics in all walks of life.

In recent years, China has also gradually improved the plastic additive standards and industry guidelines. Plastic waste in the ocean may release toxic chemicals, of which plastic additives are a major factor. Laws and standards related to plastic additives have been promulgated at home and abroad. In 2012, the United States Food and Drug Administration (FDA) has banned the use of BPA (Bisphenol A) in polycarbonate used in baby bottles. The European Union since the 1970s legislation for food contact plastic material additives, released after each instruction, asked the unified national standards. *China's National Standard for Food Safety - General Safety Requirements for Contact Materials and Products of Food (GB 4806.1-2016)* and other 53 food safety standards were issued by China's National Health and Family Planning Commission and China Food and Drug Administration in 2016, which formed a system together with the previously released hygienic standards for the production of contact materials and products of food and product migration experiments. The standards restrict the plastic additive DEHP, require that materials or products not be used in contact with some foods, and also restrict the use of plastic resins. In 2017, the Expert Committee of Food Contact Materials of China National Food Industry Association issued *the Industry Guide for Responsibility and Compliance Statement of Plastic Food Contact Materials Supply Chain*. More information of China’s main plastic-related policies in appendix 3.3.

3.3.3 Challenges of prevention and control of marine plastic debris

Although the international community has paid great attention to marine plastic pollution, and has formulated and implemented many laws and regulations, policy measures and specific action plans, there are still the following challenges in the treatment of marine plastic debris and microplastic pollution.

1) Internationally, there is no legally binding joint action to deal with and reduce marine plastic debris. And the goal of reducing the amount of marine plastic debris has not been implemented. Besides, the policy formulation and implementation progress of marine plastic pollution prevention and control in various countries are different, which means the lack of effective international supervision.

2) Different countries have different policies on environmental protection, industrial development and international trade. As a result, some international conventions and agreements cannot be strictly implemented, which may lead to the generation of plastic waste and microplastic in the source and the whole life cycle. This may cause the lack of clear regulations on how the cost of plastic recycling and treatment should be borne by producers or polluters.

3) There are still many deficiencies in the current laws and regulations. Firstly, the relevant provisions are too abstract, mostly in principle such as the lack of application of economic means. Secondly, the relevant laws and regulations on the prevention and control of plastic pollution are jointly issued by various departments resulting in the unclearness of the responsibility provisions, which makes it difficult to implement the regulatory responsibility. Thirdly, due to the insufficient evaluation of the supply and demand relationship in the plastic market and weak law enforcement, some policies were set repeatedly in the past. Some of the new policies have vague regulations on

degradable plastics and disposable plastic products and there are different interpretations of the policies in different regions, resulting in gaps in management standards and levels. The European Union has issued many policies to deal with the pollution of marine plastic debris. The report on the pollution of marine plastic debris is issued every year, which makes the pollution control of marine plastic debris more targeted. In China, there is still a blank in the special laws and regulations on the pollution of marine plastic debris.

4) The recycling and classification system of plastic debris in marine fishery, water transportation, coastal and underdeveloped areas is not well-developed. The existing marine plastic debris collection and treatment technology has poor treatment effect. Besides, the collection and recovery needs robust infrastructure and huge investment, which has not received the positive response from various countries. We also lack low-cost and efficient plastic pollution treatment technology as well as relevant investigation data and systematic management of marine plastic waste pollution sources.

5) The recycling system of waste plastics is not well-developed. The main reasons are as follows. Firstly, the source of raw materials, the supply of recyclable raw materials and the recycling rate of plastics are poor. Secondly, the raw materials need to be classified more carefully. Technological difficulties and high cost in separating mixed plastic materials result in great recovery difficulties. Thirdly, most of the recycled waste plastics are recycled into secondary plastics with low value with low recycling profit. Lastly, due to safety and quality control reasons, part of plastic wastes cannot be recycled, therefore, the range of secondary use of recycled plastics is narrow.

6) There are widespread global conflicts in the management of plastic waste because of the misunderstandings about the nature of degradable plastics still exist, and the lack of scientific assessment of the environmental impact. Biodegradable plastic bags, which are made at a higher cost, are still treated by incineration in current situation, which will produce more carbon emissions than ordinary fossil-based plastic bags. In the case of not speeding up the construction of a complete plastic waste recycling system, promoting the use of degradable plastics is in contradiction with the current situation and trend of harmless treatment of garbage through incineration.

7) Part of the public is lack of scientific understanding of the pollution of marine plastics and microplastics. The awareness and publicity of the prevention and control of plastic pollution and recycling in the society are not enough, and a healthy plastic environmental protection consumption behavior has not been fully formed.

3.4 Suggestions on pollution control of marine plastic debris and microplastics

In order to deal with the pollution of marine plastics, the whole chain input mode of marine plastics and microplastics should be established, which is "land-based production, production and processing, consumption and use, environmental migration and entering the ocean". We put forward the management framework of marine plastics and microplastics, and formulate the corresponding countermeasures for the reduction of marine plastic debris and microplastics. We are supposed to improve the capacity of waste management and treatment, enhance the technology of waste cleaning and interception, promote the circular economy, improve the laws and regulations, increase scientific research, and improve the public awareness and participation in environmental protection.

1. Further strengthen the source control of marine plastic and microplastic pollution, improve waste management and disposal capacity

Through strengthening innovation, researching, developing and promoting new technologies, minimize the sources of plastic waste, and make it easier to create new value for plastic recycling and reuse. Carry out harmless treatment and disposal of high-level domestic waste sources, select and share excellent cases of domestic waste source treatment from cities to towns. Enhance the infrastructure construction of waste collection and management, especially in the underdeveloped areas with the greatest demand.

We suggest to formulate an action plan for the prevention and control of marine debris and microplastic pollution at the national level. Research and formulate various ways and measures to prevent and control plastic waste into the sea, focusing on the pollution control of plastic waste input from rivers, coastal ships and fishery activities. The pollution of the plastic wastes entering the water should be investigated from the source, and the plastic wastes entering the sea and the fishery-related waste directly discharged into the sea should be cleaned up in time. Clean up the large plastic waste in the beach and water body of the estuary that may enter the sea, and further monitor the micro plastic. Improve the collection, cleaning and transportation system of marine plastic debris, strengthen the management and control of plastic waste, build the control and prevention mechanism of marine plastic debris with both source and sink interception, and prevent land-based plastic waste from entering the sea from the source.

2. Further improve the relevant laws and regulations, promote and participate in the International Shanghai foreign plastic and micro plastic response

We suggest that the existing relevant laws and regulations of China should be revised, supplemented and improved to make the control of marine plastic and microplastics pollution more specific and clearer, especially for the limitation of disposable plastics, the demand and advantages of them should be fully considered and properly controlled. For degradable plastics, it is suggested to be applied to plastic products which are not easy to recycle and easy to enter the ocean.

We suggest that China should formulate relevant environmental protection policies, industrial development policies and international trade policies that are suitable for the international community, and participate in the coordinated initiatives and actions that may involve the prevention and control of marine plastic debris and microplastics in the international community.

3. Promote the recycling level of plastic waste and vigorously develop plastic recycling economy

Carry out comprehensive life cycle management of plastics. In plastic production, extended producer responsibility (EPR) system should be used to refine producer responsibility. Promote source prevention and control, green design, and improve product information disclosure and supervision and evaluation system. Research and develop plastic waste chemical recovery upgrade recycling technology to promote the fine recovery, upgrade and reuse level of plastic waste. Establish a market mechanism to manage the pollution of marine plastics and increase the demand for recyclable materials. In the aspect of recycled plastics industry. We need to build a complete flow direction and supervision system of recycled plastics, and enterprise production chain. Issue flexible tax incentives and subsidies to encourage the application of recycled plastics. To promote the development of plastic recycling economy, we may establish pilot projects of plastic classification recycling, improve the plastic packaging recycling system of various industries, and implement regional large-scale recycling of typical types of waste plastics.

4. Strengthen scientific research on pollution control of marine plastics and microplastics

We suggest to further increase investment in scientific research, study the source and sink processes of marine plastics and microplastics, develop standardized and unified monitoring and analysis methods for marine plastic debris and microplastics, determine the typical marine plastic debris and microplastics fluxes, and carry out hot spot assessment of plastic waste and microplastics. Those measures would provide a scientific basis for the source control and reduction management of marine plastic pollution. At the same time, we suggest to build an international scientific research exchange platform, share the experience of scientific research and management of marine waste and better practice of source control in various countries, increase scientific cooperation among countries, strengthen research capacity-building, and enhance the capacity of countries in the collection, treatment, use and environmental impact assessment of marine waste data.

5. Enhance public awareness and participation in environmental protection

We suggest to establish and improve the public awareness of marine plastic debris pollution by carrying out high-profile governance actions, extensive coverage of new media, active response of large enterprises, and support of government agencies, publicity and education. We suggest to strengthen the popular science education and publicity activities, established a more extensive scientific understanding of the marine plastic debris and microplastic among the people, stimulate the awareness of environmental protection of citizens to change their consumption behavior and consciously form the habit of classification and recycling of plastic waste. Through cooperation with formal organizations and voluntary organizations, the public can widely understand the seriousness and harmfulness of marine pollution, spontaneously participate in the action of marine pollution control, and contribute to the goal of clean ocean.

4 Distributions, sources and trend of mercury pollution in marine environment

Mercury is a heavy metal pollutant that can be transported around the world and pose significant hazards to public health. Mercury pollution has become one of the most important environmental problems in the world. According to the <Global Mercury Assessment> published by the United Nations Environment Programme (UNEP) and the Arctic Monitoring and Assessment Program (AMAP) in 2018, global annual mercury emissions from anthropogenic sources (include re-released mercury) are estimated at about 2220 metric tons the manual and small-scale gold mining industry is the largest anthropogenic mercury emission source (37.7%) globally, followed by the fixed combustion of coal (21%). Other major sources of emissions are non-ferrous metal production (15%) and cement production (11%).

4.1 Sources, migration and transformation of mercury in marine environment

Marine ecosystem plays a key role of "source & sink" in the global land-sea-air biogeochemical cycle of mercury. It can not only receive mercury from land surface runoff (1000-5500 Mg yr-1) and atmospheric dry and wet deposition (5000-6500 Mg yr-1), but also re discharge elemental mercury (4000-5000 Mg yr-1) to the atmosphere through the reduction of mercury existed in marine environment(Amos et al., 2014; Holmes et al., 2010; Soerensen et al., 2010). Since the industrial revolution, human activities have greatly promoted the global circulation of mercury, making the global circulation factor of mercury increase by 3-5 times (Armos et al. 2013), which leads to the concentration level of mercury in the upper ocean (< 1000 m) reaching about 2.5 times before the industrial revolution (Lamborg et al. 2014). This section will summarize the main sources of mercury in the marine environment and its migration and transformation behavior in the marine environment.

4.1.1 Sources of mercury in the marine environment

The mercury and mercury compounds in the ocean come from natural and anthropogenic sources. First of all, they are widely distributed in cinnabar sediments, metal sediments such as lead and zinc, and rocks such as limestone. Nature's activities, such as ocean releases, volcanic activities, and rock weathering, can lead to mercury's natural release. Meanwhile, human's energy production and use of fossil fuels, industrial production processes such as metal smelting, waste disposal and other activities such as waste incineration also result in the emission of human-derived mercury and its derivatives (Defra and Dbeis, 2017). National or continental boundaries do not restrict mercury discharge. When mercury is released into the air, it can travel thousands of miles for long-distance migration through air circulation. Most mercury will eventually enter the aquatic ecosystem in dry precipitation or rainfall and eventually merge into the ocean (Gworek et al., 2016). Under certain conditions, microbes can convert different forms of mercury into methyl mercury, and the latter can store in fish and shellfish (Bindler, 2003; Wang et al., 2004; Mahaffey, 2004; Chen et al., 2012) (Figure 4.1). These contaminated marine fish and shellfish are a significant source of human exposure to mercury (Drevnick et al., 2015).

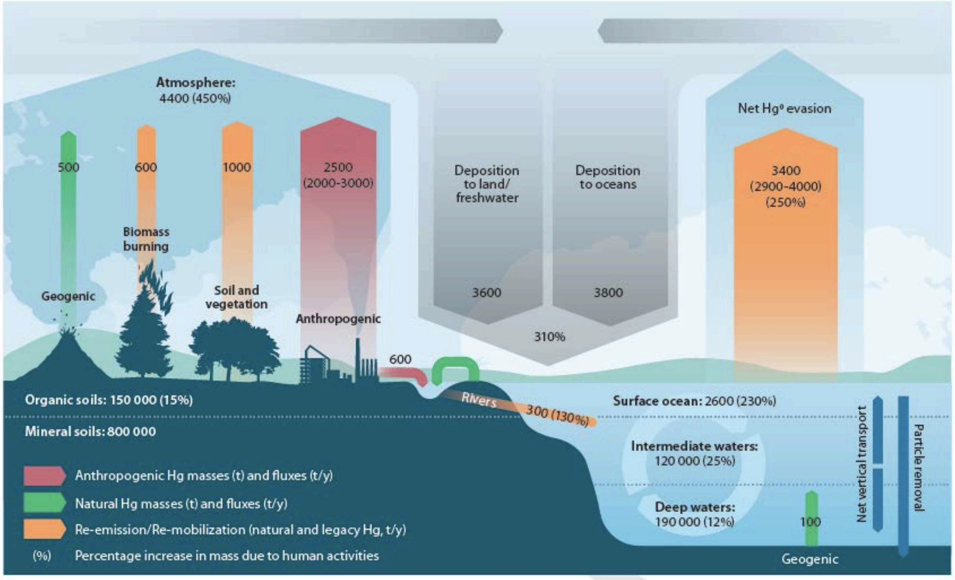

Figure 4.1 Transport of mercury in the environment Source: UNEP (2019)

4.1.2 Migration and transformation of mercury in marine environment

There are a series of complex circulation processes of mercury in offshore area between different environmental media (Figure 4.2), including: 1) the atmosphere of marine boundary layer: photo-reduction of active gaseous mercury and photo-oxidation of gaseous elemental mercury, adsorption of gaseous mercury on particulate matter and desorption of particulate mercury, dry and wet deposition of three forms of mercury from atmosphere to ocean; 2) Coastal: dissolved elemental mercury, divalent mercury and particulate mercury are transported into coastal waters with surface runoff such as rivers; 3) Seawater: photo-reduction of soluble divalent mercury and photo-oxidation of soluble elemental mercury, adsorption of divalent mercury and desorption of particulate mercury at the organic/mineral particle interface, microbial/chemical methylation of inorganic mercury and photochemical demethylation of methyl mercury, volatilization of elemental mercury from seawater to atmosphere, and deposition of particulate mercury from seawater to sediment; 4) Sediment: microbial methylation of inorganic mercury and demethylation of methyl mercury, release of inorganic mercury and methyl mercury from sediment to seawater; 5) Biology: bioaccumulation of methylmercury at low trophic level and biomagnification along food chain. To clarify the source, occurrence, migration and transformation behavior of mercury in offshore environment is of great significance for reasonable assessment of the impact of historical human activities, effective control of mercury environmental pollution and reduction of mercury health risk.

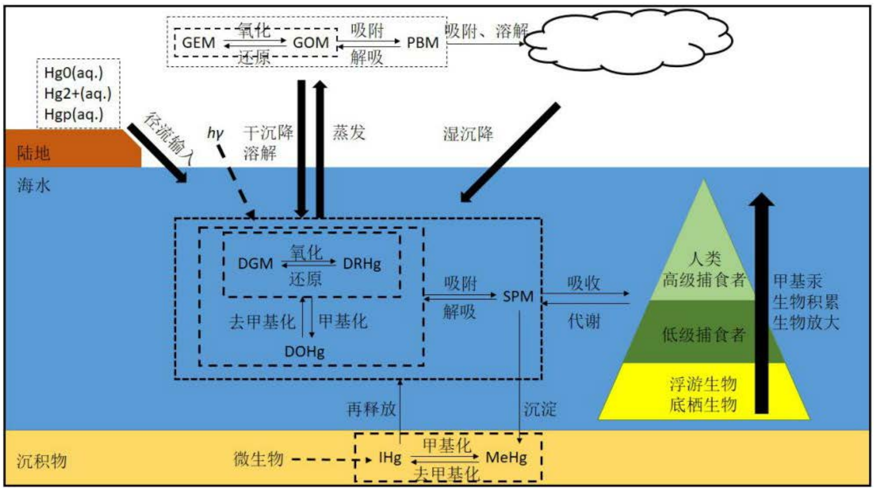

Figure 4.2 Cyclic process of mercury in different media in offshore areas.

GEM: gaseous elemental mercury; GOM: gaseous oxidized mercury; PBM: particulate-bound mercury; DGM: dissolved elemental mercury; DRHg: Dissolved inorganic Hg; DOHg: Dissolved organic Hg; SPM: Suspended particulate mercury.

4.2 Mercury pollution in coastal waters of China

4.2.1 Atmosphere

Mercury in the atmosphere can be divided into three forms: gaseous elemental mercury (GEM), reactive gaseous mercury (GOM) and particulate mercury (PBM). GEM and GOM are collectively called total gaseous mercury (TGM). The source, proportion, residence time and physicochemical processes of the three forms of atmospheric mercury are different, and they can be transformed into each other through oxidation-reduction and adsorption desorption processes, which together constitute a complex environmental process of atmospheric mercury.

In China, the monitoring of mercury in atmospheric environment is mostly seen in scientific research reports, and online monitoring methods are adopted, mainly focusing on the monitoring of background areas and urban / industrial areas. The atmospheric mercury background value in the northern hemisphere is 1.5-1.7 ng/m^3, and the atmospheric mercury background concentration in the southern hemisphere is lower, about 1.3-1.5 ng/m^3. The background level of atmospheric mercury in China's background areas is about 1.58-3.98 ng/m^3, and that in urban areas is 2.7-35 ng/m^3. On the whole, the mercury pollution level in China is at a high level in the world.

At present, there are two main ways to study the atmospheric mercury in near shore area: one is the long-term observation, that is, the morphological study of fixed sampling points carried out in coastal areas and islands; the other is the short-term observation, that is, the morphological study of mobile sampling points carried out with marine scientific research vessels. The two research methods have their own advantages and disadvantages: the former is highly comparable, convenient for instrument maintenance, and easy to achieve. It can usually be monitored for a long time, but it is easily affected by land-based air masses, and cannot fully reflect the characteristics of atmospheric mercury in the whole ocean boundary layer. The latter has significant advantages in reflecting the characteristics of atmospheric mercury in the whole ocean boundary layer, but the unfixed sampling points and short samplers are not conducive to the comparison of data, and the operation and maintenance of the instrument is difficult, which limits the extensive development of such observation. At present, the main results of atmospheric mercury speciation observation in offshore China are summarized in table 4.1.

Table 4.1. Observation results of atmospheric mercury in coastal waters of China

Sample location	Sea area	Type	GEM (ng m^{-3})	GOM (pg m^{-3})	PBM (pg m^{-3})	references
Flower Bird Island	the east China Sea	islands			230 ±150	Duan et al.,2017
Chengshantou	Yellow Sea	seacoast	2.31±0.74			Ci et al.,2011
Ningbo	the east China Sea	seacoast	3.79±1.29			Nguyen et al.,2011
Chengshantou	Yellow Sea	seacoast	2.07±0.91			Holmes et al.,2010
the open sea of the Yellow Sea	Yellow Sea	navigation	2.09±0.80			Holmes et al.,2010
Hengchun	the South China Sea	seacoast	2.15			Shen et al.,2013
Dongsha Islands	the South China Sea	islands	2.14			Soerensen et al., 2010
the open sea of the South China Sea	the South China Sea	navigation	2.01			Soerensen et al., 2010
the open sea of Bohai Sea/ Yellow Se(Spring)	Bohai Sea/ Yellow Sea	navigation	2.03±0.72	2.5±1.7	11.3±18.5	Wang et al., 2016
the open sea of Bohai Sea/Yellow Se(Autumn)	Bohai Sea/ Yellow Sea	navigation	2.09±1.58	4.3±2.5	9.0±9.0	Amos et al., 2013

Xiamen	the east China Sea	seacoast	3.50±1.21	61.05±69.41	174.41±280.63	Xu et al., 2015
Ningbo	the east China Sea	seacoast	3.3±1.4 (TGM)	6.69±4.34	179.87±113.95	Yu et al., 2015
the open sea of the South China Sea	the South China Sea	navigation	2.62			Fu et al., 2010
the open sea of the east China Sea	the east China Sea	navigation	2.32±0.49			Xia et al., 2010

The results show that the concentration of GEM in China's coastal air is higher than the background value of the northern hemisphere (1.5 – 1.7 ng/m^3) (Lindberg, SE.et al. 2007), and the concentration of GEM in coastal areas was higher than that in islands and ships. Compared with the observations of other sea areas in the world, the research results in China are also significantly higher, such as the North Sea (mean range: 1.2-1.5 ng/m^3) (Leermakers et al., 1997), Baltic (Sea) (mean range: 1.39-1.70 ng/m^3) (Wangberg et al., 2001), Mediterranean and Atlantic coasts (mean range: 1.6-1.8 ng/m^3) (Gardfeldt et al., 2003) , etc. As China is a big country of atmospheric mercury emission, the annual average atmospheric mercury emission accounts for about 1/3 of the global average (Fu et al., 2015), while higher GEM concentrations usually reflect anthropogenic emissions, especially fossil fuel combustion, indicating that China's marine areas are affected by anthropogenic emissions of varying degrees. At the same time, the onboard test data show that the GEM concentration in the South China Sea and East China Sea is higher than that in the Yellow Sea and Bohai Sea, which may be related to the strong light intensity and temperature in the low latitude sea area, resulting in the mercury in the surface water more easily being photoreduced or evaporated into the atmosphere.

Although the marine GEM is affected by anthropogenic emissions, the GOM and PBM in the marine atmosphere are affected by the relatively rapid speciation transformation and sedimentation rate, and there is no significant increase (Wang et al., 2016). Because GOM and PBM have relatively fast removal rate from the atmosphere and short migration distance, they are more likely to reflect the characteristics of local and regional mercury pollution The existing observation data show that the concentrations of GOM and PBM monitored on board are not different from other background areas in the northern hemisphere, while the monitoring results in coastal and island areas are higher than those in the background areas (Yu et al., 2015), but the PBM concentration was still lower than the average monitoring concentration (530 pg m^{-3}) (Fu et al., 2015). Most coastal areas in China are economically developed areas, and anthropogenic emissions have a strong impact on the concentrations of GOM and PBM in the local atmosphere. Under the synergistic effect of local anthropogenic emissions and marine atmospheric background air mass, the concentrations of various forms of mercury in the coastal area are in the middle of the background values and the observations of inland cities.

4.2.2 Seawater

Mercury in seawater can be divided into four forms: dissolved elemental mercury (DEM), dissolved reactive inorganic mercury (DRHg), dissolved organic mercury (DOHg) and suspended particulate mercury (SPM), and the total amount is called total mercury (THg). Four forms of mercury can be transformed into each other through oxidation-reduction, adsorption desorption, methylation demethylation and other processes, which together constitute a complex environmental process of mercury in water. Due to the low concentration of mercury in water, it is more difficult to detect various forms of mercury. Due to the limitation of many experimental conditions, there are relatively few studies on mercury concentration and speciation analysis in seawater in China, which are summarized in Table 4.2 below.

Table 4.2 Observation results of mercury concentration in seawater in China

Sample location	Sea area	THg (ng L^{-1})	DEM (pg L^{-1})	DRHg (ng L^{-1})	DOHg (ng L^{-1})	references
North coast of Bohai Sea	Bohai Sea	1.0±0.1				Luo et al., 2012;Faganeli et al., 2003
Jinzhou Bay	Bohai Sea	40.0±430			0.05 - 0.28	Wang et al., 2009; Rolfhus et al.,

						2001
The northern coast of the Yellow Sea	Yellow Sea	1.1±0.2				Faganeli et al., 2003
The open sea of the Yellow Sea	Yellow Sea		27.0±6.8 (Spring) 28.2±9.0 (Autumn)			Ci et al., 2015; Lamborg et al., 2008
The open sea of the Yellow Sea	Yellow Sea	1.69±0.35	63.9±13.7	1.08±0.28		Ci et al., 2011a; Mason et al., 1999
Chengshantou coast station	Yellow Sea	2.69±0.78	34.0±26.1	0.94±0.29		Ci et al., 2011b; Fu et al., 2015
the open sea of the South China	the South China Sea	1.2±0.3	36.5±14.9		0.12±0.05	Fu et al., 2010;Ci et al., 2015

The results have shown that the average concentration of THg in surface seawater in the offshore area of China's marginal sea is about 1.2-1.7 ng L^{-1}. Compared with other sea areas in the world, this value is higher than THg concentration in open sea areas and open sea waters, such as Mediterranean (~0.26 ng L^{-1}) (Kotnik et al., 2007), north Atlantic (~0.48 ng L^{-1}) (Mason & Rolfhus, 1998) and north Pacific (~0.23 ng L^{-1}) (Laurier et al., 2007). However, it is slightly lower than that of the Gulf and seacoast, which are greatly affected by land-based emissions, such as Trieste Bay (0.18-4.9 ng L^{-1}) (Faganeli et al., 2003), Long Island (0.46-3.98 ng L^{-1})(Rolfhus et al., 2001) and Black Sea coast (0.32-2.0 ng L^{-1}) (Lamborg et al., 2008).

From the morphological point of view, the average DEM concentration of surface seawater in China is 27.0 - 63.9 pg L^{-1}, accounting for 3 - 6% of THg. Compared with other sea areas in the world, this value is equivalent to other open sea areas and coastal areas in the world, such as Chesapeake Bay (~ 40 pg L^{-1}) (Mason RP et al., 1999), Mediterranean (11.0 - 38.9 pg L^{-1}) (Lanzillotta et al., 2002), Arctic Ocean (~ 44.2 pg L^{-1}) (Anderson et al., 2008), slightly higher than that in the North Atlantic (~ 11.7 pg L^{-1}) (Andersson et al., 2011). The DEM concentrations in the surface waters of the Yellow Sea and the South China Sea also showed a seasonal trend, with high concentrations in the warm season and low concentrations in the cold season (Tseng et al., 2013), the trend is similar to that of other sea areas in the world. Because the DEM concentration is affected by many factors, including light intensity, temperature, surface wind speed, air pressure, microbial activity in seawater, and source input intensity (such as coastal runoff input and atmospheric deposition input), the spatial distribution trend of DEM concentration is higher in offshore area and lower in offshore area, and the DEM concentration in offshore area is similar to that in other offshore areas in the world.

According to China's seawater quality standard GB 3097-1997, the mercury content of surface seawater in most of China's sea areas meets the class I water quality standard (< 0.05 µg L^{-1}). However, in the Bohai Sea area where the anthropogenic discharge is more serious, the mercury concentration is higher than the class III water quality standard (0.5 µg L^{-1}). It is urgent to study the marine mercury in mercury polluted areas, especially the exposure risk of local residents, review current standards and regulations, and strengthen to reduce mercury levels.

4.2.3 Sediment

Sediment is an important part of marine ecosystem, which acts as an important sink and secondary emission source of marine mercury cycle. At the same time, it is also a hot spot for the generation of highly toxic methylmercury. Therefore, the study of mercury in surface sediments and sediment cores has become an effective means to reveal the source, migration and transformation of mercury in both spatial and temporal scales. From 2011 to 2012, 220 surface sediments and 8 sediment cores were collected from four major marginal seas (including the Yangtze River Estuary and the Pearl River estuary) along fixed routes. The results show that the concentration (dry weight) of THg in China's coastal sediments is mostly in the range of background concentration (20 - 100 µg kg^{-1}). Most of the sampling points in the Pearl River Estuary (42/54) and one sampling points in the Bohai Sea (1/29) were significantly higher than the background value (> 100 µg kg^{-1}) (Meng et al., 2014). Compared with other sea areas in the world, THg values of marine sediments in Europe, North America, Africa and Asia are significantly lower.

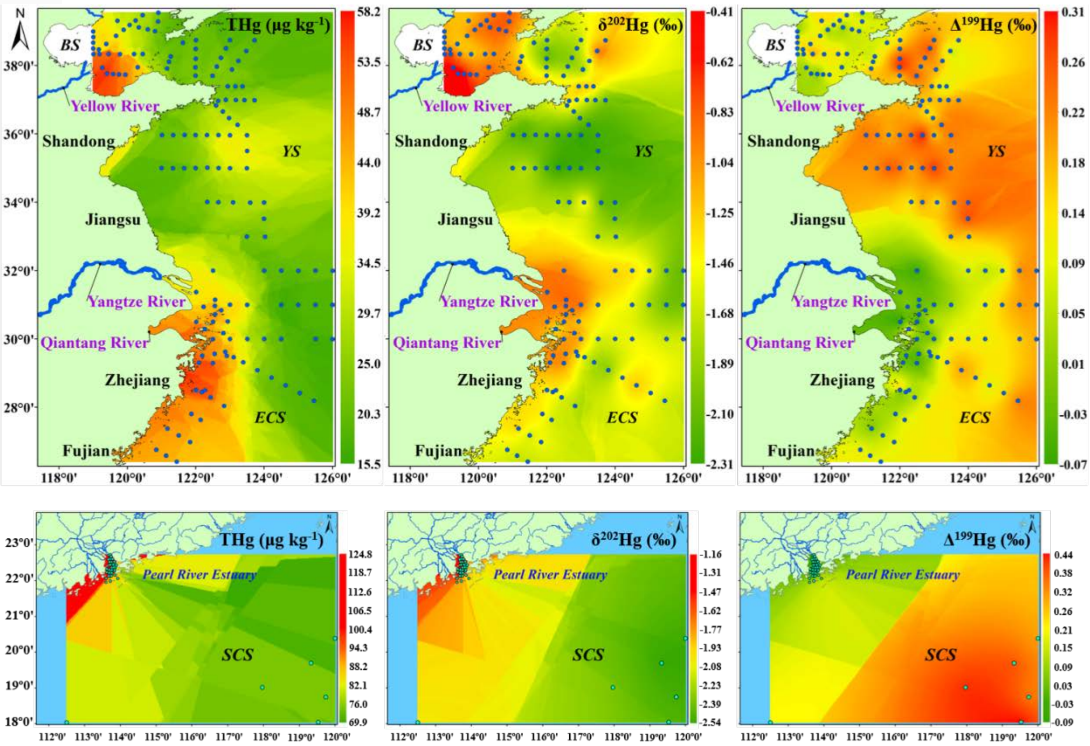

Figure 4.3 Isogram of THg concentration and its isotopic composition (δ^{202}Hg and Δ^{199}Hg) in surface sediments of four marginal seas in China. BS: Bohai Sea; YS: yellow sea; ECS: East China Sea; SCS: south China sea.

From the perspective of spatial distribution (Figure 4.3), THg concentration is the highest in the sediments of the Pearl River Estuary in the South China Sea (166 μg kg^{-1}; 15.4 - 398 μg kg^{-1}; n = 54), Bohai Sea (38.8 μg kg^{-1}; 9.7 - 160 μg kg^{-1}; n = 29), East Sea(32.8 μg kg^{-1}; 8.2 - 84.3 μg kg^{-1}; n = 71), and Yellow Sea (24.2 μg kg^{-1}; 7.0 - 47.4 μg kg^{-1}; n = 66). Moreover, the hot spots of THg enrichment are mainly distributed in the Yellow River Estuary of the Bohai Sea, the muddy area in the middle of the Yellow Sea, the muddy area of the Yangtze River Estuary and the lower reaches of the Pearl River Estuary in the East China Sea, and the lower reaches of the Pearl River Estuary in the South China Sea (Figure 4.3), This indicates that mercury in the coastal sediments of China is mainly concentrated in the muddy areas with high organic carbon content, and mainly comes from the input of coastal human activities. From the perspective of time trend, the overall performance shows an increasing trend from the bottom to the top of the core, especially near the top of the core, which indicates that the mercury input in China's coastal waters continues to increase, especially in recent decades. THg concentration in surface sediments of the Pearl River Estuary also increased significantly from 2002 to 2011, which indicates that anthropogenic mercury emissions in the Pearl River Delta have increased significantly in the past decade.

Due to the anoxic environment of the sediments, some microorganisms such as sulfate reducing bacteria, iron reducing bacteria or methanogenic archaea can convert inorganic mercury into organic mercury in the surface sediments. In addition to the common methylmercury (MMHg), an uncommon but highly toxic Dimethylmercury (DMHg) is also found in seawater, Moreover, the formation of DMHg was also related to microbial transformation in anoxic environment (Baldi et al., 1995). The detection data of organic mercury in coastal sediments in China are relatively few, and the existing data show that the concentration of MMHg is mostly in the range of 0.1-3.2 μg kg^{-1}, only relatively high concentrations of MMHg (15 μg kg^{-1}) was found in several estuaries. In the future, it is necessary to strengthen the study of mercury speciation in sediments.

4.2.4 Residue in organism tissue

According to statistics, the national marine biological catch in China reached 13.1 million tons in 2015. Seafood has become an important source of human methylmercury exposure, which poses a potential threat to human health and needs special attention. From 2007 to 2012, 11 species of mollusks (including 9 bivalves and 2 snails) were collected from the Bohai Sea. The results showed that the concentration (dry weight) of THg and MMHg ranged from 27.2 to 461.1(average 99.4), 2.1-295.5 (45.1) μg kg^{-1}, respectively (n = 431), which were lower than the limit of MMHg in seafood in China, which is 500 μg kg^{-1}(Meng et al., 2015). The concentrations of THg and MMHg in molluscs did not change significantly in this period, which reflected the relatively stable pollution status in the region; In terms of species, the percentage of MMHg in snails (57.3 - 65.8%) was significantly higher than that of bivalves (21.1 - 49.5%). MMHg in low trophic molluscs showed biomagnification effect, while inorganic mercury mainly showed growth dilution effect.

In 2013, samples of the whole food chain of the Bohai Sea were collected, including macroalgae, bivalves, snails, shrimps, crabs, cephalopods, inshore fish and pelagic fish. The results showed that the concentrations (dry weight) of THg and MMHg ranged from 44.3 - 1355.7 (average: 300.9), and 5.2 - 1210.1 (average: 183.6) μg kg^{-1}, respectively (n = 192). Among which, 9 samples (mostly inshore fish) exceeded the limit of MMHg in seafood (500 μg kg^{-1}) (Meng et al. 2020). In terms of species, the order of MMHg% was inshore fish (mean 84.4%) > pelagic fish (mean 82.0%) > crabs (mean 62.5%) > cephalopods (mean 56.5%) > snails (mean 51.8%) > shrimps (mean 51.3%) > bivalves (mean 40.9%). Similarly, the concentration of MMHg was significantly positively correlated with trophic level (0.97 - 5.48), MMHg in the Bohai Sea food chain showed biological amplification effect, while inorganic mercury mainly showed growth dilution effect.

Compared with the existing data in China, the concentrations of THg and MMHg in the Bohai Sea are close to those in the other three regions, but the reports about fish in the South China Sea show relatively higher concentrations of MMHg, as high as 1811 μg kg^{-1}(Zhu et al., 2013). Compared with other sea areas in the world, THg concentration in fish in China is relatively low, such as the Gulf of California (up to 3748 μg kg^{-1} (Ramos-Osuna et al. 2020), the southwest Pacific near the Antarctic (mean 680 ± 450 μg kg^{-1}, wet weight) (Queirós et al., 2020) some people think that this is related to the overfishing in China, which leads to the short growth cycle of marine products, that is, the short enrichment time of mercury.

The maximum tolerable value of MMHg intake recommended by WHO is 1.6 μg kg^{-1} body weight per week (FAO, 2011). The EPA recommends 0.1 μg kg^{-1} body weight per day. If the average weight of an adult in China is 60 kg, the daily intake of seafood by coastal residents is 250 g, the intake of MMHg was 4.2 ug kg^{-1} body weight per week or 0.6 ug kg^{-1} body weight per day, both of them exceeded the above limits, indicating that the coastal residents who often eat seafood have a certain MMHg exposure risk. Due to China's rapid economic development, the mercury concentration in seawater has an upward trend. On the other hand, China is strengthening the management of the total amount of marine fishery resources, reducing the number of fishing motorized fishing boats, increasing the fishing moratorium (the growth cycle may be extended), All of these may change the bioaccumulation and cycle of MMHg. Therefore, it is necessary to monitor the content of mercury, especially in coastal organisms of China in the future.

4.3 International (marine) mercury pollution monitoring

4.3.1 The Global Mercury Observation System

The European Commission (EC) funds the Global Mercury Observation System (GMOS) from 2010 to 2015. GMOS aims to establish a global mercury observing system to study and model global mercury emission scenarios, both regionally and globally, with support from network facilities[1]. The system supports the operation of the Mercury Convention by measuring atmospheric mercury in ambient air and precipitation samples, providing comparable monitoring data on mercury concentrations in air and marine ecosystems in the northern and southern hemispheres. The project has 43 ground monitoring stations around the world, some of the stations are located far from human activities areas, such as Armstrong island in Antarctica and EV-K2-CNR in the Himalayas, which is more than 5,000 meters high. GMOS monitors through field and satellite platforms, with network facilities providing real-time or recent data from participating observatories. Due to the nature of mercury emission and deposition, the monitoring covers the overall mercury cycle, including the air, sea and land. It collects data from the ground monitoring stations, ocean cruise activities and tropospheric monitoring system, analyses and

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[1] Details of the project can be found via www.gmos.eu

judges the long-term trend of mercury cycle in order to understand anthropogenic mercury emission activities, to quantitative mercury sources and deposition, and to analyse the impacts of mercury for the earth's ecosystem and human health. Through the GMOS' operations, the researchers find that mercury content significantly differs between the north and south hemispheres. For example, in 2013 and 2014, the annual average mercury content in the northern hemisphere was 1.55ng/m^3, and 1.51ng/m^3, whilst in the southern hemisphere was 0.93ng/m^3 and 0.97ng/m^3. This gradient between the northern and southern parts is attributed to the difference in the local and regional natural and/or anthropogenic emission of mercury, which shows that mercury emissions are mainly in the northern hemisphere (Sprovieri et al., 2016). Adopting a global monitoring approach, this project locates monitoring stations worldwide, covering areas with different elevations, various sea levels, and a variety of climates. By employing data from those sites, researchers can test atmospheric mercury models from a regional and global perspective to improve the understandings of global mercury migration, deposition and emissions, and provide a viable foundation for international policy-making and implementation (Gencarelli et al., 2017; De Simone, 2016). However, due to the limited data from GMOS, it is still challenging to provide more time trend information at present. There are still rooms in improving emission inventories and monitoring data, projections of future mercury observation and the cost-benefits (Sundseth, 2017).

4.3.2 EU environmental quality standards and mercury monitoring in water bodies and edible fish

The European Union (EU) has been monitoring the impact of mercury pollution on the environment since 1998. Typical projects funded by the EC include the Mediterranean Atmospheric Mercury Cycle System (MAMCS), Mercury over Europe (MOE), An Integrated Approach to Assess the Mercury Cycling in the Mediterranean Basin (MERCYMS). In recent years, monitoring projects have shifted to the benchmarks under the Mercury Convention, while various scientific attempts have been made to provide data to support the Convention.

Compared with the research and monitoring of atmospheric mercury pollution, there are relatively few studies on direct mercury discharge and treatment in water bodies in the EU and the world; neither do the clear data (AMAP and UNEP, 2013). Although it is worrisome that around 40% of the EU's water bodies are polluted (EEA, 2018), Europe remains one of the regions where water bodies are less polluted by mercury. According to rough calculations, the mercury directly discharged into water is estimated to be about 185 tons globally and about 8 tons in Europe (AMAP and UNEP, 2008). Mercury emissions from water in Europe are lower than those from other regions of the world, mainly because the primary sources of mercury emissions, such as mercury mining, the Chlor-alkali industry and small-scale gold mining, are not major industrial sectors in Europe. The European Pollutant Release and Transfer Register (E-PRTR) shows municipal sewage treatment is the primary source of mercury emissions from water, followed by chemical manufacturing and power generation (Figure 4.5). It is worth noting that sewage treatment discharges into the water body are also derived from commercial activities such as industry or dentistry. This emission structure supports the EU's policy logic on source control of mercury emissions.

The EU Water Framework Directive requires monitoring mercury and other substances following the EU Environmental Quality Standards (EQS, Directive 2008/105/EC). To assess long-term trends, the EQS calls for a monitoring plan for mercury concentrations and a watershed management plan that includes specific ecological safeguards. EU members may choose to use biota such as fish, mollusks and crustaceans as appropriate indicators for monitoring[2]. Although water bodies are not a major concern for mercury pollution in Europe, several countries have regularly monitored marine and surface water concentrations under EQS for many years, such as the Transnational Monitoring Network established in 1996. The system aims to measure the contents of mercury and other harmful substances in the Danube basin. According to the Danube Ecology Report 2015, the mercury content of fish in the river in that year exceeded the standard (ICPDR, 2015). Local marine and freshwater surveys in different countries (e.g. Sweden: Akerblom et al., 2014; Italy: Maggi et al., 2012; European countries: Nguetseng et al., 2015)

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[2] Current national and regional monitoring programmes and data can be visited via EOneet Central Data Repository.

report mercury contaminants exceeding EQS levels. Vignati et al. (2013) question these results, which are higher than the upper limit of EQS, believing that the pollution of mercury on water may be far more severe than previously estimated, but due to the lack of data, it is still unknown.

Per monitoring mercury contents in fish and controlling human exposure to mercury through eating, is part of the EU's strategy for eliminating the impacts of mercury pollution. EC's Regulation 1881/2006 sets an upper limit of 0.5 mg/kg for fish and 1.0 mg/kg for some large fish. In addition, the European Food Safety Authority (EFSA) assesses methylmercury and inorganic mercury in 2012, setting the acceptable intake at 1.6μg/kg body weight and 4μg/kg body weight (Benford et al., 2012). According to these legislations and guidelines, the EU investigates the mercury content in fish. Vinjevec et al. (2014) have summarized the studies since 2000 and noted that coastal populations have more mercury exposure than those in the mainland because they eat more fish than their counterparts.

4.3.3 UK monitoring of mercury emissions from water bodies

The United Kingdom (UK) occupies the major part of the British Isles archipelago, surrounded by the sea and crisscrossed internal water system. When monitoring mercury pollution in water bodies, the UK distinguishes marine water from fresh water and the estuarine and coastal water and takes different monitoring methods.

1) Mercury monitoring in territorial waters

The Clean Safe Seas Environmental Monitoring Programme (CSEMP), which has been in place in the UK since 1999, collects data on mercury concentration in fish, mussels and sediments in the brine system within the territorial waters (12 nautical miles) to reflect trends in mercury emissions[3]. The monitoring data from 1999 to 2017 fluctuated wildly, with only a small number of monitoring sites showing statistically significant trends, while the three monitoring objects also reflected different trends. For example, fish samples reported rising mercury emissions at three monitoring sites in the North and North-east of England; Mussel monitoring showed a decline in mercury in more areas than the Thames estuary; Sediments, on the other hand, showed a decline in mercury concentrations at a North-west monitoring site, while other sites showed little trend. Mussel monitoring results supported evidence of a reduction in mercury residue. However, the UK Environment Agency (EA, 2019) cautions that for monitoring data, significant effects of short-term conditions, such as storms and floods, may cause resuscitation of contaminated sediments, causing interference and overcovering of data trends.

2) Freshwater, estuarine and coastal waters

Unlike mercury monitoring in territorial waters, the UK adopts the EU's EQS system for monitoring freshwater, estuarine and coastal waters. The UK Environment Agency (EA, 2019) measures the mercury content of fish and mussels and compares it with the EQS threshold from 2014 to 2018. The results show that only 14 of the 70 freshwater fish samples were within the threshold, 56 of the other samples, and all of the estuarine and coastal fish samples exceeded the points. Only 7 of the 30 pieces of brine mussels were below the EU threshold (Table 4.3). In addition to elevated mercury concentrations in industrial estuaries, historical mercury retention is thought to influence monitoring results. It also suggests that historical factors, extraneous factors (such as storms and floods), and climate change in mercury emission and concentration monitoring (Krabbenhoft & Sunderland, 2013; Eagles-Smith et al., 2018; Selin et al., 2018) may influence the results.

Table 4.3: Summary of mercury concentrations in freshwater, saltwater fish and saltwater shellfish

Sample type	The region where mercury concentration is below the value in the EQS domain	Areas with mercury concentrations above the EQS threshold	Mercury concentrations (μg/kg)
Fresh water, fish	14	56	13.7-237.5
Estuarine and coastal waters, fish	0	16	28.5-260.
Estuaries and coastal	7	23	12.4-89.

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[3] The data can be seen via https://www.ices.dk/Pages/default.aspx and DOME https://www.ices.dk/data/data-portals/Pages/DOME.aspx

waters, shellfish

Source: EA (2019)

4.3.4 Mercury monitoring in Norway

In the Norwegian Action Plan for Reducing Mercury Releases (2010), the Climate and Pollution Agency is identified as the authority responsible for monitoring mercury concentration trends in the environment. The Agency is also responsible for revealing the causation and mechanisms of mercury runoff in the river basins and investigating the mercury concentrations in fish and food chains.

Long-term mercury monitoring projects take a full ecological view of mercury, including monitoring mercury loads in marine organisms, analysing time trends in biota, mercury inputs from rivers and industry, and data from North-South air monitoring stations[4]. In addition, there are other periodic projects to sample and monitor mercury, such as a national lake sediment monitoring programme that includes measurements of mercury every ten years and measurements of mercury and other heavy metals in mosses every five years. However, although a significant decline in mercury emissions is recorded in Norway, the monitoring data of mercury concentrations returned from the monitoring stations (1990-2008) is stable and does not show a decrease.

Nonetheless, the mercury content in fish does not decrease compared with the 1990s but shows a trend of high increase. For example, the mercury concentration in sea bass increases by 60%, and that in trout increases by 20% (CPA, 2010). The Norwegian environmental authorities attribute this to the long-distance transport of mercury in the atmosphere. In other words, the import of mercury pollution from outside Norway into the country through the atmospheric circulation system is more important than the production of mercury from Norway itself. However, due to the significant uncertainty in Marine mercury circulation and bioaccumulation, the actual causes are still in the blank area to be explored (Stode et al., 2007).

4.4 International and EU mercury pollution control practice

4.4.1 Mercury Convention and other international conventions

Mercury and its organic derivatives are characterised by their persistence, mobility and high toxicity (Schoeny, 1996). Their solitary effects on human health, wildlife and ecosystems are irreversible (WHO, 2019; EPA, 2018). These hazards determine that mercury pollution is a global problem and threat, which requires comprehensive actions at global and regional levels through international cooperation. Therefore, the governance of mercury pollution in various countries is not limited to specific industries, fields or regions, but is carried out in the atmosphere, water system and the overall food chain. It takes the mercury life cycle as the scope of intervention, which is the principle and foundation of international convention and cooperation to govern mercury pollution. International efforts to control mercury pollution have been underway since the late 20th century in the developed world. The earliest multilateral cooperation to control mercury pollution can be traced back to the 1998 Aarhus Protocol on Persistent Organic Pollutants under the Convention on Long-Range Transboundary Air Pollution (LRTAP, 1979) by the United Nations Economic Commission for Europe (UNECE) members. The protocol is the first international legally binding multilateral convention on mercury, with detailed provisions on unintentional mercury emissions, mercury-related products and wastes, and the public's right to know. However, its participating parties only include those from the developed countries, namely North America and Europe. The limited participation reflects that most developing countries were not industrialised in the late 20th century, and mercury emissions were primarily from industrialised developed countries. The actions first began in those developed countries. Although the Aarhus protocol opened up for non-UNECE members in the coming years, it failed to lead to effective global action on mercury control. Later multilateral pollution controlling agreements and conventions cover some parts of mercury governance, such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Basel Convention, 1989), including a mercury waste processing, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (Rotterdam Convention, 1998) containing mercury international trade issues, and the

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[4] The southern monitoring station is at Birkenes, on the North Sea coast at the southernmost tip of Norway, and the northern monitoring station is on the Arctic island of Svalbard.

Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention, 2001) covering the methyl mercury issues (Table 4.4).

Those international agreements and treaties expand participants' scope, trying to respond to mercury pollution in a global or regional context. Nevertheless, given the characteristics of mercury pollution, they cannot cover the entire cycle of mercury's lifespan; therefore, they cannot effectively prevent and control the pollution. Under this background, UNEP promotes a new independent mercury convention, namely the Mercury Convention, into the agenda to avoid the re-negotiations of existing conventions[5]. International organizations, mainly the United Nations Environment Programme (UNEP), have played a leading role in initiating and facilitating negotiations. UNEP has also produced a series of global assessment reports on mercury since 2002 to update global mercury pollution continuously[6].

4.4.2 Mercury pollution control in the EU

Europe has been the primary user and emitter of mercury since its industrialisation in the 19th century and has become the first primary practitioner of mercury control (Selin & Selin, 2016). Early interventions of mercury and mercury pollution started from the Baltic Sea, the Northeast Atlantic Ocean and the Mediterranean Sea in Europe. In mercury pollution control, Europe is different from North America, where voluntary private governance is the fundamental principle, whilst the European Union[7] always tends to enact laws and regulation to control the use and discharge of mercury, as well as the disposal of mercury waste (Selin & Selin, 2006). The first mercury-related regulation is introduced in the EU in 1979, which bans mercury-containing compounds as pesticides in the EU (Directive 79/117/EEC). By the beginning of the 21st century, mercury compounds have been identified as hazardous chemicals prohibited for export, and the export of mercury compounds outside the European Union and mercury-containing cosmetic soaps are also prohibited by legislation (Regulation (EC) 304/2003). The European Union also addresses industrial emissions through regulatory directives and procedures, such as Directive 2010/75/EU adopted in 2010, to deal with industrial emissions. On the whole, the EU has implemented numerous laws and regulations on mercury and its compounds. The public governance mechanism is underway through various sectors and departments. To prohibit and restrict mercury's use and emission from the source and control its production and trade is the most important measures. This idea of reducing pollution by reducing emissions has been confirmed in their marine mercury assessment data by UNEP (2015) and OSPAR (2018). In practice, the reductions in mercury emission sources have led to a downward trend in mercury content in North America and Europe. The EU's Mercury Strategy, formed in 2005 and revised in 2010, plays a leading role in the EU's regulatory architecture on mercury governance. In addition, the EU has also formulated a series of laws and regulations on mercury, further strengthening the management rules of mercury pollution.

1. EU mercury strategy

The EU has identified mercury pollution as a global risk since 2005 and launched the Community Strategy Concerning Mercury (Mercury Strategy, COM/2005/0020) and the corresponding Directives and Action Plan to strengthen the governance of mercury pollution through law and regulation. The Mercury Strategy is formed in 2005 and revised in 2010, serving as the guiding document for mercury control. The mercury strategy is a comprehensive plan to address mercury use and polluting issues. The core segment of the strategy is its 20 action plans, aiming at reducing mercury emissions, cutting mercury supply and demand, and protect citizens from mercury exposure.

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[5] Detailed discussion and trade-off process can be found in UNEP (2007) Review and assessment of options for enhanced voluntary measures and new or existing international legal instruments, Study on options for the global control of mercury, Bangkok, pp61-66

[6] Those UNEP publications include Global Mercury Assessment (2002), the Global Atmospheric Mercury Assessment: Sources, Emissions and Transport (2008) and the accompanying Technical Background Report to Atmospheric Mercury Assessment, the Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport (2013) and its accompanying and updated Technical Background Report, Global Mercury Modelling: Updates of Modelling Results in the Global Mercury Assessment 2013 (2015), and the Global Mercury Assessment (2018).

[7] Unless otherwise stated, 'EU' refers to the European Union and/or its predecessors, such as the European Economic Community in the following sections.

The Mercury Strategy directly contributes to enhancing EU's legislation on mercury in (i) restrictions on the use of mercury or mercury compounds in products, including measuring appliances, such as thermometers and barometers, batteries, electrical and electronic equipment; (ii) bans on exports of mercury from the EU from 2011; (iii) new rules on the safety of mercury storage; (iv) the incorporation of provisions on mercury emission in EU legislation, especially the BAT conclusions under the Industrial Emission Directive.

International cooperation has been emphasised under the Mercury Strategy framework. Based on the diffusion and circulation pathways, the EU notes that a large amount of mercury in Europe come from other parts of the world but deposit in the EU's marine environment and food chains, such as fish and seafood. Those depositions make the population expose to mercury and endangers human's health and safety, as well as the environment. For instance, EEA (2018) cites Swedish studies (EMEP, 2016) on mercury pollution assessment, reporting that only 1% of the mercury and mercury compounds affecting Sweden is produced in the country, whilst 88% comes from outside Europe (Figure 4.9). This situation is also prevalent in other European countries. Thus, although actions on reducing and eliminating the use of mercury have been in place within the EU for nearly 40 years, it is not sufficient to meet the challenge posed by the global increase in mercury emissions. It is clear that international cooperation becomes a 'have-to' choice for policymakers. Therefore, the Mercury Strategy has made international cooperation a priority, and one of the most important developments has been the active negotiation of the multilateral mercury convention (i.e., the Mercury Convention) with UNDP. The EU has played a crucial part in promoting the negotiation process. The signing of the treaty and the formation of multilateral cooperation are also important achievements of the EU in their green diplomacy.

2. EC Regulation 2017/852

Although existing regulations and directives relating to mercury control had generally met the requirements of the Mercury Convention, the EU introduces further measures in 2017 to go beyond the treaty's requirements and strengthen the laws by adopting Regulation 852/2017 (replacing Regulation 1102/2008). This Regulation covers the entire life cycle of mercury, reinforcing and complementing previous environmental regulations, where emphasise are on the followings:

(i) Prohibiting the export of mercury and its compounds;

(ii) Prohibiting the manufacture and international trade of a large number of mercury-added products;

(iii) Ending the use of mercury catalysts and large electrodes in industrials;

(iv) Reducing the use of dental amalgam to eliminate pollution and taking measure to assist the phasing out of mercury use in dentistry;

(v) Ending mercury's future uses in industries and products; and

(vi) Ensuring permanent safe storages for mercury waste in the environment.

Dental amalgam is the only active large-scale mercury use in the EU. The Regulation sets detailed restrictions in Article 10 to give requirements in dentistry. It requires member states to make national plans and take various measures, such as using only pre-dosed encapsulated dental amalgam and specific device, to cut off the use of mercury and to prevent the exposure of the patients and practitioners. The amalgam waste is also required to be handled and collected by authorised waste management establishments, and no direct or indirect release is allowed into the environment.

By implementing the Directives and Regulations mentioned above, the EU has tried to create a mercury-free economy and achieved encouraging results. By banning mercury's use in products, such as batteries, switches and relays, sphygmomanometer, scheduling the deadline of using mercury in the Chlor-alkali industry and reducing the use of the dental amalgam, the EU has reduced mercury emission to air from 211 tons to 57 tons from1990 to 2004, which is a 73% drop (Figure 4.4). Currently, the EU only accounts for less than 5% of the annual mercury emissions globally. Mercury consumption in the EU has dropped 80% from 2007 to 2018, and a further 40% reduction is expected from 2018 to 2021. Mercury discharge to water has been reduced from 11.3 tons to 3.3 tons, a 71% drop from 2007 to 2014.

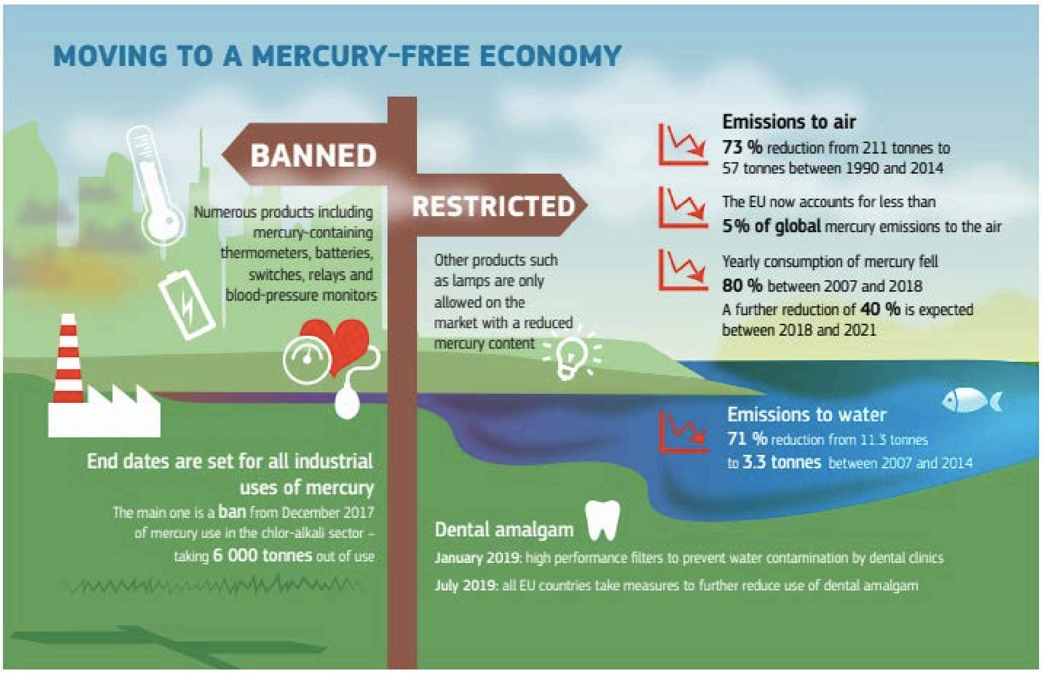

Figure 4.4 EU Action Plan on Mercury and Results (Source: EU (2018))

4.4.3 Mercury pollution control in the UK

The UK has reduced mercury emissions by 88% since 1990 by putting restrictions on mercury use and discharge (Figure 4.11). This decline of emissions is linked to less use of coal and the prohibition of mercury cells in the production process in the chlorine-alkali industry. Emissions from coal-burning have decreased by 90% due to the declining use of coal. The manufacture of chlorine in mercury cells was a major source in the 1990s, but emissions have fallen by 97% since then due to improved controls on mercury cells and, subsequently, their replacement by diaphragm or membrane cells (NAEI, 2021[8]). The primary sources of mercury emissions in the UK in 2018 were coal use in public electricity and heat production and industrial combustion, iron and steel production processes, cremation, and emissions from the disposal of mercury products. This emission structure has shown that the emissions to air in the UK are far greater than those directly released into the water, with coal-burning and equipment being the most comprehensive industrial sources. In line with its commitment to reduce the hazardous chemicals in the environment, the UK Government (HM Government, 2018) plans to further reduce land-based mercury emissions into the atmosphere and water by another 50% by 2030.

The UK has legally completed the Brexit in late 2020, but no new rules on mercury control are introduced at this reporting stage. The UK still employs those EU Directives and Regulations as their guiding rules and performs those EU provisions, keeping the same practices as the EU in manufacturing, trade, storage and reporting. In response to the EU's requirements, the UK develops national plans for dental mercury use to provide roadmaps to phase out the dental amalgam. Besides the action to restrict the use of amalgam, the UK also proposes action to improve citizens' oral health as the primary 'soft' vehicle for reducing mercury use. A range of oral health improvement schemes are promoted to reduce the prevalence of dental decay amongst children and vulnerable groups. Trials of a new approach to the existing dental care system are also initiated to encourage dentists to focus on prevention, thereby further reducing the prevalence of decay.

4.4.4 Mercury pollution control in Norwegian

Norway is located in the west part of Scandinavia, facing the North Sea and the Norwegian Sea, with a long coastline and a developed marine industry. Since the primary path for humans' exposure to mercury is through the consumption of mercury-containing fish and seafood, people in coastal countries and the Arctic region, such as Norway, are more sensitive to mercury

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[8] Details can be visited via https://naei.beis.gov.uk/overview/pollutants?pollutant_id=15

pollution. As a non-EU state, Norway tends to adopt more stringent measures on mercury use than the EU in its attitude of mercury control. The country has banned all new mercury uses since 2008 (NEA, 2010). The decline in mercury emissions (Figure 4.5) indicates that the measures taken by Norway to eliminate mercury have been quite effective.

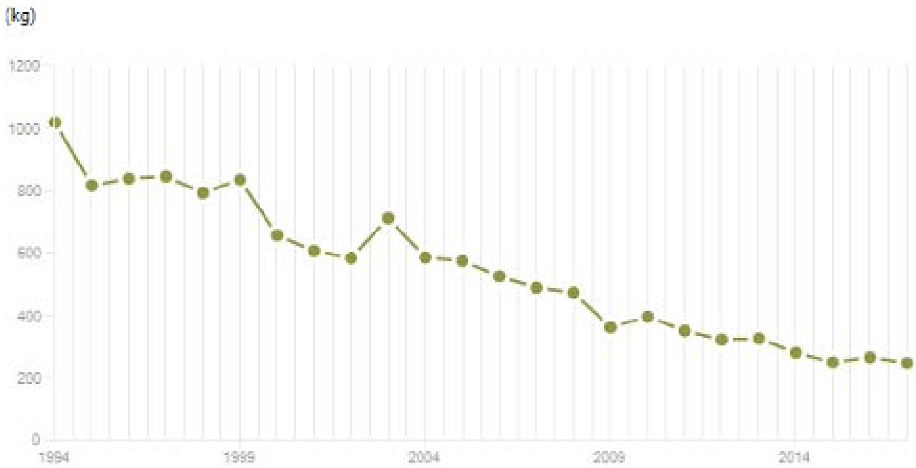

Figure 4.5 Total calendar year emissions of mercury (kg/year) into Norwegian air from 1994 to 2017[9]

Although Norway is not an EU member, it shares a similar idea in mercury control and governance. Based on laws and regulations, public governance is the primary means in Norway to control and manage mercury pollution. Furthermore, Norway has set higher standards than the EU to minimise mercury use and emissions. For example, in 2008, Norway banned all mercury use in new products, and dental amalgam was also wholly banned in the same year. Under the Agreement on the European Economic Area, Norway shares EU legislation on chemicals. Furthermore, in its own country, based on the Product Control Act (1976) and the Pollution Control Act (1983), Norway implements a licensing system as the primary policy instrument to deal with mercury pollution. The Product Control Act (1976) aims to prevent products and services from causing damage to people's health and to ensure that products and services are safe. It is also intended to prevent products from causing the environmental disturbance. It applies to the production, import, marketing, use and other handling of products. The Pollution Control Act (1983) is an enabling act, which authorizes the pollution control authorities to adopt regulations and issue individual discharge permits. Its purpose is to prevent and reduce pollution, reduce the quantity of waste and promote better waste management.

Norway has developed offshore oil and gas industry and a strong manufacturing sector, which contributes to most of its mercury emissions and pollutions. As mentioned before, polluting activities are controlled and managed through a permit system in Norway. Those permits are issued on the condition that the activities comply with the best available technology (BAT) at a certain time. It means that only relatively advanced production processes, methods and technical routes can be approved by the authorities, while advanced emission reduction technology means that pollutants can be best controlled under the current conditions and can keep an up-to-date dynamic. Figure 4.6 shows the results of mercury reduction for about ten years from 1995. The oil and gas industry has shown a significant reduction in emission, whilst manufacturing and products have also shown significant reductions in mercury emission.

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[9] Data and details can be found via Norwegian Environmental Agency websites, https://www.norskeutslipp.no/en/Components/Emission/Mercury/?ComponentType=utslipp&ComponentPageID=74&SectorID=90

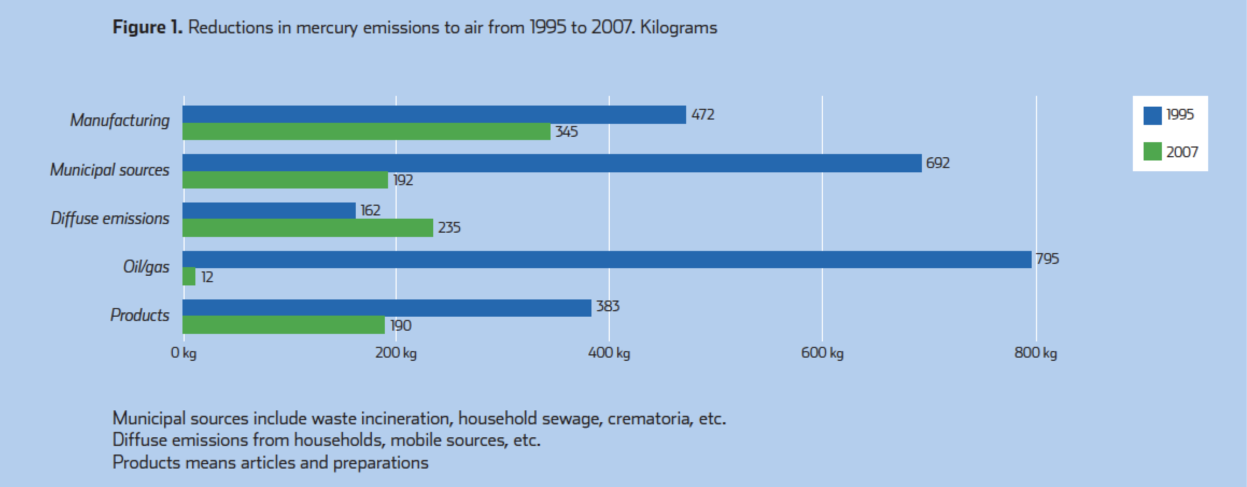

Figure 4.6 Reduction in mercury emissions from 1995 to 2007 (kg) Source: NEA (2010)

The oil and gas industry does not use mercury-containing substances in its production, but mercury is naturally presented in natural gas products and produced water. For such mining and producing activities, the regulatory authorities require a zero-emission policy for hazardous substances, resulting in a significant reduction within the ten years. Unlike those major countries in the EU and the UK, metal smelting is one of Norway's competitive industries. However, the smelting industry uses high mercury ores, so the industry's emissions are very high. Those industrial characteristics contribute to stricter standards by the environmental authorities. This approach required by the production sector is to use more advanced mercury removal technologies. For example, the iron and steel industry and the manganese smelting industry have used the activated carbon adsorption technology to significantly reduce mercury emissions, reducing tailpipe emissions by 85% and 98%, respectively.

4.4.5 Policy analysis of mercury pollution control

The EU and major non-EU countries, such as the UK and Norway, start the mercury control process earlier than other parts of the world. They establish a relatively perfect policy framework and achieve fairly positive results during the decade's practice, providing a valuable experience for other countries.

(1) Experience

Firstly, European countries put emphasise combining global multilateral and domestic law and regulation-based governance. The European have emphasised multilateral governance since the mercury pollution issues emerging in the late 1980s. Through the continuous development and revision of a series of multilateral agreements, the European ensure the cooperation on track between major polluting countries and try to solve the free-rider problems in mercury control. Later with mercury pollution becoming severe issues in developing countries, the European countries play an active role by cooperating with international organisations, such as the UNEP, to promote the transformation of mercury governance from a regional to a global level. To achieve this transformation, comprehensive international treaties, such as the Mercury Convention, are proposed in a global perspective, with the broad participation of both developing and developed countries. Those endeavours provide a solid institutional framework for the solution of mercury pollution global governance. The negotiation and signing of the Mercury Convention also contribute to the formulation and implementation of domestic policies in European countries. The evolution of mercury law and regulation in the EU is clearly related to the institutional arrangements of the international convention. At the same time, those countries' policies are tailored to the specific industries and their domestic development, which offers strong pertinence to the primary polluting industries, manufacturing and international trade activities, and lifespan monitoring politics and regulation. This pertinence contributes to the sharp decline of mercury pollution in the past decades.

Secondly, the core idea of mercury pollution control in Europe is based on strict policies, supplemented by market-based tools and soft policies. Law and regulation take precedence, providing clear exit schedules and industrial standards and mandatory and quantitative standards in dimensions, such as transition periods and industrial-specific mercury indicators. Meanwhile, the policies try to keep as transparent and continuous as possible, conducive to the relevant industries and stakeholders to locate and adjust their expectations and prepare for the transformation in advance. According to the characteristics of mercury pollution and primary industries involved, there is a clear policy priority in those countries. Key polluting industries are first rectified, and other industries are treated later, resulting in a gradual completion of the countries' whole industry. Tax instruments and other follow-up service policies are critical, for example, supporting the R&D and using alternative technology, reducing mercury-related product demand, and addressing employment and livelihood issues in transition. In addition, developing environmental and ecological compensation schemes and raising public awareness of mercury pollution act as the institutional foundation of the goal of a mercury-free society.

Thirdly, in such a pluralist policy framework, the European mercury strategy includes top-level design and emphasizes the need for collaboration amongst various local government authorities and the need for public participation. The ultimate goal is to build a cross-industry and cross-sector policy implementation network (Adelle et al., 2015). The polluting sources include mining, power generation, metal smelting, petrochemicals and other industries, whilst the use of mercury in the circulation sector involves lighting equipment, battery production, cosmetics, preservatives and pesticides, measuring devices, medical supplies. Additionally, the whole monitoring process covers urban and rural areas, including rivers, land, atmosphere and ocean. Therefore, it is the premise of pollution control to coordinate the relationship between multi-stakeholders and establish unified and effective governance and cooperation network.

(2) Lessons

It should be noted that although European countries are pioneers in mercury pollution control and leaders in international governance, there are also some lessons to be learned from the development of their governance process. First, although the rapid decline in mercury pollution reflects the positive effects of active policy interventions by Europe, it is more a result of the relocation of a large number of polluting industries and manufacturing industries to less developed countries due to globalization. While strengthening mercury pollution standards, European countries have not solved the problem of 'pollution flight' well. Due to the ever-upgrading environmental protection pressure in domestic countries, many mercury-related industries have transferred many pollution technologies and investment to emerging markets, where fewer environmental protection laws and regulations are in place. Those transfers cause the global mercury pollution situation. Therefore, European countries need to continue strengthening export control of mercury-related technologies and products and have the responsibility and obligation to provide more financial, technical and capacity support for mercury pollution control in developing countries. By doing so, those countries can have a way to make up for the loss of pollution flight caused previously.

Second, the performance of monitoring in European countries needs to be improved. Monitoring data provide a reliable scientific basis for policy design, but at present, those countries' focus is still on controlling rather than monitoring. Once mercury pollution emerges, it is not easy to quickly restore the ecological environment through policy and technical means. Therefore, policymakers tend to strictly control emissions at the source and limit circulation areas as significant policy goals. However, comprehensive and complete monitoring data can reveal the historical trajectory of mercury pollution, local and extraneous factors, and the impact of natural events, and therefore have essential policy feedback value. Transparent and comprehensive monitoring data can also have a far more significant impact on behaviour at the consumer part, such as food safety awareness and eating habits, than at the production part.

The EU's mercury policy has not yet been linked to major global issues, such as climate change, which have a very close relationship. On the one hand, reducing carbon emissions from high-carbon industries, such as coal-burning and oil, and rectifying mercury pollution have clear room for policy integration. The combination of two policy measures may have more significant benefits than in the one plus one form. On the other hand, changes in floods, hurricanes, precipitation, and ocean currents due to climate change will change the distribution and migration of mercury pollution, as well as the degree of exposure to human (Sundsesh et al., 2015), which requires close cooperation between meteorological and environmental monitoring agencies. However, at present, there are few attempts in this respect.

4.5 Recommendations on monitoring and control of mercury pollution in China's coastal waters

1) To establish a perfect monitoring system to ensure the accuracy and reliability of monitoring data

China's coastal economy is still developing rapidly, and the mercury concentration in seawater has a certain upward trend. At present, the national level monitoring of mercury and its compounds in marine environment is still in the stage of total mercury, and the speciation analysis data of mercury in marine sediments and seawater (such as MMHg concentration) is relatively limited, In particular, there is a lack of studies on the dynamic changes of MMHg concentration with time in sediments and seawater at fixed stations, and there are few studies on the rate of photo induced demethylation of MMHg in seawater. There is a lack of long-term monitoring data on the content of mercury in marine organisms, especially MMHg. It is suggested to speed up the development of monitoring methods for mercury speciation analysis in marine environment, promote the development and application of relevant reference materials, and build a perfect mercury speciation analysis and evaluation standard system; We should strengthen the training of relevant analysis technology and quality control technology, and strengthen the capacity building of form analysis of business monitoring institutions.

2) Strengthen source analysis and control key pollution sources

The existing mercury isotope endmember mixing models usually use direct industrial source, river source (mixed source) and atmospheric source for general calculation. It is suggested that the establishment of the list of mercury emission point sources and isotope "fingerprint spectrum" around China's coastal areas should be strengthened. Only by establishing a complete source spectrum database, can it help to achieve fine traceability and realize "scientific, comprehensive and comprehensive" In order to achieve the ultimate goal of mercury pollution control and emission reduction, we should control the pollution sources and access to the sea by "precision".

3) Pay attention to the research of environmental behavior and strengthen the risk analysis of transformation products

The physic-chemical transformation and deposition process of mercury in the ocean boundary layer atmosphere are still unclear, so it is necessary to strengthen the in-situ and long-term observation of three forms of mercury (especially gaseous elemental mercury) in the boundary layer atmosphere, including its concentration, input flux and isotopic composition, the characteristics of real-time meteorological cyclones, and the control experiments of possible transformation reaction of mercury in the upper atmosphere or boundary layer, The distribution and transformation of atmospheric mercury deposition in seawater were revealed. Mercury mainly exists as inorganic mercury in the atmosphere, but when it enters the water environment, it will be converted into alkyl mercury under certain conditions. Alkyl mercury has much higher toxicity than inorganic mercury, and is also the main form of mercury amplification along the food chain. It is of great significance to strengthen the research on the speciation, concentration and isotopic characteristics of mercury in marine phytoplankton, zooplankton, molluscs and other low trophic organisms in the food chain to reduce the risk of mercury exposure.

5. Conclusion and Recommendations

Recommendation 1: Establish and improve the marine environmental protection pattern, promote the formation of a joint prevention and control mechanism for ecological environmental protection in watersheds - estuaries - nearshore waters

Establish a sound marine environmental protection pattern. To deepen the organization and implementation of the fight against pollution as an opportunity to further improve the marine ecological environmental protection mechanism with “central government responsible for overall planning, provincial-level governments assuming overall responsibility, and city and county governments responsible for program implementation”. Powers and regulatory responsibilities of the central and local governments should be divided more definitely and finely. The responsibility system of Party committees and governments for overall responsibility and industry administrative authorities for regular supervision responsibility should be reinforced. To implement the marine ecological environmental protection target responsibility system and assessment system, and effective interface with the central ecological environmental protection inspectors.

Build a watershed-estuary-nearshore sea pollution prevention and control linkage

mechanism. The Ministry of Ecology and Environment, the Bureau of watershed and marine areas, provincial ecological and environmental departments and other industries and fields in charge of the functions, in accordance with the principle of land and sea integration, to explore the establishment of coastal, watershed and marine areas in concert with the integrated management system, to promote estuaries, watersheds, nearshore marine environmental management of the integrated interface, to promote the formation of watersheds - estuaries - nearshore marine ecological environmental protection joint prevention and control mechanism. To further focus on the key, and make great efforts to solve the outstanding environmental problems and institutional shortcomings of key bays and estuaries.

Recommendation 2: Promote the synergy between marine pollution reduction and climate change, and improve the quality and resilience of marine ecosystem

Promote the synergy between marine pollution reduction and climate change addressing. Strengthen the integrated management of land and sea pollution, further reduce the nitrogen and phosphorus pollutants from riverine input, continuously reduce the eutrophication of the coastal waters, alleviate the ecological deterioration in the context of climate change, including ocean acidification, hypoxia, HAB and green tide. Improve the quality of marine ecosystems and their resilience in adapting to climate change.

Promote trans-sectoral cooperation and integrated management of hypoxia sea areas. Integrate the reduction of pollutants and the comprehensive management of hypoxia zones, and make the comprehensive management of hypoxia zones one of the work objectives in the 14th Five-Year Plan to fight the battle of pollution prevention and control. Strengthen the integration of land and sea, to promote pollutant emissions reduction from land-based sources, mariculture, agricultural pollution from non-point sources, and atmospheric deposition as a whole. Consider the feedback of climate change on pollutant emission reduction and hypoxia zone management, strengthen the synergistic effect of pollution reduction and climate resilience improvement.

Strengthen the protection and restoration of coastal ecosystems. Promote the synergy between marine and coastal zone ecological protection and restoration and adaptation to climate change, incorporate climate adaptation goals into marine ecological environmental protection planning; promote the construction of marine ecological reserves, implement a regulatory system for marine ecological protection red lines, carry out monitoring and evaluation of the effectiveness of protection and adaptation of coastal climate fragile ecosystems such as mangroves, sea grass beds, salt marshes, coral reefs, sand dunes and islands; carry out coastal ecosystem restoration and enhance the capacity of wetlands for water purification, carbon sequestration and sink, etc., improve the quality, stability and climate resilience of marine ecosystems.

Recommendation 3: improve the ecological environment monitoring system, strengthen the source of control

Improve the integration of land and sea ecological and environmental monitoring system. In accordance with the principle of land-sea integration and unified layout, optimize the construction of a full-coverage, refined marine ecological environment monitoring network, strengthen grid monitoring and dynamic real-time surveillance monitoring, online real-time monitoring of the main rivers into the sea, land-based sources into the sea outfalls, etc., to provide data support for the source control of marine pollution.

Strengthen the analysis and monitoring of mercury pollutants and traceability capacity building. It is recommended to accelerate the development of monitoring methods for the morphological analysis of mercury in the marine environment, promote the development and application of relevant standard substances, and build a perfect system of standards for the morphological analysis and evaluation of mercury; strengthen training on relevant analytical techniques and quality control technologies, enhance the capacity building of morphological analysis in operational monitoring institutions. Build a full-source database including the list and isotope "fingerprint spectrum" of relevant mercury emission point sources around China's offshore area, improve the ability of fine traceability, build a control system of pollution sources and their entry routes to the sea.

Strengthen the source control of marine plastic pollution and microplastics, improve waste management and disposal capacity. Strengthen technological innovation, improve the capacity of plastic waste reduction, harmless and resource disposal, accelerate the construction of waste recycling and management infrastructure; develop a comprehensive action plan for the prevention and control of marine litter and marine microplastics pollution at the national level, build a "source and sink" double interception of marine plastic litter control and prevention mechanism from the source, prevent plastic garbage from land-based sources from entering the sea. Efforts will be made to move forward with the pilot project to achieve zero plastic discharge in coastal areas, with upstream/downstream coordination, waste recycling infrastructure, and public awareness campaign; link zero plastic goals to broader carbon neutrality target.

Recommendation 4: Establish and improve the joint scientific and technological research mechanism to enhance the scientific knowledge of marine pollution problems

Establish and improve the joint science and technology research mechanism. Strengthen the major national science and technology projects on key sea areas to fight the battle of pollution prevention and control of science and technology support role. Marine-related universities, institutes jointly carry out scientific and technological research to accelerate the solution of bottleneck technology and difficult issues. Strengthen marine pollution regulation and governance theory and applied technology research, increase investment in the construction of talent teams and capacity building, actively promote the transfer of scientific and technological achievements and pilot demonstrations, focus on solving and tackling marine pollution management and protection of major issues and technical difficulties. Strengthen the application of scientific and technological innovation and the transformation of results to enhance the modernization of marine ecological and environmental governance capabilities.

Strengthen the scientific and technological support for marine pollutant control. Conduct research on key technologies and major issues such as pollution source analysis in nearshore waters, total nitrogen reduction in watersheds, water quality evaluation in estuaries, and protection of key marine species, response to climate change, and marine ecological protection and restoration. Based on the three-dimensional monitoring data of mercury and plastics/microplastics in different environmental media, we will carry out research on the transport paths and environmental behavior of typical and new pollutants such as mercury, plastics/microplastics, assess the impact of pollutants and their transformation products on marine ecosystems, and improve the scientific knowledge of mercury and plastics/microplastics pollution.

Regularly implement special surveys of marine pollutant baselines. Through regular special surveys, identify the types, levels and distribution of pollutants in China's marine environment, identify the bottom line, assess the effectiveness of marine pollution control, prepare and regularly update the priority control list of new marine pollutants, optimize and improve the marine environmental quality monitoring network.

Recommendation 5: Enrich the development of global marine public goods and participate deeply in global marine environmental governance

Promote China's governance experience and strive to provide global public goods. Benchmark the international level of marine ecological and environmental governance in the Great Bay, build the Guangdong-Hong Kong-Macao Greater Bay Area into a pioneering demonstration area for the protection and construction of "beautiful bays", show the world the successful cases of China's comprehensive marine ecological and environmental governance and green and high-quality development in the region, and take the lead in promoting China's marine ecological and environmental management experience in regions along the "Silk Road" and the Beibu Gulf region. We will make the enrichment and development of global public goods an important strategic goal of China's marine ecological and environmental protection work in the 14th Five-Year Plan and even in the future period, and realize the profound transformation from expanding from the jurisdictional waters to the global oceans, and from concentrating on solving our own problems to deeply participating in global marine environmental governance. We will also actively explore the provision of global public goods in key areas such as marine litter and microplastic management, ocean hypoxia and acidification, polar environment and climate change.

Promote global marine environmental governance system toward a fairer and more equitable way. Under the guidance of the idea of maritime community with a shared future, we will fully participate in global marine environmental governance and enhance our capability to comply with international conventions. Make full use of the platforms e.g. UN General Assembly, the United Nations Environment Assembly, the Conference of Signatories to United Nations Convention on the Law of the Sea, and the Informal Consultative Process on the Law of the Sea, to put forward China's proposal of win-win cooperation, boost the development of global marine environmental governance rules. To promote the building of the Blue Partnership, active participation in the international governance of the polar regions, and the promotion of marine cooperation with European countries. In the South China Sea, promote cooperation in the field to address climate change, and marine plastic debris, form a benign pattern driven by overall cooperation and bilateral cooperation with sustained and tenacious efforts. Organize a summit on marine ecological and environmental protection, actively bring "host diplomatic advantages" into full play, propose Chinese solutions.