THE GARBAGE PATCH IN THE OCEANS: THE PROBLEM AND POSSIBLE SOLUTIONS

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EXECUTIVE SUMMARY

A study was conducted to assess the size and impact of a Garbage Patch in the Oceans. The findings from the study were compiled from a combination of mathematical and physical models estimates and data from expeditions (Table 1).

The primary findings are:

- There are potentially five Garbage Patches scattered globally, located in the North and South Pacific Ocean; North and South Atlantic Ocean; and Indian Ocean.
- The total amount of plastic garbage estimated is 36,000 ton, unequally dispersed.The data results in 9,064 ton of garbage plastic in the North Atlantic and 20,240 ton in North Pacific.
- The model estimation results in 2,590 ton of marine plastic debris in the South Atlantic Ocean, 2,860 ton in the South Pacific Ocean, and 2,185 ton in the Indian Ocean, which are in alignment with the data.

Table 1: Summary Calculations of Garbage Patches.

	Patch Name	**Geographic Location**	**Surface Area (km^2)**	**Particle Density (pieces/km^2)**	**Amount plastic (ton)**
1	Eastern Garbage Patch	North Pacific Ocean	8,095,000	25,000	20,240*
2	Western Garbage Patch	South Pacific Ocean	715,520	40,000	2,860†
3	Atlantic Garbage Patch	North Atlantic Ocean	3,625,753	25,000	9,064*
4	Atlantic Garbage Patch	South Atlantic Ocean	1,296,180	20,000	2,590†
5	Indian Garbage Patch	Indian Ocean	2,183,480	10,000	2,185†
Total			**15,915,933**		**36,939**

* data; † model

This total quantity of plastic debris in the earth's oceans amounts to approximately 0.125% of all plastic produces in the US in 2009. However the ecological impacts of the Garbage Patch range from over a million of sea-birds and one hundred of thousand marine mammals killed by ingestions of plastics or entanglement, to economic impacts estimated between US$1000million and US$ 3000 million in beach cleanups (excluding volunteering efforts), tourism losses, and damages to fishing and aquaculture industries.

1. INTRODUCTION

Plastics are a synthetic organic polymer that has been around only for just over a century. Its characteristics of lightness, durability, strength, relatively low cost of production, and versatility of use have contributed to its entering all aspects of everyday life. On the other hand, the same characteristics that helped increase plastic production together with careless management of its disposal are also responsible for making the material a serious hazard for the environment.

In 2009, global plastic production was roughly 230 million tons (Plastics-Europe) of which 29.8 million tons were used and discarded in the U.S.. According to the 2009 EPA report on municipal solid waste, of this amount only approximately 7.1% or 2.1 million tons were collected and recycled, the rest was combusted with other municipal solid wastes (MSW) in waste-to-energy (WTE) facilities to generate energy (approx. 10%), and the majority was disposed in landfills (approx. 85%) (EPA).

Non-regulated landfills sited nearby rivers and in coastal areas coupled with illegal dumping, littering and ocean-based dumping have the potential to introduce plastic wastes into the oceans , as noted by several authors:.

> "In the US, overflow mechanisms, built into sewage system to divert the wastewater and stormwater to avoid overloading the sewer system, are one of the major land-based source of plastics." (Nollkaemper)

> "…overused and poorly managed landfill and transfer stations can increase marine debris. Trash that is improperly covered during transport or deposition into landfills can be carried by wind into the marine environment or into other aquatic systems that transport the trash to the marine environment." (Interagency Marine Debris Coordinating Committee).

Mathematical and physical models have shown that with time the ocean currents aggregate the marine debris and create the so-called "garbage patches". The models utilized to estimate the rate and location of aggregation are typically calibrated using both drifting buoy ("drifters+) trajectories and surface drift simulations using ship drift data.

Figure 1: Satellite-tracked surface drifting buoy.

Source: The Global Drifter Program. Web Access July 2011. <http://www.aoml.noaa.gov/phod/dac/gdp_drifter.php>

The drifters (Figure 1) consist of a surface buoy and a subsurface drogue, attached to the buoy by a chain, and weigh 22 kilograms. The buoy measures sea surface and subsurface temperature, barometric pressure, wind, ocean color, and salinity and have a transmitter to send the data to satellites. The drogue is suspended at a depth of 15 meters beneath the sea surface. While the buoy size varies, manufacturers try to keep a drag area ratio - defined as the ratio of the drag area of the drogue over the drag of the non-drogue element - of 40, which allows minimization of the downwind slip - the horizontal motion of a drifter due to wind currents that differs from the lateral motion of currents averaged over the drogue depth (e.g., 0.7 cm/s of water movement in 10 m/s winds). (The Global Drifter Program).

Although the drifters may not seem representative of the plastic garbage, they are extremely useful and accurate in predicting how plastic wastes aggregate at certain areas in the oceans:

> “Location of the North Pacific cluster […] coincides with the location of the so-called Great Garbage Patch (e.g., Moore et al., 2001). Location of the North Atlantic cluster is also consistent with the observations revealing high concentration of defragmented plastic (Law et al., 2010).” (Maximenko, et all)

Finally, two different drifters , the Martinez and Maximenko models are in agreement in analyzing movement of the marine debris, concluding that drifters trapped in the middle of a gyre can leave the area, with exception made for the gyre in the South Pacific Ocean (Martinez, et all).

1.1. The Garbage Patch

The garbage patch is a concentration of marine debris in the ocean. It consists mainly of plastic objects with an approximate concentration of about 46,000 pieces per square mile, according to the United Nations Environmental Programme 2006 estimates (UNEP). There are five main garbage patches. The largest is referred to as the Great Pacific Garbage Patch and consists of the Eastern Garbage Patch and the Western Garbage Patch. The first one extends within the North Pacific Subtropical High, an area between Hawaii and California; the second one is a small “recirculation gyre” between Japan and Hawaii. Also, floating trash concentrates in certain areas of the Indian Ocean and the Atlantic Ocean (Figure 2).

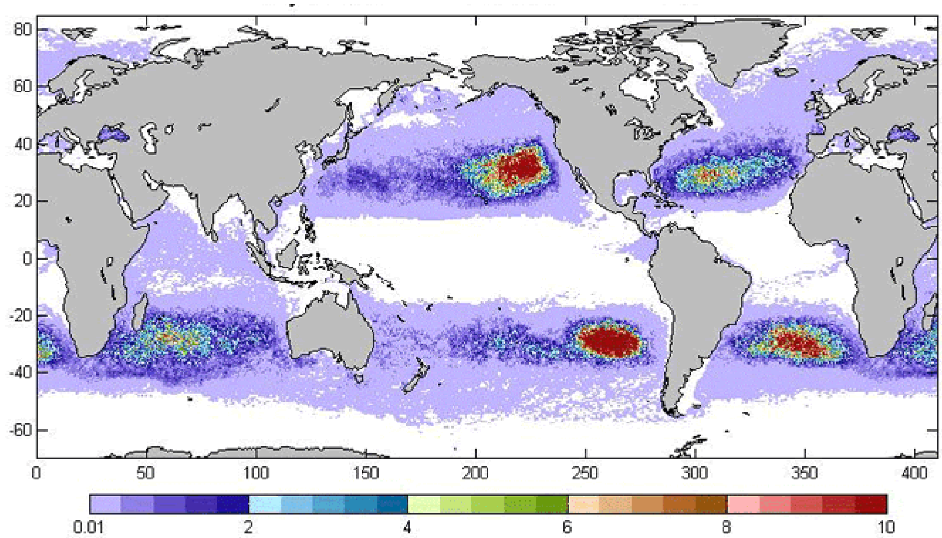

Figure 2: A model simulation of the projected distribution of marine litter in the ocean in ten years.

Source: UNEP. “Plastic Debris in the Ocean. Year Book 2011”. United Nation Environmental Programme. 2011. Web Access July 2011 < http://www.unep.org/yearbook/2011/pdfs/plastic_debris_in_the_ocean.pdf>.

The sources of plastic debris can be land-based (estimated at eighty percent) or ocean-based and they relate to four main categories: sewage, tourism, fishing, and waste from ships and boats. The first one includes trash that comes from storm water discharges, combine sewer overflows, and solid waste disposal and landfills; it is carried to the sea in streams, rivers, and, surprisingly, underground waterways. Trash discarded in the streets, sidewalks, gutters and elsewhere is carried by water flow or wind and eventually ends up in the ocean. This is also true with garbage carelessly discharged in the toilets or sinks at home. Furthermore, industrial products can become marine debris if not properly disposed of. Tourist littering is one of the major causes of beach pollution that eventually is transformed to marine debris. Finally all boats and ships and off-shore industrial platforms are potential sources of ocean pollution, as they can generate trash, either intentionally or accidentally.

It should be noted that there are four main dimensions to the problem of the plastic trash patch: a) Plastic is highly dispersed as it floats and moves in the vast ocean; b) there is a continuous accumulation of waste, as plastic does not biodegrade; c) it is a global rather than a national issue; and d) it is difficult to prove causation between amount of plastic wastes in the oceans and effects on the ecosystems in the ocean.

The Sea Education Association (SEA) has been conducting research on the garbage trash patch for over 25 years. Neuston nets (335 µm mesh and 0.5 m by 1.0 m opening) are towed at the ocean surface from a ship to collect samples and analyze them (Law, et all). As of this date, more than 6100 net tows have been conducted in the Atlantic Ocean and Caribbean Sea and 400 tows in the North Pacific subtropical gyre. The majority of collected samples are less than one cm in size and mass of about 0.1 g and are made of high density polyethylene (HDPE), low density polyethylene (LDPE), and polypropylene (PP). The highest plastic concentrations were observed in the Sargasso Sea, a slow circulation area approximately 700 miles wide and 2,000 miles long off the coast of Bermuda:

> "The highest concentration of plastic debris was observed in subtropical latitudes and associated with the observed large-scale convergence in surface currents predicted by Ekman dynamic […] Sixty-two percent of all net tows contained detectable amounts of plastic debris. The highest plastic concentrations were observed between 22° and 38°N, where 83% of total plastic pieces were collected." (Proskurowski)

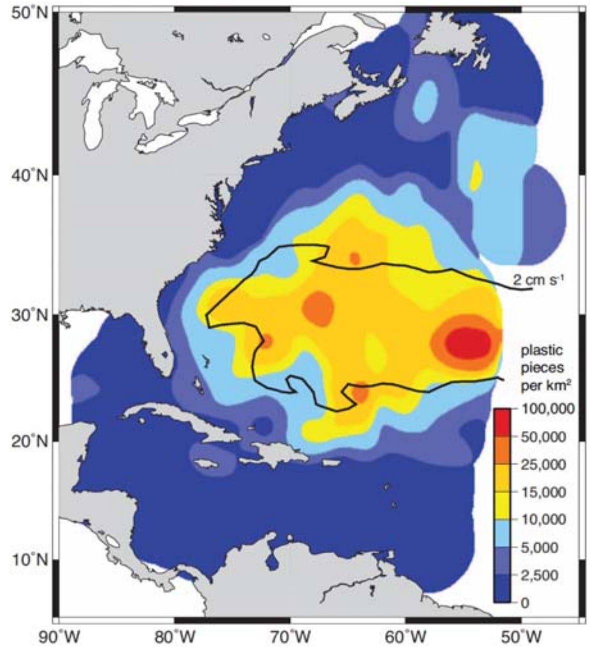

Figure 3: Average plastic concentration in the western North Atlantic Ocean.

Source: Kara Lavender Law, Skye Morét-Ferguson, Nikolai A. Maximenko, Giora Proskurowski, Emily E. Peacock, Jan Hafner, Christopher M. Reddy. "Plastic Accumulation in the North Atlantic Subtropical Gyre", Science. September 2010. Vol 329, Pg 1185-1188. Web Access June 2011 <www.sciencemag.org>.

Efforts in assessing the problem of marine debris have been concentrated on the monitoring and clean-up of the sea surface, at less than 30 m depth. Plastic is buoyant so it is most likely located on the water surface or at shallow depth.

Also, the assessment of the presence of marine debris on the seafloor using the most convenient method, bottom trawling nets, is not applicable on rocky terrain, and items cannot be exactly located, because the catch is integrated over the length of the tow:

> "The fate of plastic particles that become dense enough to sink below the sea surface is unknown, and we are unaware of any studies of seafloor microplastics offshore of the continental shelf. However, analysis of particle trap data in the center of the high plastic region near Bermuda shows no evidence of plastic as a substantial contributor to trapped sinking material at depths of 500 to 3200 m" (Skye Morèt-Ferguson, et all).

In an attempt to estimate how much garbage is present in the ocean, we first considered data gathered from the SEA, Woods Hole Oceanographic Institution (WHOI), and the expedition of the University of Hawaii at Manoa (UHM) in the Atlantic Ocean, in particular in the Sargasso Sea. We assumed that if the samples were to be collected with a net at the same depth and put side by side we would have an average concentration of 25,000 plastic pieces per km^2 (Figure 3). In addition we considered an approximate water surface affected of 3,625,753 km^2, and an average weigh per piece of 0.1 grams. The quantity of plastic debris in the volume of water affected wase estimated roughly at 9,064 tons.

Secondly, based on Algalita Marine Research Foundation sampling of the North Pacific Subtropical gyre, we assumed that if the samples were to be collected with a "manta" trawl that skims the ocean surface and can trap particles as small as 1/3 of a millimeter at the same depth and put side by side we would have an average concentration of 25,000 plastic pieces per km^2 (WHOI). Also, we considered an approximate water surface affected of 8,095,000 km^2 (Maximenko, et al) and that each piece weights on average 0.1 grams (Algalita Marine Research Foundation). The quantity of plastic debris in volume of water affected was estimated roughly at 20,000 tons.

Finally, a sampling expedition was carried out in the South Pacific Ocean in January 2011, but publication of the results is pending. Also,, in the South Indian Ocean and South Atlantic Ocean sampling expeditions confirming the existence of a garbage patch in these areas was conducted in 20111 by a team of researchers of the Five Gyres Institute, but data have not been disclosed.

In the effort to approximately size the dimension of these three patches, we took into account Maximenko's drifters model (Maximenko, et all). His results show that the convergence zones of the drifters concentration are in fact in the subtropical gyres. In addition, drifters measurements in the North Atlantic Ocean are consistent with was has been reported by SEA, WHOI, and HUM, as well as by Algalita Marine Research Foundation in the North Pacific Ocean (IPRC).

If we consider Maximenko's model for these areas, we can assume is that the South Pacific patch has higher plastic particle density than that of the North Pacific (assumed average density of 40,000 pieces per km^2), that the South Atlantic Ocean patch has slightly lower density than the North Atlantic one (assumed average 20,000 pieces per km^2); and finally that the Indian Ocean patch has lower density than the North Atlantic one (assumed average 10,000 pieces per km^2) [(Maximenko, et al; Martinez, et all)]. Based on Maximenko's axes of main subtropical collection areas, we assumed an approximate water surface affected of 715,520 km^2 in the South Pacific Ocean, 1,296,180 km^2 in the South Atlantic Ocean, and 2,183,480 km^2 in the Indian Ocean (Maximenko, et all). If we assume that plastic type, weight and size are comparable with those observed in the North Atlantic and North Pacific Ocean patches - a safe assumption given that samples between the North Atlantic and North Pacific Ocean patches were consistent (WHOI) - we estimated that the quantities of plastic debris in the volumes of water affected were 2,860 ton in the South Pacific Ocean, 2,590 ton in the South Atlantic Ocean, and 2,185 ton in the Indian Ocean.

In summary, based on data gathered from expeditions, the garbage patch of the Atlantic Ocean gyre and the North Pacific Subtropical gyre contain approximately 9,064 ton and 20,240 ton respectively. Since expedition data for the other three garbage patches are not currently available, the estimation based on Maximenko's model resulted on approximately 2,860 ton in the South Pacific Ocean, 2,590 ton in the South Atlantic Ocean, and 2,185 ton in the Indian Ocean. All together, these garbage patches contain an estimated 36,950 tons of of plastic garbage. These results are summarized in Table 1.

This total quantity of plastic debris in the earth's oceans derived (36,950 ton) equals to only 0.125% of all plastics produced in the US in 2009. While it is small compared to the total produced and properly disposed, it has the potential to adversely impact the marine habitat.

Table 1: Summary Calculations of Garbage Patches.

	Patch Name	Geographic Location	Surface Area (km^2)	Particle Density (pieces/km^2)	Amount plastic (ton)
1	Eastern Garbage Patch	North Pacific Ocean	8,095,000	25,000	20,240*
2	Western Garbage Patch	South Pacific Ocean	715,520	40,000	2,860†
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Total			**15,915,933**		**36,939**

* data; † model

1.2. Environmental impacts of garbage patch

Even if the patch sizes are not exactly defined and the debris material is a very small fraction of the l U.S. generation of plastic wastes, the potential for damage it can cause to the marine environment is still high. Environmental impacts include entanglement of marine fauna, plastic ingestion, transport of species to non-native waters, and concentration and transport of toxic chemicals such as polychlorinated biphenyl (PCB) compounds (Kara Lavender Law, et all).

Although there is a need for additional and methodic long term monitoring, it has been estimated that at least 267 species worldwide (José G. B. Derraik) and in particular over a million sea-birds and one hundred thousand marine mammals and sea turtles are killed each year by ingestion of plastics or entanglement. (UNEP). In a study conducted in the North Pacific eight out of eleven sea birds have been found with plastic in their stomach.

In addition floating plastics can also affect marine ecosystems by providing a ready surface for organisms to live on. These plants, animals and microbial species can then be transported on the plastic far outside their normal habitat, invading new habitats and possibly becoming nuisance species.

Plastics in the oceans can also negatively affect photosynthesis, and zooplankton. Marine debris in fact is acting as a light and air filter that hinders algae photosynthesis and promote their reactive oxygen species production (Priyanka Bhattacharya, et all) both at the oceans' surface levels and throughout "mixed layers" at a depth of 250 feet into the ocean, leaving zooplankton consuming algae with a smaller content of carbon. This may disrupt Earth's natural balance since it can impact CO_2 levels in the atmosphere that are influenced by current as well as zooplanktons (Kostigen).

2. EXISTING LEGISLATION

Despite plastics greater production and consumption, the reported size of the garbage patch has not increased in the last 30 years, as reported below:

> "Although no direct estimates of plastic input to the ocean exist, the increase in global production of plastic materials [fivefold increase from 1976 to 2008 (23)] together with the increase in discarded plastic in U.S. municipal solid waste (MSW) [fourfold increase from 1980 to 2008 (24) (Fig. 3)] suggest that the land-based source of plastic into the ocean increased during the study period. Ocean-based sources may have decreased in response to international regulations prohibiting dumping of plastic at sea (25). Given the measured steady plastic concentration in the western North Atlantic, loss terms must exist to offset the presumed increase in plastic input to the ocean. […] This trend suggests that efforts to reduce plastic input at a land-based source may be measurably effective " (Proskurowski).

To this end the focus of enacted policies so far has been on cleanups and preventing more garbage from entering rivers as well as oceans, following the idea that if it's impossible to prevent was has already occurred, future tonnages of trash can be at least keep out of the water to help contain the issue. Over the past 40 years, a series of Federal, State and local treaties, conventions, and laws as well as more comprehensive international agreements has been enacted. The first ones concern local marine pollution problems; the second ones provide uniform standards to address worldwide marine pollution concerns.

2.1. Legislation in the US

In the US specifically, the Federal Water Pollution Control Act (Clean Water Act) was enacted in 1972, with the aims to protect and maintain the chemical, physical and biological integrity of the waters in the US, introducing permitting on point sources dischargers as a way to accomplish this. In addition, to establish a comprehensive waste management system to regulate disposal of materials in marine waters the Marine Protection, Research, and Sanctuaries Act (MPRSA) was legislate at the federal level in 1972 and amended in 1988 by the Ocean Dumping Ban Act.

MPRSA was enacted to prevent dischargers from evading the Clean Water Act by dumping wastes in the ocean as an alternative to land-based sites. Two are its main purposes: regulate the intentional disposal of materials in marine waters, for which the Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers are responsible; and to promote related researches, under the supervision of the EPA and the National Oceanic and Atmospheric Administration (NOOA).

MRPSA bans dumping of all materials in the ocean except when it can be shown that it is not going to "unreasonably degrade" the environment. It is regulated with permits (Title I) that are issued both by EPA for non-dredged materials and the U.S. Army Corps of Engineers for dredged materials. Wastes is defined as "…including, but not limited to dredged material; solid waste; incinerator residue; garbage; sewage; sewage sludge; munitions; radiological, chemical and biological warfare agents; radioactive materials; chemicals; biological and laboratory waste; wreck or discarded equipment; rocks; sand; excavation debris; and industrial, municipal, agricultural, and other waste…" (EPA) Any private person, employee, agent, department, agency, or instrumentality of the Federal Government, of any State or local unit of government, or of any foreign government must comply or pay an administrative civil penalty up to $50,000 for noncompliance and up to $125,000 for dumping of medical wastes with additional criminal penalties.

EPA is responsible for developing criteria to be followed in the dumping process to make sure that the disposal of debris in the ocean, when permitted, is not going to be harmful to the environment. Moreover, dumping of industrial waste and sewage sludge is banned by the Ocean Dumping Ban Act and no permit can be granted to except it. In addition, Title V addresses water quality monitoring under the authority of the US Coastal Guard (USCG), which is in charge of conducting surveillance and other appropriate enforcement activities to prevent unlawful dumping.

2.2. Legislation in the EU

Overseas, for example in Italy, a new legislation that acknowledges EU directive 94/62/CE on packaging and packaging waste, has been approved on plastic bags in an effort to reduce the national contribution to the dumping of plastic bags in the Mediterranean Sea. Starting on January 1st 2011, the production, commercialization, and use of non-biodegradable plastics bags was banned since they account for the second greater amount of plastic debris in the Mediterranean Sea after plastic bottles (Ocean Conservacy).

A report from the EU Commission to the Council and the European Parliament of 6 December 2006 on the implementation of Directive 94/62/CE notes improvements in recycling and packaging procedures between 1996 and 2002. In addition, the Commission Report of November 2009 on the implementation of Community legislation on waste states that the Directive was properly transposed by all Member States and the level of enforcement was satisfactory.

Another EU directive - The Marine Strategy Framework Directive 2008/56/EC - also addresses the problem, calling on member states to comply with the Directive by 15 July 2010. This directive sets goals with a two years incremental timeframe to first assess the current state of the sea, then to set environmental targets and associated indicators, and finally to establish metrics to achieve “good environmental status” for their waters and monitoring it.

2.3. International Regulations

Local solutions of the problem are complicated by the ability of marine debris to travel long distances driven by ocean currents. Moreover, once the waste enters the ocean, it knows no boundaries. Hence the urge for marine debris to also be regulated internationally.

As ships are one of the four main causes of marine debris The United Nation General Assembly addressed this concern in the Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL). MARPOL initial provisions to reduce pollution by oil, chemicals and harmful substances in packaged form, sewage and garbage, were implemented in 1983 by Annex V that completely ban the disposal of plastic at sea. In addition, since 1988 it prohibits the discharge of garbage from ships, and governments have to provide port facilities to receive this garbage. Although the legislation is in place, it has been estimated that vessels still discharge discard 6.5 million tons per year of plastics in the seas (José G. B. Derraik).

Another major cause of marine debris is beach littering due to people unawareness of the issue as well as illegal dumping on land of solid waste. To this end the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) with its 1996 Protocol (the London Protocol) aims to control the dumping of wastes at sea that have been generated on land to protect marine and coastal environment.

3. STAKEHOLDERS ANALYSIS

The majority of waste entering the ocean originates on land, so the problem of marine debris is closely related to how effective national policies on waste minimization are; how efficiently prevention, reduction, and management of marine debris are incorporated in solid waste management services for municipal/industrial solid waste and wastes generated from commercial and recreational marine activities (5^{th} International Marine Debris Conference); and how well stakeholders, namely the plastic industry, retailers, and consumers, will respond and contribute to their implementations. "Thinking globally and acting locally" is a fundamental attitude to reduce marine debris treat (José G. B. Derraik).

3.1. Prevention, Reduction, Management

Illegal dumping on land, littering (i.e.: street littering, household littering, loading and unloading docks and work areas), and littering associated with recreational beach activities and events can be reduced by promoting activities that promotes the "4Rs" of reduction, reuse, recycling, and recovery in local waste management. Local recycling program that divert plastic from the waste stream could be developed. Local authorities should establish adequate procedures and provide adequate equipment and infrastructures to facilitate their implementation and use. These should include easily reachable receptacle areas, and provision of adequate collection and removal of waste in well defined points. In addition, public awareness on ways to dispose of plastic and engage local communities should be fostered to drive the agenda forward (5^{th} International Marine Debris Conference).

3.2. Government's Role

The Government should impose requirements that manufacturers provide information on their products and that retailers share information on the potential for reducing the environmental impact of their products through a low waste labeling system. Provided information will cover the raw materials incorporated as well as the design, production and disposal of plastic products. Information can also be used to complement other instruments to accelerate desired changes in behavior. Examples would include appealing to altruism or social censure (e.g., use of name and shame), bringing media and public opinion into the picture, and incentivizing the adoption of best practices as well as product stewardship from those involved with the creation, procurement and disposal of the products to prevent materials from entering the ocean water system and becoming marine debris.

In addition manufacturers could be offered tax credits in order to incentivize them to invest in activities that produce less/more of the negative/positive externality. Government could incentivize innovative ways of handling plastic waste, such as the development of recycling programs and the implementation of a take-back program. Tax credits will also place the least cost on the industry, but at the same time ensure that best practices will be adopted, leading to increased efficiency of the plastic waste cycle in reducing plastic disposal in landfills.

3.3. Education

Public awareness programs involving multiple sectors of user groups on litter prevention and proper waste disposal options as well as programs that address public perceptions about littering and marine debris could be conducted. To this end educational materials and training to help modify the public's perception of littering and its impacts – litter-free events, litter-free public outdoor areas, litter-free schools, businesses, etc., as well as outreach campaigns on improper disposal of solid waste could be planned by public local entities (5th International Marine Debris Conference).

Best management practices information could be shared among countries and industries to develop initiatives for integrated solid waste management programs that include marine debris issues and reduce the amount of plastic waste generated, developing a framework legislation that takes into account extended producers responsibility, cradle to cradle methodology, and "end of life" plastic management issues (5th International Marine Debris Conference).

3.4. Developing and Near-Developed Countries

Finally a major concern are developing and near-developed countries. The way their cities are rapidly developing and growing, which as a consequence brings lifestyle changes, is causing a shifting in the waste composition from mostly organic to mainly plastics, paper and packaging materials that are more complex type of waste to deal with. Waste management systems are becoming more sophisticated and costly as the source of waste become more diversified. Hence it is unlikely that these countries, where the economy is either just recently starting to grow or is foreseen to grow in the future, will reduce their use of plastic or monitor its dumping in the oceans (Idris, et all).

This dynamic is also fed by the less stringent regulations and control under which companies in countries undergoing economic development can usually operate. Although this greater flexibility allows them to be more competitive in the marketplace of plastic, it also makes their processes more dangerous for the environment and less socially responsible. More stringent international regulation should be enacted to prevent this pattern.

3.4.1. Latin America

On one hand in researches and surveys conducted in Latin America and the Wider Caribbean Region (WCR) countries year after year the findings have been consistent in identifying plastic, mostly bags and bottles, as the most abundant marine debris on the shore and in the waters, with an average percentage of 55%, and with a peak of approximately 80% on Brazil coasts.

The data cannot be strictly correlated to beach recreational activities as it is consistent during the dry as well as rainy seasons and seems to decrease in magnitude as one moves away from the metropolis of Buenos Aires and Montevideo. The problem in most cases has been associated with inadequate solid wastes collection and disposal of marine debris, and with poor management of waste from ocean- based and land-based sources (Ivar do Sul, et all).

3.4.2. Asia

On the other hand in Asia, although there is an increase in the proportion of recyclable materials in the waste stream, investigations and surveys revealed that "… MSW methods are outdated and show a lack of proper waste characterization, waste stream analysis, and landfill and dump site data. Many disposal sites are still open dumps, and are managed poorly either by the local authorities or by other landfill operators…" (Idris, et all).

Recent studies highlight the production of plastic in various countries in Asia. Top producer of plastic are Thailand and the Philippines with about 16% of plastic production, followed by Malaysia and China which produced about 13% plastics, and by Indonesia and Vietnam which have the lowest production at 8% and 3%, respectively.

In China landfilling is the predominant method for municipal solid waste (MSW) disposal. In addition, separate collection of recyclables is not conducted in most of the 138 cities investigated by the study conducted by Idris, et all in 2000. According to the same study disposal percentage are as follow: landfilling 96.9%, composting 1.3%, and incineration 1.8%. In addition the study concludes that since separate collection of recyclable item is not practiced and incinerators are too expensive to install and operate for most of these cities, these percentages are not expected to change significantly in the future (Idris, et all).

However, these predictions have not materialized since the Chinese government, since200, has provided financial incentives for new waste to energy plants. As a result, there are now 66 WTE plants operating in China and more are under construction (private communication, Yani Dong, Earth Engineering Center, August 2011).

Nonetheless, positive auspice in terms of waste management and best practices are coming from two countries in Asia: Taiwan and South Korea.

In Taiwan the amount of landfill disposal is about 40.20% , the rate of improper disposal is 3.64%, which includes non-sanitary landfills (2.76%), and recycled waste is approximately 15.5%, but the recycled amount that returns to the market in not controlled. Also, Taiwan has several WTE plants. As of 2002, 19 out of the 36 large-scale MSW incinerators that were supposed to be built in Taiwan were operating, burning 54.2% of MSW and 2% of industrial waste, the Taiwanese Government has committed to a “zero waste” policy with attainment goals of MSW reduction of 25% by 2007, 40% by 2011, and 70% by 2020 (Idris, et all).

In South Korea a solid waste management system was instituted in 1988 and revised in the early 1990s. It focused on waste reduction, recycling, and proper treatment as alternative domestic waste disposals to landfill. (Idris, et all).

In Singapore all the waste generated is either recycled or combusted, with no MSW landfilled.

4. SOLUTIONS

So far the main focus of enacted policies has been on prevention of marine debris as a long term strategy. However, a complete and well rounded marine debris mitigation strategy should include concrete actions and responses to marine debris that is already present in the environment, until prevention goals are attained. These would include shore cleanups, enforcement of laws related to marine debris, and research and technology development.

4.1. Shore Cleanups

International and local non-profit organizations are the major organizers of beach cleanups, which are generally driven by volunteering community and researchers involvement, and contribute to the education and understanding of marine debris issues. International Coastal Cleanups have been organized by the Ocean Conservancy since 1986. In twenty five years a total of 166,144,420 items was collected in 152 different countries and locations. Plastic items such as plastic bags, bottles and six-pack holders account for a 11% of the total amount (Ocean Conservancy).

4.2. Economic Impact

Another aspects to consider in addressing the issue of marine debris are its economic implications, such as tourism losses and debris removal costs, which are not generally been addressed by researchers. To be able to overcome this lack of knowledge the economic status of marine debris on key sectors should be researched with reports that assess the direct impact of marine debris on loss in services and cost of cleaning up coastal areas (5th International Marine Debris Conference).

The economic evaluation of the impact of marine debris is extremely challenging as it affects not only ocean themselves, but also several different industries that rely on marine environment such as, but not limited to, municipalities, fisheries and aquaculture. On one hand, municipalities face costs related to the removal of litter from beaches and aesthetic intangible costs related to people's perception of the quality of the environment, which lead to tourism losses as a consequence of unclean and spoiled beaches. On the other hand, fisheries and aquaculture bear indirect costs due to lost fishing time which is spent in cleaning litter from nets. In addition, incidents and damages that occur to vessels (i.e.: fouled propellers and blocked intake pipes) can result in loss of time and increase in expenditure such as repairs and changing in fishing locations (5th International Marine Debris Conference).

Examples of cost estimates are as follows:

- Beach cleanups. The Netherlands and Belgium spend approximately US$13.65 million annually in cleaning up their beaches (UNEP). In the US alone in twenty five years of beach cleanups, done by 241,002 between volunteers and unpaid researchers, was collected at total of 2,167,065 items, of which 252,694 were plastic bags, 222,670 were bottles, and 10,430 were six-packs holders (Ocean Conservancy).
- Tourism losses. Ofiara and Brown estimated tourism losses between $706 million and $2,977 million (in 2008 US$) as a result of marine pollution and wash-ups in New Jersey in 1988 (Ofiara and Brown 1999).
- Fisheries and Aquaculture. Marine litter costs the Scottish fishing industry an average of between US$15 million and US$17 million per year, the equivalent of 5 % of the total revenue of affected fisheries (UNEP). In 1989 a survey conducted by Wallace on commercial vessels in the eastern oceans in the US revealed that over 45% of their propellers, over 30 % of their gears and over 35% of their cooling systems fouled due to plastic clogging. The numbers for recreational vessels were 28%, 15%, and 21%, respectively (Nash).

4.3. Best Practices - Private/Nonprofit Partnerships

Moreover, in an effort to implement best practices collaborative private/nonprofit partnerships have been created to help reduce and prevent marine debris. Project Kaisei, a nonprofit organization that organizes plastic cleaning expedition in the Pacific Ocean, and Covanta Energy, a Fairfield-based company that owns waste-to-energy power generation plants, under the auspices of the Global Clinton Initiatives (GCI) partner up to clean up the ocean debris starting with the plastic in the North Pacific Gyre, with a yearly conversion target of 50 tons of marine debris into renewable energy.

Covanta Energy uses the debris collected by Project Kaisei to "test its new waste-to-fuel technology to convert the plastic into a diesel substitute using a catalytic process for converting solid organic materials directly to mineral diesel fuel" (Covanta Energy), and to showcase how waste, and in particular plastic, can have added value if properly recycled. This in the hope that a larger scale cleanup effort will take place, helping protect the ocean and the marine wild life (Covanta Energy).

4.4. Enforcement and Monitoring

Various agencies, such as the EPA, the USCG, and the NOAA are delegated to enforce the laws and the enacted policies on marine pollution. They are in charge of identify illegal dumping or discharging and act to verify violators compliance through monitoring, inspections, review of waste management systems, and eventually fines. On one hand, the EPA refers violation under statutes administer by itself for criminal or civil enforcement. On the other, the USCG is responsible to perform inspections and to enforce action for MARPOL Annex V non-compliance, which includes written warnings, imposition of monetary penalties, and referral of cases for criminal prosecution or civil judicial enforcement action. Finally NOAA has both the authority to enforce statues as well as the administrative and civil power to enforce actions to protect the marine environment.

4.5. Research and Technology Developments

Although the plastic trash patch, and in general marine debris, is not precisely quantifiable in all its aspects, it is the symptom of a bigger problem: plastic end-of-life use. Research and new technology development are essential in order to assess next steps, address gaps, and reduce plastic from entering the marine environment. Research should assess the impact of persistent material on the oceans, on the other hand technology should consider prevention, removal, and ways of recycling.

To be able to clearly understand the marine debris problem in order to implement efficient and realistic programs it is also important to have data on the amount, distribution, and impact of such pollution. Relevant information is available, but as of today it is not enough to cover all aspect of the issue and many quantitative data are hypothesized. One of the main problems is the absence of science-based monitoring and consistent and widespread sampling. Currently various different methodologies of sampling and monitoring are employed, making it difficult to harmonized the data across time and space. The issue of gaps in monitoring and assessment of the status and impact of marine debris should be addressed at global and regional level, by implementing standards and increasing research programs and funds dedicated to the issue of marine debris (5th International Marine Debris Conference).

5. CONCLUSIONS

There are four main dimensions to the problem of the plastic trash patch - plastic is extremely diffuse in the oceans, it does not biodegrade, it affects the ecosystem, and it is a global issue – which relate to how effective national policies on waste minimization in developed and near-developed countries are; how effective municipal, industrial, commercial and recreational solid waste management services and programs are; and how well stakeholders will respond and contribute to their implementations.

Eighty percent of marine debris is generated on land. It either comes from sewer overflow, solid waste disposal and landfills, illegal dumping, recreational activities on the beach, or the fishing industry.

Based on the findings of this study, compiled from a combination of mathematical and physical models estimates and data from expeditions, plastics in the five plastic trash patches amount to 36,950 ton which equals approximately to 0.125% of all plastics produced in the US in 2009.

Although this numeric value can seem an insignificant portion of the overall plastic production, the potential for environmental and economic damages it can cause both on marine environment and on different industries that rely on it is still high and should drive future policies, technology, and research developments.

Marine debris can spread species moving them away from their native habitat possibly making them nuisance species in the new habitat. On the other hand, it can also negatively impact photosynthesis and zooplankton, which might impact CO_2 level in the atmosphere and disrupt Earth's natural balance. In addition, it has been estimated that 267 species worldwide, over a million sea-birds and one hundred thousand marine mammal and sea turtles are killed or entangled by plastic.

Moreover, economic impacts have been estimated raging between US$1000 million and US$3000 million in beach cleanups, tourism losses, and damages to fishing and aquaculture industries. Considering that the Netherlands alone pays approximately US$ 13.65 million annually on beaches cleanups, the economic estimate would be significantly higher if the twenty five years of International Coastal Cleanup were not to be organized and carry through by the Ocean Conservancy on a volunteer basis.

From a legal prospective the focus of enacted policies - such as the Clean Water Act, the Ocean Dumping Ban Act, the EU Marine Strategy Framework Directive 2008/56/CE, the EU directive 94/62/CE and the relative national legislations to acknowledge it, the MARPOL Annex V, and the London Convention and Protocol – has been prevention of additional plastics to enter the marine ecosystem. This long-term prevention scheme should be implemented with mitigation strategies which should include enforcement of laws related to marine debris, shore cleanups, and research and technology development, until prevention goals are attained.

Finally, data on the amount, distribution, and especially environmental and economic impacts of such pollution are key in dealing with the problem of plastic end-of-life use and implementing programs, as well as science-based monitoring and consistent widespread sampling. Greater research and new technology development effort are needed to assess next steps, address gaps, and prevent plastic to enter the oceans.

As a show case of best practice that could lead the way to greater public awareness on the issue of plastic disposal and recycling. For example a partnership between Project Kasei and Covanta Energy set a goal of conversion of plastic to fuel of 50 tons per year.

The hope is that a larger scale cleanup effort, which will help protect the ocean and the marine wild life, will take place as a result of this project. In addition, it is an excellent opportunity for the private sector to test a new technology as a viable solution to address plastic dumping, and to create secure, financial business opportunities and help identifying recycling cost-effective solutions.

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