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Global Plastic Waste Accumulation in Ocean Gyres From 2000 - 2019: An Analytical Comparison of Regional Microplastic Concentration

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ABSTRACT

Oceanic plastic pollution has significantly increased over the past decades and has accumulated into ocean gyres creating great garbage patches, including the North Pacific Garbage Patch (NPGP), South Pacific Garbage Patch (SPGP), North Atlantic Garbage Patch (NAGP), South Atlantic Garbage Patch (SAGP), and Indian Ocean Garbage Patch (IOGP). The largest patches, the North Pacific and North Atlantic, are well studied but little is known about the other 3 patches or the origins of plastic pollution. This study aims to create a comparison of the 5 garbage patches, address how plastics are discharged into the ocean, and the policies surrounding the issue using public online data sets and papers. The Global Marine Microplastics Database from the National Oceanic and Atmospheric Administration (NOAA) and the 'Plastic Waste Accumulated in the Ocean' dataset from My World In Data were used to compare microplastic concentrations, total plastic amounts, and garbage patch sizes. Data analysis showed a majority of plastics emitted into the ocean originated from China, Europe, and the Americas as major economic contributors and trade communities. In 2000, the ocean contained 8.47 million plastic tonnes, with Asia (2.65 million tonnes) and the Americas (2.58 million tonnes) accounting for most plastics emitted. Over the span of 2 decades, countries with increased manufacturing contributed to a sharp increase in oceanic plastic. As of 2019, out of 30.41 million plastic tonnes in the ocean, Asia contributed an estimated 12.94 million tonnes, the Americas contributed 7.56 million tonnes, and Europe contributed 5.05 million tonnes. National organizations and countries have implemented policy change, but it is difficult to abolish single use plastic due to widespread use. Ultimately, more studies on plastic effects on the environment are important to generate a more complete perspective of the problem and engineer solutions.

INTRODUCTION

The widespread human use and pollution of plastics contributes significantly to the degradation and damage of the environment. In the span of 65 years, from 1950 to 2015, humans have produced 6.3 billion tonnes of plastic (Rohdes, 2018). Of the plastic produced, 79% has either accumulated in landfills or has been released into the environment. Plastics are not biodegradable and incineration is the main way to destroy them (Verma, 2015; Kumar, 2022). However, this process can release air pollutants including dioxins, furans, mercury, and hazardous halogens, all of which have harmful environmental consequences. Dioxins are a toxic persistent organic pollutant that can be carried by the wind or water and have been associated with malignancies, neurological damage, irritation of the respiratory system, and disruption of reproductive systems (Verma, 2015). The impacts of these toxic chemicals on the environment and human health have yet to be fully understood. Plastic waste and air pollutants can also have detrimental effects on oceanic marine life and ecosystems.

Oceanic waste materials, primarily composed of plastics and marine debris, accumulate in giant circular currents known as gyres. These large garbage patches contain materials from fishing industry equipment, household items, and plastics, with trash pieces ranging in size from large ship debris to microscopic pieces (Lebreton, 2017). Plastic trapped in these subtropical ocean gyres do not dissolve, and instead break down into smaller pieces, called microplastics, due to UV exposure and the impact of waves (Lebreton, 2018; MacLeod, 2021). Microplastics represent the greatest proportion of trash in these gyres by count, and can be categorized by type and size. In trawl samples, where a net is dragged through the water column or ocean floor by boat, plastics have been grouped by categories including hard plastics, filaments, and foam (polystyrene), with sizes ranging from megaplastics (>50cm) to microplastics (0.05-0.5cm). Microplastics can sink, extending from the surface of the patch to the bottom of the ocean in a process called fallout (Egger, 2020). Garbage not only travels up and down the gyre, but can also be carried across the ocean to other patches (Sebillie, 2012).

Five major oceanic garbage patches have been documented: the North Pacific, South Pacific, Indian Ocean, North Atlantic, and South Atlantic garbage patch (Filho, 2021). There are limited published comparative analyses across the five major oceanic gyres. The most well-known patch is the North Pacific, most commonly referred to as the Great Pacific Garbage Patch (GPGP), located between Hawaii and California. Extensive studies have been conducted on the GPGP with trowl tests for oceanic pollution from boats and satellite surveillance finding rapid growth over time as debris continues to accumulate (Lebreton, 2018). These studies helped to establish the size, depth, and composition of the GPGP. The other garbage patches are less well studied but some, such as the South Atlantic Patch, are predicted to grow while others, such as the South Pacific Patch, are predicted to shrink in size over time (Sebille, 2012). Current estimations of patch sizes report the smallest gyre is the South Atlantic, at approximately 0.7 million km^2, and the largest being the GPGP at approximately 1.6 million km^2 (Filho, 2021).

Plastic patches and ocean debris cover great distances allowing many large marine organisms to ingest or become entangled in plastic materials (Thushari, 2020; MacLeod, 2021). Sea turtles have been found washed up on shore with plastic in their stomachs and whales caught in ghost nets have been dragged to the bottom of the ocean (Richon, 2023; Filho, 2025). Microorganisms, particularly bacteria, have built communities around the plastic, inhabiting and thriving in this environment (Bryant, 2016; Cholewinska, 2025). The full scale of the environmental, ecological and oceanic impacts of these garbage patches are still unknown and will be seen for many years to come. Continued studies and research are needed to understand the impacts of the garbage patches.

Few publications have compared the densities, and composition of plastic and marine debris between the 5 major garbage patches and most research has been conducted on the GPGP (Zhang, 2010; Morishige, 2011; Lebreton, 2018; Egger, 2020; Filho, 2025). Research on all garbage patches is important to allow for greater predictive power and to inform implementation of specific mitigation strategies tailored to individual patches and to reduce the widespread global problem of plastic waste in the ocean. This paper provides a policy-linked regional interpretation of marine debris by conducting a qualitative and quantitative comparison of oceanic plastic waste accumulation across the GPGP and other major garbage patches using data sets from the NOAA and other publicly available sources.

METHODS

This analysis used three publicly available datasets to compare plastic concentration measurements among 5 ocean gyres and discharge of plastic from several regions. The NOAA and Our World in Data datasets were selected for longer term data collection, and the peer-reviewed Lebreton et al. was selected for its accessibility and comprehensive data. Microplastic sampling data were obtained from the NOAA Global Marine Microplastics Database (1972 - present), estimates of accumulated marine plastic waste were obtained from ‘Plastic Waste Accumulated in the Ocean’ (Our World In Data, 2023), and particle size distributions within the Great Pacific Garbage Patch were obtained from the supplementary dataset ‘Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic’ (Lebreton, 2018). All datasets were imported into R (version X.X.X) using the readxl and readr packages and processed using the tidyvere suite of packages.

The NOAA microplastics collection methods included manta net, intake seawater pump, and grab sampling. To survey concentrations of plastics, NOAA deployed sampling methods such as manta trawl, mega trawl, and red, green, blue (RGB) mosaic. Collected microplastic samples were categorized as ocean surface, nurdle patrol, ocean sediment, ocean subsurface, and beach, and were taken directly from the NOAA Marine Microplastics database. Within these categories, NOAA classified samples by microplastics concentrations of very high, high, medium, low and very low; different scales were used for each method (Table 1). For example, ocean surface concentrations were categorized by pieces/m^3 (very high, ≥10 pieces/m^3; high, 1-10 pieces/m^3; medium, 0.005-1 pieces/m^3; low, 0.0005-0.005 pieces/m^3; and very low, 0-0.0005 pieces/m^3), while nurdle patrol were categorized by pieces/10 minutes (very high, >200 pieces/10 minutes; high, 40-200 pieces/10 minutes; medium , 2-40 pieces/10 minutes; low, 1-2 pieces/10 minutes; and very low, 0 pieces/10 minutes). Plastic concentrations and sizes were compared across the garbage gyres.

Our World in Data reported accumulated plastic in tonnes (metric ton, equivalent to 2204.62 lbs) entering oceans by individual countries and geographic regions. To more clearly make comparisons between regions, geographic areas and countries were combined into continental groupings. China, India, and Asia (excluding China and India) were combined and renamed into Asia. Similarly, The United States and the Americas (excluding USA) were combined and renamed into Americas. Accordingly, annual accumulated plastic values were summed within each region using groupby () and summarize () functions to produce total estimates for each region for each year.

The supplemental data from Lebreton et al. (2018) database was used to summarize the size distribution of plastic particles collected from the GPGP. Using the same groupby () and summarize () functions as the Our World In Data dataset, samples were categorized according to published "Size class (cm)" and the total number of particles per size class was calculated. Any blank or missing observations were removed from the totals with na.rm=TRUE.

The datasets were analyzed to assess the similarities and differences in plastics from different garbage gyres and geographic regions. These analyses do not directly equate emission estimates with ocean concentration measurements, but instead, analyze them as complementary indicators of plastic discharge pressure and the state of marine pollution.

RESULTS

Overall, since 1972, NOAA has recorded approximately 22,530 sampling measurements globally. The vast majority of the measurements have been collected in the Pacific and Atlantic Oceans. The highest concentrations of microplastics (very high and high) were mapped to the Pacific Ocean, primarily in the location of the GPGP, followed by the Atlantic Ocean. In sampling of debris from the GPGP, microplastics measuring 0.15 - 0.5 cm in size accounted for over 90% of the pieces sampled (Lebreton, 2018). The Pacific and Atlantic Oceans and coasts represented a much higher density of sampling measurements and collections, relative to other regional oceans. Figure 1 depicts the global distribution of marine microplastics sampling locations and the corresponding concentrations of microplastics.

The 5 major ocean gyres are depicted with approximate longitudinal and latitudinal locations and their relative sizes in Figure 2. The NPGP, with an area of 1.6 million km^2 is positioned at approximately 30˚ latitude and -140˚ longitude and is the largest of the 5 patches. The NAGP, the second largest garbage patch, is 1.5 million km^2 in area and positioned at approximately 33 degrees latitude and -50 degrees longitude. Following these two largest patches, in descending order by size, are the SPGP and IOGP, which are similar in size, and the SAGP which is smallest in size.

The amount of plastic waste accumulated in the ocean more than tripled from 2000 - 2019. In 2000, an estimated total of 8.47 million tonnes of plastic was recorded in the oceans, and more than doubled over the next 10 years to 17.53 million tonnes in 2010. From 2010 to 2019, the accumulated plastic nearly doubled to 30.41 million tonnes. The tonnage of plastic waste originating from individual regions, including the Americas, Asia, Europe, Middle East and North Africa, Oceania and Sub-Saharan Africa are measured beginning in 1951 (Figure 3). In 2000, the largest contributors of total plastic waste were Asia and the Americas, with both regions releasing similar amounts of plastics into the ocean at 2.65 million tonnes and 2.58 million tonnes, respectively. These regions were followed by Europe, Sub-Saharan Africa, the Middle East and North Africa, and lastly Oceania in tonnage of plastic waste. Over time, nearly all regions had steadily increasing amounts of plastic waste, however, Asia and the Americas had the sharpest increase over the nearly 2 decades. As of 2019, the highest contributor of released plastics is Asia with 12.94 million tonnes released in total; approximately 40% of the plastics flowing into the ocean from Asia, originated from China and India. The Americas follow with 7.56 million tonnes of plastics; the US accounts for 3.35 million tonnes and the remainder of the Americas accounts for 4.21 million tonnes. Europe contributed 5.05 million tonnes in 2019, with other regions contributing significantly less.

DISCUSSION

Globally, total oceanic plastic waste has more than tripled in the past 20 years. While all global regions have contributed to this rise, certain countries, including those in Asia and the Americas, have played a more significant role in marine plastic waste accumulation. Although plastics circulate around the world due to currents, the largest garbage patches, the GPGP and NAGP, are adjacent to the Americas, Europe, and Asia, suggesting a possible relationship to these regions as major sources of plastic waste. In 2000, Asia was already a leading region in contributing to the plastic pollution in the ocean and by 2015, Asia produced nearly half the total amount of accumulated plastic in the ocean (My World In Data, 2023). The Americas are another high contributor with 7.56 tonnes produced and released in total in 2019. Several factors contribute to the rapid increase in plastic production and waste. Globalization and economic reform, as well as China's entry into the World Trade Organization (WTO) in 2001 helped to propel China and other Asian countries like Vietnam and India into manufacturing hubs (Lu, 2024). Another factor is continuous and rapid industrialization, which made plastic production more efficient and its incorporation into manufacturing ubiquitous. The manufacturing boom combined with limited or lax regulations to protect the environment and reduce waste, likely contributed to the significant increase in plastic waste since the year 2000.

Due to the rapid increase in microplastics over the past 20 years, the ocean's environmental conditions have been altered (MacLeod, 2021; Richon, 2023; Filho, 2025). Some organisms, including bacteria have been observed to thrive within the plastics, but the overall effects of plastic pollution are negative and long-term effects are largely unknown. Plastic does not degrade easily as it is not a natural material, but will break down due to weathering from waves, wind, and UV radiation into microplastics. The rapid multiplication of microplastics, have resulted in ingestion by marine species and successive bioaccumulation up the food chain (Filho, 2025; Thashari, 2020; Richon, 2023). Predators higher on the food chain will ingest the plastic accumulated in the different prey they consume. Due to the fact that plastic does not degrade easily, microplastics can accumulate in the stomachs of animals, causing starvation and other health problems. Larger plastic and fishing debris can entangle marine life in nets and plastic bags inhibit their ability to swim or move.

In order to mitigate the accumulation of plastics in oceans, countries and world organizations have recently implemented regulations in order to address plastic waste and limit single use plastics. The United Nations (UN) has established an Intergovernmental Negotiating Committee with representation from over 175 countries to create a global plastic treaty that addresses plastic production, plastic product design, ban of certain plastics, plastic waste management, and the pollution of plastics into the environment (UN Plastic Treaty, 2023; Brander, 2024). The complexity and challenges of this work are compounded by influence from the fossil fuel and plastics industries, as well as limited representation from communities who are most greatly impacted by plastic waste. The Association of Southeast Asian Nations (ASEAN) has also created a policy, the ASEAN Regional Action Plan (ASEAN, 2021 - 2025) for Combating Marine Debris, that targets plastics at the production level, while also managing current production. However, the adoption and implementation of policies are fragmented and vary across countries. World wide economies, and southeast asian countries in particular, are greatly dependent on plastics to support the manufacturing industries and employment. In order to successfully implement these plastic policies, countries must find alternatives to replace the economic reliance on plastic. In addition to these large scale treaties and policies, China has its own goals for becoming more eco-friendly (Sun, 2022). As of 2025, their long term goals include reducing non-biodegradable and single use plastics, reducing landfill plastic waste, and ensuring most plastic packaging is reusable or biodegradable. Although policies and regulations have been put in place to reduce the use and production of plastics, they may not mitigate existing plastic waste which have already polluted and impacted the environment, and whose effects may be unknown for many years to come (Borelle, 2020; Richon, 2023).

Limitations of this analysis include the use of NOAA datasets, which are derived from different methods of plastic measurements and data collection over multiple sites and time. Measurements taken from one region cannot be directly compared to another region, due to differences in collection methods, measurements and sample size. Additionally, some data are collected from local/regional communities (i.e. NOAA), therefore the consistency and quality of the data inputs are not known. Further, while collection of data from the North Pacific and Atlantic regions in the Northern Hemisphere were abundant, collected data were scarce from other regions, resulting in potential bias in the amounts and concentrations of plastics measured. Consequently, higher plastic concentrations observed in the Pacific and Atlantic oceans may reflect increased sampling, rather than actual higher plastic levels. Uneven sampling can result in an artificially inflated perception of the magnitude and scope of the NPGP and NAGP, leading to disproportionate focus and policy directed at these gyres, while the SPGP, SAGP and IOGP are largely neglected. Lastly, this analysis did not take into account additional factors impacting the movement of plastics, such as ocean currents.

In order to address disparities between garbage patch data, future research can focus analysis on the lesser known patches, IOGP, SAGP and SPGP. Researchers may also consider utilizing the same sampling methods across gyres to more accurately compare plastic composition, microplastic concentrations, and patches. Additional studies to understand plastic movement beginning from their source and throughout the ocean from patch to patch, are important to understand the cycle of plastic from origin to final destination in the environment. These research and data can provide a better overview of oceanic plastic behavior and help mitigate the growing accumulation of plastic.

CONCLUSION

Plastic pollution in the environment and the oceans have increased significantly over time as plastic production continues to increase year over year due to large-scale manufacturing and industrialization. While leading world organizations and countries have made strides in the implementation of policies to mitigate the effects of plastic waste and reduce plastic production, progress is slow and the effects of decades of plastics pollution may not be reversible. This paper adds to the overall body of literature on plastic pollution and describes the regional and global differences in plastic discharge, which contributes to ocean pollution. Importantly, inconsistent sampling methods and efforts across regions and between ocean gyres lead to disproportionate knowledge gaps. Continued research is warranted to understand the sources of plastic pollution, and impacts of microplastics to the environment and to human and animal life.

FIGURE 1

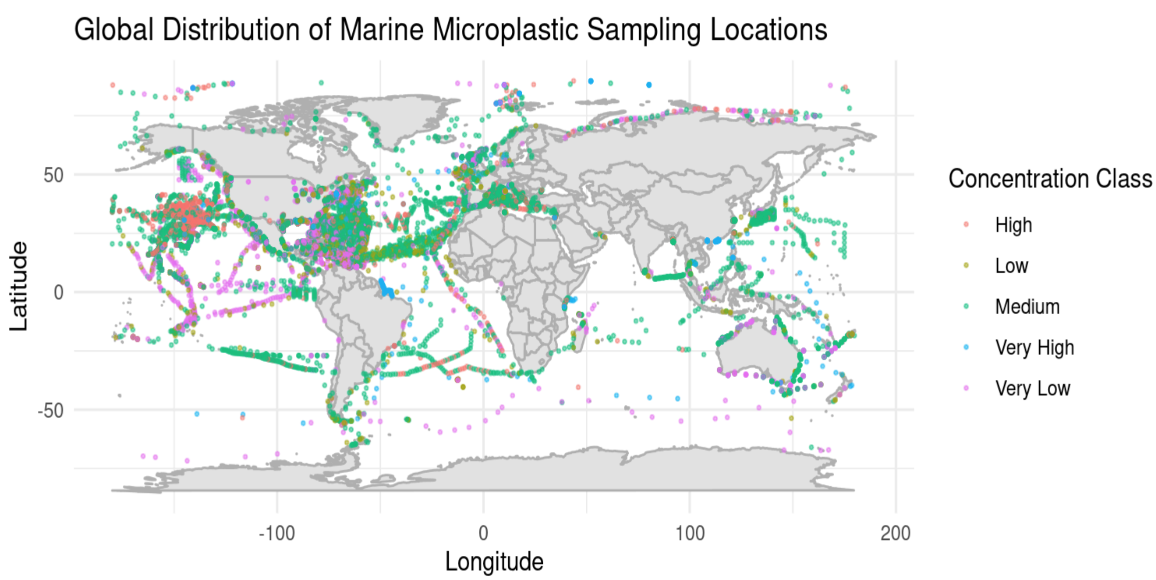

Figure 1. Approximate locations and relative concentrations of microplastics sampled through various methods across different geographies and topographies, as reported to the NOAA (Data Source: NOAA). Samples collected were measured by pieces/m³, pieces/10 mins, and pieces/kg dry weight depending on collection method. Relative concentration classes are classified as high, low, medium, very high, or very

low for each respective collection method (ocean surface, nurdle patrol, ocean sediment, ocean subsurface, and beach). See Table 1 for plastic concentration classes by method of assessment in NOAA.

FIGURE 2

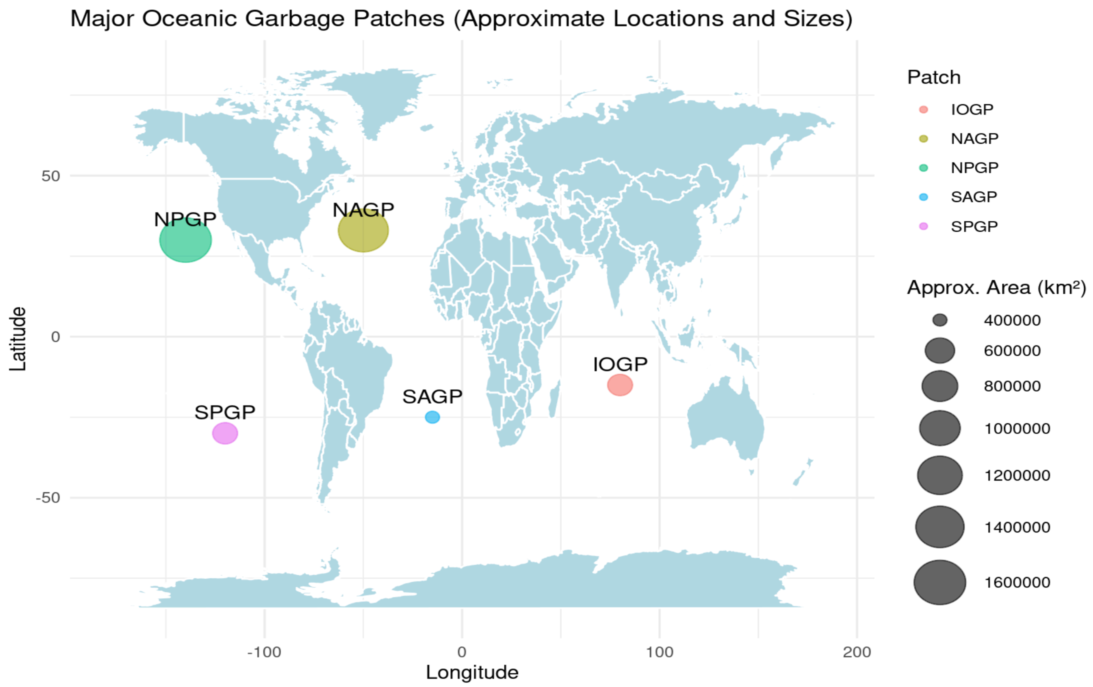

Figure 2. Maps the locations of the 5 great garbage patches by latitude and longitude, including the relative area of each patch (km^2) (Data Source: NOAA). Note that location coordinates and patch sizes are approximate, and are intended to provide a relative scale rather than exact measurements.
Abbreviations: NPGP=North Pacific Garbage Patch; NAGP=North Atlantic Garbage Patch; SPGP=South Pacific Garbage Patch; SAGP=South Atlantic Garbage Patch; IOGP=Indian Ocean Garbage Patch

FIGURE 3

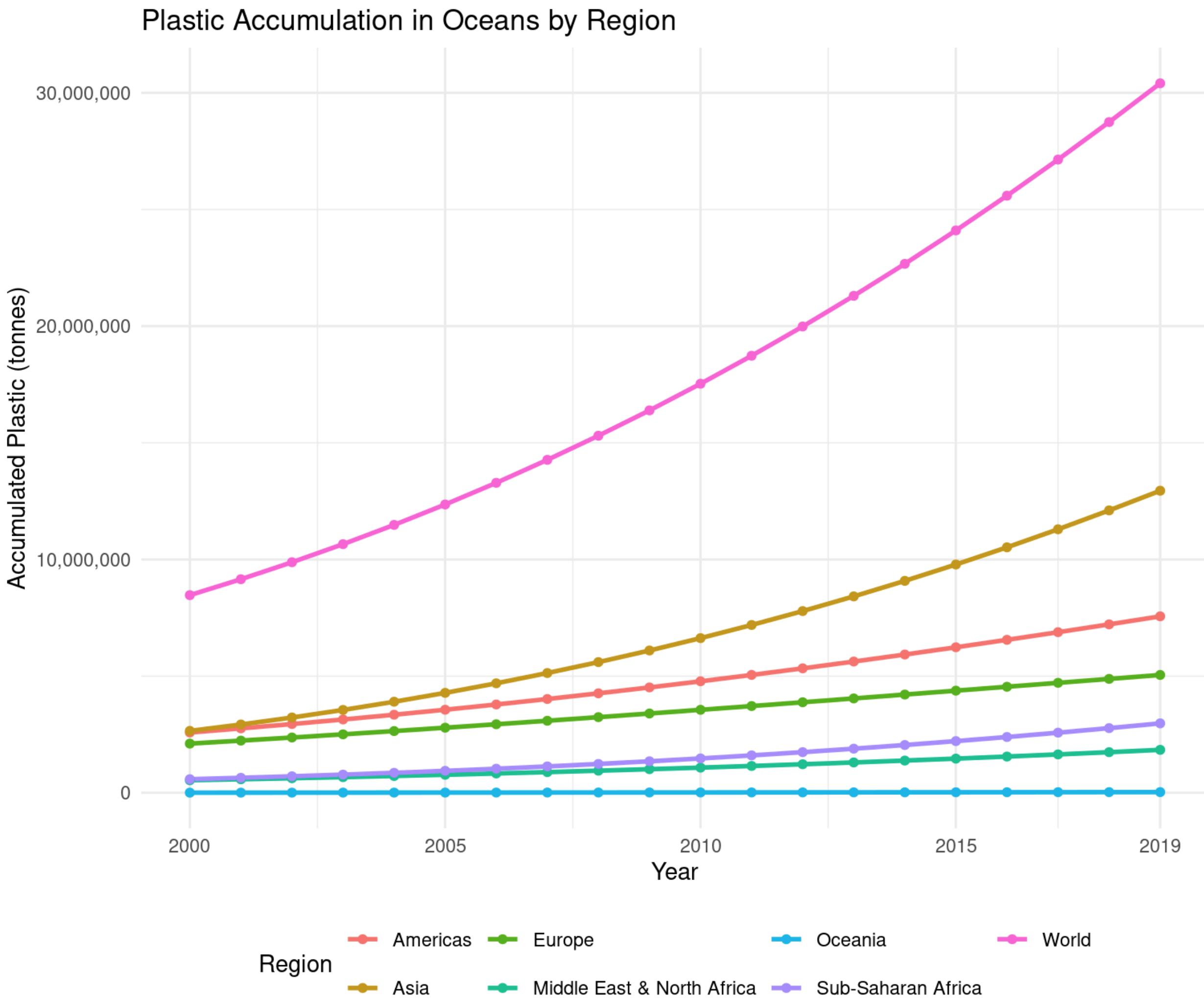

Figure 3. Graphs regional data for oceanic plastic accumulation between the years 2000 - 2019 (Data Source: Our World in Data). Plastic accumulation is measured in tonnes (metric ton, equivalent to 2204.62 lbs). Individual regions are color coded, with their total accumulated plastic represented by the "World" graph line. The regions include countries as defined by the Organization for Economic Co-operation and Development (OECD).

TABLE 1

	NOAA - Plastic concentrations by Method of Assessment				
	Very High	High	Medium	Low	Very Low
Ocean Surface	≥10 pieces/m³	1 - 10 pieces/m³	0.005 - 1 pieces/m³	0.0005 - 0.005 pieces/m³	0 - 0.0005 pieces/m³
Nurdle Patrol	>200 pieces/10 mins	40 - 200 pieces/10 mins	2 - 40 pieces/10 mins	1 - 2 pieces/10 mins	0 pieces/10 mins
Ocean Sediment	>200 pieces/kg DW	150 - 200 pieces/kg DW	20 - 150 pieces/kg DW	2 - 20 pieces/kg DW	0 - 2 pieces/kg DW
Ocean Subsurface	≥10 pieces/m³	1 - 10 pieces/m³	0.005 - 1 pieces/m³	N/A*	0 - 0.0005 pieces/m³
Beach	>40000 pieces/m³	30000 - 40000 pieces/m³	500 - 30000 pieces/m³	100 - 500 pieces/m³	0 - 100 pieces/m³

(Data Source NOAA).
*Data not available per the NOAA Marine Microplastics Concentrations Database.
Abbreviations: DW=Dry Weight; kg=kilograms; m=meters; mins=minutes; N/A=Not Available; NOAA=National Oceanic and Atmospheric Administration.

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