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Distribution and Solutions for Marine Debris: A Case Study on the Great Pacific Ocean Garbage Patch

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Abstract. In recent years, with the development of society, the amount of marine debris is rising rapidly, and human beings have caused great damage to the marine environment. This study introduces sources and impacts of marine debris, analyses distribution and effects with an example of the Great Pacific Ocean Garbage Patch by studying the direction of ocean current and using QGIS technology, and provides some control measures. Results show that plastic is the predominant constituent of marine debris. Sources of marine debris include land-based and ocean-based. Marine debris has great impacts on creatures and people living in the sea and remote areas. Ocean currents are the main reason for the formation of the Great Pacific Garbage Patch, which is the movement of seawater driven by force acting on it. The temperature and salinity of seawater, and the trade and prevailing wind are long-term factors affecting the distribution of ocean currents, and the tropical cyclones are short-term factors. It suggests that the government should salvage and recycle marine debris, establish legislative regulations, incinerate it for power generation, and construct artificial islands. For personal, they should use reusable products, recycle reasonably, reduce energy use and avoid products that contain microbeads and microfibers.

Keywords: Marine Debris; Sources; Impacts; Great Pacific Garbage Patch; Effects; Control Measures.

1. Introduction

Ocean, as a source of life, covers over 71% of our mother Earth. However, most pieces of plastic people consume end up in the sea. Every piece of plastic people consume is likely to end up in the sea. Plastic bags, plastic bottles and other plastic packaging now fill our lives, forming a 'white' world. Since the American oceanographer Charles Moore discovered the Great Pacific garbage patch (GPGP) in 1997, its area has kept rising every day, which contains the area of trash as twice the area of Texas, or a triplex area of France, about 1.6 million square kilometers [1].

Marine debris is indicated as solid artificial trash along the coastal line and in marine that last for a long time, which includes from fishnets to daily plastic products and cigarettes. According to a report by the United Nations Environment Programme, such worldwide troublesome problems of floating trash in the ocean and along the coastline keep rising. Progressively increased marine pollutants could be

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identified as a sign of ascending pollution problems, which lead to unreasonable management of recycling and disposing of trash. Such debris may float on the sea surface, be moved by ocean currents away from the shallow area, or wash up on the shore, and others sink to the ocean floor, which jeopardizes the marine economy by influencing the landscape, unbalancing the marine ecological equilibrium, and uncertain marine traffic security. If nothing is done, the oceans are going to be overwhelmed and humans might eventually be difficult to survive. Therefore, a more comprehensive understanding of marine debris is necessary, which assists society to reduce the amount based on its source, improving the recycling plan referring to its distribution, and establishing relevant regulations and developing solutions.

2. Background of marine debris

2.1 Types of marine debris

For centuries, people have tended to dispose garbage into the ocean as a nuisance. All dumped pollutants and litter finally made their way to the sea by river, boats, atmosphere, etc. Denser contaminants may sink to the middle or bottom of the water, and some may be decomposed and then dissolved in the seawater, while some may just be floating on the sea surface. However, most of them degrade slowly, mainly through mechanical abrasion and exposure to UV radiation, which pose a threat to the marine environment [2].

Plastic is a predominant constituent of ocean litter, accounting for 86.9% of the observed floating marine debris (FMD) [3]. It can be divided into seven categories (Table 1) [4].

Table 1. Seven types of marine debris [3,4].

Types	Explanation
Chemical sludge	A chemical soup results from sources such as storm runoff, industrial processes, agricultural runoff, shipping and wastewater from cities.
Microplastics	Small particles of plastics come from sources such as synthetic clothing, cosmetics and industrial processes. These small plastic particles are a concern because they enter the food chain at a low level when small organisms consume them.
Secondary microplastics	Small particles of plastic result from the breakdown of plastic garbage or products such as tires.
Packaging&bags	Plastic bags and discarded packaging include bottles, bottle caps, wrappers, cups and cans.
Products	Consumer products include cigarette butts, straws, cosmetics, paper, diapers, batteries and shoes.
Fishing equipment	Commerical fishing equipment includes ghost nets, floaters, fishing line and traps.
Large debris	Large items that have been dumped or spilled such as tires, vehicles, electronics, construction materials and drums of chemicals. Natural disasters such as tsunami and hurricanes are also a significant source of large marine debris.

2.2 Detection and amount of marine debris

In the Pacific, the severe accumulation of garbage in the marine environment has led to a new continent-like chunk in the sea areas between Hawaii and California (Figure 1). As the Eighth Continent, it is actually the largest landfill of millions of tons of floating marine debris carried by sea. Although it has not yet formed a consolidated landmass like any other continent, the area it occupies is growing at a mind-boggling speed--twice than it was in the last decade. Over 7 million tons of trash is concentrated here with more than 1.4 million square kilometers, twice the Texas area in America and each square kilometer contains 3.3 million pieces of plastic debris in various sizes [5].

The patch and garbage gathering would happen whenever there are ocean gyres. Garbage continents like the one in the Pacific as mentioned above are expected to exist in two places in the Pacific, the northern and southern parts, two of the five largest-scale gatherings of marine trash on Earth. In area

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where marine debris is of high concentration, each cubic kilometer of the sea contains 10kg of plastics--equal to approximately 800 plastic bottle [5].

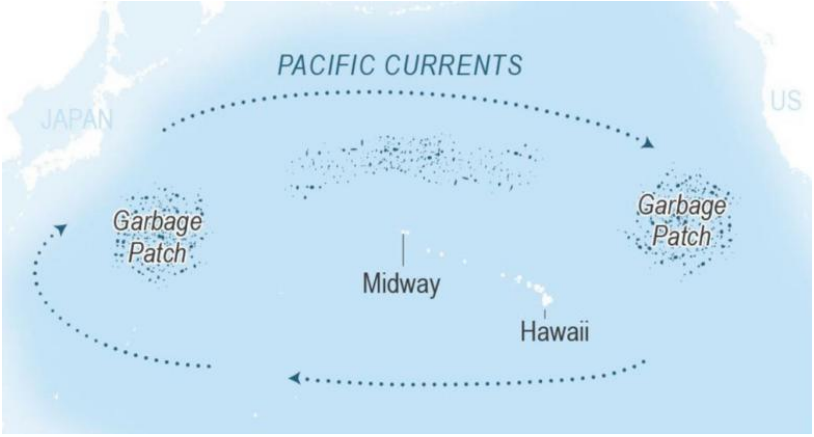


Figure 1. Concentrations of garbage patched circle in the North Pacific [6].

Plastic takes up a large proportion of marine debris and is projected to increase with the increasing use and dumping of plastic trash. However, research conducted by American scientists states that the total amount of sea garbage has almost remained unchanged in the past few decades. The main factor is that those plastic debris decompose faster than imagined affected by the sunlight and sea waves. Therefore, the tiny pieces are suspended in seawater, which means that they can hardly be captured by large trawls to detect the amount of ocean debris [5].

Unfortunately, the data on marine trash is far more smaller than the actual one. This is not only because tiny plastic particles may escape through the relatively wide grid of the detecting trawl, but also, some may be frozen in the ice layer so that cannot be found especially in areas near the poles. Moreover, the ability of glacier or ice sheet to trap plastic particles is greater than that of seawater. Denser debris might sink to the middle or bottom of the water. The “garbage patch” made up of microplastics cannot be revealed on satellite imagery. Thus, as estimated, suspended marine debris might account for millions of tons more in the sea than the data derived [5].

2.3 Sources of marine debris

As estimated, land-based sources are responsible for up to 80% of total marine trash while the rest is due to sea-based activities [3].

2.3.1 Land-based sources Garbage can be produced in two main ways: industrial activities and urban utilization.

Industrial or side products that are disposed of may deter the marine environment when they are poured into the sea. The industrial process demands a large amount of usage of all kinds of material, from plastic and metal to toxic chemicals and harmful drugs. Once discarded improperly, they may eventually find their way to the sea by the drainage system or wind pattern between the continent and the sea.

In densely populated regions inland or coastal areas, a great amount of garbage is produced, consumed and discarded, corresponding to intense human activities. Municipal solid waste (MSW), trash generated by cities, consists of everyday items that are used and thrown away, eg. product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries [7]. The disposal of MSW presents considerable cost, so ocean dumping, a convenient and inexpensive way, is an excellent way to deal with those land-occupying or even harmful MSW.

There are three ways of migration of marine debris to be transported into the sea. (1) Some lighter garbage, such as plastic bags and plastic bottles in the landfill may be blown by the wind directly into the sea. (2) During a rainfall event, intense precipitation may wash the waste on the land into river

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channel as surface runoff and finally enter the sea. In addition, waste may be collected into the sewage pipes leading to the ocean as contaminants. (3) Although dumping litter into the sea is legal, this behavior can still be commonly found.

2.3.2 Ocean-based sources Ocean-based sources can be divided into four categories: commercial fishing, recreational boaters, merchant, military and research vessels, and offshore oil and gas platforms and exploration [3]. (1) Commercial fishing: Fishing gears such as hooks or nets may become marine trash once discarded in to the sea. (2) Recreational boaters: Boaters may deposit bags and food packaging when cruising. (3) Merchant, military and research vessels: Solid waste generated by crews or rubbish thrown accidentally will end up as marine debris. (4) Offshore oil and gas platforms and exploration: Personal items like hard hats and gloves, storage drums and storage materials may be casually dumped into the sea.

2.4 Impacts of marine debris

2.4.1 Impacts on creatures and people in the sea A vast number of seabirds, sea turtles, and other sea animals may die each year by getting tangled in plastics or fishing lines and nets. Many sealife are trapped by fishing gears [7]. Besides, entanglement happens when the vessels' propeller is disturbed by marine debris and thus hinders the operation of the ship machine, leading to a marine accident.

This also endangers marine organisms when they ingest the marine litters, which are indigestive or even toxic because some may absorb heavy metals harmful chemicals. Once the pollutants are taken in, the toxic substance will accumulate in the creature’s body. Up the marine trophic level like sharks or dolphins, they have more toxins or debris built up in their bodies through a process called bioaccumulation [8].

2.4.2 Impacts on wider areas Many debris released could drift to remote places. If they reach another country, inevitable conflicts may be aroused. For example, some garbage labeled “made in China” was found along the beach in Japan and Korea [5]. It indicates that marine debris carried by the ocean current may have a wider range of impact than imagined.The endless drift of marine debris could affect favorable aesthetic of the ocean. The impact is emphasized when the maritime area is used for attracting visitors and relies on tourism. The trash may act as eyesore to the ocean landscape and impede the development of local economy.

3. Distribution of Great Pacific garbage patch

The GPGP is a trash vortex with coordinates around 135°W to 155°W and 35°N to 42°N that separated into two regions, the ‘Eastern Garbage Patch’ at northeastern Hawaii and approximately 1000 sea miles away in California; and patch with extension from Japan to Hawaii is the western one [9]. Its acreage in 2018 was estimated at about 1.6 million km2 and drifting trash at the sea surface weighed 45-129 kilotons, derived from the Pacific Rim countries [10].

Ocean currents are the main reason for the formation of the GPGP, which is the movement of seawater driven by force acting on it. Tide, temperature, salinity difference, and wind affect ocean currents' distribution. These factors can be classified with long-term and short-term effects on ocean currents [11].

3.1 Long-term effect

3.1.1 The temperature and salinity of seawater This study analyzes the temperature and salinity difference of seawater around Japan using Quantum GIS to make the graph with the source of satellite images from Copernicus.

Results show that the areas near Japan demonstrate a large seawater temperature and salinity variability using 40°of north latitude as a boundary (Figure 2).

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The deviations between the salinity and temperature at different marine areas lead to seawater density differences. Referring to the thermohaline circulation, the difference in density causes the upper layer of seawater to go down, thus promoting the slow movement of deep layer sea water from the west of the Pacific Ocean to the east as a clockwise ocean current.

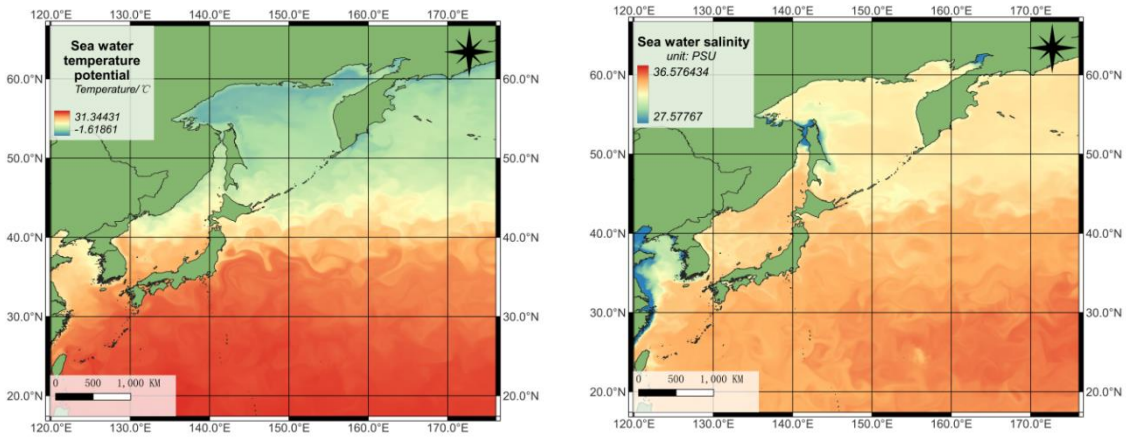


Figure 2. Temperature and salinity.

By investigating ocean currents' directions and sea surface height, using the plugin 'VectorFieldCalc', 'Point Sampling Tool', and 'Contour Plugin' in Quantum GIS, the sea surface heights vary with the boundary of north 40-degree latitude using Tokyo, Japan as a reference point (Figure 3). With complex current lines and vortex around the Japan Trench, ocean currents produce a force toward the Central North Pacific. Compared with the present concentrated location of rubbish, it indicates that by promoting of Kuroshio current and North Pacific Current, rubbish floating off the coasts of China, Japan, Korea, and South Korea is carried towards Hawaii or stays in the southeast of Japan, forming the 'Western Garbage Patch'.

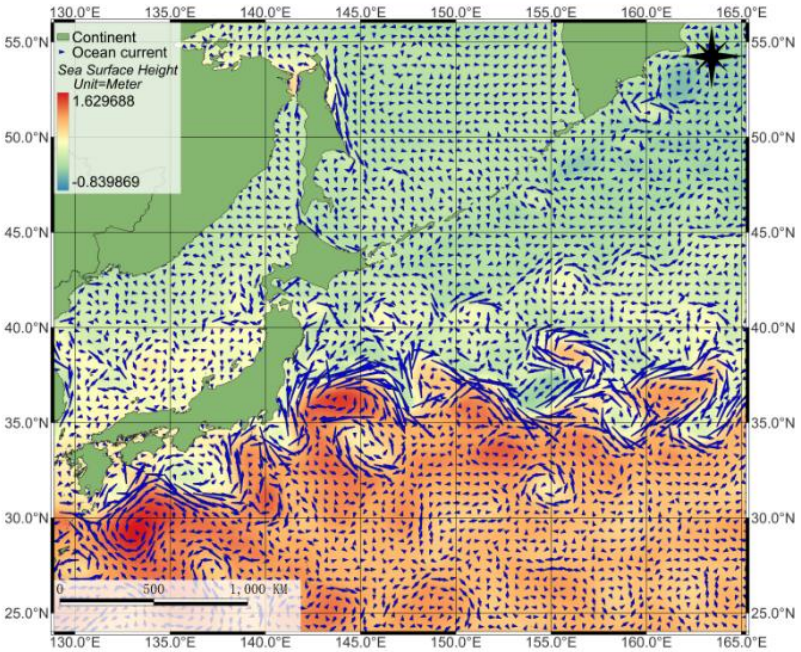


Figure 3. Ocean current near the Japan.

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3.1.2 The trade and prevailing wind The trade and prevailing wind help the formation of ocean currents that promote the trash flow from sea areas around Southeast Asia to Japan, western America to California. Referring to higher atmospheric pressure at 30° latitude of north and south than at the equator, the wind blows from these two dimensions toward the equator, because of the Coriolis force. Coriolis effect leads to the direction of wind curve to the equator, forming trade wind promoting the Pacific ocean water moves from east to west (Figure 4). In the northern hemisphere, North Equatorial Current driven by trade wind turns toward Japan with obstruction of land, forming the Kuroshio Current. Prevailing westerlies continue the Kuroshio Current at a higher latitude than North Pacific Gyre. As it reaches California, the US, part of the North Pacific Gyre, moves toward the lower latitude region as compensation current 'California current'. This pattern of clockwise current in the Pacific ocean promotes the trash retain or replacement between Western Garbage Patch and the Eastern Garbage Patch.

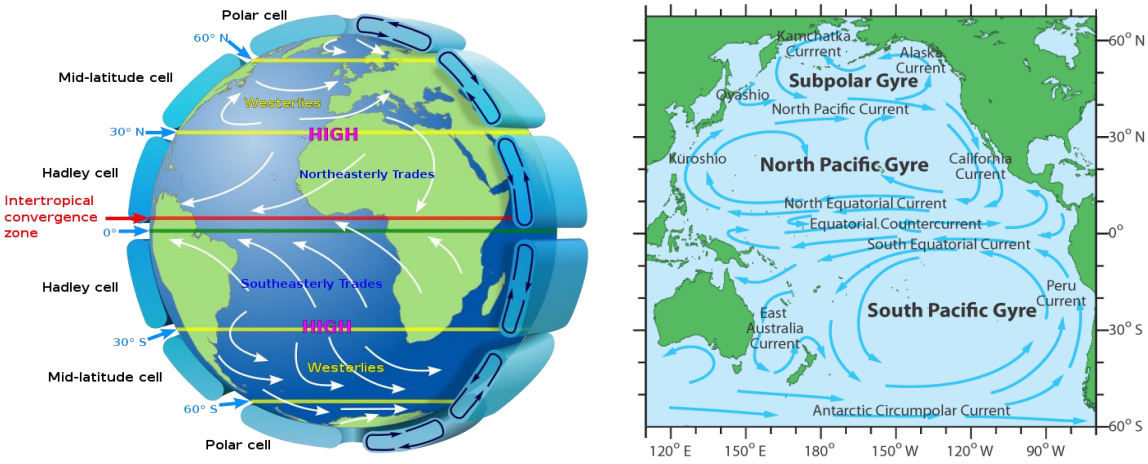


Figure 4. (a) Earth Global Circulation; (b) major currents.

3.2 Short-term effect

3.2.1 The tropical cyclones As a short-term wind source, the tropical cyclones temporarily improve ocean currents' speed along their track (Figure 5).

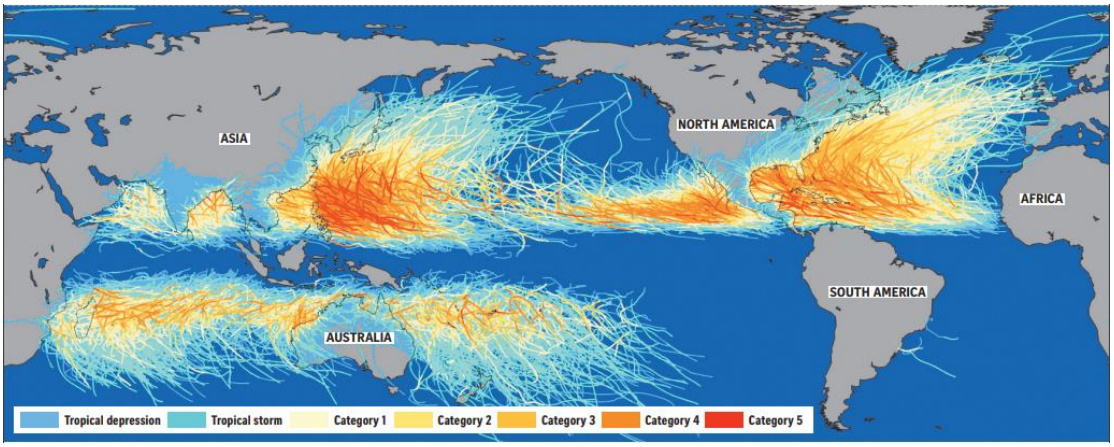


Figure 5. Intensity and tracks of tropical cyclones globally since 1851 [12].

The track graph illustrated that most of the tropical storms are located near the Philippines in the western Pacific Ocean, and America and Mexico in the eastern Pacific ocean. Refer to the cross ventilation of

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hot and cold air formed by relative higher ocean surface temperature and sufficient Coriolis force, a higher category of storms formed and moved toward Japan and Hawaii, which influenced the ocean current and promoted the movement of floating trash either through wind stress equation and Ekman's theory about the ocean surface current speed. Wind stress equation is as follows.

$$\tau = cW^2 \tag{1}$$

According to the wind stress equation, greater wind speed forms larger frictional force on the sea surface and further leads to higher current speed. Ekman's theory of surface current speed in a homogeneous infinite ocean is as follows.

$$u_0 = \frac{\tau}{\rho\sqrt{A_z f}} \tag{2}$$

Referring to relatively less salinity difference in the west and east of the pacific ocean, the density(ρ) and eddy viscosity (Az) will not show much difference. With this equation, an increase in wind stress provides faster ocean current speed along the track of tropical storms. Thus the movement of tropical storm transport the floating trash from Southeast Asia to the coast of Japan, and hence trash moves through Kuroshio Current to Hawaii or stays in the Western Garbage Patch.

The same approach can be applied to the tropical storm-prone areas between the southwestern United States and Mexico. Floating trash along the coast was diverted to Hawaii by storms, the expansion of the area of the Eastern Garbage Patch.

It is noticed that, although tropical storms only affect the ocean current in the short term, it has faster wind speed with a direction of spiral, which could move coastal or heavier trash into the path of ocean currents, causing it to drift towards the garbage patch. Therefore, tropical storm plays an indirect role in promoting the formation of garbage patch.

3.3 Further change of the Great Pacific garbage patch

With global warming, faster ocean current patterns along the Pacific ocean shorten the time for floating trash to move to the Western or Eastern Garbage patch, which increases the growth rate of the GPGP. Scientists have discovered that global warming leads to a dramatic increase in ocean current speed by 15% each year over 23 years from 1990 to 2013 two years ago. Shrinkage of upper layer sea water led by water temperature transfer improves the ocean current speed [13].

4. Solutions for Marine debris

4.1 Governmental solutions

In the face of a huge amount of marine garbage, governments of all countries should master its types, quantities and sources, assess its evolution trend, use the power of science and technology to remove it while monitoring, strengthen public education, and raise citizens' awareness of marine environmental protection.

4.1.1 Salvage and recycling People often say that garbage might be misplaced resources. In a complete ecosystem, resource chains are interlinked, and much garbage can be further used. Regular location search, salvage and transportation of floating garbage can effectively control garbage pollution in the ocean. There are a lot of plastic products, glass bottles, wooden boards, fishing nets and so on in the marine debris. It is important to collect and classify them for recycling. Some programs also encourage boat owners to remove any trash they accidentally catch while fishing.

Collecting and removing ocean and river trash include using garbage salvage vessels. These devices can be used when floating debris poses a navigational threat. In some places, "trash traps" are installed in rivers to catch garbage before it reaches the sea.

At the same time, using GPS satellite trackers installed on the ships, the clean-up vessels can be accurately tracked to remove the garbage with the information they receive. GPS tracking technology

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combined with satellite imagery can help locate waste in real-time, which would greatly improve the capacity and efficiency of cleaning up [14,15].

However, there is a problem that the act of removing marine debris from the ocean may have more advantages than disadvantages. As clearing garbage could accidentally pick up some plankton, which is the main lower food group in the marine food chain and the key to generating more than half of the photosynthesis on Earth [16].

4.1.2 Legislative regulations The government needs to clarify legal responsibilities and severely punish units that do not dump waste following the law. The relevant authorities should set up a punishment system, restrict open waste facilities near waterways, prohibit garbage dumping into the sea, and set up warning signs in coastal areas.

The ocean is globally shared, so producers generally do not feel the negative externalities of marine garbage. For decades, countries have finally recognized the importance of government intervention in cleaning up marine pollution [17]. Presently, dumping at sea is regulated by international law, such as the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, the MARPOL convention, the United Nations Convention on the Law of the Sea, Fishing Grounds, and Sea Routes Protection Act.

4.1.3 Incineration of power generation and construction of artificial islands Most of the debris at sea is plastic, and almost all the plastic is petroleum-based, made up of hydrocarbons that burn and release huge amounts of energy. Therefore, after salvage, collection and classification of Marine garbage, it can be used for incineration to generate electricity. At the same time, to maximize the use of resources, the use of fuel derived from waste is also advocated. Used plastic with a low salvage value usually cannot be recycled and is more likely to leak into the ocean [18]. However, if these useless plastics are turned into waste-derived fuels, they can be further used as supplementary fuels in various fields.

When waste is incinerated, it creates a lot of ash, which can be sealed and filled into the sea to create artificial islands, such as Pulau Semakau in Singapore. In 1998, the Singapore government built the island from ashes from four incinerators. The birth of Pulau Semakau provides a new way to solve the problem of Marine debris.

As for Community and school, the community principals should organize and lead the community clean-up from time to time. Collect trash on beaches, lakes, rivers, streams, and local streets to prevent it from being marine pollution. School education is also an important part of reducing marine debris. By having marine garbage courses and organizing related activities, teachers and students can have a more comprehensive understanding of the relevant knowledge of marine garbage, to realize its harm and the importance of disposing of garbage responsibly [19].

4.2 Personal solutions

Although marine pollution comes from many different sources, if people reduce the amount of litter produced, the amount of litter that could become marine waste could also be reduced.

Everyone can take part in keeping the beach clean so that the ocean's ecosystem can be improved when going out and playing by the water. Bringing a trash container can help people keep track of where their trash is. There are also some simple actions around the house to reduce waste.

(1) Use reusable products: It suggests reusing plastic bottles and shopping bags can significantly reduce marine pollution, greenhouse gas emissions and energy use. Disposable utensils such as straws, cutlery, glasses and plastic bags should be reduced.

(2) Recycle reasonably: One of the most cost-effective ways to help reduce the amount of plastic entering the ocean is to find ways to recycle different materials and buy recyclable products.

(3) Reduce energy use: There are many easy ways to reduce using energy. Riding a bike, walking or using public transportation could help decrease the level of energy use. It is advised to use efficient appliances at home and turn off appliances seldomly use.

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(4) Avoid products that contain microbeads and microfibers: The fibers in wastewater often come from the clothes people wash at the laundry. By using laundry pods, bags, or filters to capture microfibers before they go out with the wastewater, people can reduce the amount of fiber that comes out of the washing machine [20].

5. Conclusion

This study interprets the types, amount, sources and impacts of marine debris, analyzes the direction of ocean currents in promoting the distribution of it with an example of the GPGP, and actions governments and each person should take to reduce and recycle marine trash.

Marine debris is criticized as the " worst invention", and one of its representatives, the GPGP has not only a horrible area for marine animals and people who live in the sea or along the seaside, but also a great warning for the human beings. The condition of GPGP can still be exacerbated by more general usage of plastic products, dumping trash into the ocean without awareness of protecting the ocean environment, or the release of greenhouse gases that contribute to the speed of ocean currents, thus increasing the rate of enlargement of the garbage patch. This thesis suggests the government establish legislative regulations, facilitating more comprehensive salvage and recovery of marine debris, incinerating it for power generation, or constructing artificial islands. Moreover, the public should enhance the awareness of using reusable products, recycling trash reasonably, reducing energy use, and avoiding products that contain microbeads and microfibers.

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