Plastic Pollution in East Asia: Macroplastics and Microplastics in the Aquatic Environment and Mitigation Efforts by Various Actors

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Contents

Abstract Plastic pollution has become an increasingly worrying threat to the aquatic environment. The oceans and seas in East Asia are among the world's most polluted. Therefore, East Asian societies should make concerted efforts to

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tackle the problem. In this review, we summarize the current state of scientific research about macro- and microplastic contamination of the aquatic environment, including biota, consecutively for four East Asian countries (China, Japan, South Korea, and Taiwan). For the same four countries, we also summarize mitigation efforts to decrease the plastic pollution in these four countries, which includes government policies and waste management; education, media, monitoring, and outreach campaigns by NGOs; and inventors and businesses developing alternative products and methods of production and recycling. This review aims to give an overview which will hopefully inspire a more concerted effort by East Asian governments to support the relevant science but also to tackle the plastic pollution problem with much needed policies and management solutions.

Keywords Coastal pollution, East Asian seas, Microplastic contamination of food, Plastic pollution, Plastic waste management, Recycling

1 Introduction

Plastic pollution is a rapidly worsening environmental problem in terrestrial habitats [1] but even more in aquatic habitats such as freshwater, coastal, and oceanic ones [2–6]. Since global plastic production and waste generation have been growing exponentially, with production at approximately 335 million metric tons (MT) in 2016 [7–9], plastic pollution will continue to worsen unless emissions are seriously curtailed. Between 4.8 and 12.7 million MT of plastics are estimated to enter the oceans annually [10], while the remainder is either recycled, incinerated, or landfilled or enters other ecosystems [7].

Once in the environment, plastic objects and fragments (1) damage and endanger ships; (2) cause the injury and death of animals through entanglement and ingestion; (3) visually and structurally damage oceanic, coastal, and freshwater ecosystems; (4) spread invasive species and diseases; and (5) degrade to meso-, micro-, and nanoplastic particles which can either enter the food chain directly or contaminate it via chemical leaching [2, 5, 11–16]. Possible human health impacts are (1) accidents; (2) the direct ingestion of microplastics and the possible resulting internal injury [17, 18]; (3) the indirect contamination of air, food, and water with unhealthy chemicals [1, 19]; and (4) microplastics serving as pathogen vectors [20].

Concerns about plastic pollution should be especially relevant to East Asian societies because man-made debris pollution made up predominantly by plastic materials has reached pervasive and catastrophic proportions in East Asian rivers, oceans, and coastlines, with some of the world's highest levels of plastic pollution reported [10, 21–29]. Moreover, a relatively high proportion of people's diet comes from seafood [29–31].

Therefore, East Asian societies should make concerted efforts to tackle the growing plastic pollution. While cleanup efforts certainly help alleviate the problem at least locally, given the scale and speed of the problem, any serious solutions to decrease and finally eliminate plastic emissions into the environment must (1) introduce source reduction policies (including bans, charges, deposits, fees, fines, incentives, penalties, refunds, and taxes); (2) improve waste management and recycling with the ultimate goal of a completely circular materials economy, education, and behavioral change [32–47]; (3) replace plastic packaging with biodegradable materials (e.g., [48, 49]); and (4) clean up affected areas such as lakes, rivers, beaches, and the oceans themselves [29, 50, 51]. Furthermore, new or improved international and national instruments and treaties including effective enforcement are needed [35].

From our review, it is obvious that such much-needed solutions are only beginning to be implemented. What is encouraging is that research of the problem of plastic pollution as well as possible solutions has been increasing in recent years. In order to survey the problem of macro- and microplastic pollution in the aquatic environments of East Asia as well as mitigation efforts by various actors, we reviewed the available scientific literature of four countries (namely, China, Japan, South Korea, and Taiwan).

2 Methods

This study is a literature review of macro- and microplastic pollution research of the aquatic environments of East Asia and the ensuing mitigation efforts by various actors and stakeholders. For ease of communication, we use the shorthand names for the following countries: China for the People's Republic of China, North Korea for the Democratic People's Republic of Korea, South Korea for the Republic of Korea, and Taiwan for the Republic of China. Of the six East Asian countries, we a priori excluded two, namely, Mongolia and North Korea, because of the scarcity of any relevant research. Furthermore, Mongolia is a landlocked country, which thus precludes research on coastal and oceanic pollution.

All the authors have worked on this topic for several years. Therefore, a lot of the literature which we base this review on was already known to us, and some more was supplied by other experts in the field (see Acknowledgements). Additionally, we performed a standard literature search for English-language sources by searching Google Scholar and Web of Science using appropriate keywords or keyword combinations (e.g., "macroplastic," "microplastic," "plastic pollution," "recycling" in various combinations with the country names China, Japan, Korea, and Taiwan). The literature searches and writing process lasted from July to October 2019.

Currencies are given in United States dollars (USD), Japanese Yen (1,000 JPY = 9.21 USD on 1 October 2019), South Korean won (1,000 won = 0.84 USD on 1 October 2019), and New Taiwan dollars (1,000 NTD = 32.68 USD on 1 October 2019). All abbreviations are given in Table 1. Taiwan's Environmental

Table 1 Abbreviations used in main text

Full name	Abbreviation
Asia-Pacific Economic Cooperation	APEC
Coordinating Body on the Seas of East Asia	COBSEA
Commonwealth Scientific and Industrial Research Organisation, Australia	CSIRO
Environmental non-governmental organization	ENGO
Environmental Protection Law (China)	EPL
Expanded polystyrene (colloquially called "Styrofoam" in Canada and the USA)	EPS
Extended Producer Responsibility	EPR
Fourier transform infrared spectroscopy	FTIR
Greenpeace	GP
International Coastal Cleanup	ICC
International Convention for the Prevention of Pollution from Ships	MARPOL
International Convention on Civil Liability for Oil Pollution Damage	CLC
International Convention on Oil Pollution Preparedness, Response and Co-operation	OPRC
Japan Environmental Action Network	JEAN
Japanese Ministry of the Environment	MOE
Japanese Yen	JPY
Korea Marine Environment Management Corporation	KOEM
Korean Women's Environmental Network	KWEN
Kuroshio Ocean Education Foundation	KOEF
Metric ton	MT
Ministry of Ecology and Environment, China	MEE
Ministry of Environment, South Korea	ME
Ministry of Ocean and Fisheries, South Korea	MOF
New Taiwan dollars	NTD
Non-governmental organization	NGO
Northwest Pacific Action Plan	NOWPAP
Northwest Pacific Region Environmental Cooperation Center	NPEC
Our Sea of East Asia Network	OSEAN
Polyester	PES
Polyethylene	PE
Polyethylene terephthalate	PET
Polypropylene	PP
Polystyrene	PS
Society of Wilderness	SOW
State Oceanic Administration, China	SOA
Taiwan Environmental Information Association	TEIA
Taiwan's Environmental Protection Administration	TEPA
United Nations Environment Programme	UNEP
United States of America	USA
United States dollars	USD
Wild at Heart Legal Defense Association	WHLDA
World Wide Fund for Nature (formerly World Wildlife Fund)	WWF

Protection Administration (TEPA) defines single-use as those products which are produced for single-use and almost always disposed after one use. The term "disposable" is also often used for these kinds of products, but we use the term "single-use" throughout this manuscript because of the TEPA's definition.

3 Results

3.1 China

3.1.1 Macro- and Microplastic Contamination of the Aquatic Environment

Chinese scientists began research on microplastics in 2013, covering topics such as the microplastic abundance of various habitats, analytical methods of microplastic detection and estimation, ecotoxicology, ecological risk assessment, microbial degradation, and pollution control and management of plastics and microplastics.

Microplastic pollution of China's inland water systems was recently reviewed by Wu et al. [52] and Zhang et al. [53], while Wang et al. [24] reviewed research and management of plastic pollution in China's coastal environments. We therefore relied on these two reviews (and references therein) for some parts of our review but also attempted to add to it by reviewing publications and other information not included in them.

As Wang et al. [24] emphasized, China is the world's biggest consumer of plastic products and biggest contributor of plastic waste; consequently, most of China's aquatic environments suffer from plastic pollution at various levels, but often catastrophic ones. For example, 81% of China's coastal regions are heavily polluted with plastic debris, damaging ecosystems but also local economies because of lower real estate and tourism value, continuous cleanup costs, and damage to ships and business sectors which use the polluted water.

Wang et al. [24] reviewed 30 studies on plastic pollution in China's coastal environment which had found plastic debris (both macro- and microplastic) in a wide variety of environments: in surface waters and underwater sediments of estuaries, mudflats, rivers, and seas and on the surface as well as in the sediments of beaches (see also [53–68]). Other studies have found microplastics in coral reefs [69–71], dams [53], deep-sea submarine canyons [72, 73], lakes [53, 74–79], mangroves [80, 81], reservoirs [53, 82], and rice-fish co-culture systems [83]. Plastics were also recovered from zooplankton, sea cucumbers, bivalves, clams, mussels, oysters, fishes, Asian finless porpoises, and birds [24, 31, 53, 84–90] as well as table salts [91]. The most common polymer types were cellophane, polyester (PES), polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), and polystyrene (PS) [24, 53].

Sources of plastic pollution are the usual suspects: mismanaged waste disposal and fishing gear, tourism-related activities, construction sites, agriculture, manufacturing, wastewater treatment plants, laundry effluent, primary microplastics from personal care products and resin pellets, rubber tire abrasion, etc. [24, 53, 92]. For example, it was estimated that about 39 MT of primary microplastics are released annually into the Chinese environment from shower gel products alone [93], and Cheung and Fok [94] estimated that 209.7 trillion microbeads (or 306.8 MT) were annually released into China's environment. Bai et al. [95] estimated the annual input of plastic waste into the sea from China in the 2010s. In 2011, 0.5–0.8 million MT of plastic waste entered the seas in China, with an annual growth rate of 4.6% until 2017. Wang et al. [96] reviewed and estimated the emissions of primary microplastics in China.

Many microplastics are contaminated with hydrophobic organic compounds [97], other persistent organic pollutants, phthalates, plasticizers, and trace metals [24, 98]. Microplastics in seawater also accumulate microbial communities which appear to facilitate degradation of the microplastics [99].

In addition to the rapidly increasing scientific activity on the plastic pollution issue, the Chinese government has also begun monitoring and research activities. In 2007, the Chinese government began to monitor marine debris at about 50 coastal sites which include agricultural and fishery areas, tourist spots, and ports [100, 101]. In the 2017 China Marine Environmental Quality Bulletin, which is the annual report of the State Oceanic Administration of the People's Republic of China [102], the density of drifting debris, coastal debris, and sea bottom debris was estimated to be 2,845, 52,123, and 1,434 pieces per km^2, respectively. Among the eight categories of debris (namely, plastic, metal, rubber, glass, cloth, paper, wood, and others), plastic items were predominant (74–87%).

In 2014, the Chinese Ministry of Science and Technology launched research on microplastics with the aim to reveal the impact of microplastics pollution on marine ecosystems; established national standards of analysis and monitoring methods, ecological risk assessment; and began research on the sources and control of the pollution and other key technologies [24]. In 2017, the Marine Debris and Microplastics Research Center was established under the National Marine Environmental Monitoring Center to focus on technologies, methods, and management strategies for pollution prevention and control of marine debris and microplastics. In the same year, the State Oceanic Administration (SOA) sampled microplastics along six transects, each on four offshore seas and six beaches. The most prevalent types of drifting microplastic were pellets, fibers, and fragments, and the predominant polymers were PP and PS. The most prevalent types on beaches were pellets, fibers, and lines, while the predominant polymers were also PP and PS [102]. According to officials from the Ministry of Ecology and Environment (MEE), the microplastic pollution in Chinese ocean waters was lower than the global average and similar to the levels detected in the central western Mediterranean Seas and around the Seto Inland Sea of Japan [103].

3.1.2 Mitigation Efforts to Decrease the Plastic Pollution

Since China is associated with some of the world's most polluted oceans and is itself one of the worst polluters, its efforts of combating marine debris need to be addressed. China has been participating in two regional frameworks which have been developed under the United Nations Environment Programme and one partnership which was developed under the United Nations Development Programme (Table 2).

The first regional framework is the Coordinating Body on the Seas of East Asia (COBSEA), a regional intergovernmental policy forum, with China and eight Southeast Asian countries as participating members. Aiming to protect marine and coastal environments, the Action Plan for the Protection and Development of the Marine Environment and Coastal Areas of the East Asian Seas Region (the East Asian Seas Action Plan) was adopted in 1981 and revised in 1994. In recent meetings in 2018 and 2019, the revised COBSEA Regional Action Plan on Marine Litter outlined efforts in the East Asian region to tackle marine litter. It also supports regional organizations, e.g., ASEAN, and addresses global priorities such as Sustainable Development Goal 14 identified by the UN Environment Assembly.

The second regional framework is the Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific Region (NOWPAP) which was adopted in 1994 in order to protect the marine environment from land-based activities in the Northwest Pacific Region. Since 2005, NOWPAP has responded to the growing threat of marine debris in the Northwest Pacific Region through regional cooperation on scientific research and annual discussion in the Tripartite Environment Ministers Meeting. One tangible outcome is the NOWPAP Regional Action Plan on Marine Litter (RAP MALI) [104]. The prevention of marine litter input into marine and coastal environments has been identified as one of the key elements in the next phase of the RAP MALI [104].

Table 2 List of regional frameworks which deal with plastic pollution

Abbreviated name	Founding year	Member states
APEC	1989	Australia, Brunei, Canada, Chile, China, Hong Kong, Indonesia, Japan, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, Philippines, Russia, Singapore, South Korea, Taiwan, Thailand, USA, Vietnam
COBSEA	1993	Cambodia, China, Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand, Vietnam
PEMSEA	1993	Cambodia, China, Indonesia, Japan, Laos, North Korea, Philippines, Singapore, South Korea, Timor-Leste, Vietnam
NOWPAP	1994	China, Japan, Russia, South Korea
ASEAN Plus Three (APT)	1997	10 ASEAN members include Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, plus 3 cooperation entities: China, Japan, and South Korea

See text for more details

Developed under the United Nations Development Programme, the Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) is an intergovernmental organization operating in East Asia to foster and sustain healthy and resilient oceans, coasts, communities, and economies across the region. PEMSEA's partners include 11 countries, NGOs, scientific institutions, industry, and regional programs. In its implementation plan for 2018–2022, pollution reduction and waste management, including the reduction of marine debris and plastics among PEMSEA countries, is clearly outlined as one of the priorities (p. 14 in PEMSEA [105]).

Additionally, two regional intergovernmental and economic cooperation bodies have also contributed and addressed (1) the management of land and sea-based waste and (2) the study of the impact from marine debris. The Asia-Pacific Economic Cooperation (APEC) recognized the threat from marine debris in 2005 [106]. McIlgorm et al. [107] estimated that marine debris has a direct cost of approximately 1.265 billion USD to the 21 Asia-APEC member economies. Under the APEC framework, there are regular meetings of the Oceans and Fishery Working Group, Oceans Ministerial Meetings, seminars, and roundtable meetings between government officials, academics, NGOs, and industry experts. Furthermore, the Association of Southeast Asian Nations (ASEAN) Plus Three (APT) has offered funding to support several environment fora to enhance the awareness of the issue of marine debris and its impacts [108].

Through bilateral or multilateral agreements and cooperation actions, marine debris has become one of the topics which the Chinese government has embraced in order to work with other countries. Chinese President Xi Jinping visited the United States of America (USA) for the 2015 China-US Strategic and Economic Dialogue, and one of the outcomes was to bring together "Sister Cities" for the prevention and control of marine debris. The first two pairs of "Sister Cities" are New York and Weihai and San Francisco and Xiamen which formed partnerships to implement measures to promote waste collection, management, reuse to reduce, and prevention of mismanaged waste entering the ocean. Another example is the Canada-China Joint Statement on Marine Litter and Plastics in which both countries agreed to forge a partnership to combat marine litter [109]. Through the Joint Statement, both sides acknowledged that plastic pollution resulting from current practices has negative impacts on ocean health, biodiversity, economic sustainability, and potentially human health. Moreover, both leaders recognized the importance of embracing a sustainable lifecycle approach to the management of plastics in order to reduce marine debris.

Laws, regulations, and policies to control marine debris have increased in number over the years (Table 3). The very first Chinese law which dealt with waste management and mitigation of marine debris was implemented as Environmental Protection Law (EPL) in 1989; further waste management laws and regulations were introduced in the 1990s. Plastic waste is considered a type of solid waste and should therefore be managed in accordance with China's solid waste-related legislation under the EPL. Zhang [53] listed further regulations implemented through several amendments of the EPL until 2015. However, one of the crucial measures to curb marine plastic pollution, namely, legislation which regulates source reduction and effective waste recycling, remains weak in China. Compared

Table 3 China's laws, regulations, and policies on plastic waste and marine pollution (information taken from Zhang et al. [53] and Wang et al. [112] and other sources)

Name of law, regulation, or policy	Year issued	Authorized departments
Regulations on the control over dumping of wastes in the ocean	1985	State Council of the People's Republic of China
Environmental Protection Law	1989	Ministry of Environmental Protection
Regulations on the prevention of pollution damage to the marine environment by land-based pollutants	1990	State Council of the People's Republic of China
Implementation measures of regulations on the control over dumping of wastes in the ocean	1990	SOA
Law on the prevention and control of environmental pollution by solid waste	1995	State Council of the People's Republic of China
Marine Environmental Protection Law	1999	State Council of the People's Republic of China
Law on Promoting Clean Production	2003 (revised in 2012)	MEE
Interim provisions on dumping sites management	2007	SOA
Technical specifications on pollution control of plastic waste collection and recycling (trial)	2007	MEE
Law on circular economy promotion	2009 (revised in 2018)	MEE
Measures on the administration of imports of solid waste	2011	MEE, National Development and Reform Commission (NDRC), Ministry of Commerce of the People's Republic of China (MOFCOM), General Administration of Customs of the People's Republic of China (GACC), General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ)
Administrative regulations on the pollution control of plastic waste recycling	2012	MEE
Technical regulations for the monitoring and evaluation of marine litter	2015	SOA
Standard and administrative interim measures on industrial conditions of the comprehensive utilization of plastic waste	2015	MIIT
Latest revision of the law on the prevention and control of environmental pollution by solid waste	2016	MEE
Catalogues of solid waste import management	2017	MEE, MOFCOM, NDRC, GACC, AQSIQ

to other countries who have introduced regulations and bans of plastic bags, primary microbeads in cosmetics, plastic straws, and other single-use items, China has only introduced one plastic bag limitation measure in 2008 [110]. In 2009, the National Development and Reform Commission estimated that supermarkets had reduced plastic bag usage by 66%. However, no reduction of plastic bags in the marine litter was detected, so the ban's effectiveness is doubtful [111]. Furthermore, disposable expanded polystyrene (EPS) food service products were banned in 1999, but the ban was never enforced and then rescinded in 2013 [32].

Since China is a contracting party of relevant international conventions of marine pollution control, the Chinese government has been working to improve national laws, regulations, and policies in order to fulfill the obligations of these conventions (summarized in Wang et al. [112] and CCICED [113]). The Marine Environmental Protection Law issued in 1982 was revised several times in order to incorporate relevant regulations from international pollution conventions, including the Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships 1973 (MARPOL 73/78), the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), and the International Convention on Civil Liability for Oil Pollution Damage (CLC) [114]. This law is China's basic law for the protection of the marine environment, and it provides an overarching framework for pollution mitigation, ecosystem protection, and resource conservation. However, its regulations mainly focus on oil spills and chemical pollution but not on plastic pollution of the marine environment.

Mismanaged plastic waste released into the environment is the main source of marine plastic pollution to the oceans (see Introduction). One effective solution is recycling of plastic waste, but the relevant recycling processes and practices in China developed only slowly in the past two decades. The 1989 EPL already included the concept of waste reduction, recycling, and waste management of household waste [114]. However, local government officials usually care more about economic growth and have lackadaisical attitudes toward supervision and enforcement. Relevant regulation or initiatives on waste management and recycling were introduced slowly and met with a lot of problems and resistance by the public. Furthermore, the limited input of civil society due to the authoritarian structure of the Chinese government means that pressure to enforce environmental laws and regulations is weak and ENGOs, journalists, lawyers, and ordinary citizens are all tightly constrained in what they can do to protect the environment [115, 116].

Since 2000, several local initiatives have tried to improve the separation of recyclable materials from household waste, mostly in big cities such as Beijing, Guangzhou, Nanjing, and Shanghai [117–121]. However, due to the lack of public awareness and weak enforcement and supervision, several researchers and media outlets emphasized that the implementation is not effective [120, 122–126]. Not until 2015 did two critical framework guidelines [127, 128] address the effective implementation of the sorting of household waste and separation of recyclables. Subsequently, the 13th Five-Year Plan [127] and the Implementation Plan of the Household Waste Sorting System [129] clearly outlined the relevant regulations and the sorting system for household waste in 46 key cities. Shanghai was the first city to implement them. The remaining 45 key cities have adopted or are planning action and implementation plans for household waste sorting in the near future [130]. These regulations and actions by the Chinese government sped up the adoption of household waste recycling in these key cities in 2019, with a goal of a recycling rate of 35% by the end of 2020.

As mentioned above, the Chinese government regulated the sale of certain plastic bags in 2008; for instance, since 1 June 2008, the production, sale, and use of plastic bags with a thickness of <0.025 mm is banned [53]. However, there is a great lack of inspection and enforcement. Department stores, retailers, and supermarkets should not offer free plastic bags [130], but many plastic bags are still given out in the food and business industries as well as in private shops and markets [24]. Therefore, some media criticized that this regulation was not effective and that the usage of plastic bags has even boomed after the regulation [131]. The ENGO "China Zero Waste Alliance" also reported that this regulation was not effective when it surveyed 1,101 retailer shops in nine cities throughout China [132].

Since 1992, China has imported a large amount of the world's plastic waste [133]. Since plastic pollution and its impact on oceanic environments have since been widely reported, China's national government and local governments have also been eager to solve the problems of waste recycling [112]. In 2013, the Chinese government launched a 10-month intensive inspection named the "Green Fence Operation" to enforce their import regulations, to crack down on "foreign garbage" smuggling activities, and to seize illegal waste [134]. In 2017, the Chinese government announced its National Sword program in order to crack down on the illegal smuggling of foreign waste into China, especially targeting electronic scrap, industrial waste, and plastics [135] and permanently banned the import of nonindustrial plastic waste [53, 133]. With a short notice to the World Trade Organization, the National Sword program banned the import of 24 types of waste materials from 2018 onward [136]. In 2019, the Chinese government has continued to tighten the regulations on imported waste to more types [137] which caused repercussions around the world [133, 138].

To summarize, Chinese national legislation and policies related to plastics waste were lacking prior to 2008. To respond to the emerging serious environmental problems, the Chinese government has sped up its responses during the last decade. However, public awareness in Chinese society of the impact of plastic pollution remains in its infancy. As Zhang et al. [53] emphasized: "Although many laws and regulations already exist regarding the management and control of plastic waste in China, the implementation of these laws and regulations has been largely ineffective and sometimes difficult." Therefore, there is an urgent need to improve laws, policies, regulations, standards, and enforcement for source control as well as for waste management as well as to better educate the public [112].

Local governments have also increased their efforts to control marine debris. To tackle the marine debris problem, China's coastal provinces and municipalities, including Dalian, Guangzhou, Shanghai, and Xiamen, have been proactively carrying out relevant work to control and dispose sea-based marine litter through an effective control and management system. For example, the Dalian municipal government has collaborated with private environmental protection organizations and has also reinforced the management of port sewage and ship garbage. Each year, they have received >6,000 MT of ship garbage from about 7,800 ships. The Fujian government introduced a special plan of marine environmental sanitation in its harbor city of Xiamen by setting up an offshore ship-based garbage collection system [139].

Furthermore, the Chinese government has recently outlined its determination to eliminate pollution in other kinds of water bodies. In the last few years, the Chinese Ministry of Water Resource and the State Oceanic Administration created the so-called leader systems to enforce the management and protection of rivers [140], bays and beaches [141], and lakes [142]. For instance, there are now about 760,000 so-called River Leaders at different administration levels, and even citizens can join as volunteers to conduct regular patrols along local rivers and lakes. Further actions, such as the inspection of solid waste, protection of riverbanks, removal of garbage, and cracking down on illegal sand dredging, have been implemented since 2017.

Finally, we very briefly reviewed some examples of education, outreach, and media. Founded in 2007, the Shanghai Rendu Ocean NGO Development Center (Rendu) is the biggest Chinese ENGO that focuses on marine debris. As part of its mission to clean the ocean, Rendu has mobilized more than 10,000 volunteers in over 200 beach cleanups over the past 12 years to collect about 26 MT of marine debris from Shanghai's coastline. Moreover, it has become the International Coastal Cleanup (ICC) coordinator in China from 2015 onward and has since invited local communities, NGOs, and private sector participants to join the ICC cleanups in September every year. Together with other NGOs, Rendu has also organized a bimonthly beach monitoring project at 25 coastal spots since 2015, with the findings released in annual reports [143]. One result is that four out of the top five most abundant debris items are made from plastic, the top one being plastic bags [144]. Furthermore, Rendu volunteers presented marine environmental education programs at four primary schools in Shanghai [145].

With regard to the impact from media, local filmmaker Wang Jiuliang and his documentaries "Beijing Besieged by Waste" (2011) and "Plastics China" (2017) were influential. After 4 years of investigation, Wang Jiuliang delivered a set of photographs and the documentary "Beijing Besieged by Waste" to reveal the landfill pollution in Beijing. Later, "Plastics China" traced how plastic waste from across the globe was transported to China. Although Wang achieved fame and various awards, the documentary was never screened in China, and reactions to the documentary soon disappeared from the Internet in China [146]. However, the impact of Wang's work continues to stir up Chinese policy-making behind the scene. For example, Wang later found out that most of the illegal dump sites exposed by him had been closed or turned into legal landfills when he revisited the sites [147]. Within a relatively short time period after Wang had received recognition and awards overseas, the Chinese government announced the import ban for solid waste (the National Sword program; see above). While no official statements confirm the consequences caused by Wang's documentaries, the fact that China has recently moved in the direction of better waste management and improved recycling suggests that his work had significant impacts behind the scenes.

3.2 Japan

3.2.1 Macro- and Microplastic Contamination of the Aquatic Environment

Japan is an island country which is comprised of a stratovolcanic archipelago along East Asia's Pacific coast. It is surrounded by eight ocean currents including the Kuroshio and Tsushima Currents which are part of the North Pacific Ocean gyre. In recent years, marine litter which drifts toward Japan owing to these ocean currents has become a major problem for Japan and a study subject for researchers, ENGOs, and government agencies.

The prominence of plastic materials within the floating marine debris was identified in the late 1990s and early 2000s from surveys of the waters around Japan [148–150] and stranded debris [151–155]. Furthermore, the Fisheries Agency of Japan conducted a Pacific-wide sighting survey of floating marine debris from 1986 through 1991 relevant to the North Pacific Ocean and its adjacent waters [150]. The total debris density in coastal waters was 20–40 objects per square nautical mile, whereas that in the north equatorial current area (5°–15° N, across the central Pacific) was approximately 0.2 objects and that in the subarctic boundary area 1–3 objects. The average marine debris composition was 10% non-petrochemical fishing gear, 60% total petrochemical (including fishing gear, Styrofoam, and other plastic debris), and 30% natural objects (e.g., logs and seaweeds).

Beach litter surveys have been conducted by various organizations in Japan. However, there are few quantitative survey data that can be compared. Since 1996, the Northwest Pacific Region Environmental Cooperation Center (NPEC) in Toyama, Japan, has conducted an international research project on marine litter with municipalities and ENGOs from China, Japan, South Korea, and Russia to comprehend the present situation of marine litter in the Northwest Pacific Region. Specifically, this survey was always carried out at the same time of the year using the same survey method along the coast of the Sea of Japan. To quantitatively evaluate the amount of stranded litter on the beach, 10 × 10 m survey units (100 m^2) were set continuously from the water's edge to the backshore zone of beaches. Generally, two or three lines of survey units were set parallel to the coastal line. In each survey unit, the litter was collected and sorted into categories (namely, plastics, rubber, Styrofoam, paper, cloth, glass/pottery, metals, and other artificial items). For the period from 1996 to 2017, the changes in the amount of stranded debris per unit area in 16 different survey sites located within 9 different locations along the Japanese coastline were investigated [156]. The mean weight of debris was 2,334.6 g per 100 m^2 during the study period (ranging from 1,236.9 g to 4,376.2 g per 100 m^2). "Plastics" made up an average of 62.4% of the total weight of all collected debris (ranging from 54.5 to 71.5%), followed by "other artificial items" at 16.9%. These trends were almost identical over all the years, strongly suggesting that there was no decrease in the amount of marine debris in the study area. Another unique characteristic of the NPEC survey is that it investigated buried litter including plastic debris in the coastal sand. The analytical method was developed by Ogi and Fukumoto [154] who had been concerned about the effects of microplastic on the marine ecosystem, based on the results of a stomach content survey of seabirds [157]. To collect the buried litter, 8 L of sand from a 40 × 40 × 5 (depth) cm space was collected using a box-shaped stainless steel frame (after removing visibly stranded litter on the sand) and placed into a bucket. The sand was then mixed with seawater and stirred, after which the supernatant was filtered with a net (0.3 mm mesh) to collect the floating plastic particles. The plastic particles were put into plastic bags and sent for sorting to the Toyama Prefectural University. The buried litter was identified, classified according to size (from less than 1 × 1 mm to over 10 × 10 mm), counted, and weighed after drying. The mean concentration of buried litter in Japan and Russia in 2000 was 9.03 and 2.70 g per m^2, respectively [155]. The stranded (or non-buried) litter was also quantified, with the mean concentration of stranded litter in Japan and Russia in 2000 being 21.44 and 13.44 g per m^2, respectively. The total weight ratio of buried litter to stranded litter averaged over all 26 sampled beaches was 0.65, indicating the significance of buried litter when evaluating the total amount of litter on beaches. Resin pellets were observed on 12 Japanese beaches, albeit on none of the Russian beaches (such pellets were also detected by Mato et al. [158], Endo et al. [159], and Ogata et al. [160] who measured their toxic chemical contents; see also [161]).

In addition to the above surveys, the ICC is conducted by the Japan Environmental Action Network (JEAN) in Japan. JEAN is a nonprofit ENGO, which works toward environmental preservation of the oceans and rivers by conducting marine litter investigations and cleanup activities. According to the 2017 survey results [162], three (hard plastic fragment, plastic sheet or bag fragment, and PS foam fragment) out of four categories which describe different kinds of fragments were in the top 10 most abundant categories by number (the three categories together added up to 29.1%). Considering the litter sources, the proportion of land-based litter (48.9%) was the highest; the second highest was ocean/river/lake-based litter (19.6%). Moreover, plastic products used for beverages, food, smoking products, etc. accounted for over 90% of the land-based debris. During the 27 years sampled from 1990 to 2017, the proportion of the top 10 items did not alter significantly.

In addition, several coastal surveys [163, 164] were conducted to study the sources and geographical distribution of beach debris. For example, the likely sources of marine debris that drifted onto Japanese beaches were studied using disposable lighters as indicators [163]. From August 2003 to May 2004, 6,609 lighters were collected from 120 beaches by nationwide beach combers. Chinese-made lighters accounted for over half of those collected in coastal areas from Yonaguni Island (Okinawa) in the south to Yaku Island (Kagoshima) in the north. Moreover, they accounted for approximately 10–20% of the lighters observed along the coast of the Sea of Japan from Kyushu in the south to Yamagata in the north. South Korean lighters accounted for about 10% in the coastal areas from Okinawa to west of Kyushu, but accounted for >50% of the lighters observed on the coast of the Sea of Japan from Shimane to Fukui which are geographically closer to South Korea. Japanese lighters accounted for >90% of all lighters along the coasts of the Seto Inland Sea and Tokyo Bay and at the Pacific coast north of Shikoku. Lighters from other countries were observed in the coastal areas of Guangdong and Zhejiang (in China) and across South Korea and Taiwan. By studying these lighters, various connections between discharge and flow could be identified.

The Japanese Ministry of the Environment (MOE) conducted a beach survey to establish measures to reduce and collect the marine debris [164]. Eleven coastal locations were selected from seven prefectures as model sampling areas. The coastal debris was surveyed for about a year from October 2007 to September 2008. Based on the country-wise survey of stranded debris using the language descriptions on plastic bottles as an index, many bottles found on remote islands, such as Iriomotejima (54% foreign, 6% Japanese, unidentified 40%), Ishigakijima (47% foreign, 8% Japanese, unidentified 45%), and Tsushima (62% foreign, 16% Japanese, unidentified 22%), likely originated from foreign countries. However, in other areas, the percentages of bottles from Japan were >50% to almost 100%. Based on the examination of the proportion (by weight) of different materials, plastics accounted for 30–40% on the Sea of Japan side. However, natural objects (driftwood and shrubs) accounted for 70–90% depending on the region. The above surveys revealed the following issues. On remote islands, disposal of collected marine debris may not be feasible owing to the inadequate capacity of incineration facilities. In addition, the disposal costs of collected debris were a significant financial burden on these municipalities. Based on the results of these surveys, a new law was enacted to subsequently combat marine debris (see Sect. 3.2.2).

As shown in the previous studies, the majority of marine debris was comprised of plastic, and many fragments were derived from these plastic products. As research on marine debris issues has progressed worldwide, the impact of smaller plastic fragments (or microplastics) on ecosystems has attracted increased attention. In particular, after microplastics were defined by Arthur et al. [165], microplastics in Japan were detected in the oceans [166], rivers [167], sediment [168], and fish [169, 170].

To investigate the concentrations of pelagic microplastics (<5 mm in size) and mesoplastics (>5 mm) in the East Asian seas around Japan, field surveys using two vessels were conducted in the summer 2014 [166]. The total particle count (pieces per km^2) was computed based on the observed concentrations (pieces per m^3) of small plastic fragments (both micro- and mesoplastics) collected with neuston nets. The total particle count of microplastics within the study area was 1,720,000 pieces per km^2, which was 16 times higher than documented for the North Pacific and 27 times higher than in the oceans worldwide. The proportion of mesoplastics increased upstream of the northeastward ocean currents; therefore, the small plastic fragments collected likely originated in the Yellow Sea and East China Sea southwest of the study area.

The distribution of microplastics in 18 Japanese rivers was investigated by Kudo et al. [167]. The magnitude of the density of microplastics in the rivers (0.0064–2.5 pieces per m^3) was an order of magnitude lower than that in the sea near Japan (0.6–4.2 pieces per m^3). With the decrease in size, the number of microplastics increased. The proportions of microplastics less than or equal to 1 mm and 2 mm accounted for about 50% and 80% of all microplastics collected, respectively. PE and PP accounted for over 70% of all microplastic particles.

Matsuguma et al. [168] extracted microplastics from sediment cores collected in Japan, Malaysia, Thailand, and South Africa and used density separation after hydrogen peroxide treatment to remove biofilms. The microplastics were identified using Fourier transform infrared spectroscopy (FTIR). Most of the microplastics were in the range 315 μm–1 mm. The abundance of microplastics in surface sediments varied from 100 pieces per kg of dry sediment in a core collected in the Gulf of Thailand to 1,900 pieces per kg of dry sediment in a core collected in a canal in Tokyo Bay. The significantly higher numbers of PE and PP microplastics found in sediment samples compared to those found in surface water samples collected in a canal in Tokyo Bay suggested that sediments are an important sink for microplastics. In dated sediment cores from Japan, microplastic pollution started in the 1950s, and microplastic numbers increased markedly toward the surface layer corresponding to the 2000s. In all sediment cores from Japan, Malaysia, Thailand, and South Africa, the abundance of microplastics increased toward the surface which is of course linked to the global increase of oceanic microplastic pollution over time.

Microplastics in the digestive tracts of Japanese anchovies (*Engraulis japonicus*) sampled in Tokyo Bay were detected in 49 out of 64 (77%) individuals, with 2.3 pieces on average and up to 15 pieces per individual [169]. Polymers identified by FTIR were again mostly PE (52.0%) and PP (43.3%). Most microplastics were fragments (86.0%), but 7.3% were beads, a few of which were microbeads similar to those found in facial cleansers (microbeads in coastal waters make up at least 10% of all microplastics; see [171]). 80% of the microplastics ranged in size from 150 to 1,000 μm, which is smaller than the reported size range of floating microplastics on the sea surface. The reason may be that the anchovy forages not near the sea surface, but in subsurface waters where microplastics may have a different size range. Since *Engraulis* spp. are an important food for many humans and other organisms, microplastics and their contaminants could thus enter the food chain.

Ushijima et al. [170] documented microplastics >100 μm in seven fish species from five Japanese bays and Lake Biwa. A total of 140 microplastic particles were observed in the digestive tracts of 37.6% of the investigated 197 fishes. All the species (except *Sardinella zunasi*) had ingested microplastics in all the sampled locations, and the mean number of microplastic particles was 1.89 ± 1.41 per fish. The most abundant polymer types were again PP (40.7%) and PE (35.0%). The median size of microplastic particles was 543 μm. The fish species were divided into filter feeders and others on the basis of their ingestion mode. 54.6% of 97 individuals of filter feeders had ingested microplastics, with the total number of particles being 112 and the mean number of microplastics per fish being 2.11 ± 1.54. In contrast, only 21.0% of 100 individuals of the other (non-filter feeding) group had ingested microplastics, with the total number of particles being 28 and the mean number of microplastics per fish being 1.33 ± 0.80. These differences indicated that the ingestion mode influences a fish's ingestion of microplastics.

Recent surveys indicated that microplastics are universally present in the aquatic environment of Japan, including seas, bays, rivers, sediments, and fishes. Moreover, the amount has undoubtedly increased in recent years. It is therefore pertinent to understand how the future will unfold.

The secular variations in the pelagic microplastic abundance in the Pacific Ocean from 1957 to 2066 were predicted based on a combination of numerical modeling and transoceanic surveys conducted meridionally from Antarctica to Japan [172]. The results of the numerical model incorporating removal processes on a 3-year timescale indicated that the weight concentrations of pelagic microplastics around the subtropical convergence zone would increase approximately twofold and fourfold by 2030 and 2060, respectively. Therefore, extensive and strenuous efforts to reduce plastic emissions are crucial in order to reduce the impact of plastic pollution in the future.

3.2.2 Mitigation Efforts to Decrease the Plastic Pollution

In the past, municipalities and voluntary groups mainly collected stranded debris on beaches, but little effort was made at source reduction. However, as mentioned in Sect. 3.2.1, the presence of marine litter including plastics became a pressing environmental issue for Japanese society. Therefore, the Act on Promoting the Treatment of Marine Debris Affecting the Conservation of Good Coastal Landscapes and Environments to Protect Natural Beauty and Variety was passed in 2009 [173]. Since then, the Japanese government has been working extensively on marine litter issues. The MOE has promoted the following activities: (1) collecting and preventing marine litter on Japanese coasts, (2) monitoring the amount and distribution of marine litter (including microplastics) and the toxic substances in it on Japanese coasts and in the seas around Japan, and (3) collaborating internationally with other Asian countries as well as global international frameworks to address marine litter. The Japanese government provided approximately 16 billion JPY of financial support to local governments from fiscal years 2009 to 2015, and approximately 190,000 MT of beach litter was collected and processed nationwide. From fiscal years 2016 to 2018, approximately three billion JPY were provided annually to support marine litter collection and treatment as well as generation control measures in each region. In June 2018, the Act was partially amended, and efforts to combat the problem of microplastics have now been included into it.

As described in Sect. 3.2.1, it was evident that the majority of marine debris collected around Japan was plastic. Furthermore, it was estimated that 20,000–60,000 MT of plastic waste was released from Japan into the ocean annually [10]. The amount of plastic containers and packaging consumed per capita in Japan is the second highest after that of the USA [7].

Meanwhile, the plastic waste generated in 2013 in Japan was 9.4 million MT, with a recycling rate of only 24.8% (material recycling and chemical recycling) and a heat recovery rate of 56.8%, yielding an effective utilization of 81.6% [174]. However, because some of the 24.8% recycling rate was achieved not by domestic recycling but by exporting the plastic waste, import bans in China (see Sect. 3.1.2) and other countries from 2018 onward compelled the establishment of a domestic resource recycling system.

It is evidently necessary to adopt comprehensive measures to address plastic production and pollution, including generation control. At the 2018 G7 Charlevoix Summit in Canada, the “Ocean Plastic Charter” was proposed. However, the Japanese government did not sign it because “Domestic laws had not been prepared” and was subsequently criticized by Japanese ENGOs [175]. One reason is the complete absence of any national bans on single-use plastics in Japan.

In 2019, the Japanese government formulated the “Resource Circulation Strategy for Plastics” as a comprehensive approach to plastics [176]. The fundamental principle of this strategy is “3R + Renewable” (through the implementation of 3R and replacement with renewable resources). It includes (1) reusing or recycling all used plastics by 2035; if this is challenging from technical and economic perspectives, then realize a 100% effective use which includes heat recovery through collaboration with various national parties, (2) doubling the recycling of plastic (use of recycled materials) by 2030, (3) substantially reducing microbeads in washing and scrubbing products by 2020, and (4) reusing or recycling 60% of plastic containers and packaging by 2030. The quantitative targets in this strategy are similar to those of the G7 “Ocean Plastic Charter.”

In September 2019, the MOE set up a subcommittee in order to consider legislation for banning the free distribution of plastic bags so that they would need to be purchased instead in 2020 at the earliest [177]. On a more local level, 19 prefectures have been promoting payments for plastic bags through agreements or registration with business operators, and some municipalities are pushing for charges by ordinance.

In response to these movements, various efforts are being undertaken by industries and local governments. These include improvements in the recycling and reuse of plastic packaging materials for in-house products, non-use/suppression/reduction of one-way plastic products used in the organization, and use of paper/wooden straws rather than plastic straws. In the retail industry, shopping bags are being abolished (or charged), and/or usage is being reduced [174].

Furthermore, the following efforts have been undertaken for reducing microplastics. The Plastics Industry Federation and other plastic-related organizations prepared a resin pellet leakage prevention manual [178] and called on the industry to prevent leakage. Nevertheless, resin pellets have since been detected in domestic surveys [155]. Therefore, more thorough implementation is essential. In March 2016, the Japan Cosmetic Industry Association called on 1,100 member companies to voluntarily regulate microbeads. In a survey conducted in 2016, 150 products of facial cleansers and body soaps were purchased as personal care products. Moreover, it was checked for each product whether it correctly indicated on its label whether it contained microbeads or not [179]. From this analysis and the component labeling, it was ascertained that there were two types of face wash among the 150 products which evidently contained microbeads. Because of this relatively low number, it is concluded that the self-regulation of companies with regard to microplastics was progressing.

As described above, substantial efforts in Japan are based on the actions and self-regulation by industries, local governments, and individuals rather than on legal regulations. Therefore, achieving the goals of the "Plastic Resource Recycling Strategy" will continue to be a significant challenge.

3.3 South Korea

3.3.1 Macro- and Microplastic Contamination of the Aquatic Environment

The first studies investigating macro- and microplastic pollution in South Korea were published by Lee et al. [180] and Lee et al. [181], respectively. Subsequently, researchers from South Korea have reported some of the highest levels of ocean microplastic contamination in the world along the country's southern and western coasts [22] and southern coasts [23], as well as in its sandy beaches [21], thus further establishing that the oceans and seas in East Asia are among the world's most polluted (see Introduction).

We first reviewed marine and river plastic pollution. Lee et al. [180] determined the types, quantities, and distribution of marine litter items (categorized into 14 types) pulled up with bottom trawl nets from the seabed of the East China Sea and the South Sea of Korea during 1996–2005 cruises. Litter densities were higher in coastal seas than in the open sea. Fishing gear items, such as fishing lines, nets, octopus jars, and pots, predominated while the contributions of other items, such as clothing, glass, metal, plastic, rubber, vinyl, and wood, remained mainly below 30%. Floating debris sampled in the southeastern sea of Korea south of the Nakdong River Estuary in 2012 resulted in microplastic particles being found at all 20 sampling points, whereas Styrofoam particles only peaked at a few stations far from the Nakdong River Estuary [182]. The dominant particle types were fibers (PES), hard plastic (PE), paint particles (alkyd), and EPS, while less prevalent types were films, pellets, and other foamed plastic materials. There was large spatial and temporal heterogeneity in the samples. Kim et al. [183] estimated the quantity of discarded fishing traps and gill nets in South Korea's coastal waters to be about 11,436 MT and 38,535 MT, respectively.

Chae et al. [22] sampled ocean waters near Incheon harbor in 2013 and found that the microplastic abundance was greater in the ocean's surface microlayer than in the underlying surface seawater and that most of these microplastics originated from ship paint particles (a result mirroring the findings from Song et al. [184]). Song et al. [23] also sampled ocean waters in Jinhae Bay in southern South Korea in 2013 and also found that fragmented microplastics, which included paint resin particles derived from ship paints, accounted for 75% of all particles, followed by spherules, fibers, EPS, and sheets. Song et al. [185] sampled ocean waters in eight coastal areas along almost all parts of South Korea's coastline in 2016–2017 in order to determine the vertical distribution and composition of microplastics >20 μm. The mean microplastic abundance was 871 particles per m^3, was significantly higher in the surface water (0–0.2 m) than in the underlying water column (3–58 m), and was significantly lower near rural than near urban areas. The predominant polymers were PP and PE.

The microplastics (>20 μm) in the Nakdong River itself were sampled in 2017 at three sampling points each in the upstream, midstream, and downstream parts of the river in order to determine their spatiotemporal distribution [186]. The mean microplastic abundance ranged from 293 ± 83 (mean ± S.D.) particles per m^3 in water in the upstream part to 4,760 ± 5,242 in the downstream part. PP and PES accounted for 42% and 23% of all particles in the water, respectively, followed by 28 other polymer types all with <5%. PP and PE accounted for 25% each of all the particles in the sediment, respectively, followed by 20 other polymer types all with <6%. Microplastic particles >300 μm accounted for 74% and 81% in the water and sediment samples, respectively, and the distribution peaked in the 50–150 μm size range. The authors estimated that the annual load of microplastic particles in the river in 2017 was between 5.4 and 11.0 trillion particles weighing between 53.3 and 118.0 MT. Finally, most particles were detected in the wet season, making up 71% in number and 81% in weight.

As shown in numerous studies, the ocean-based pollution can then enter the marine food web. Jang et al. [187] showed that some of the Styrofoam microplastics found in oceans and coastal areas originate from polychaete worms burrowing into Styrofoam debris, especially Styrofoam buoys. These findings suggest that microplastic formation from larger plastic items is due not only to physical or chemical processes [188] but also to biological activities (see also Davidson [189]). Another source of marine microplastics was illuminated by Lee et al.'s [190] study of the percentage of microplastics released by three different kinds of sewage treatment facilities. While they all had treatment efficiencies of about 98% or more due to the large amount of effluent, more than four billion microplastic pieces were released annually from each facility into marine environments. However, many sources and pathways of marine plastic pollution remain unclear. Using a mass balance approach, Kim et al. [191] estimated that the total unaccounted mass of high- and low-density PE in the marine environment from 1995 to 2012 was 28 MT and that the corresponding contribution to marine plastic debris would be approximately 25,000 MT.

South Korean researchers also studied the effects on the biota. Hong et al. [192] found that 21 marine species had been affected by marine debris, including birds, mammals, and one crustacean. To assess the potential impact of microplastics on zooplanktivores, Kang et al. [193] measured the abundance ratio of neustonic microplastics to zooplankton in Geoje eastern Bay and Jinhae Bay, both in the southern sea of Korea, in 2012–2013. The mean microplastics to zooplankton ratios were higher during the earlier dry than during the later rainy season in both years. The authors suggested that zooplanktivores could confuse microplastics with prey items and that this risk is higher in the dry season. Another study by Cho et al. [30] demonstrated unequivocally that certain marine organisms take up microplastics from their environment. Since bivalves are known to accumulate microplastics when they filter large volumes of seawater, the authors examined four popularly consumed bivalve species bought in markets in three major cities in 2017. The four species, namely, Manila clam (*Tapes philippinarum*), mussel (*Mytilus edulis*), oyster (*Crassostrea gigas*), and scallop (*Patinopecten yessoensis*), account for ~80% of total shellfish consumption on South Korea. They found about one microplastic particle per examined individual, whereby particles smaller than 300 μm were the dominant size. The dominant polymers were PE, PP, PS, and PES. This level of contamination was estimated to lead to a mean annual microplastic intake of 212 particles per year for the average South Korean person.

We then reviewed coastal plastic pollution. Marine debris sampled by volunteers on 20 beaches along all parts of South Korea's coastline in 2008–2009 was used to assess the levels of debris pollution and to identify its main sources [194]. The number of items, weight, and volume of marine debris per 100 m of beach was estimated to be 480.9 ± 267.7 (mean ± S.D.) items, 86.5 ± 78.6 kg, and 0.48 ± 0.38 m^3, respectively (cf. estimates for Japan and Taiwan in Walther et al. [29]). Plastics and Styrofoam made up most of the debris composition both in terms of number (66.7%) and volume (62.3%). The main debris sources were assumed to be fishing activities and marine aquaculture, followed by recreational activities along the shoreline. Less than 6% was related to other sources such as smoking, illegal dumping, and medical and hygiene products.

Heo et al. [195] investigated the spatial distribution of small plastic debris on Heungnam beach in 2011. They determined the abundances of small plastic debris items (>2 mm) along the high strandline and the cross-sectional line of the beach. The mean item abundances were 976 ± 405 (mean ± S.D.) items per m^2 at the high strandline and 473 ± 866 particles per m^2 at the cross-sectional line. Styrofoam items accounted for 91% of the total abundance at the high strandline and 96% at the cross-sectional line, while less prevalent types were plastic fragments, pellets, and intact items. Furthermore, there was large spatial heterogeneity among the sampled high strandline and cross-sectional quadrats.

Plastic debris sampled on six beaches near the Nakdong River Estuary in 2012 was placed into three size categories, namely, macroplastics (>25 mm), mesoplastics (5–25 mm), and large microplastics (1–5 mm) [181]. In 1 m^2, the researchers found on average 1 macroplastic, 238 mesoplastic, and 17,906 microplastic particles, with Styrofoam being the most abundant meso- and microplastic debris item, while intact plastic items were most common in the macroplastic debris. All three size categories exhibited significant and positive correlations with each other. Microplastic particles sampled on three beaches on Soya Island west of Seoul in 2013 determined a very high microplastic abundance of 46,334 ± 71,291 (mean ± S.D., range 56–285,673) particles/m^2 [196]; at the time, it was one of the highest levels reported globally. The most prevalent polymer type was PS. Jang et al. [197] sampled 752 plastic debris items (>25 mm) from six beaches along almost all parts of South Korea's coastline in 2013 in order to determine the debris' sources. The items were mostly made of fiber and fabric (55%) but also hard plastic (16%), Styrofoam (12%), film (11%), foamed plastic other than Styrofoam (3%), and other polymers (3%). 56% of all the collected items appeared to be ocean-based while the remainder was land-based.

Plastic debris sampled on 12 beaches along almost all parts of South Korea's coastline in 2013–2014 showed the increasing abundance of particles as particle size decreases. In 1 m^2, Lee et al. [21] found on average 1 macroplastic (>25 mm), 37.7 mesoplastic (5–25 mm), and 880.4 microplastic (1–5 mm) particles, with Styrofoam and fibers being the most abundant types. Unlike Bancin et al. [28] in Taiwan, Lee et al. [21] detected no significant differences between the particle abundances in the high strandline and the backshore for any of the three size groups. Plastic debris sampled on 20 sandy beaches along all parts of South Korea's coastline in 2016 demonstrated the highly heterogeneous distribution of microplastic abundance between beaches [198], with abundances of large microplastics (1–5 mm) ranging from 0 to 2088 particles per m^2 and small microplastics (0.02–1 mm) ranging from 1,400 to 62,800 particles per m^2. Again, abundance increased with decreasing particle size. The main polymers were EPS, PE, and PP. Some of the plastic abundances showed positive relationships with human population, precipitation, abundance of macroplastic debris on the beach, and proximity to a river mouth (this last result was mirrored in Taiwan by Bancin et al. [28]).

Mesoplastic marine debris (5–25 mm) sampled on 20 sandy beaches along all parts of South Korea's coastline from March to May 2016 (Won Joon Shim, in litt. 2019) determined that the mean mesoplastic abundance was 13.2 items per m^2 and the mean weight was 1.5 g per m^2 [199]. Hard plastic (32%) and Styrofoam (49%) were the dominant types by number, but their proportions were highly variable among the beaches. Furthermore, there was large spatial heterogeneity among the beaches both in terms of the number and weight of mesoplastic particles.

Relatively little is still known about how the influx of plastic debris may enhance the spread of toxic chemicals into the aquatic environments of East Asia. Therefore, Jang et al. [200] examined the levels of a flame retardant, namely, hexabromocyclododecane, in EPS which is the predominant marine debris originating mainly from fishing and aquaculture buoys. Marine debris samples of EPS were obtained from buoys and microplastics collected along the South Korean coast from 2013 to 2015 as well as from 12 other countries in the Asia-Pacific region. Hexabromocyclododecane was detected extensively in the examined samples which suggest that this hazardous flame retardant may contaminate aquatic environments and food webs worldwide via the marine debris route.

3.3.2 Mitigation Efforts to Decrease the Plastic Pollution

We first reviewed relevant governmental policies and waste management (see also Chen [35] who reviewed South Korea's initiatives on marine litter which began in 1999).

A new branch of the Ministry of Ocean and Fisheries (MOF) was created in 2000, the Korea Marine Environment Management Corporation (KOEM), which is categorized as a public sector organization. Its goals are to efficiently promote the conservation, management, and improvement of the marine environment, as well as marine pollution control, in order to ensure a clean and rich marine environment in the future [201]. In 2013, KOEM estimated the annual inflow and existing volume of marine waste in South Korea in its “2nd Framework Plan for Marine Waste Management” [202]. Jang et al. [203] estimated that 91,195 MT of marine debris (which includes plastic debris) enters the marine environment annually (of which 36% is from land-based sources and 64% from ocean-based sources). The total stock of marine debris on all South Korean coasts in 2012 was estimated to be 152,241 MT (8% on all coastlines, 90% on the seabed, and 2% in the water column). KOEM also estimated that 44% of the total marine waste was collected (probably through cleanup activities) but that the remaining 56% leaked into the marine environment where it may decompose if the waste is biodegradable [202].

To monitor the ongoing situation, the MOF organized 40 local governments and KOEM to monitor marine debris in the ocean waters along South Korea’s coastlines every 2 months [202]. During the six surveys conducted in 2016, 68,421 items were collected, which weighed 11,836 kg and had a volume of 65,404 L [202, 204]. These items were collected in 40,100-m sections distributed all along the South Korean coastline; each section was then subdivided into 20 5-m-wide transects whereby each transect begins at the water’s edge at low tide and ends at the first barrier at the back of the shoreline, and 4 out of the 20 transects were then randomly chosen for sampling according to the methods outlined by Opfer et al. [205]. Therefore, the total sampled length was 4 km × 0.2 = 0.8 km. 56.5% of the 68,421 items were made from plastic and 14.4% from Styrofoam; the remaining 29.1% were other types [202]. Plastic and Styrofoam items were also the two greatest types by weight and volume [202]. Naturally, some of that waste does not originate from South Korea but from other neighboring countries and even some Southeastern countries [202].

A number of studies have addressed possible policy and technological solutions. Cho [206] described the generation of sea-based marine debris in South Korean coastal waters and some of the resulting environmental and economic problems. Even though the South Korean government continuously removed marine debris, the generation of marine debris needed to be prevented. Therefore, the government initiated an incentive program for fishermen to collect fishing gear or other marine debris while fishing. The program paid 9.3 million USD for 11,000 MT of collected marine debris from 2003 to 2006. Jung et al. [207] described practical engineering approaches and infrastructure which address the problem of marine debris in South Korea. These changes began in 1999 with a nationwide 10-year project called “A Practical Integrated System for Marine Debris” which developed fundamental changes to the infrastructure and consisted of four linked types of technology: prevention, deep-water survey, removal, and treatment (recycling). Together, they reduced the generation and improved the retrieval of marine debris pollution. Hong et al. [208] evaluated the cost efficiency of three management measures to reduce the pollution from derelict fishing gears and suggested that the current management measures need to be reorganized to improve preventive measures.

The increasing scientific knowledge about the plastic pollution problem as well as the resulting media coverage led to rising public awareness. Choi and Lee [209] enumerated the willingness of Seoul residents to pay for removing the microplastics in the ocean. According to their survey, most South Korean people voiced their concern about microplastic pollution, favored the implementation of progressive government policies to control it, and would be willing to pay some money for it. Another study conducted at the request of Greenpeace (GP) interviewed 1,000 South Korean adults [210]. 86% of the respondents agreed that the self-regulation of companies was lacking and therefore was not working. As a result, this study emphasized the need for compulsory regulations by the government as well as the expansion of environmental risk studies. It also outlined possible ways to manage plastic pollution and separated them into the following strategies: risk management standards setting, expansion of plastic recycling policies, stricter legal regulations and reinforcement of governance, and collaborations with private organizations or research institutes.

With the public increasingly favorable toward decisive action, actual action by the government was then triggered, as is often the case, by a crisis moment. The significant event in this case was the "waste crisis" in the Seoul Metropolitan area in April 2018 which occurred because the private recycling companies declined to collect waste plastics from residential districts, the reason being that they could not make a profit anymore [211–213] because of China's import ban (Sect. 3.1.2) [214]. This "waste crisis" forced the government to come up with solutions which would prevent this problem from happening again [212].

The South Korean government had already enacted the "Framework Act on Resource Circulation" (which is a set of laws that promote sustainable development and proper waste disposal) in 2016 which was enforced in January 2018 [212, 215]. Under this general framework and in response to the waste crisis, the "Basic Plan on Resource Circulation (2018–2027)" was subsequently established in order to set up the mid- to long-term policy goals and strategies [212], and the government also set up a "Comprehensive Measure of Waste Recycling" which aims to reduce plastic waste by 50% and raise the plastics recycling rate to 70% by 2030 from the current 34% rate [211, 216]. With these policies and regulations, the government aimed to establish a "comprehensive system of resource cycling" all the way from production to consumption to management and recycling, thus reducing waste generation, promoting the recycling of high quality waste materials, and optimizing community-based waste management by participatory governance [212]. In contrast to current government policies centered on recycling existing waste, these new laws and regulations aim to reduce waste throughout production, consumption, management, and recycling. Furthermore, the government wants to completely eliminate consumer use of disposable products and restrict excessive packaging [215]. All these new measures are attempts by the current government to aggressively address environmental sustainability because domestic waste generation has continued to grow at alarming rates; in 2016, South Korea produced 156 MT of waste which constituted a 30% rise over 2006 [215].

Since the government introduced these measures, several central administrative agencies (Ministry of Environment (ME); MOF; South Korean Coast Guard; Ministry for Food, Agriculture, Forestry and Fisheries; Ministry of Food and Drug Safety) have begun to manage plastic pollution [210]. The government also announced it would raise financial support for recycling firms by 1.7 billion won [217]. Another part of these efforts is some recently introduced bans on single-use plastics (see below).

We now specify the work of three different government ministries and their efforts to introduce policies to prevent plastic pollution.

Ministry of Environment (ME) Since 2003, the ME has implemented a "producer liability recycling system" by supplementing and improving the waste deposit system that has been in operation since 1992 [202]. This system commits producers to a recycling obligation and levies a non-compliance charge onto producers who do not oblige [202]. According to the standards set by the ME, the mandatory recycling rate for marine products of fish farming (much of it Styrofoam buoys) was 28.1% in 2015 [202], but even this relatively low rate was not achieved in 2015 when only a 23% recycling rate was achieved. Specifically, the fish farming industry used 2026 MT of products, but only 465 MT (23%) were recycled [202]; the remaining 1,561 MT were assumed to have leaked into the ocean [202]. This rate is certainly much lower than the average recycling rate of 61.8% for other plastic items [202].

In May 2018, the ME announced its long-term plan to reduce plastic waste by 50% by 2030 and also that it partnered up with 21 of South Korea's largest cafe and fast-food franchises which promised to make disposable cup material more recycle-friendly and to encourage reusable cup usage by offering 10% discounts for customers who bring their own cups [214, 218] (Taiwan implemented such a discount system in 2011). Action was partially triggered by a comprehensive report found that the number of single-use cups disposed annually had jumped from 19.1 billion in 2009 to 25.7 billion in 2015 [214].

Consequently, the ME banned single-use plastic cups in coffee shops and fast-food shops for in-shop diners (but not take-out diners) in 2018 [214, 217] and plastic bags (with some exceptions for frozen products and wet products, such as fish, meat, tofu, some fruits, and vegetables) at bakeries, department and discount stores, and large (but not small) shopping malls and supermarkets in 2019 [219–221]. Approximately 13,000 supermarkets are affected and are now required to offer customers reusable or recyclable cloth or paper bags. Smaller-sized stores, traditional markets, and bakeries can still provide single-use plastic bags but must charge for them. The cup ban led to a 72% decrease in usage by May 2019, although some shops simply replaced them with single-use paper cups, while other shops actually switched to multi-use cups; plastic bottles, lids, and straws were not banned [214]. Therefore, the ME has recently reviewed the possibility of extending the ban to also apply to single-use paper cups and plastic straws [214]. The ME also announced in July 2019 that all government offices would stop using single-use cups [218]. In 2020, the government will enforce that all plastic beverage bottles must be colorless and transparent for better recycling and that plastic straws will be included into the products which must then be recycled [211].

Ministry of Food and Drug Safety [202] On 29 September 2016, this ministry revised the "Regulations on Safety Standards for Cosmetics" which redefined the term "microplastic" and banned it as an ingredient of cosmetics. Therefore, cosmetics which contain microplastics (defined by the regulation as solid primary plastic particles of <5 mm length, which thus includes microbeads which are <1 mm length) have been banned from being manufactured or imported since July 2017. In July 2018, their sale was also banned. However, this regulation only applies to cleanser or scrubbing products which only account for 0.56% of total cosmetic sales. All other cosmetic products (e.g., makeup products) which include microplastics actually make up 24.5% of total cosmetic sales. Therefore, only 2.3% of cosmetic products which contain microplastics are currently regulated. In January 2017, the "Regulations on Permit, Report and Review of Medical Supplies" was also partially revised which banned medical supplies that include microplastics from being manufactured or imported; in July 2018, their sale was also banned.

Ministry of Ocean and Fisheries (MOF) The MOF, the Korea Institute of Ocean Science and Technology and the Korea Institute of Marine Science and Technology Promotion have been conducting research about microplastics and their impacts since 2011; many conclusions and recommendations from this research were summarized in "The Second National Marine Litter Management Plan (2014–2018)" [202] and "The Third National Marine Litter Management Plan (2019–2023)" [222].

The aims of the Second National Marine Litter Management Plan (2014–2018) were to minimize the occurrence of marine waste, to strengthen public projects of collecting marine waste, and to establish a scientific infrastructure and policies which deal with marine waste [202]. The specific strategies were (1) intensive management of sources of marine waste (68.5 billion won); (2) strengthening marine waste collection projects which focus on the daily lives of people (2385.3 billion won); (3) building a basic management system for marine waste (199.7 billion won); and (4) education and promotion for various targets (e.g., education of fishermen, plastic product companies, students, household recycling, etc.) (49.3 billion won) [202]. Each strategy was then subdivided into four to six initiatives [202].

The MOF planned to establish a basic plan of fishery management regulation every 5 years which includes regulations relevant to marine plastic pollution [202]. For instance, "The Third Fisheries Management Basic Plan (2017–2021)" was published in 2017 which aimed to make it mandatory to only use eco-friendly buoys not made from Styrofoam for fish farms, ensure sustainable yields from ocean fishing, and introduce new certification standards for improved fishery materials and equipment, e.g., to reduce and regulate the use of toxic materials [202] (see also how participatory workshops were held to develop policy ideas and solutions to the Styrofoam buoy debris problem in Lee et al. [223]). "The Third Fisheries Management Basic Plan" contains 3 major initiatives, 9 main tasks, and 25 detailed tasks and has a total budget of 172.4 billion won [202].

We next reviewed some examples of education, media, monitoring, and outreach campaigns by ENGOs. On 14 July 2016, GP Seoul released a joint statement with six other ENGOs (Citizens' Institute for Environmental Studies, Environmental

Justice Foundation, KFEM Ocean Committee, KWEN, OSEAN, WWF) [224] which urged the government to come up with a bill banning microplastic "microbeads" in cosmetic and household goods [224]. Below, we reviewed the campaigns for a microbead ban of three important ENGOs (which was implemented in 2017; see above). Park et al. [224] suggested that ENGOs should consider expanding their topics and campaigns to improve people's awareness of plastic pollution and to push companies and the government to reduce plastic pollution.

The *Korean Women's Environmental Network (KWEN)* [224] is the first ENGO in South Korea to launch activities about microplastic pollution. KWEN is a member of the "Beat the Microbeads Campaign of Plastic Soup Foundation." This is an ENGO of women activists founded in 1999 which cares about the environment in order to achieve an equal and sustainable society. Under the theme of "Eco Cosmetics," KWEN headed a campaign called "Plastic Ocean: Face to Fish" to ban microbeads from cosmetics and personal hygiene products; it also released a list of microplastic-containing cosmetics on its website based on a survey of cosmetics sold in South Korea.

Greenpeace (GP) [224] is a global ENGO, is a member of the "Break Free From Plastic" movement and has participated in a campaign called the "International Plastic Bag Free Day." "Break Free From Plastic" is one of the most active movements campaigning against plastic pollution. Since its launch in September 2016, "Break Free From Plastic" has been joined by more than 1,000 NGOs from around the world, including GP, with the aim of reducing disposable plastic debris and ultimately resolving the plastic pollution problem. The GP East Asia Office published a report about the use of microbeads in cosmetics and personal hygiene products produced by different companies, and it has led consumer movements to pressure these companies. The GP Seoul branch has also led many consumer campaigns, including the aforementioned joint statement with six other ENGOs, and it has three plastic-related activities among its 12 main activities.

The *Our Sea of East Asia Network (OSEAN)* is also a member of "Beat the Microbeads Campaign of Plastic Soup Foundation" [202] and registered under MOF [225]. OSEAN focuses on solutions to marine environmental problems, with a special focus on the marine waste problem [225]. Their three main activities are research, education and promotion, and cooperation with other groups (e.g., with international groups which campaign against marine debris, groups working for ocean protection, citizen groups, marine environmental groups, etc.) [225].

Finally, we reviewed the efforts of some South Korean inventors and businesses who have developed alternative products and methods of production and recycling. Producers can alleviate plastic pollution in two ways: either by reducing the use of plastics or by producing alternative products, e.g., made from biodegradable materials [224]. Since the 1990s, research institutes, major established companies, and venture companies have been researching biodegradable plastics; however, the market scale remains small in South Korea because these alternative materials remain too expensive [226]. As a result, the South Korean domestic market for these products is $<2\%$ of the total global market for biodegradable plastics [226]. Therefore, the development of the South Korean bioplastic technology is underdeveloped compared to that of many other developed countries. Most South Korean companies do not have sufficient technological know-how or investment to be able to fulfill the rather strict standards which the government has imposed on biodegradable products; and even if the companies can fulfill the standards, profits remain poor. To improve profits, the government has recently eased their standards but still profits are not good, so bioplastic products are not being commercialized.

The *Samyang Genex Corporation* [227] was the first company in South Korea to produce a bioplastic made from corn called "isosorbide" in 2014. It has high biodegradability, good transparency, excellent surface hardness, and non-toxicity. Therefore, it will be used for electronic products such as mobile devices, television sets, smartphone displays, car dashboards, food containers, and eco-friendly house building materials.

SK [227] will soon commercialize bioplastics made from CO_2. When this bioplastic is incinerated, it decomposes into CO and CO_2 and produces no toxic fumes. It also has a high transparency and good blockage of oxygen and moisture.

Samsung [227] produced the "Eco-friendly Cellular Phone (SCH-W510)" which has a battery cover which contains 40% of cornstarch-based bioplastic. It was the first South Korean cellular phone which received an eco-friendly mark. Its packaging also used biodegradable craft paper with no use of any plastic packaging. For the packaging of some TV accessories (e.g., remote controls), Samsung used sugarcane-based bioplastics.

3.4 Taiwan

3.4.1 Macro- and Microplastic Contamination of the Aquatic Environment

Given that Taiwan is an island nation and thus completely surrounded by some of the world's most plastic-polluted waters (see Introduction), that much of its coastline is ravaged by extremely high levels of marine debris pollution, and that a relatively high proportion of Taiwanese people's diet comes from seafood, it is somewhat surprising that less than ten scientific publications have focused on this topic.

In Sect. 3.4.2, we outlined how Taiwanese ENGOs began to monitor marine debris along Taiwan's coastlines and to publish reports about it in the 2000s, which was a decade before the first scientific publication appeared. So far, only four publications have investigated the levels of large marine debris on Taiwan's coastlines. The first publication surveyed four beaches on a small island in southern Taiwan from August 2009 to October 2011 and documented the types and proportions of debris types [228]. 78.3% of the items were made from plastic materials, with other types being glass, metal, and paper. A very high percentage of items was assumed to originate from shoreline and recreational sources and the second highest percentage from ocean and waterway sources.

Later, Kuo and Huang [229] surveyed six sites in northern Taiwan from June 2012 to May 2013 and documented the types, proportions, categories, and sources of marine debris types. The percentage of items made from plastic materials was even higher (85.5%), with the other types again being glass, metal, and paper. Levels of pollution were higher on rocky shores than sandy beaches and fishing ports. Again, most of the debris items originated from recreational sources and the second highest percentage from ocean and waterway sources.

Most recently, Walther et al. [29] used a 12-year dataset collected by volunteers (or citizen scientists) and collated by the Society of Wilderness (SOW) to estimate overall pollution levels for the entire coastline of Taiwan. In total, data from 541 coastal cleanup events held between October 2004 and December 2016 were analyzed. During each event, volunteers sorted and weighed 19 categories of large coastal debris items. The volunteers collected 904,302 items weighing 131,358.3 kg. The five most common debris categories were plastic shopping bags, plastic bottle caps, disposable tablewares, fishing equipment, and plastic drinking straws. 63.6% and 27.2% of items were made of either plastic or plastic mixed with other materials, respectively, and most of these items were made for single-use (e.g., 60% of the items originated from the single-use food and drinks packaging industry, and 15% were plastic bags). One estimate based on multiple linear regression analysis yielded a mean pollution level of 5,937 debris items and 831 kg of debris per km of coastline. Extrapolated to the length of 1,339 km for the entire coastline, it means that, on average during the 12-year period, about 7.9 million items weighing 1,110 MT polluted Taiwan's coastline. Walther et al. [29] concluded by making seven recommendations how to improve the data gathering and verification during cleanup events.

Another study which tracked the changes of large marine debris over several years (2012–2016) was conducted in a remote Taiwanese island in the northern South China Sea [230]. The amount and weight of debris varied greatly between months and years, with Styrofoam and plastic bottles being the most abundant, followed by fishing gear and other plastic products. About half of the debris originated from China and Vietnam.

The study of the levels of microplastic pollution on Taiwan's coastlines is even more recent. The first evidence of this problem was actually provided by an investigation conducted by SOW [231] which measured the density of microplastics in the range of 0.1–2.5 cm on three beaches in New Taipei City, Tainan City, and Kaohsiung City (see also Sect. 3.4.2). This investigation showed microplastic pollution in all locations, with a maximum of 787 microplastics per m^2 of which 72% were Styrofoam particles but also primary microplastics such as pellets.

The first scientific publication was conducted by Kunz et al. [232] and used synchrotron-based FTIR to positively identify microplastic particles collected on four beaches in northern Taiwan in 2015. The polymer types of the 1,097 particles were PE (44%), PP (43%), PS (12%), and ABS (1%).

While Kunz et al. [232] only took one sample per beach, Bancin [28] took 80 samples from one beach in northern Taiwan in 2017 in a systematic manner with 4 transects beginning at the intertidal and ending in the dunes and covering the entire length of the beach. This systematic sampling scheme plus the use of resampling curves allowed a very accurate estimation of the mean pollution level of the beach which was 96.8 microplastic particles per m^2 or approximately 6.8 million particles with an estimated weight of 250.4 kg for the entire 70,130 m^2 beach. The approximate percentages of the polymer types were PE (51%), PP (34%), and PS (15%). The sampling also revealed a high heterogeneity among the samples, and therefore the resampling curves indicated samples sizes of $n \leq 10$ are very unreliable and that sample sizes of at least 10–20 samples are required at a minimum, but to reach truly reliable estimates, sample sizes of $n \geq 50$ are required.

Microplastics were detected in table salts from Taiwan [233, 234]; clams, mussels, oysters, and scallops [235, 236]; and coral fishes and turtles [237].

3.4.2 Mitigation Efforts to Decrease the Plastic Pollution

In response to the growing awareness of the plastic pollution problem, Taiwan's government, ENGOs, and other actors and stakeholders have made efforts to alleviate the problem of waste in general and of single-use plastics in particular since the 1990s, but especially in the 2000s. Below we describe briefly the timeline of the policies of Taiwan's government, followed by the actions of ENGOs to influence public opinion and the government. A more detailed description will be published separately (Walther et al., unpublished manuscript). It should also be interesting to the general reader because it is widely acknowledged that Taiwan has been comparatively successful in tackling some aspects of the problem of plastic pollution, such as one of the world's highest recycling rates.

However, things were quite different only 30 years ago, as economic growth, rising living standards, and soaring consumption had created so much waste that Taiwan earned the nickname "garbage island" in the 1990s; almost no waste was recycled, and two thirds of landfills had reached capacity [238]. The first response of Taiwan's government was to build 24 incinerator plants. It also incentivized companies and consumers to waste less and recycle more beginning with an Extended Producer Responsibility (EPR) policy in 1997, followed by other policy and waste management initiatives (see below). One key part of this system was the compulsory nationwide garbage sorting program introduced in 2006 which forces people to separate different kinds of waste [35, 239–241]. As a result, the average waste produced per capita was reduced by about 30% over the last two decades [238], while the recycling rate increased to approximately 52% of household waste and 77% of industrial waste [238–241] which is a >100% increase using 2002 as baseline [35]. These policies also created thousands of new jobs in about 1,600 recycling companies with an annual revenue of >2 billion NTD [238]. In 2017, about 10% of the total weight of all recycled materials in Taiwan was plastic materials, amounting to 426,345 MT [242].

Despite these successes, a large amount of waste pollution has been and still is being released into Taiwan's environment for a number of reasons. First, a lot of people still throw their garbage into the outside environment (such as ditches, rivers, roadsides, etc.) for various reasons (e.g., they simply do not care or do not want to pay garbage charges, lack of garbage bins in public spaces, etc.). Second, some recycling businesses also fly-tip some waste for various reasons, but often because some waste is uneconomical to recycle. Third, some waste deposit sites are leaking, e.g., during typhoons. Fourth, a lot of waste is also continuously entering the oceans surrounding Taiwan [25, 27, 41, 166, 243, 244], and some of that waste is continuously deposited along Taiwan's coastlines (see Sect. 3.4.1).

To decrease these plastic emissions, Taiwan's government has implemented ten policies which were aimed specifically at the reduction of single-use plastics. The first-ever policy to encourage the recycling of single-use plastics was the "4-in-1 Recycling Program" introduced in 1997. This policy can be classified as an EPR. For each kg of single-use plastic item produced, the plastic producer has to pay a certain recycling fee which in turn is used to support two parts of the recycling industry: the collectors and the certified recycling factories. The collectors receive money from the recycling factories when they sell their collected recyclables to the factory. This program has helped to establish a nationwide recycling industry (see also above).

The second policy was introduced in 2002 and was the first-ever source reduction policy which aimed to reduce the use of plastic bags and single-use tablewares made from plastic [245]. Specifically, the policy banned the handing out of shopping plastic bags thinner than 0.06 mm, and customers had to pay for shopping plastic bags thicker than 0.06 mm. The government promoted the ban with about 1,375 promotional activities [245]. According to a survey of retailers conducted by the TEPA in 2006, the number and weight of plastic shopping bags actually declined by 58% (or 2 billion bags annually) and 68%, respectively, from 2003 to 2006 [35, 246], and the number of people using their own bags had increased by over 60% [245].

In 2005, the third policy introduced regulations against overpackaging, which established rules for the packaging of various goods, e.g., cosmetics, pastries, processed foods, wines, etc., and specifically targeted overpackaged gift boxes which are very popular in Taiwan [247]. In 2006 and 2007, these bans were expanded [248, 249].

In 2011, the fourth policy aimed to reduce the use of single-use cups by encouraging customers to bring their own cups through a reward system (a discount price or a coupon) [250].

In 2012, the government further amended the 2007 policy to decrease the use of single-use plastic trays and package boxes [248]. In the same year, the Tainan city government banned Styrofoam cups [251]. In 2016, the Taipei city government announced that schools, government buildings, and governmental sections must stop selling bottled water; however, this ban did not extend to any other kind of drink sold in single-use plastic or other type of container. Furthermore, schools and governmental departments had to replace their single-use tablewares with multiple-use stainless steel bowls, chopsticks, plates, and other utensils [252].

The eighth policy was a ban of microbeads in personal care and cosmetic products introduced in 2018. Originally, the ban was to be introduced in 2020, but pressure from four Taiwanese ENGOs and a public petition caused the government to advance the ban to 2018 [249].

In 2018, the 2002 plastic bag ban was extended to include another seven businesses which were banned to provide plastic bags for free [249]. The TEPA [253] estimated that this ban would lead to the annual reduction of 1.5 billion plastic bags.

The tenth policy was introduced in 2019 when the TEPA banned single-use plastic straws and expanded its 2006 ban on single-use utensils for eat-in consumers in many restaurants [254, 255]. After the ban on plastic straws was announced, new products and companies quickly sprang up to fill the void of plastic products [254, 256–258].

While Taiwan's government deserves credit for initiating one of the world's best recycling system and, more recently, announced a ban for most single-use plastics during the 2020s, much credit also needs to go to Taiwanese ENGOs who began monitoring plastic pollution levels long before scientists did, educated and then involved the public in cleanup events in order to increase awareness of and information about coastal pollution, and pressured the government through various education, media, and outreach campaigns. Again, a more detailed description will be published separately (Walther et al., unpublished manuscript).

Taiwan's government has financed cleanups of the coastal environment since 1997 [35], which have been augmented by volunteer cleanups, often but not exclusively organized by ENGOs [29, 259]. However, the government did not monitor coastal or marine debris, which eventually caused ENGOs to begin monitoring efforts. When the increasing pollution of Taiwan's coastline with debris (most of it plastic debris) became evident in the early 2000s, Taiwanese ENGOs began (1) to interact with international allies, learning methods from them and adopting them in Taiwan; (2) to organize conferences and workshops, education and outreach campaigns, and coastal cleanup events including data gathering of coastal debris using citizen scientists; and (3) to interact with stakeholders and decision-makers in order to promote source reduction and other relevant policies. For example, SOW began in 2008 to organize coastal cleanup events in order to (1) decrease coastal pollution, (2) educate and actively involve Taiwan's public and media, and (3) document the types, weights, and numbers of debris items. One of the aims of collecting these data was to influence the government's policies by documenting what types of wastes accumulate on Taiwan's coasts.

Another ENGO which played a critically important role was the Kuroshio Ocean Education Foundation (KOEF) because it introduced the ICC method from the USA and adopted it for Taiwan's needs. Through further international cooperation, Taiwanese ENGOs learned how to survey macro- and microplastic pollution from scientists. Through these interactions with international experts and academies, Taiwanese ENGOs not only recognized this issue much earlier than the government but were able to organize international conferences before any public sectors or research institutions got involved in this topic.

In 2010, the National Museum of Marine Science and Technology and four Taiwanese ENGOs, namely, KOEF, SOW, the Taiwan Environmental Information Association (TEIA), and the Tainan City Community College, formed an alliance called Taiwan Ocean Cleanup Alliance (TOCA) and agreed to pool all data generated during the coastal cleanup events. These data then became an important reference for policy-making because reports were published which detailed the amount of coastal debris collected. The release of each report was accompanied by a press conference, with successful media coverage in newspapers and on television. Later, the entire dataset was analyzed in Walther et al. [29] (see Sect. 3.4.1 for details) which again generated media coverage (e.g., [260, 261]).

Moreover, Taiwanese ENGOs learned to use analysis of monitoring data to foster policy changes and therefore pursued several other data collection projects. For example, SOW [231] demonstrated the presence of microplastics on three Taiwanese beaches (see Sect. 3.4.1 for details). This was the first published evidence of microplastic pollution for Taiwan, which also generated media coverage (e.g., [262, 263]), and was then followed by two peer-reviewed publications (see Sect. 3.4.1).

In 2017, SOW worked with CSIRO to collect samples of microplastics from sea water, coastal and terrestrial areas, and rivers in southern Taiwan [264]. Furthermore, GP used manta nets to trawl the ocean surface waters in southern Taiwan, which was then followed up by a similar study from KOEF which trawled the ocean waters around all of Taiwan's main island as well as most important islands totaling 51 sampling points in 2018 [265]. In 2018, GP and SOW used a rapid assessment method for monitoring the existing volume of marine debris pollution around Taiwan's coastline. Counting black bags of waste at 121 different sites, it was estimated that approximately 12.66 million liters of debris are found around Taiwan's coastline. Derelict fishing equipment, plastic bottles, and foamed plastics (such as Styrofoam) were the top three most abundant debris types [266]. Highlighting these results, GP then suggested to the government (1) to focus cleanup activities on such pollution hotspots, (2) to tailor management and recycling methods for different types of fishery waste as soon as possible, (3) to develop alternative fishing gears to replace PS foam floats (also called Styrofoam buoys) used in oyster farming [243, 244], and (4) to set up recycling centers for discarded fishing gear.

In 2018, TEIA and the Wild at Heart Legal Defense Association (WHLDA) conducted a brand audit using the labels on PET bottles to identify the brand and the country of production. The results were then used to call on the Taiwanese government and consumers to promote source reduction and better recycling rates.

The media began to cover the issue of marine debris pollution in 2010 and more intensively beginning in 2017 and certainly also played a large part in moving the current government to adopt more aggressive source reduction policies, such as the planned ban on single-use plastics (the role of media will be covered more extensively in Walther et al., unpublished manuscript).

All the education, monitoring, and media work by Taiwanese ENGOs finally paid off when the election of President Tsai Ing-wen in 2016 ushered in a government with a much friendlier ear toward environmental policies. The starting point for a more collaborative approach between ENGOs and the government began in July 2017 when eight Taiwanese ENGOs (GP, HiiN Studio, KOEF, Tse-Xin Organic Agriculture Foundation, Sea Citizens Foundation, SOW, TEIA, and WHLDA) formed an alliance called the Marine Debris Governance Platform (1) to lobby the government and the public, (2) to work with the TEPA to launch a large-scale quantitative beach debris monitoring program, and (3) to educate the public and reduce the use of plastic products that cause marine pollution [267, 268].

This alliance then worked together with the TEPA to publish the "Action Plan of Marine Debris Governance in Taiwan" [249, 269] in February 2018 which includes a timeline of phasing out four single-use plastic items. The four pillars of the Action Plan are source reduction, prevention and removal, monitoring and surveying (including research), and outreach and public participation. To achieve source reduction, the Action Plan calls for a reduction of single-use plastic items, including a phased ban of most single-use plastic items by 2030, but many additional measures are also planned [249, 267, 270, 271]. Such close collaboration between ENGOs and the government in forming and implementing policies and measures is certainly unprecedented in Taiwan and probably even in East Asia.

4 Discussion and Conclusion

Only a few years ago, Chen [35] wrote "A comprehensive national program to assess or remediate marine litter is currently not available in Taiwan, although marine litter is pervasive along its coastline. No clear integral mechanism exists for solving marine litter problems." The recent successful collaboration between TEPA and several ENGOs to shape and then implement the ambitious "Action Plan of Marine Debris Governance in Taiwan" [249] demonstrates that progress on the plastic pollution problem is possible when top-down and bottom-up approaches coalescence and governments decide to take action while using the accumulated expertise of scientific experts and ENGO representatives to help them formulate effective policies and strategies for source reduction, recycling, and waste management.

However, what our review also reveals is the great disparity between countries due to their different socioeconomic-political systems. While intensive scientific research on plastic pollution has been pursued in the four reviewed countries for about a decade (although with different starting points and much less in Taiwan than in the other three reviewed countries), almost no research is being conducted in Mongolia and North Korea because of these countries' completely different situation. Likewise, the mitigation efforts to decrease the plastic pollution differ greatly between each of the four reviewed countries; the reason again is their different systems of economy and government.

Even though marine plastic pollution is becoming a regional problem which all countries share (e.g., the plastic pollution in the East China Sea and Yellow Sea affects all the surrounding countries), the economic and political decisions to deal with the problem differ wildly between these countries. It is true that scientific collaborations and other exchanges of expertise, e.g., between ENGOs of these countries, have increased in recent decades and that there are now some regional frameworks and other collaborations which deal with plastic pollution (Table 2 and Sects. 3.1.2, 3.2.1, 3.2.2, and 3.4.2). However, when we consider the specific mitigation efforts of each country, they differ greatly in their ambition, scope, and means.

For example, let us consider bans of plastic products. China has banned only one plastic product, namely, some kinds of plastic bags in 2008, and that ban is probably not effective. Japan has no bans on a national level whatsoever. South Korea has only banned some kinds of plastic bags, coffee cups, and microplastics in some products, although admittedly have now proposed some ambitious measures, including bans, for the next decade. Therefore, Taiwan is by far the most ambitious country with its intended (although not yet implemented) ban of many single-use items in 2030 and a host of other policies and measures to promote source reduction, prevention and removal, monitoring and surveying, and outreach and public participation, as outlined in its Action Plan. To begin to understand the reasons for these disparities would go far beyond this review, as we would have to consider the peculiar cultures, economies, histories, and political systems of each country. Thus, it remains true that most environmental policies are shaped within nations by national governments, some are shaped also by regions or municipalities, and very few are shaped by supranational or global organizations or treaties. While a global treaty on plastic pollution would be a very important tool to alleviate the problem [33, 272, 273], current efforts will have to focus on influencing national governments. Therefore, we suggest some lessons can be learned from this review of the efforts of the East Asian governments and ENGOs to tackle the plastic pollution problem.

First, progress on pressing environmental issues often moves along the following steps. First, scientists and ENGOs raise an issue, and eventually the media takes it up (more so in democratic countries, but even in dictatorships, the media covers environmental issues as soon as the government decides that they need to be tackled, e.g., [116]). This is usually followed by calls for voluntary action, such as recycling plastics, which almost invariably proves to have a negligible impact for various reasons. Given enough pressure, governments can then up the ante by taxing undesirable products (e.g., Taiwan's EPR policy) or subsidizing desirable products or systems (e.g., subsidies for certified recycling factories). However, such measures often also fall short of dealing with the problem as plastic emissions continue to rise [9]. Finally, governments can limit or completely ban plastic products (see examples in Part 3).

Many environmentalists would argue that, for many uses of plastic, especially single-use plastics, only banning them will prove to be sufficient to avert further plastic pollution of the biosphere [33, 261], similar to the global bans of ozone-destroying chemicals [273, 274] and persistent organic pollutants [272] and the proposed global ban of burning fossil fuels [275]. However, given that a global ban is likely a long way off, ENGOs and concerned citizens should focus their attention on lobbying national governments for greatly expanded bans of plastic products but also much better plastic recycling and, very importantly, much more research and development of alternative, biodegradable, and non-toxic products [262, 276] which can then quickly substitute the traditional products (see a few examples in Part 3).

Second, even though we appear to be moving toward a post-truth era in many areas of politics [277], many people (and perhaps a majority) can still be influenced by scientific data and its proper analysis. Even better results are achieved if the people themselves are involved in collecting data as citizen scientists [29, 259, 278–280] because this involves education and training which broadens the public's understanding of the problem but also often leads to more people joining activist movements. Therefore, it is important for ENGOs to engage in data collection, analysis, and publication (in popular media and social media but also scientific journals) and to work with scientists because it increases their credibility and the issue's credibility.

Third, we observed in Taiwan that the "plastic reduction wave" really caught on in recent years because of the emerging citizen power and the increasing role of ENGOs in the people's democratic dialogue with its government. We therefore recommend that ENGOs in neighboring Asian countries use Taiwan's example to go beyond their usual focus of mainly promoting environmental education and beach cleanups and embrace policy advocacy and collaboration with governments as much as possible.

Fourth, we note that, to our knowledge, no research on nanoplastic particles [281–286] has been carried out in East Asia. Therefore, governments should fund this important new emerging research field.

Finally, we hope that this review will hopefully inspire a more concerted effort by East Asian governments to support the relevant science but also to tackle the plastic pollution problem with much needed policies and management solutions. For that to happen, we need more of everything which we described above (research, education, campaigns, government actions, etc.), but we would also advocate for much more interregional collaborations between scientists, ENGOs, and governments.

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