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Abstract – We estimated the global inflow and stock of plastic marine debris. In South Korea, we estimated that the annual inflow of plastic marine debris (72,956 tons) was about 1.4% of annual plastics consumption (5.2 million tons) in 2012. By applying this 1.4% ratio to global plastics production from 1950 to 2013, we estimated that 4.2 million tons of plastic debris entered the ocean in 2013 and that there is a stock of 86 million tons of plastic marine debris as of the end of 2013, assuming zero outflow. In addition, with a logistic model, if 4% of petroleum is turned into plastics, the final stock of plastic marine debris shall be 199 million tons at the end. As the inflow and the stock are different units of measurement, better indicators to assess the effectiveness of inflow-reducing policies are needed. And, as the pollution from plastic marine debris is almost irreversible, countermeasures to prevent it should be valued more, and stronger preventive measures should be taken under the precautionary principle. As this is a preliminary study based on limited information, further research is needed to clarify the tendency of inflow and stock of plastic marine debris.

Keywords: Plastic marine debris(플라스틱 해양쓰레기), Inflow(유입량), Stock(현존량), Material flow analysis(물질흐름분석), Policy indicators(정책 지표)

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1. Introduction

How much plastic marine debris is there in the ocean? How much is entering the ocean every year? These questions are increasingly important (UNGA [2005]; Ryan et al. [2009]) as scientific evidence mounts that marine debris, and plastic marine debris in particular, is harmful to both human health and marine ecology (Rochman et al. [2013]). For example, it is estimated that plastic marine debris costs approximately US$13 billion per year in environmental damage to marine ecosystems (UNEP [2014]). A problem can be managed only when it is adequately understood, and information on the amount of plastic marine debris is a vital step toward finding a solution (UNEP [2014]).

Previous efforts to answer these questions can be divided into two groups: those addressing the ‘inflow,’ and those addressing the ‘stock’ of marine debris. A ‘flow’ is measured for a certain period of time, while a ‘stock’ is measured at a specific moment in time. Regarding inflow, NAS [1975] estimated that 6,360,000 tons of marine debris enters the ocean every year from ocean-based activities, while Cantin et al. [1990] estimated that 337,306 tons enter US waters. Kataoka et al. [2013] estimated that at least 2,115 m$^3$ of grass flows into Tokyo Bay, Japan annually via rivers. Jang et al. [2014A] estimated that 91,195 tons of marine debris enters the ocean from activities on land and at sea. The highest estimates suggest inflow as high as 7 billion tons per year (GBRMPA [2006]), though these may be overestimates (Cheshire et al.[2009]).

Likewise, several recent studies have examined the stock of marine debris. Cozar et al. [2014] estimated that the global stock of plastic debris in surface waters of the open ocean ranges from 6,600 to 35,200 tons, based on samples collected from 442 sites in 2010. Similarly, Eriksen [2014] estimated that there are 269,000 tons of plastic in global ocean surface waters based on 26 expeditions over 6 years. Jang et al. [2014A] estimated that 152,241 tons of marine debris could be found on the coast, sea floor, sea surface, and water column of the South Korean sea.

However, these studies provide only a very limited picture of global pollution from plastic marine debris. The NAS [1975] estimate is outdated and limited to debris from activities on the ocean, only 0.7% of which is plastic (Lebreton et al. [2012]); instead, the estimate includes other materials such as metals, and even organics such as food waste. The estimate from Cantin et al. [1990] is also limited to debris from activities in US waters. Most of the debris described by Kataoka et al. [2013] is grass, not anthropogenic in origin. Likewise, the findings of Jang et al. [2014A] are limited to South Korean waters, and the two remaining estimates of debris stock (Cozar et al. [2014]; Eriksen et al. [2014]) are limited to surface debris, not including debris on the coast or sea floor.

Here, we estimate the global inflow and stock of plastic marine debris based on rates of plastic consumption. First, we estimate the inflow ratio (plastic marine debris inflow / plastic consumption) from plastic material flow analysis in South Korea. Material flow analysis is a method of analyzing the amount of materials in a certain system, and is proper for polluting materials (OECD [2008]). Second, we apply this inflow ratio to data on the global production of plastic (1950-2013) to estimate the global inflow and stock of plastic marine debris. Third, we speculate on the inflow and stock of plastic marine debris after 2013, under the assumption that a constant proportion of petroleum is made into plastics. Finally, we discuss conceptual differences between plastic marine debris inflow and stock.

2. Methods

2.1 Inflow ratio of plastic marine debris

We defined the inflow ratio of plastic marine debris as follows:

\[
\text{Inflow ratio of plastic marine debris} = \frac{\text{Annual plastic marine debris inflow to the ocean}}{\text{Annual plastic consumption}}.
\]  

Here, we applied the inflow ratio for South Korea globally. The annual plastic marine debris inflow for South Korea was derived from Jang et al. [2014A], which is a national-level synthesis of previous studies.

Annual plastic consumption in South Korea was estimated by a material flow analysis (OECD [2008]) of plastics. Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time (Brunner [2004]). In this case, various data on plastics production and consumption in South Korea were used. Under South Korean law, any large business that manufactures or imports plastic products (excluding packaging materials) for domestic consumption must pay a tax for the waste. Moreover, any business that manufactures or imports plastic packaging materials must recycle a certain proportion (about 80%) (Act on the Promotion of Saving and Recycling of Resources [2014]) under Extended Producers Responsibility regulations (OECD [2001]). Thus, the government collects various data related to plastics consumption.

To simplify the calculation, we assumed that the lifetime of all plastic products is less than one year. That is, the amounts of plastic production, consumption, and waste in a given year were
assumed to be the same, although some products are in use for longer periods. For example, the percentage of packaging material in the usage of plastic is 37% in the United Kingdom (Hopewell et al. [2009]) and 39% in the Europe (Plastics Europe [2013]). However, even when the lifetime of products are longer than one year, it does not affect the final discharge amount of debris, as there shall be only time gap.

For the material flow analysis, the study site was defined as the territory and sea of South Korea, and the time as the calendar year 2013, except where 2013 data were not available, in which case 2012 data were used.

### 2.2 Global inflow and stock of plastic marine debris (1950-2013)

Next, the inflow ratio was applied to data on global plastic production estimated by Plastics Europe (2011, 2012, 2013, and 2014) to estimate the global inflow and stock of plastic marine debris from 1950 to 2013. For this purpose, we assumed that plastic marine debris outflow, such as beach cleanup efforts or plastic biodegradation, does not occur. That is, although there are in fact some outflows, we assumed there were none for simplicity, an assumption we address below. We also assumed that the inflow ratio is the same irrespective of nation or year. Under these assumptions, the accumulation of inflow from 1950 to a certain year becomes the stock at the end of that year (Eq. 2). We discuss the reliability of these assumptions in the discussion section below.

Stock of plastic marine debris at the end of a certain year = Accumulated sum of the inflow of plastic marine debris from 1950 to that year (2)

### 2.3 Speculating on the plastic marine debris level after 2013

We speculatively estimated the potential level of plastic marine debris after 2013, assuming that the ratio of plastic marine debris inflow to plastic production, and the ratio of plastic production to petroleum production, are both constant over time. About 4% of total petroleum is made into plastics (Hopewell et al. [2009]; British Plastics Federation [2012]), and a further 4% is used for this production (Thompson et al. [2011]). Although plastics can be produced from other sources such as coal and gas, we analyzed plastics made from petroleum only, and used speculative petroleum production data from Gallagher [2011].

If 4% of petroleum is made into plastics, and the same proportion of plastics becomes marine debris each year, then the plastic marine debris will follow the same pattern as petroleum production—a logistic curve (Hubbert [1956]). The well-known logistic function (Verhulst [1838]) is given by Eq. (3):

$$ S(y) = K \left(1 + \left(\frac{y}{S_0} - 1\right)e^{-r} \right) $$

where $S(y)$ is the stock of plastic marine debris in tons as a function of time (year); $K$ is the final stock of plastic marine debris (carrying capacity); $S_0$ is the initial stock; $r$ is the growth rate, which is the same as that for petroleum production; and $y$ is the year (time).

As we assumed that plastic marine debris follows the same pattern as petroleum production, $r$ is the same as for petroleum, and $K$ is calculated as a portion (4% $\times$ inflow ratio) of the final cumulative petroleum production.

As a special feature of the logistic curve, maximum inflow occurs when the stock is half of the final stock, $K$ (Gallagher [2011]). Thus, the inflow curve is shaped like a bell or peak, of which the center is the maximum.

### 3. Results

#### 3.1 Inflow ratio of plastic marine debris into the ocean

To determine the inflow ratio of plastic marine debris into the ocean, we conducted a material flow analysis of plastics and plastic marine debris (Fig. 1). In 2012, 13,355,000 tons (‘B’ in Fig. 1) of plastic pellets (a precursor to most plastic products) were produced in South Korea; 7,487,000 tons (‘D’) were exported, an additional 465,000 tons (‘E’) were imported, and 5,868,000 tons (‘C’) were used to produce 6,333,000 tons (‘F’) of plastic products (Korea Plastic Manufacturing Cooperatives, 2014). In 2013, 5,176,358 tons (‘J’) of plastic products were consumed, comprising 4,036,358 tons (‘G’) of products manufactured domestically and 1,140,000 tons (‘I’) imported (Korea Packaging Recycling Cooperative, 2014; Korea Ministry of Environment, 2014). After consumption, 4,500,351 tons (‘K’) were treated at waste plants (Korea Environment Corporation, 2012).

The annual inflow of marine debris in 2012 was estimated at 72,956 tons (‘R’ in Fig. 1). This was calculated by multiplying the total annual inflow (91,195 tons in South Korea; Jang et al. [2014A]) by the 80% ratio of plastics in marine debris (Derhaar [2002]), and is the sum of the inflows from activities in the sea (‘M’ $= 58,370$ tons $\times 80\% = 46,696$) and on land (‘N’ $= 32,825$ tons $\times 80\% = 26,260$). Thus, the plastic marine debris inflow ratio is approximately 1.4% (72,956 / 5,176,358 = 1.4%) (Table 1).

#### 3.2 Global inflow and stock of plastic marine debris

To estimate the stock of plastic marine debris, we applied the
1.4% ratio (Table 1) to data on global plastic production provided by Plastics Europe (2011, 2012, 2013, 2014). However, as only general production trends in plastic production are publicly available in these documents, we obtained specific data for each year via personal communication with Plastics Europe. Though plastics were produced before 1950, this was dismissed for simplification. Annual plastics production information is attached as an appendix below.

Using these data, we calculated the global plastic marine debris stock at the end of 2013 as 86 million tons and the plastic marine debris inflow from the ocean to the activities in the ocean. 

\[
\text{Annual plastic marine debris inflow} = \frac{72,956}{5,176,358} = 1.4\%
\]

#1. Though Derraik [2002] has shown 60 to 80% are plastic, 80% was applied for simplification.

### Table 1. Plastic marine debris inflow ratio for South Korea (2013)

<table>
<thead>
<tr>
<th>Items</th>
<th>Amount (weight, ton)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual marine debris inflow</td>
<td>91,195</td>
<td>Jang et al. [2014A]</td>
</tr>
<tr>
<td>Ratio of plastics in marine debris</td>
<td>80%</td>
<td>Derraik [2002]; #1</td>
</tr>
<tr>
<td>Annual plastic marine debris inflow</td>
<td>72,956</td>
<td>91,195 x 80% = 72,956</td>
</tr>
<tr>
<td>Annual plastic consumption (‘J’ in Fig. 1.)</td>
<td>5,176,358</td>
<td>MOK [2014]; KPRC [2014]</td>
</tr>
<tr>
<td>Plastic marine debris inflow ratio</td>
<td>1.4%</td>
<td>72,956 / 5,176,358 = 1.4%</td>
</tr>
</tbody>
</table>

![Material Flow Analysis of Plastics and Plastic Marine debris in South Korea in 2013 (Unit: t = ton)](image)

**Fig. 1.** Material flow analysis of plastics and plastic marine debris in South Korea in 2013. (Drawn by this research based on data from Korea Plastic Manufacturing Cooperatives (2014), Korea Packaging Recycling Cooperative (2014), Korea Ministry of Environment (2014), Korea Environment Corporation (2012), and Jang et al. (2014A)).

**Fig. 2.** Plastic marine debris inflow and stock worldwide, under the assumption that 1.4% of plastic production enters the ocean. As the stock is the accumulation of the inflow, the stock is around 20-fold larger than the yearly inflow as of 2013.
debris inflow for the single year 2013 as 4.2 million tons (Fig. 2). As the stock is the accumulation of the inflow, the stock is around 20 times larger than the yearly inflow as of 2013.

3.3 Speculation on plastic marine debris levels after 2013

According to Gallagher [2011], the total accumulated production (carrying capacity) of petroleum will ultimately be 2.24 trillion barrels, and peak oil occurred in 2009. Next, we apply the 4% ratio of petroleum turned into plastics and the 1.4% ratio of plastic marine debris inflow. As 1 barrel equals 0.1589 tons, the final total plastic marine debris stock (K in the Eq. 3) will be about 199 million tons (= 2.24 trillion barrels × 0.1589 × 0.04 × 0.014), and the maximum inflow of plastic marine debris will be 2.9 million tons (30.2 billion tons × 0.1589 × 0.04 × 0.014) in 2009 (Fig. 3). As the maximum inflow occurs when the stock is half of K, the stock in 2009 is 99 million tons (half of 199 m tons). Although these estimates of petroleum production may change if new petroleum resources are found, this figure gives a glimpse into the potential plastic marine debris volume of the future. The speculative estimate of plastic marine debris inflow and stock based on petroleum production (Fig. 3) differs from the estimate based on plastic production (Fig. 2). For example, for the year 2009, the inflow is similar but not the same (3.5 million tons ≠ 2.9 million tons), and the stock is likewise (70 million tons ≠ 99 million tons). Such differences are brought about by different input factors, such as growth rates, initial stock, and carrying capacity. In particular, for the speculative estimate after 2013, we assumed that only petroleum, and no other material, was used to make plastics.

4. Discussion

4.1 Review of assumptions

In this study, we assumed that the inflow ratio (annual plastic marine debris inflow per unit of plastic consumption) was the same for all countries and years from 1950 to 2013. But the inflow ratio can change. For example, Liu et al. [2013] found that strong recycling policies regarding plastic bags and bottles decreased these types of debris on beaches in Taiwan vs. the USA. We can generally assume that the inflow ratio will decrease as waste management improves. Although we assumed that the inflow ratio was the same for all countries and years, further studies are needed to determine the inflow ratios for specific countries and years.

We further assumed that plastic is not degraded in the ocean. The final stage of degradation is called mineralization, wherein carbon in polymers is converted into CO$_2$ (and ultimately incorporated into biomass), and there are some polymer types, such as aliphatic polyesters, that progress to this stage (Andrady [2011]). There are several methods of measuring polymer degradation, including molecular weight loss (Shah et al. [2008]). For example, Kim et al. [2006] found that polybutylene succinate (PBS) lost about 13% of its molecular weight while high-density polyethylene (HDPE) lost almost nothing when they were kept on experimental compost soil for 80 days. Thus, our assumption of no plastic degradation is not always true.

Although plastics might degrade in the marine environment, we can assume that this occurs very slowly. For example, Lambert et al. [2013] found that many nano-sized plastic particles are produced when the molecular weight of the plastic is lost. That is, more harmful pollutants are made when the original plastics are seemingly degraded, if they are not completely mineralized. And, as sunlight and oxygen, important factors in degradation, are limited in the marine environment, degradation is likely much slower in the ocean than on land (Andrady [2011]).

The degradation speed of plastics is unknown, especially in the ocean. If we suppose that plastics degrade in 600 years, for example, then the stock of plastic marine debris will lose 1/600 of its weight each year. In this case, the plastic marine debris stock in the year 2013 would be calculated as follows:

$$\text{Plastic marine debris stock in the year 2013 (with 600 years of degradation)} = \sum \text{Inflow of plastic marine debris each year} \times \left(1 - \frac{(2013 - \text{year})}{600}\right) = 84 \text{ million tons}$$

Here, 84 million tons is about 98% of the 86 million tons we originally estimated. Thus, the assumption of no biodegrada-
tion does not significantly affect the result.

We also assumed that plastic marine debris collection is zero. Although a certain amount of plastic debris is collected around the world, the amount is insufficient to significantly influence the result. For example, only 570 tons of debris was removed for the 10 years from 1997 to 2006 in the USA (NOAA [2008]). Globally, 52,617 tons of debris was removed by millions of participants in the International Coastal Cleanup campaigns in the 21 years from 1986 to 2006 (NOAA [2008]).

For the speculative estimate after 2013, we used the peak oil estimate from Gallagher [2011]. Although there are fierce debates on the extent of petroleum reserves and the timing of peak oil (Chapman [2014]), this is not the focus of our study. Regardless of the extent of petroleum resources, it appears certain that the stock of plastic marine debris will hardly decline even if the production of plastics decreases in the future.

4.2 Comparison with previous estimates

In this study, the inflow ratio (annual plastic marine debris inflow / annual plastic consumption) was estimated at 1.4% (72,956 ton / 5,176,358 tons = 1.4%) in South Korea and then extrapolated worldwide. However, both debris inflow and plastic consumption may be underestimated. For example, to estimate marine debris inflow, we used data from the Han River in 2000 (Incheon City [2001]) as the inflow from land sources. That study used a 5-cm mesh net to collect debris from the river and, consequently, debris smaller than 5 cm, such as micro-beads (Fendall and Sewell [2009]), is not included in the inflow estimate. Plastic consumption was also underestimated because small businesses are not taxed for waste and are exempted from reporting the manufacture or importation of plastic (Korea Ministry of the Environment [2014]). Thus, it is unclear whether 1.4% is an over- or under-estimate.

Thompson [2006] suggested that up to 10% of plastics enter the ocean (Cole et al. [2011]). If 1.4% changes to 10%, then the inflow in 2013 would be 30 million tons and the stock at the end of 2013 615 million tons, based on our estimates (see Appendix). As there is no scientific basis on the 10% assumption of Thompson [2006], it is unclear if 10% is relatively large or small. Again, more work must be done to estimate the inflow ratio. In this respect, a recent attempt to estimate plastic debris inflow from the land on a per-country basis (Jambeck et al. [2015]) is highly valuable. The estimate of plastic marine debris inflow from the land in 2010 in South Korea (33,747 tons) by Jambeck et al. [2015] is not much different from our own estimate (26,260 tons). However, because debris inflow from activities in the ocean can exceed that from activities on land in some countries (Jang et al. [2014B]), it is important to also consider debris inflow from activities in the ocean.

Our estimate of plastic marine debris inflow from activities in the ocean is much smaller than that of NAS [1975], which estimated it at 6,360,000 tons in 1975. This is markedly larger than our estimates of 560,000 tons of inflow in 1975 and 4.2 million tons in 2013 (see Appendix). Such a difference can be explained in part by the fact that the NAS [1975] estimate occurred before MARPOL 73/78 (IMO [1997]) which prohibited pollution from ships, including plastics and other materials such as metal (cargo boxes) and food waste. Notably, 88% (5,600,000 / 6,360,000 tons) of the garbage from NAS [1975] was lost cargo from merchant shipping, and such losses have been dramatically reduced with the development of shipping technology. Moreover, only 0.7% (44,520 tons) of the 6,360,000 tons of NAS [1975] was plastic (Lebreton et al. [2012]).

The two previous estimates of stock, 6,600-35,200 tons (Cozar et al. [2014]) and 269,000 tons (Eriksen [2014]), are much smaller than our estimate of 86 million tons. This difference can be explained in part by the fact that a large portion of plastic marine debris accumulates on the sea bottom. For example, Jang et al. [2014A] estimated that 90% of marine debris stock (152,241 tons) is on the sea floor, 8% on the beaches, and only 2% in the water column and on the sea surface in South Korean waters. If we take 2% of our 86,219,000-ton stock estimate, we obtain 1,724,380 tons as an estimate of plastic marine debris on the sea surface and in the water column. This is still larger than 269,000 tons; however, the estimates of Eriksen [2014] and Cozar et al. [2014] consider only plastic marine debris on the surface and would presumably be higher if they included debris in the water column.

Regarding plastic marine debris on the sea floor, we must remember that formerly floating debris can eventually become submerged. Although some plastics are lighter than water, these light plastics can gain weight and accumulate on the sea floor for various reasons, such as plankton fouling (Andrady [2011]). Likely because of this, there are reports of plastic marine debris on the sea floor as deep as 1000 m (Debrot et al. [2014]; Eryasa et al. [2014]; and Galgani et al., [2000]). Furthermore, fishing nets and ropes made of polypropylene and polyethylene (Jang et al. [2014B]) are the main components of marine debris collected from the sea bottom in South Korea (MLTM [2009]). Again, Cozar et al. [2014] and Eriksen [2014] considered only the water surface, and did not consider plastic marine debris in the water column.
4.3 The value of preventive measures against irreversible pollution and adequate indicators

If biodegradation of plastic debris in the ocean is close to zero, we might say that pollution from plastic marine debris is irreversible, much as the discharge of non-degradable pesticides is irreversible (Arrow and Fisher [1974]). If a certain type of pollution is irreversible, countermeasures to prevent it should be valued more, and stronger preventive measures should be taken under the Precautionary Principle (Gollier et al. [2000]). Moreover, when pollution is irreversible, reducing the stock is almost infinitely costly. Thus, we must develop more policies to reduce the inflow of plastic marine debris into the ocean.

However, the effectiveness of policies to reduce the inflow of plastic marine debris should be measurable and evidence-based (Sanderson[2002]). If certain policies are more effective in reducing plastic debris inflow, they should be more supported financially. To that end, the conceptual difference between inflow and stock should be clarified when developing policy indicators. In other words, we need to understand that current flow-reducing policy has very little effect on the marine debris stock. According to our estimate, for example, there is a stock of 86 million tons of plastic marine debris as of the end of 2013, yet only 4.2 million tons entered the ocean in 2013. Thus, even if marine debris inflow were completely eliminated in 2014, the stock at the end of 2014 would still be 86 million tons. Clearly, the effectiveness of policies to reduce inflow can hardly be measured by indicators based on marine debris stock.

As the effects of policy intervention differ according to the type of policy instrument used, the indicators should also differ (Table 2). For reducing debris inflow, the main policy indicator should be the amount of debris entering the ocean in a given period. For example, we might ask fishermen how much litter they produced during the past year. For reducing debris stock, the policy indicator should be the amount of debris found in the ocean. For example, we might measure the amount of marine debris on beaches at a certain point in time. The various types of policy strategies to cope with marine debris are listed on ‘The Honolulu Strategy: A Global Framework for Prevention and Management of Marine Debris’ (NOAA and UNEP [2011]. Unfortunately, there are few studies on the inflow of plastic marine debris, while many studies focus on the abundance—the stock—of marine debris in the ocean (Ryan et al. [2009]; Cheshire et al. [2009]; Cole et al. [2011]).

4.4 Future studies needed

Our study has many limitations. Many of the parameters used generally in this study are derived from the specific case of South Korea. Thus, more research is needed. First, plastic consumption should be investigated in more detail for specific countries. UNEP [2014] also emphasized that any problems ‘can be managed when measured.’ However, while UNEP [2014] is calling for participation from the business sector in measuring plastics, government should play the central role in this regard, as government policy impacts the management of plastic consumption and pollution. Material flow analysis will be a useful approach, of which Mutha et al. [2006] present a good example from India.

Second, estimating plastic marine debris inflow at the national level is vital but challenging. Jang et al. [2014] reviewed several previous studies for this purpose in South Korea. These included (1) measuring debris inflow from rivers by capturing debris with nets across the Han River (Incheon City [2001]); (2) measuring debris inflow from rivers during a flood event (Geoje City [2013]); (3) measuring lost fishing gear and general garbage produced by ships via interviews with fishermen (MLTM [2009]); and (4) measuring lost aquaculture buoys via interviews with fishermen. These data were combined with governmental statistics to estimate the marine debris inflow.

Though the accuracy of these types of measurement may be questioned, they appear to be the best of the methods currently available; clearly, better methods are needed. In particular, dumping, which determines debris inflow, is a human activity, and might be measured using social scientific methods.

Third, when estimating the stock of plastic marine debris,

<table>
<thead>
<tr>
<th>Classification</th>
<th>Policy instruments</th>
<th>Policy indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing</td>
<td>(1) Collecting debris in rivers with booms.</td>
<td>(1) Amount of debris collected in a given period.</td>
</tr>
<tr>
<td>marine debris</td>
<td>(2) Changing aquaculture practices.</td>
<td>(2) Fishermen’s responses to the question of how much litter they produced in a given period.</td>
</tr>
<tr>
<td>inflow</td>
<td>(3) Increasing the legally required ratio of recycling certain products via Extended Producers Responsibility.</td>
<td>(3) Actual recycling ratio for the products.</td>
</tr>
<tr>
<td>Reducing</td>
<td>(1) Collecting from beaches.</td>
<td>(1) Amount of marine debris on beaches at a given point in time.</td>
</tr>
<tr>
<td>marine stock</td>
<td>(2) Collecting from the seabed.</td>
<td>(2) Amount of marine debris on the seabed at a given point in time.</td>
</tr>
<tr>
<td></td>
<td>(3) Collecting from the water surface and column.</td>
<td>(3) Amount of marine debris on the water surface and in the column at a given point in time.</td>
</tr>
</tbody>
</table>
debris travel must be considered. For example, debris on beaches moves between the beach and sea many times each day (Kako et al. [2010]). Thus, care should be taken when estimating debris stock on beaches based on observations on beaches alone, because a beach is part of the sea. Estimating the stock on the sea surface might have the same challenges. As floating plastic debris moves through the water column via the process of plankton fouling (Andrady [2011]) and the water surface is part of the ocean, we should be careful when interpreting the abundance of floating plastic debris. Monitoring the abundance of plastic debris on the sea floor is also limited by technology and financial cost as huge sample sizes are required to overcome the very large spatial heterogeneity in plastic litter (Ryan et al. [2009]).

5. Conclusion

In this study, we estimated global plastic marine debris inflow and stock by applying material flow analysis of plastic marine debris in South Korea to global plastic production. We estimated that there is 86 million tons of plastic marine debris stock as of the end of 2013, 20-fold greater than the annual inflow (4.2 million tons for 2013). Thus, even if we reduce further inflow to zero, the stock will still be considered. Consequently, the effectiveness of inflow-reducing policies cannot be measured using indicators showing changes in the stock. As pollution from plastic marine debris is irreversible, the value of reducing debris inflow is much greater than for reversible pollution. Therefore, we must develop more methods of reducing inflow. As policies are more supported if their effectiveness is clear, better indicators are needed to show changes in inflow. To this end, we must pay careful attention to the conceptual difference between inflow and stock.

Acknowledgments

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물질흐름분석을 활용한 전세계 플라스틱 해양쓰레기의 유입량과 현존량 추정: 예비적 접근 271

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European latest plastics production, demand and waste data. 37p.


Appendix. Calculation of inflow and stock of global plastic marine debris under the assumption that 1.4% of plastics enter the ocean and none is collected or biodegraded

<table>
<thead>
<tr>
<th>Year</th>
<th>Year</th>
<th>Plastics</th>
<th>Plastic marine debris inflow</th>
<th>Plastic marine debris stock (c = accumulation of ‘b’)</th>
<th>Plastics</th>
<th>Plastic marine debris inflow</th>
<th>Plastic marine debris stock (c = accumulation of ‘b’)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>1,700,000</td>
<td>23,800</td>
<td>23,800</td>
<td>1982</td>
<td>63,000,000</td>
<td>882,000</td>
<td>11,403,000</td>
</tr>
<tr>
<td>1951</td>
<td>2,000,000</td>
<td>28,000</td>
<td>51,800</td>
<td>1983</td>
<td>69,000,000</td>
<td>966,000</td>
<td>12,369,000</td>
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<td>1952</td>
<td>1,900,000</td>
<td>26,600</td>
<td>78,400</td>
<td>1984</td>
<td>74,000,000</td>
<td>1,036,000</td>
<td>13,405,000</td>
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