MASKS ON THE BEACH

The Impact of COVID-19 on Marine Plastic Pollution

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About OceansAsia

OceansAsia is a marine conservation organization dedicated to investigating and researching wildlife crimes, and exposing and bringing to justice those destroying and polluting marine ecosystems.

We use the latest technologies, creative ingenuity, and a wide range of investigative and research techniques to identify criminal activity in the fisheries supply chain, and to keep one step ahead of those under investigation.

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Executive Summary

This report provides an overview as to scale, sources, and negative impacts of marine plastic pollution, with a particular focus on marine plastic pollution resulting from the increased use of personal protective equipment (PPE) resulting from COVID-19. The number of masks entering the environment on a monthly basis as a result of the COVID-19 pandemic is staggering. From a global production projection of 52 billion masks for 2020, we estimate that 1.56 billion masks will enter our oceans in 2020, amounting to between 4,680 and 6,240 metric tonnes of plastic pollution. These masks will take as long as 450 years to break down and all the while serve as a source of micro plastic and negatively impact marine wildlife and ecosystems.

Plastic Pollution

Marine plastic pollution poses an existential threat to marine wildlife and ecosystems. Plastic production has been steadily increasing, such that in 2018, more than 359 million metric tonnes was produced. Estimates suggest that 3% of this plastic enters our oceans annually, amounting to between 8 to 12 million metric tonnes a year.

This plastic does not 'go away,' but rather accumulates, breaking up into smaller and smaller pieces. Annually, it is estimated that marine plastic pollution kills 100,000 marine mammals and turtles, over a million seabirds, and even greater numbers of fish, invertebrates, and other marine life. Plastic pollution also profoundly impacts coastal communities, fisheries, and economies. Conservative estimates suggest that it could cost the global economy $13 billion USD per year, and lead to a 1-5% decline in ecosystem services, at a value of between $500 to $2,500 billion USD.

COVID-19 and Plastic Pollution

Plastic pollution has been exacerbated as a result of the COVID-19 pandemic. Hygiene concerns and greater reliance on take-away food has led to increased use of plastics, particularly plastic packaging. At the same time, a number of measures designed to reduce plastic consumption, such as single-use plastic bag bans, have been delayed, paused, or rolled back. In some jurisdictions, reusable options have been banned.

The use of PPE, in particular face masks, and to a lesser extent gloves and face shields, has become widespread and a common tool used in preventing the spread of the pandemic, with many jurisdictions mandating the wearing of masks in public. The production of PPE has expanded in an attempt to meet skyrocketing demand, and PPE waste has also increased dramatically.

The value of the global face masks market was ~$0.79 billion USD in 2019, but expanded to an estimated ~$166 billion USD by the end of 2020. One report in June predicted that the volume of this market will peak at more than 52 billion units by the end of 2020. This rapid increase in production still falls short of demand – in June the World Health Organization (WHO) and others estimated that 129 billion face masks and 65 billion gloves would be needed on a monthly basis in order to protect people worldwide.

Single-use face masks are made from a variety of meltblown plastics and are difficult to recycle due to both composition and risk of contamination and infection. These masks enter our oceans when they are littered or otherwise improperly discarded, when waste management systems are inadequate or non-existent, or when these systems become overwhelmed due to increased volumes of waste.

Calculating Mask Loss

We develop a formula for estimating the number and weight of face masks entering our oceans. An overall loss rate of 3% can be applied to reliable mask consumption numbers to yield the overall number of face masks that enter the environment. Multiplying this number by 3 to 4 grams approximates the weight of these masks.

"Using an annual global production estimate of 52 billion masks, we calculate that 1.56 billion masks will enter our oceans in 2020, amounting to between 4,680 and 6,240 tonnes of plastic pollution."

Solutions

Action at every possible level is needed to address the serious threat posed by marine plastic pollution. When possible, individuals should choose to wear reusable masks and masks made from sustainable materials. Masks should always be disposed of responsibly. In general, individuals should strive to reduce their consumption of unnecessary single-use plastic, purchase from companies that offer these alternatives, and encourage other companies to reduce their use of plastic.

The transition away from single-use plastic can be facilitated by the development and use of non-plastic alternatives, which exist for most products. Alongside increased demand and production, an extensive range of innovative mask designs have emerged. These include self-cleaning masks, and disposable and reusable masks made from more sustainable materials. Efforts to improve and facilitate face mask disposal and recycling are being developed, as have processes for extending the life of single use masks.

Governments have a central role to play in efforts to reduce single-use plastic. There are a wide range of policy instruments that can be implemented, which include measures designed to change consumer behaviour, bans on unnecessary products, market-based instruments, legislation designed to hold producers accountable, and incentive and support programs. With respect to masks, governments should implement policies designed to encourage the use of reusable masks, such as releasing guidelines regarding the proper manufacture and use of cloth masks.

Other policies include such measures as educating the public about, and removing barriers to, safe mask disposal, coupled with effective fines for littering. Governments should also support innovation and the development of reusable and sustainable alternatives to single-use plastics and accelerating efforts to reduce their use.

Policy innovation need not be limited to the domestic arena, and international cooperation has a critical role to play in efforts to reduce marine plastic pollution. Existing international treaties, agreements, plans of action, and campaigns should be adhered to and strengthened, and new agreements should be developed to address emerging issues and fill gaps left by existing measures.

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Introduction

Around the world, as a result of the COVID-19 pandemic, the production and use of personal protective equipment (PPE), such as masks and gloves, has skyrocketed. While PPE offers important protection from the virus, the improper disposal of single-use plastic PPE has led to a surge in plastic pollution, most notably in our oceans and waterways.

This increase was brought to world attention when we first reported finding face masks washing up on remote beaches in the Soko Islands, Hong Kong in late February 2020. Since then, with each visit, we have continued to find masks on beaches around Hong Kong.

Unfortunately, this problem is not limited to Hong Kong; divers with Opération mer propre found masks on the sea bed during a clean up near the Côte d'Azur, France,[1] photographer Dan Giannopoulos photographed over 300 discarded gloves and masks found around Southampton, United Kingdom (UK) over the course of 4 days.[2] The news is full of stories of PPE littering cities around the globe.[3]

The proliferation of masks in the environment reveals weaknesses in our waste management systems and irresponsible practices/habits on the part of individuals. It also serves to illuminate an issue that has been accumulating for decades – unchecked plastic pollution contaminating our environment. The accumulation of plastic in the environment is not a recent phenomenon, but it is one that is becoming increasingly problematic and unavoidable – encountering plastic debris on a visit to the beach is almost inescapable.

“Marine plastic pollution poses an existential threat to marine wildlife and to ecosystems.”

The unfortunate reality is that marine plastic pollution poses an existential threat to marine wildlife and to ecosystems. It is a problem that will not go away on its own. Without considerable effort on our part, oceans will continue to fill with plastic and do so at an accelerating pace.[4]

This report provides an overview as to scale, sources, and negative impacts of marine plastic pollution, with a particular focus on marine plastic pollution resulting from the increased use of PPE resulting from COVID-19. In addition to providing a review of recent research into the impact of plastic on wildlife and on marine ecosystems, the report seeks to assess the impact of COVID-19 on plastic entering our oceans. The principle focus of this report is on face masks as marine plastic pollution. Other PPE like gloves and face shields have also been employed to protect people during the pandemic. The use of these other forms of PPE has been less widespread outside of medical settings. In contrast, the use of masks has been mandated by states and sub-state authorities in numerous jurisdictions across the planet.[5]

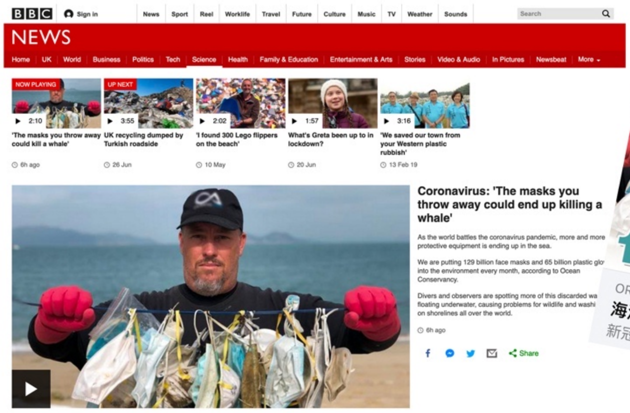
Background

In late February, 2020, OceansAsia visited a remote beach on Tai A Chau in the Soko Islands, south of Lantau, Hong Kong. On a typical visit, our team might expect to encounter one or two face masks along with piles of other plastic pollution; however on this occasion 70 masks were found spread along a 100 m stretch of beach. This occurred about six weeks after the widespread adoption of mask-wearing in Hong Kong due to COVID-19.

Our team had been visiting this beach every two weeks for five months as part of an ongoing survey and research project on marine plastic pollution. On a typical visit the team would collect data, including microplastic samples and aerial photos. A boat access only beach was selected in order to ensure that the plastic on the beach originated from the ocean, rather than being left there by visitors.

Images of Gary Stokes, OceansAsia Director of Operations, with some of the masks he collected were posted on OceansAsia's Facebook page.[6] We have continued our regular visits to the beach – the following week, there were 30 new masks, and with at least a dozen masks found on each subsequent visit. On November 27th, as this report was going to press, two OceansAsia volunteers collected 54 masks over the course of one hour from our original test beach.

The initial Facebook post received a lot of attention and quickly turned into a global news story, attracting thousands of follow-up stories in over a 100 countries. This was significant; as it served to bring critical awareness to the issue of marine plastic pollution, and specifically to the impact of protective measures being taken as a result of COVID-19 on marine pollution.



Over the course of conversations about the issue, the question often arises as to how many masks are entering the marine environment, and why? This report seeks to answer these questions, and to provide an overview of the issue of marine plastic pollution and the impact of face masks on our oceans.

Methods and Data

Two principle methods for gathering the information and data were relied on in this report. For general information pertaining to the scale, sources, and negative impacts of marine plastic pollution, a literature review was conducted, concentrating primarily on peer reviewed research, and to a lesser extent grey literature,[*] with a focus on research from the previous five years. While it is recognizing that there is a wealth of research on marine plastic pollution extending back decades, our intent is to highlight recent research, particularly in light of the publication of a number of recent articles directly related to plastic pollution, PPE, and COVID-19.

With respect to these sources, readers will occasionally note a discrepancy between various statistics pertaining to marine plastic pollution. For example, considerable and significant variations were uncovered in estimates on the annual cost of marine plastic pollution, and on estimates as to the amount of plastic entering our oceans. These differences can be attributed to variations in parameters, variables, methodologies, and data employed in studies. For example, in the case of the cost of marine plastic pollution, some studies sought to determine direct economic costs, while others included the impact of marine plastic on ecosystem services and calculated the cost of replacing these services. Where such discrepancies exist, this report will endeavour to offer a range of values, and to provide details of the studies involved.

For information concerning face masks, evaluating their impact on marine environments, and determining mask production and consumption numbers, grey literature, industry reports, and news media stories were relied upon. This was necessary due to the ongoing nature of the pandemic and dramatic escalation in global PPE production.

Challenges with respect to the reliability of this data are recognized given the ongoing nature of the pandemic. Reports of dramatic increases in mask production abound. It is often difficult to determine the current number of masks that have been or that are currently being produced from reports concerning manufacturing projections.[7] Projected numbers, for example, are typically linked to discussions of increased production capacity, but production capacity, is not necessarily, or even typically, linear. Knowing projections provides scant insight into current outputs and these numbers are being constantly updated.

Furthermore, knowing historical and current production levels is not necessarily indicative of consumption levels, as not all masks that are manufactured are used immediately. There have been a number of news stories reporting potential cases of hoarding both on the part of individuals and states,[8] as well as reports of people in places facing PPE shortages sterilizing and reusing single-use masks multiple times.[9] Additionally, an accurate understanding of consumption levels does not indicate the manner in which these masks are disposed. Unlike masks worn by members of the general population, masks used in a professional medical setting, such as a hospital or clinic, are much more likely to be properly disposed of by wearers, and having entered the waste management system, to be incinerated.

[*] Non-academic research products like reports, policy papers, government documents, etc.

Throughout this report we endeavour to use the most reliable information available and instances where concerns regarding the reliability of data will highlighted. When it comes to estimating the number of masks entering marine environments, a number of assumptions will be required in order to arrive at workable numbers. Wherever such an assumption is made, it will be clearly identified.

Scale of Plastic Pollution

Plastic is incredibly versatile. It is a lightweight material, capable of being fashioned into thin transparent and seemingly ephemeral films, or shaped into highly durable building materials. Given this versatility, it is little wonder that plastic production and use has expanded dramatically since the first Bakelite.[10]

Humans produce a lot of plastic, with production increasing steadily since it became a consumer product – “from 1950 to 2012, plastics growth averaged 8.7 percent per year.”[11] In 2018, annual global plastic production totalled ~359 million tonnes.[*12] One study estimated that as of 2017, humans had produced 8,300 million tonnes of virgin plastics.[13]

This dramatic increase in plastic production has been motivated by the versatility of plastic, and also by demand from an expanding 'throw-away' culture.[14] Throw-away culture not only pervaded general consumer behaviour and products, but the medical profession as well, as hospitals moved towards “a total disposable system,” in the late 1960s.[15]

As is implied by the name, throw-away culture results in a considerable amount of plastic being discarded. The 359 million tonnes of plastic produced in 2018 generated an estimated 6.9 million tonnes of plastic waste.[16] Unfortunately, the vast majority of this plastic is not recycled, nor is it disposed of appropriately. A recent exposé by NPR and PBS Frontline found that “the vast majority of all plastic produced can’t be or won’t be recycled. In 40 years, less than 10% of plastic has ever been recycled.”[17] This exposé explained that the plastic industry has spent millions promoting recycling while simultaneously believing that “recycling plastic on a large scale was unlikely to ever be economically viable,” and that the industry did so in order to keep plastic bans at bay and because increased recycling would result in reduced profits to oil and gas companies.[18]

There is considerable variation when it comes to estimating what happens to plastic waste, due largely to differences between waste management systems and practices. The 10% number cited in the NPR/PBS exposé is consistent with reports on recycling in the United States of America (USA). Other studies have offered slightly varying numbers. Geyer *et al*. estimate that only 9% of plastic is recycled, the rest is incinerated (12%) or accumulates in landfills (79%).[19] Whereas Patrício Silva *et al*. suggest that “approximately 22% …incinerated, 25% recycled, and 42% inefficiently treated (i.e., either littered or inadequately disposed of in dumps or open landfills).”[20]

There are, of course, notable differences around the world. Gourmelon noted that in 2012, 26% (6.6 Mt) of post-consumer plastic produced in Europe was recycled, with 38% entering landfills and 36% being incinerated for energy recovery.[21] Whereas in the same year, only

[*] Please note that unless otherwise specified, the unit of measure provided is in metric tons (tonnes).

9% (2.8 Mt) of plastic was recycled in the USA, and that plastic recovery rates were even lower in other parts of the world, citing a United Nations Environment Programme (UNEP) estimate that "57 percent of plastic in Africa, 40 percent in Asia, and 32 percent in Latin America is not even collected, being instead littered or burned in the open."[22]

In addition to alarming low level of recycling, the waste management systems that handle this plastic are not closed systems, and not all plastic enters waste management systems. Waste management systems that are considered poorly managed or mismanaged include such features as open or uncontrolled landfills or open transport methods. Open landfills, for example, are prone to losing waste into the surrounding environment – wind can easily blow light items away, and rain can wash away larger items. Likewise, transport systems that include open barges or vehicles can be prone to loss.[23]

Waste may also enter the environment through littering; "Littered waste is distinct from 'inadequately disposed' waste in that it represents plastics that are dumped or disposed of without consent in an inappropriate location."[24] A study by Jambeck *et al*. assumed a littering rate of 2% of total plastic waste generation, across all countries.[25]

Plastic in the Environment

A shocking amount of plastic enters the environment in the form of plastic pollution each year, with much of this plastic eventually reaching our oceans. While it is difficult to determine the exact amount, numerous studies have sought to estimate the amount of plastic pollution entering our oceans annually. The UNEP suggests the number to be around 8 million tonnes, which constitutes about 3% of global annual plastic waste.[26] Other studies have suggested higher numbers or a range of numbers: One study estimated as much as 11.8 million tonnes of plastic, or the equivalent to a full garbage truck every minute, was entering our oceans annually.[27] Yet another study calculated the number to be between 4.8 and 12.7 million tonnes.[28]

This plastic does not 'go away,' but rather accumulates, breaking up into smaller and smaller pieces, with a devastating effect on marine ecosystems and wildlife (explored in detail below).

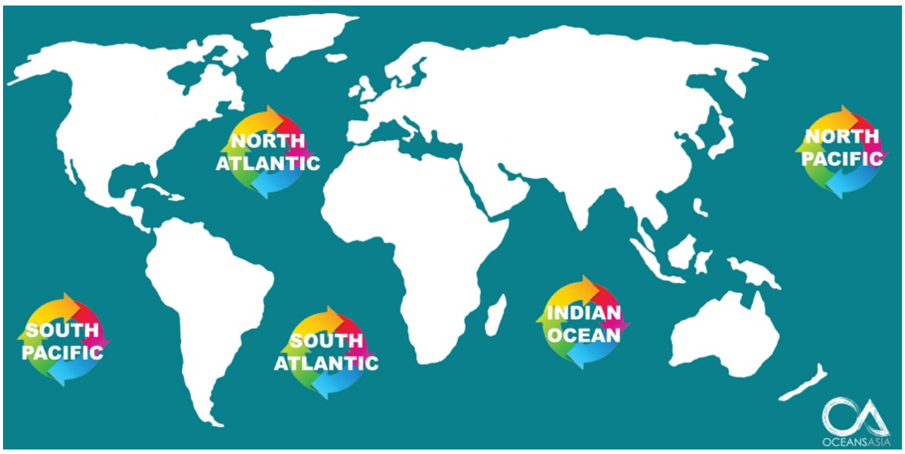
So much plastic chokes our oceans that one study found a significant ocean cleanup would require "removing at least 135 million tons of plastics" and that the cost of such a cleanup effort could be as high as €708 billion, or 1% of the world gross domestic product (GDP).[29]

A yet more recent study calculated that if we were to implement all feasible interventions, we would succeed in reducing "plastic pollution by 40% from 2016 rates and 78% relative to 'business as usual' in 2040," and that by 2040, even with concerted action, "710 million metric tons of plastic waste [will have] cumulatively entered aquatic and terrestrial ecosystems."[30]

While the number of pieces of plastic floating on our oceans is difficult to calculate due to a number of factors, including such things as the constant inflow of pieces, the ongoing breakup of larger pieces into smaller ones, and variable levels of buoyancy for types of plastics and plastic products, the numbers of pieces suggested by scientists is alarming.

Due to marine currents, floating marine plastic pollution tends to accumulate in a number of large marine gyres. One such gyre is the so-called 'Great Pacific Garbage Patch' a section of the North Pacific Oceans of roughly 1.6 million km^2 that is estimated to contain over 1.8 trillion pieces of plastic.[31] To contextualize this enormous number, that is 231 pieces of plastic for every person on the planet.

The North Pacific Gyre is but one of five oceanic gyres on the planet, the others being the North Atlantic Gyre, the South Atlantic Gyre, the South Pacific Gyre, and the Indian Ocean Gyres, each of which also accumulates floating plastic pollution.[32] Estimates of the total number of pieces of plastic floating in our oceans are as hard to conceptualize as they are to calculate, owing to such factors as variable concentrations due to oceanographic factors and the size of plastic included in the calculus. Estimates in 2014, for example, suggested that 5.25 trillion pieces of plastic could be found floating in our oceans, weighing roughly 268,940 tonnes.[33]



Subsequent studies have argued that this number was too low, and suggest that between "15 to 51 trillion particles, weighing between 93 and 236 thousand metric tons" could be found floating in our oceans.[34] Van Sebille *et al*. noted that the weight of plastic found floating accounted for a mere ~1% of global plastic entering our oceans annually.[35] The discrepancy between the amount of plastic that enters our oceans and the amount found floating on the surface of the ocean is often referred to as the 'missing plastic problem.'[36] A number of researchers are working to resolve the issues highlighted by this problem.[37]

Sources of Plastic Pollution

Where does all this plastic come from? Before exploring various studies on sources of plastic pollution, we recognize that there is some variation between the numbers calculated by one study or another. This is understandable, given differences in methodology and sources of data. New research that includes exported and illegally dumped waste has also challenged the findings of previous studies that identified Asia as the continent most responsible for marine plastic pollution.[38]

As our purpose is to estimate the impact of single-use plastic items resulting from the COVID-19 pandemic, the exact ranking of each country or river system, with respect to its overall contribution to marine plastic pollution, is less relevant. This information is presented in order to contextualize the issue of marine plastic pollution and to highlight the importance of broadly addressing plastic pollution. Furthermore, plastic waste does not remain in the area of the ocean where it was initially deposited, but tends travels long distances and spreads throughout our global oceans.

A 2017 study ranked major river systems based on the amount of plastic they deposit into the ocean. Of these rivers, the Yangtze River (Chang Jiang River) carries by far the most plastic waste, with a staggering 1.47 million tonnes of plastic each year, considerably higher than the 2nd ranked Indus River at 164 thousand tonnes.[39]

Plastic Loads for Top Ten Ranked River Systems[40]

River	Receiving Sea	Tonnes of Plastic
Chang Jiang (Yangtze River)	East China Sea (Yellow Sea)	1,469,481
Indus	Arabian Sea	164,332
Huang He (Yellow River)	Yellow Sea	124,249
Hai He	Yellow Sea	91,858
Nile	Mediterranean Sea	84,792
Meghna, Brahmaputra, Ganges	Bay of Bengal	72,845
Zhujiang (Pearl River)	South China Sea	52,958
Amur	Sea of Okhotsk	38,267
Niger	Gulf of Guinea	35,196
Mekong	South China Sea	33,431

In light of these numbers, it is unsurprising that many studies have identified Asian countries, and in particular China, as major sources of plastic pollution.[41] For example, Ritchie and Roser note that the “East Asia and Pacific region dominates global mismanaged plastic waste, accounting for 60 percent of the world total.”[42] And they note that other regions produce considerably less: South Asia (11%), Sub-Saharan Africa (9%), the Middle East and North Africa (8.3%), Latin America (7.2%), Europe and Central Asia (3.6%); and North America (1%).[43] However, recent research has cast a new light on this issue.

A recent study in *Science Advances*, by Law *et al*. identified the USA as the largest contributor of marine plastic pollution when waste exports and illegal dumping within the country were taken into consideration.[44] Like most supply chains in today’s globalized world, waste management systems extend beyond their borders. Countries like the USA and the

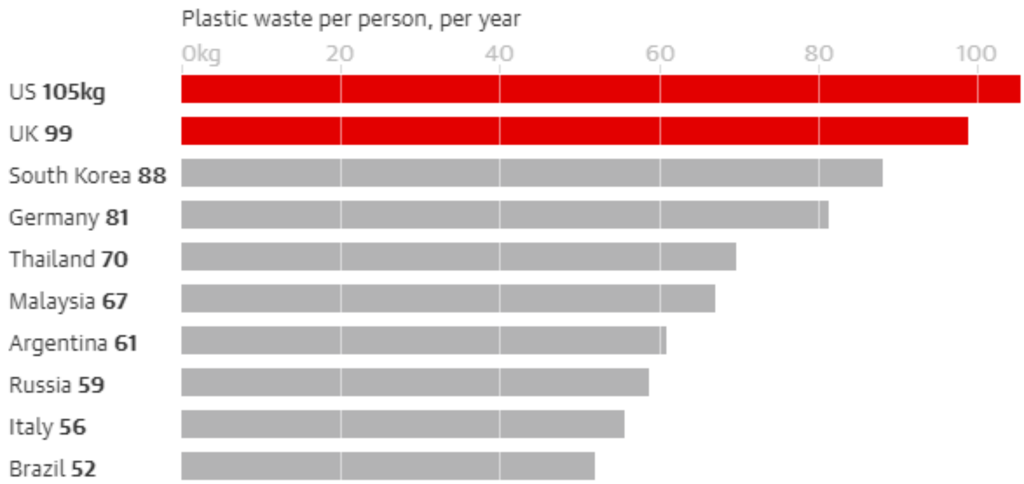
UK, with otherwise robust domestic waste management systems, export considerable amounts of their waste and recycling to other countries. In this way, "years of exporting had masked the US's enormous contribution to plastic pollution."[45]

While roughly 9.3% of plastic waste generated in the USA in 2016 was collected for recycling, as much as half of this plastic was shipped abroad, "mostly [89% of the time] to countries already struggling to manage plastic waste effectively."[46] This practice is not unique to the USA – developed countries like Canada, Australia, and the UK, have long shipped their waste abroad. This practice was severely disrupted in January 2018 when China launched its 'National Sword' policy, which "banned the import of most plastics and other materials headed for that nation's recycling processors."[47] This policy was implemented by China to protect its environment and allow it to develop its domestic recycling capacity.[48] A number of other countries like Malaysia, Thailand, and Vietnam have followed suit, challenging countries that previously used Asia as their dumping ground to more effectively manage their waste domestically.[49]

Despite the fact that Americans account for only 4% of the world's population, they produce 17% of plastic waste.[50] Law *et al*. found that the USA produced the most plastic waste globally, ~42 million tonnes in 2016. Their estimate included data that had not been considered in previous studies, namely waste that was dumped illegally inside the USA (0.14 to 0.41 million tonnes), and waste that was "inadequately managed in countries that imported materials collected in the United States for recycling" (0.15 to 0.99 million tonnes).[51]

As a result, Law *et al*. estimated that "in 2016, the United States contributed between 1.1 and 2.2 million metric tons of plastic waste to the oceans through a combination of littering, dumping and mismanaged exports."[52] As compared with estimated in 2010, this represented a fivefold increase in the amount of plastic waste generated in the USA that was estimated to enter our oceans, "rendering the United States' contribution among the highest in the world."[53] It is noteworthy that while India and China were ranked second and third behind the USA, given the large populations of these countries, the per capita plastic waste for their residents was less than 20% of that of Americans.[54]

Plastic Waste Per Person, Per Year (kg)[55]



Guardian graphic | Source: Law et al, Science Advances 2020

Types of Plastic Entering Our Oceans

The type of plastic pollution entering waterways varies depending on location and country. Overall, the UNEP estimates that 80% of marine litter globally originates from land-based sources.[56] The remaining 20% comes from marine-based sources, of which roughly half originate from fishing fleets in the form of abandoned, lost, or otherwise discarded fishing gear (ghost gear), such as nets, lines, and traps.[57] Other sources suggest this number is slightly higher, and that 28% of plastic in our oceans originates from marine sources.[58]

The question then is what type of plastic is entering our oceans from terrestrial sources? This is difficult to accurately estimate owing to such issues as the aforementioned 'missing plastic problem' and also to the methods used for measuring and surveying marine plastic debris, which may more easily identify plastic that is likely to float and, as such, to wash up on beaches. With these limitations in mind, two sets of data, plastic waste generation by industry and beach surveys, can be examined.

With respect to industries, the packaging industry is by far the largest producer of plastic waste, followed by the textile sector.[59] Geyer, Jambeck, and Law calculated plastic waste generation by industrial sector for 2015:

Plastic waste generation by industrial sector, 2015[60]

Industry	Waste Generation (million tonnes)
Packaging	141
Textiles	42
Other Sectors	38
Consumer and Institutional Products	37
Transportation	17
Electrical/Electronic	13
Building and Construction	13
Industrial Machinery	1

The fact that packaging accounts for half of plastic waste is unsurprising as packaging is designed for short term use. For example, the 'in-use' lifetime of plastic packaging is 6 months or less, whereas the in-use lifetime of plastic in other industries is: "building and construction (35 years), industrial machinery (20 years), transportation (13 years), electrical/electronic (8 years), textiles (5 years) and consumer and institutional products (3 years)."[61]

While only representing a limited sample of a particular type of marine plastic pollution, beach surveys can also serve to indicate the types of plastic entering our oceans. The Ocean Conservancy has been coordinating and recording the data from annual International Coastal Cleanups since 1986. They record the type of plastic recover by volunteers during their annual International Coastal Cleanup, which in 2018 involved over 1 million volunteers from 122 countries, and which recovered 10,584 tonnes (97.45 million items). The Ocean Conservancy noted that each of the ten most common items recovered in 2017 and 2018 were plastic. It is telling to note that non-plastic and reusable replacements exist for each of these items.

"Non-plastic and reusable replacements exist for each of these items."

2018 International Coastal Cleanup, Top Ten Items Collected[62]

Rank	Item type	Count
1	Cigarette butts	5,716,331
2	Food wrappers	3,728,712
3	Straws, stirrers	3,668,871
4	Forks, knives, spoons	1,968,065
5	Plastic beverage bottles	1,754,908
6	Plastic bottle caps	1,390,232
7	Plastic grocery bags	964,541
8	Other plastic bags	938,929
9	Plastic lids	728,929
10	Plastic cups, plates	656,276

Impact of Marine Plastic Pollution

Once it enters our oceans, plastic does not just disappear. It spreads everywhere and breaks up into smaller and smaller pieces, eventually becoming micro (<5mm) and nano (<1µm) particles.[63] Marine plastic pollution wreaks havoc on marine wildlife and ecosystems, and the communities and people that depend on them.[64]

Impact on Animals

Plastic pollution recognizes no boundaries and plastic can be found throughout our oceans.[65] Studies consistently find plastic pollution on remote beaches, for example the Adaman and Nicobar Archipelago,[66] remote uninhabited coral reefs of Nansha Islands, South China Sea,[67] Cousine Island, Seychelles,[68] and in Antarctic sea ice.[69] Plastic has also been reported in food grade sea salt,[70] and even in sea spray and snow.[71]

Recent studies have reported the discovery of plastic inside deep sea creatures, in marine trenches, and in sediment.[72] One study in *Nature* found microplastic in every deep-sea filter feeder tested.[73] Such is the scale of marine plastic pollution and the concern of scientists that a crustacean species, newly discovered 20,000 feet down in the Mariana Trench was named *Eurythenes Plasticus* after the plastic found in its gut.[74]

Eurythenes Plasticus

A UN report found that over 800 species are negatively impacted by marine plastic pollution.[75] This number is likely very conservative and low, given that, for example over 7,000 species of echinoderms (sea lilies, feather stars, and sea cucumbers) have been described.[76]

"Estimates suggest that more than 100,000 marine mammals and turtles, and over a million seabirds are killed by marine plastic annually, and these numbers do not include fish, invertebrates and other marine life.[77]"

Marine plastic pollution impacts wildlife and ecosystems in a number of ways depending on, among other things, the type of plastic and its size.

Large agglomerates of ghost gear from the fishing industry can scour and smother benthic species, such as corals, destroying critical and threatened habitat on the sea floor.[78] Nets and larger pieces of marine plastic pollution can entangle marine animals, leading to impaired mobility, infection, limb amputation, starvation, suffocation, and death.[79] Recent research has found that plastic pollution can promote microbial colonization, and in so doing, spread disease to species such as corals.[80] Floating plastic of all sizes can serve as a vector for spreading invasive species, which can adversely impact distant ecosystems and species.[81]

Smaller pieces of plastic impact marine species and ecosystems in a number of ways. Marine plastic adsorbs toxins and organic pollutants, which means that particles of pollutants adhere to the surface of the plastic as a toxic film.[82] As a result, marine animals that ingest plastic can be poisoned. This can kill them outright, but is more likely to weaken them, making them more susceptible to other threats.[83] These toxins can also impair reproduction, growth and the development of young.[84] Ingested plastics interfere with the function of internal organs, and fill stomachs, thereby reducing food intake, leading to starvation.[85]

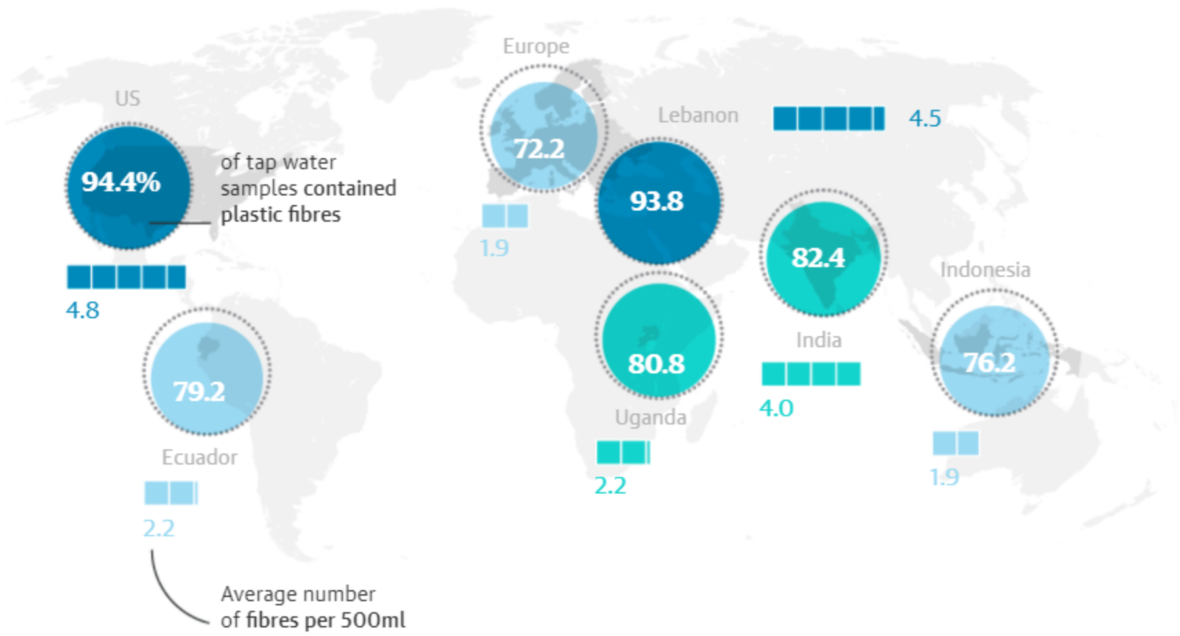
Unfortunately, plastic is actively and passively ingested in vast amounts by marine wildlife. Plastic may be intentionally eaten by marine animals mistaking it for food, or be accidentally consumed alongside prey by filter feeders, or by predators ingesting a prey animal with plastic inside its body. A recent study found that sea turtles are particularly susceptible to actively eat marine plastic due to the smell of algal growth on that plastic.[86] Other studies have examined plastic ingestion in various fish species,[87] sea birds,[88] sea turtles,[89] and incidental ingestion in large filter feeders such as humpback whales,[90] other baleen whales, sharks, and rays.[91]

The extent to which plastic is ingested by marine animals is considerable. One study found plastic in the gut of 60% of sea birds, calculated that "90% of all seabirds alive today have eaten plastic of some kind," and estimated that if current trends continue, plastic ingestion will affect 99% of the world's seabird species by 2050.[92] Another study found that every bird inspected on Lord Howe Island had plastic in its stomach.[93] For context, Lord Howe Island is located 600 km east of mainland Australia, and has a population of roughly 350 people. It has strict limits on the number of tourists who can visit, and markets itself as one of the 'cleanest places on earth.'[94]

Once ingested, plastic can bioaccumulate, concentrating plastic particles and toxicity in predators. These predators include humans.[95] Numerous studies have found plastic in fish destined for human consumption.[96] One study found plastic pellets in the stomachs of 22% of the fish it examines.[97] Another study, published in *Environmental Pollution*, calculated that "the annual dietary exposure for European shellfish consumers can amount to 11,000 microplastics per year."[98]

Plastic has become so ubiquitous that is found in tap water. A study by Orb Media found plastic fibres in 83% of all tap water samples tested.[99] Tiny plastic fibres have been found in beer,[100] honey and sugar,[101] in the air in urban environments,[102] and even in the air of people's homes.[103] Such is the ubiquity of microplastic that it has even been found in snow and stream samples on Mount Everest in a recent study.[104]

Tap water is widely contaminated by plastic[105]



Guardian graphic | Source: Orb Media

There are hundreds of different types of plastic and many have been found to have harmful effects on people. Concerns over the potential human health impacts of micro- and nanoplastic particles are being increasingly raised by researchers.[106] Recent studies and reports note that these particles can cause physical damage, such as "inflammation in tissue, cellular proliferation, and necrosis and may compromise immune cells."[107] Plastics can also have other effects when they "release plastic additives and/or adsorb other environmental chemicals, many of which have been shown to exhibit endocrine disrupting and other toxic effects."[108]

These chemicals can cause considerable harm to the body; they can, among other things, serve as endocrine disruptors, interfering with the body's production of hormones. Estrogenic chemicals, found in high density polyethylene (HDPE) mimic the hormone estrogen, and have been linked to breast cancer, endometriosis, altered sex ratios, testicular cancer, poor semen quality, early puberty, and malformations of the reproductive tract.[109] The hormone-disrupting bisphenol A (BPA), found in many plastics, has been linked to hormonal changes, reproductive problems, asthma, and obesity.[110]

Impact on Coastal Communities, Fisheries and Economies

In addition to destroying ecosystems and killing marine animals, plastic pollution profoundly impacts coastal communities, fisheries, and economies. When marine ecosystems and wildlife are adversely impacted by marine plastic pollution, this has a concomitant impact on economies that depend on these animals and ecosystems, as a result, plastic pollution negatively impacts tourism, cultural heritage and fisheries.

Estimates as to the overall economic impact of marine plastic pollution vary considerably. The UNEP has suggested that marine plastic pollution costs about $13 billion USD per year, which its report notes is likely a significant underestimation.[111] A study funded by Deloitte calculated the economic impact of marine plastic pollution in 2018 to be between $6 and $19 billion USD for 87 coastal countries.[112]

And a recent article in *Marine Pollution Bulletin* estimated that marine plastic pollution could result in a 1 – 5% decline in marine ecosystem services, equating to "an annual loss of $500–$2,500 billion [USD] in the value of benefits derived from marine ecosystem services," with each tonne of plastic negatively impacting ecosystem services by up to $33,000 USD.[113]

Tourism, which is often a key source of revenue for coastal communities, can be acutely impacted by plastic pollution. Numerous studies have sought to measure the impact of marine plastic pollution on tourism.[114] One study found that tourists stay longer at sites which are cleaner.[115] When researchers measured the economic impact of marine debris that washed up on the beaches of Geoje Island, South Korea after a period of heavy rainfall in 2011, they found that visits from tourists declined by 63% with a loss of between $29-37 million USD in tourism revenue.[116] Such negative impacts can be particularly severe for small island nations for which tourism comprises a significant proportion of their economy. For example, the tourism sector in the Bahamas accounts for 50% of that country's GDP, with estimates suggesting annual losses in tourism revenue as a result of plastic pollution to be $8.5 million USD.[117]

Much of the beach pollution that directly impacts tourism revenue is left by tourists themselves. Studies have documented considerable seasonal variation in beach plastic; at popular beaches in Brazil, for example, an almost 50% increase in marine litter was recorded in the summer as compared with the winter.[118] A study of the Great Barrier Reef system similarly showed beach plastic accumulation variation linked with increased human activity in both the diversity and amount of waste found on beaches.[119]

Marine plastic pollution also adversely impacts fisheries and associated industries. All the previously recorded impacts of marine plastic on marine animals adversely impact fisheries that harvest those animals. Fish that are poisoned or killed by plastic cannot be caught by fishers. Marine ecosystems that are degraded by plastic will support fewer animals. Abandoned, lost, or otherwise discarded fishing gear (ALDFG or ghost gear), a very common form of marine plastic pollution, can have a devastating effect on marine wildlife.

Estimates suggest that ALDFG comprises roughly 10% of marine litter (by volume).[120] Fishing gear is designed to catch fish, and it does not cease doing so when it is lost or discarded. Though its capacity may be reduced over time, ALDFG can continue to kill marine animals for years after it enters the marine environment.[121] The scale of 'ghost fishing' by ALDFG is considerable. Some estimates suggest that more than 5% of the annual global commercial catch die in ghost nets, and in some fisheries this number may be as high as 30%.[122] ALDFG and other macro marine plastic are responsible for wide range of economic impacts, including compromised yields in fisheries, lost time spend disentangling vessels that become entangled in ghost gear, the cost of replacing lost gear, and retrieval programs, to name but a few.[123] A 2009 study estimated that ALDGF cost Asia-Pacific Economic Cooperation (APEC) countries $1.3 billion USD in 2008.[124]

Other negative physical impacts on humans resulting from marine plastic pollution include such things as increased chance of injury from cuts on debris, entanglements and exposure to unsanitary items.[125] Plastic pollution negatively impacts the aesthetics of beaches and serves as a breeding ground for disease vectors. Before it enters the marine environment, discarded plastic can cause blockages in drainage and wastewater systems leading to flooding and significant expense.[126]

COVID-19 and Plastic Pollution

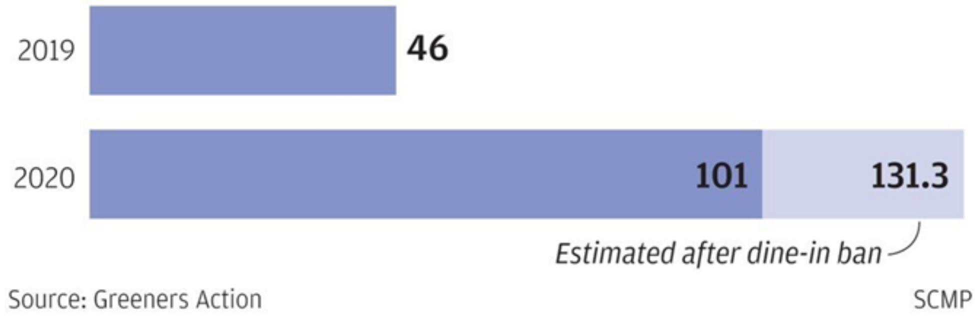
Plastic pollution has been exacerbated as a result of the COVID-19 pandemic for a number of reasons, including the increased consumption of plastic for general use, the pausing or even rolling back of efforts to reduce plastic consumption, and a dramatic increase in the use of PPE, including, in many jurisdictions, legislation mandating the wearing of masks in public. The focus of our report is on PPE, however, it is illuminating to briefly survey these other factors.

Plastic use on the Rise

Consumer habits have shifted as a result of the COVID-19 pandemic. Many of these changes have resulted in increased plastic consumption. Hygiene concerns have led many people to prefer fruit and vegetables individually packaged over unpackaged items. For example, in Italy, consumer spending on packaged mandarin oranges increased over 111% in the first week of March, 2020, as compared with the previous year.[127] In Lithuania, "the use of disposable plastics has increased by 250-300%, with people throwing away personal protective equipment, using reusable bags and containers for fear of the virus spreading."[128] This trend towards disposable plastic items in an attempt to be more hygienic is one that has been observed during previous outbreaks.[129]

In addition to concerns over hygiene, more people are turning to take-away food options as a result of lockdowns, quarantine, physical distancing and other regulations, invariably leading to increases in plastic waste. For example, in Hong Kong, the government implemented a ban on dinning in at restaurants from 6:00 pm to 5:00 am in July, 2020. More people turned to take-away food, resulting in a dramatic increase in waste. Greeners Action, an environmental group, estimated that Hong Kongers were discarding 101 million pieces of single-use cutlery and food containers per week in April, 2020, more than double that of the same month the previous year (46 million pieces).[130] This number increased after the dine-in ban.

Single-use takeaway containers and cutlery (million pieces/week)[131]



There have been similar reports of increased plastic waste resulting from home food deliveries around the world. For example, the Thailand Environment Institute reported that plastic waste "increased from 1,500 tons to 6,300 tons per day, owing to soaring home deliveries of food.[132]

McKinsey & Company, a management consulting firm, described three likely phases of plastic and packaging consumption resulting from the pandemic. The first phase features a sharp rise in demand for packaging of groceries, healthcare products, and e-commerce transportation, with a decline in demand for industrial, luxury and business-to-business packaging. The second phase features lower demand as a result of reductions in household disposable income, with the exception of healthcare and certain food categories. And the third 'rebound' phase features a gradual increase in demand for packaging, though with variable changes in demand depending on the sector.[133]

Rollback and Pause of Plastic Reduction Efforts

Despite some of the worrisome statistics concerning plastic production and pollution as outlined, a variety of initiatives have been undertaken to reduce plastic consumption and waste, particularly in the past few years. As consumers have been inclined to increasingly reach for single-use plastic items for hygiene considerations, concern over cross-contamination from the use of reusable bags and containers and for convenience, a number of efforts to ban or disincentivize single-use plastic have been withdrawn, postponed, or rolled back. Lobbyists for the plastic industry are often driving this effort.[134]

The European Plastics Converters (EuPC), which describes itself as a leading EU-level trade association for plastics converting companies that "represents more than 50,000 companies, producing over 50 million tons of plastic products a year" called on the EU to roll back years of single-use plastic legislation in the face of COVID-19.[135] Fortunately, Brussels did not heed this call.[136] In the USA, the Plastics Industry Association, a lobby organization for the plastics industry, sent a letter to the US Department of Health and Human Services, urging them to "make a public statement on the health and safety benefits seen in single-use plastics."[137] These lobbying efforts have had an impact.

As Patrício Silva *et al*. note, governments have delayed single-use plastic bans "amid COVID-19 concerns [in] the province of Newfoundland and Labrador in Canada, states of New York, Delaware, Maine, Oregon, Connecticut, Oregon, Hawaii, in the U.S., the United Kingdom and Portugal."[138] Elsewhere, single-use plastics have been reintroduced and the US states of Massachusetts and New Hampshire have gone so far as to ban reusable alternatives.[139]

Many companies are turning away from reusable options, and even banning them. For example, Starbucks temporarily banned the use of reusable mugs,[140] and the western Canadian grocery chain Save-On-Foods banned reusable bags,[141] as did the Midwestern US grocery chain Hy-Vee, among others.[142] Such measures were adopted despite the fact that "the contribution of reusable grocery bags in the transmission of SARS-CoV-2 remained questionable, especially in conjunction with proper hygiene practices, such as regular hand washing and frequent laundering of reusable bags."[143]

These rollbacks and general de-prioritization of single-use plastic reduction efforts are worrisome because invariably consumer habits that accompany legislative efforts can take time to develop.

PPE and the Response to COVID-19

The use of PPE, face masks, and to a lesser extent gloves, face shields and gowns, has become widespread and a common tool used in preventing the spread of the pandemic. In medical settings, where frontline staff face high risks of infection, extra precautions have been adopted. These measures are necessary in order to keep healthcare workers safe, but they have resulted in the increased generation of medical waste. For example, during the peak of the virus in Wuhan, China, authorities estimated that hospital waste had increased six times at the height of the outbreak – with 240 tonnes of waste produced daily, as compared with 40 tonnes during normal times.[144] In the United States, predictions suggest that a years' worth of medical waste may have been generated in only two months.[145]

The use of PPE on the part of frontline service workers and members of the public dramatically increased, often propelled by legislation mandating the wearing of masks in public settings. Researchers have identified more than 50 countries that require "the use of masks in public places and transports, including Venezuela, Portugal, Spain, Czech Republic, Bosnia and Herzegovina, Cuba, Ecuador, Austria, Morocco, Argentina, Luxembourg, and El Salvador," with this likely expand to as countries enter different stages of the pandemic.[146]

The production of PPE has expanded in an attempt to meet with demand (see 'Scale of Mask Production and Demand' below) with PPE waste increasing significantly. Before exploring these numbers in detail, it is valuable to have a greater understanding about masks, their composition, and their potential impacts on wildlife and on the environment.

PPE Waste in Kenya

A recent study of litter in Kenya found a significant amounts of PPE waste. In June 2020, 100 days after the first confirmed case of COVID-19 in Kenya, Okuku *et al*. surveyed 14 streets, 21 beaches, and conduced 157 transects for floating litter. They found that "COVID-19 related items contributed up to 16.5% of the total litter encountered along the streets." [147] While they found few PPE items on recreational beaches, they attributed this to beach closures. However, they did find high densities of PPE items (wipes and single-use plastic masks) on two urban beaches, Mkomani (55.1%) and Nyali (2.6%), which they attributed to illegal beach visitation and runoff from the streets. [148]

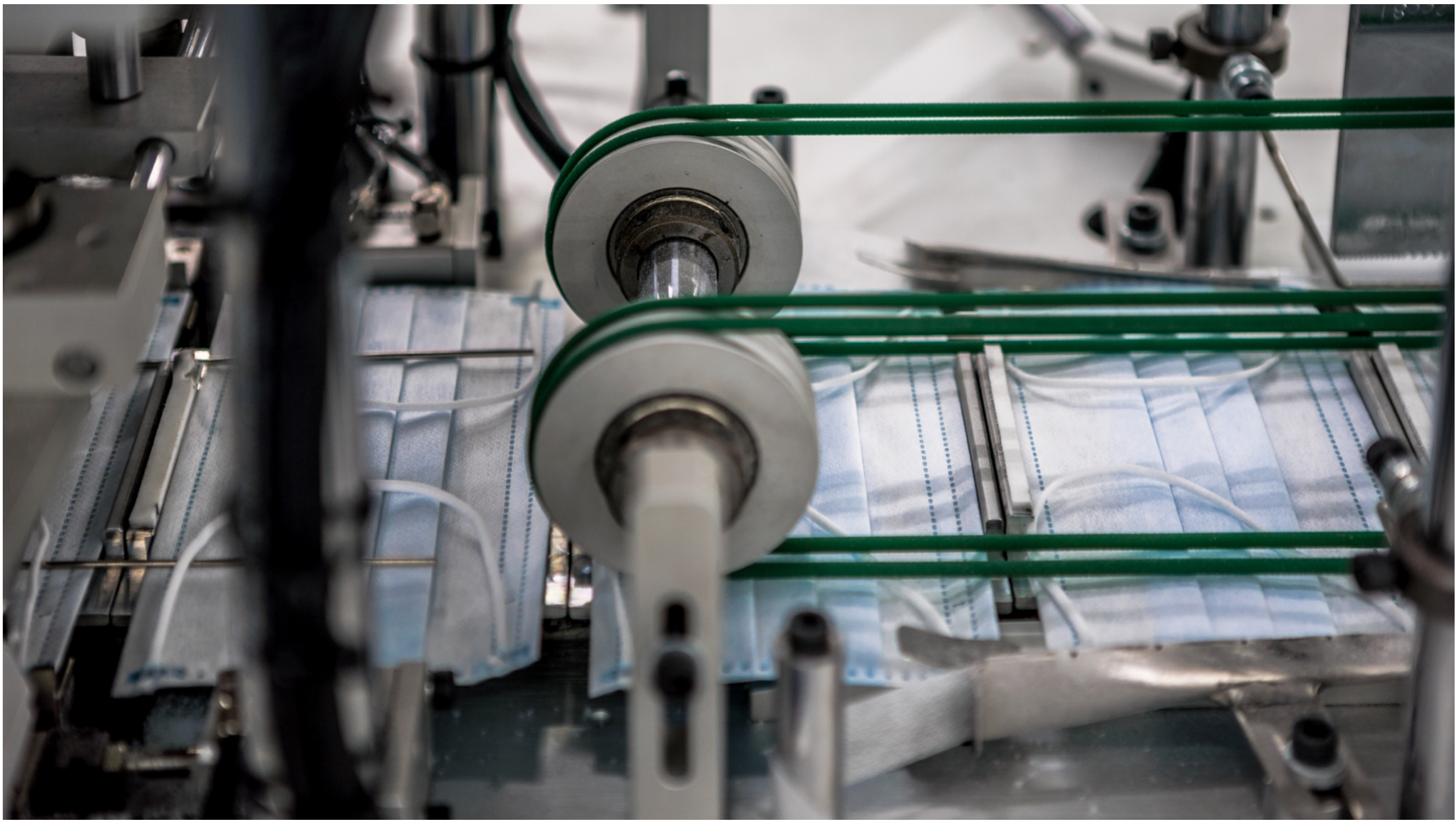
Types and Composition

A wide range of face masks are available.[149] Masks vary in design, materials, and applications. N95 respirators will often be used in medical settings where maximum protection is required. These masks are designed to seal tightly against the face in order to prevent exposure to tiny droplets that can remain suspended in the air, and "health care workers who wear them undergo a fit-test to find the right make, model and size to ensure a tight seal."[150] They are designed to filter our 95% of particles.[151] Governments have discouraged members of the public from using these types of masks for everyday use, given shortages faced by healthcare providers.[152]

Other respirators used in medical settings include the N99 (which offers 99% filtration), N100 (99.97% filtration), the R95 offers 95% filtration and which is partially oil resistant, and a range of 'P' respirators that offer equivalent filtration and which are strongly oil resistant.[153]

Other commonly used type of masks are procedural or surgical masks. These are the typical light blue or white paper-like masks and are generally thin and flat. They are not close fitting, offering protection against larger respiratory droplets from coughs and sneezes. They do not provide the same level of protection as respirators, yet are never the less used by health care workers in numerous circumstances and they are commonly worn by members of the public.[154] Cone-style masks are similar to surgical masks but are moulded into a cup shape that covers the mouth and nose. They typically include a metal strip along the top so that the wearer can secure the mask to the bridge of their nose.[155]

These face masks are all designed for single use. In the face of shortages, a number of health care systems adapted methods to extend their use.[156] Research into the efficacy of various types of masks and reusable options, is ongoing, and a subject in need of further research.[157]



These masks are all generally made from nonwoven materials – spunbond and meltblown spunbond plastics such as polypropylene, polyurethane, polyacrylonitrile, polystyrene, polycarbonate, polyethylene, or polyester. [158] The most common material used is polypropylene.[159] A typical surgical mask will consist of three layers: "an inner layer (soft fibres), middle layer (melt-blown filter), and an outer layer (nonwoven fibres, which are water-resistant and usually coloured)."[160] As Fadare and Okoffo explain, "the melt-blown filter is the main filtering layer of the mask produced by the conventional fabrication of micro- and nanofibers, where melted polymer is extruded through tiny nozzles, with high speed blowing gas."[161] This method is used "in order to obtain fibres of a small diameter in a random pattern that can trap small particles."[162]

Masks will typically have a nose strip, which allows the mask to bend around the bridge of the nose. These are typically made from metal (aluminium, galvanized iron, or steel). Masks are held against the face using a variety of methods that include ties made from materials similar to the rest of the mask or elastic ear loops made from nylon spandex.[163]
Respirators are generally manufactured in a similar fashion, with a two significant differences: 1) "The prefiltration layer is … run through a hot calendaring process, in which plastic fibres are thermally bonded by running them through high pressure heated rolls. This makes the pre-filtration layer thicker and stiffer, so it can be moulded to form the desired shape," and maintain shape.[164] And 2) "the filtering is enhanced through high efficiency melt-blown electret non-woven material, involving higher tech machines and increasing production costs."[165]

As we have seen, plastic in the marine environment can have a devastating impact on wildlife and ecosystems. The following section explores the specific harms associated with face masks.

Face masks in the marine environment serve as a source of microplastic. Products of similar materials to face masks are estimated to take as long as 450 years to fully decompose,[166] and throughout this process of decomposition they become a source of microplastics. Meltblown polypropylene and polyethylene used in masks can easily break up into micro-plastics, contributing to the many concomitant negative impacts these have on species and ecosystems.[167] While studies examining the decomposition of face masks are limited,[168] a recent study of plastic pollution in the Magdalena River, Columbia, found that “the degradation of nonwoven synthetic textiles was the predominant origin of micro-plastic microfibres found in both water and sediment samples.”[169] Other studies have described microplastic fibres as vectors for potentially harmful contaminants.[170]

The design of face masks, and particularly ear loops, makes them a possible entanglement risk for wildlife. In July, 2020, the Royal Society for the Prevention of Cruelty to Animals (RSPCA) in the UK reported encountering a gull near Chelmsford with its feet tangled in the straps of a face mask. They have since been promoting a campaign encouraging people to ‘snip the straps’ of their masks before disposal.[171] Steve Shipley, a photographer from the UK, shared pictures of a juvenile peregrine falcon with its talons ensnared in a face mask.[172] A group of volunteers conducting a beach cleanup in Miami, USA, found “a dead, bloated pufferfish tangled in the ear loops of a disposable blue facemask.”[173] And Instituto Argonauta, a Brazilian marine conservation organization reported finding a Megellanic penguin with an N95 mask in its stomach on Juquehy Beach in Sao Paulo.[174]

The composition of masks may make them more prone to algal growth as compared with smoother surfaced marine plastics. As a result, this could increase the possibility that masks, or portions of masks, being mistaken as food and consumed by marine wildlife, most notably sea turtles, in light of recent studies into the impact of algal growth on sea turtle consumption of marine plastic.[175]

Reasons for Loss

There are numerous reasons why single-use plastic face masks may end up in the environment. Canvassing the literature identifies a number of causes. Face masks are difficult to recycle – they contain several types of plastics, which would need to be separated before being processed.[176] Given the decreasing costs of 'virgin plastic,' incentives to recycle plastics are low, as is the drive to innovate new methods of improving the efficiency of recycling processes and to increase resource recovery.[177] As one waste management company representative noted, "it costs more to collect, separate and recycle the PPE than the value of the resulting recycled material. If the economics do not work, authorities do not have the incentive to collect and recycle PPE."[178] Further confounding efforts to recycle PPE are concerns that PPE may be contaminated and infectious, thus putting waste and sanitation workers at risk.[179] These concerns are magnified with respect to those working in the informal waste economy, particularly in developing countries.[180]

Given the challenges of recycling face masks and PPE, much of it has been allowed to enter general waste systems. It should be noted that PPE used in a hospital is much less likely to enter the environment than PPE used by the general public. In a hospital setting and other medical environments, there are typically systems in place for the safe disposal of PPE, which often entails segregation and incineration.[181] Such systems are not impervious to being overwhelmed by increased volume, or to accidental loss, however, these systems have been set up specifically to treat potentially contaminated PPE.

Unlike medical settings, public waste systems tend not to have segregated systems for potentially contaminated PPE, as a result, this waste is typically mixed in with general household waste. Given significant increases in household waste production as a result of the pandemic, both in the form of PPE and in plastic waste, in many places, this waste is overwhelming and overloading existing waste management systems.[182] Overwhelmed systems inevitably result in waste entering the environment.[183]

The problem is further compounded by the fact that "many waste-management services have not been operating at full capacity, owing to social-distancing rules and stay-at-home orders."[184] As a result, in some jurisdictions in the USA, "curb side recycling pickup has been suspended in many places, including parts of Miami-Dade and Los Angeles counties."[185] Elsewhere, for example, in the UK, there has been a dramatic 300% increase in illegal waste disposal (fly-tipping) during the pandemic.[186] Similar stories have been reported in Canada, the USA, and Ireland.[187]

Not all jurisdictions are able to provide well-functioning waste management systems. The World Bank notes, "in low-income countries, over 90% of waste is often disposed [of] in unregulated dumps or openly burned. These practices create serious health, safety, and environmental consequences."[188] These systems are particularly prone to losses, leading to pollution. Face masks, other PPE, and other single-use plastic items are often "lightweight and if discarded in open dumps can be easily carried by wind and surface currents, quickly spreading to natural environments."[189] Informal, unregulated, and overwhelmed waste management systems serve as a source of marine plastic pollution.

Another source of face masks entering the environment is through littering. Refuse that has been disposed of incorrectly, is a significant source of plastic pollution.[190] There is an extensive literature exploring what drives people to litter, but generally speaking "people tend to litter because they feel no sense of personal ownership to the objects being discarded."[191] There is also an environmental/social effect: people are "susceptible to the littering behaviour of those around them… people tend to litter more when in an already littered environment."[192] A small amount of litter can lead to a positive littering feedback loop.[193]

A study by Jambeck *et al*. assumed a littering rate of 2% of total plastic waste generation, across all countries.[194] While lacking quantitative evidence to indicate how this value might have changed as a result of COVID-19, anecdotal evidence suggests that it has not diminished, and has most likely increased. In addition to the aforementioned news stories about illegal dumping in numerous jurisdictions, reports from around the world reveal apparent increases in littering of PPE.[195] It is possible that littering rates have remained constant and it is only that masks being relatively large and uniform pieces of litter are more noticeable.

While pre-COVID-19 rates of waste mismanagement vary considerably around globally, Jambeck *et al*. estimate that 3% of global annual plastics waste enters the ocean.[196] Given increased plastic consumption resulting from the response to the pandemic, and evidence that waste management systems have been overwhelmed by this increase, it is likely that this number has increased. However, because it is still too soon to measure how the global response to the pandemic may have altered this number, we employ the 3% loss in our calculations. It is also worth noting that this number is a conservative one, and averaged out across the world. Some researchers have suggested that the amount of plastic likely to escape into the environment in some jurisdictions could be considerably higher.[197]

"Conservatively, it is estimated that 3% of single-use plastic face masks enter the marine environment where they pose a threat to wildlife and ecosystems…"

Conservatively, it is estimated that 3% of single-use plastic face masks enter the marine environment where they pose a threat to wildlife and ecosystems.[198] As such, in order to determine the number of masks entering the environment, it is necessary to know how many masks are being manufactured and put to use. Answering this question is challenging, in so far as mask production and consumption has increased dramatically as the pandemic has unfolded. There are serious inconsistencies in reporting/trade data across jurisdictions, and pre-2020, there is scant disaggregated data on mask production. As a result, fluctuating and inconsistent estimates of national and global mask production were encountered.

For example, China, a major global manufacturer of PPE, increased daily production of face masks (of all types) in February, from a reported 20 million to 110 million units, a 450% increase.[199] Daily production reached a reported 200 million by the end of March, and 450 million in April, matching a steep increase in demand and use.[200] It is worth noting that "before the pandemic, half the world's masks were manufactured in China; [by April 2020] with production there shifting into overdrive, that figure may be as high as 85%."[201]

As the pandemic progressed, many countries found that early estimates of their need for face masks were inadequate, orders for masks increased dramatically, as did production. For example, in February, US officials were estimating a need for 300 million face masks for healthcare workers.[202] In March, the Trump administration claimed to have ordered 500 million masks.[203] One month later, an order of 600 million masks was said to be insufficient to confront the virus at its peak.[204]

Elsewhere, some countries were ordering masks by the billions. In early May, the government of Hong Kong announced that it would be distributing reusable masks to the city's 7.5 million residents, and later in June, that it would distribute packs of 10 single-use plastic masks to every household (totally over 30 million masks).[205] In April, France ordered 2 billion masks from China, and Japan ordered 600 million.[206] Such was the demand for masks that China reported exporting 3.86 billion masks between March 1 and April 1, 2020.[207]

The need for masks has far outstripped production. In early May, the Organisation for Economic Co-operation and Development (OECD) noted that mask supply might be ten times lower than demand.[208] Estimates in Italy (population ~60 million), which was particularly hard hit by the pandemic and which ordered 22 million masks in March, calculated that 1 billion masks and half a billion gloves would be required on a monthly basis as the country moved out of lockdown.[209]

With respect to global demand, numbers originating in a study by Prata *et al*. published in mid-June and later adopted by the World Health Organization (WHO), suggested that 129 billion face masks and 65 billion gloves would be needed on a monthly basis in order to protect people worldwide.[210] Given that this number far outstrips current production capacity, but represents the number of masks necessary to ensure maximal protection globally, this will be used as our upper threshold.

Estimates of the need for PPE to protect only healthcare workers helps contextualize the sheers magnitude of global demand. According to the WHO, there are 43 million healthcare workers worldwide.[211] An OECD policy paper, published in May 2020, elaborates on the need for PPE for these healthcare workers, noting that:

> "masks are generally assumed to be effective for about four hours and need to be regularly changed, and "assuming that only around one third of healthcare workers need a mask (accounting for the fact that not all countries are affected at the same time, and not all health workers are in contact with COVID-19 patients), and that each health worker uses on average two masks per day, global demand for surgical masks would be around 28 million per day. Adding in care givers and suspected COVID-19 patients further increases this demand, possibly by another 12 million per day."[212]

With these numbers, the global monthly demand for healthcare workers alone (in a 30 day month) calculates to be 840 million masks, with an additional 360 million masks for care givers and suspected patients.

A global scramble to meet this demand resulted in factories being converted to PPE production.[213] New factories sprung up rapidly, and innovative production methods were developed. For example, one Turkish export company proposed setting up factories on idle ships, creating 'floating factories' that could manufacture masks while en-route to their final destination, significantly reducing on shipping time.[214]

This massive production led to an unprecedented expansion of the global medical face mask market. The scale of this market varies from report to report. One report in June predicted that the volume of this market will peak at more than 52 billion units by the end of 2020, and will likely stabilize in 2021, levelling out to 29 billion units by 2025.[215] The value of this market has also expanded dramatically. In 2019, the value of the global face mask market was ~$0.79 billion USD, it is estimated to be valued at over $166 billion USD by the end of 2020.[216] This is due to the massive rise in production, but also a significant increase in the cost of an individual mask.

The Price of a Mask

According to one report, a basic surgical mask that sold for a couple of cents prior to the pandemic was selling for as much as $1.25 USD, and a N95 mask that previously sold for $1.25 USD, was selling for $25 USD in May.[217] In March, Bloomberg reported that masks that had previously sold for $0.58 USD in New York, were being sold for $7.50 USD.[218] There were numerous reports of price gouging and of hoarding.[219]

Calculating Mask Loss

Market estimates provide insight into the direction that PPE production may be going, but they remain estimates. There are numerous, and sometimes conflicting reports regarding national consumption levels, with most countries data deficient. As a result, given current available data, it is challenging to calculate or even estimate a single global number for monthly mask consumption, and by extension, the extent to which they escape into the environment.

In order to avoid multiplying inconsistencies, we have developed a formula that will provide reasonable estimates of the number of face masks entering the environment, given reliable mask consumption numbers. This formula can then be used to shed light on the current and potential number of masks entering the environment given various scenarios and contexts. This formula is followed by a discussion of its limitations, the assumptions we made, and justifications of our choices.

Mask Loss Formula

The formula assumes an overall loss rate of 3%, which is the number of masks one can expect to see entering the environment as a result of loss, including those masks which were properly disposed of, but which escaped from the waste management system. This number can be applied to the overall number of single-use face masks used in any given jurisdiction.

Depending on the available data and context, masks used in medical settings can be excluded, or the very conservative loss rate of 1%, proposed by the World Wide Fund for Nature (WWF), can be employed.[220] Those wishing to estimate the number of masks found littering the streets can use the 2% littering rate.

The weight of lost face masks can then be calculated by multiplying the number of lost masks by the approximate weight range for single-use plastic masks of 3 – 4 grams.

Limitations, Assumptions and Justifications

It is important to note the limitations of this approach and to list some of the assumptions made. The focus of this report is face masks, but the formula is well suited to gloves. Given that they are more commonly used in medical settings where proper disposal would ensure lower levels of loss, the formula would likely over-estimate environmental escape of PPE such as gowns and face shields.

Increased use of PPE results in an increase in PPE waste, and also associated waste from packaging, with additional pollution from manufacturing and transportation. While packaging waste can be a serious source of plastic pollution, and greenhouse gases and other pollutants result from manufacturing and transportation, these have not been included in the formula.

A recent study from the University College London (UCL) by Allison *et al*. provides a detailed exploration of the other environmental impacts of PPE in general, and face masks specifically. Using detailed trade and waste disposal statistics, this team of researchers calculated that "if every person in the UK used one disposable surgical mask each day for a year, this would create over 124,000 tonnes of unrecyclable plastic waste (66,000 tonnes of contaminated waste and 57,000 tonnes of plastic packaging)."[221] The team calculated that this scenario would have ten times the climate change impact than if reusable masks were used, and that the quantity of expected waste would be reduced by 95% if every mask were a reusable mask.[222]

This level of analysis is laudable. However, it relies on accurate and detailed data, and while this data may be available in certain jurisdictions, such as the UK, this, unfortunately, is not the case in most jurisdictions. A number of confounding variables are encountered when attempting to expand this type of analysis beyond a given national context. For example, factors such as greater variability in supply chains, type and size of packaging (individually packaged masks, packets of two or more, boxes of 50 or more, etc.), reuse rates among members of the public, types of masks typically worn, etc. all confound analytical efforts.

Our formula cannot accurately account for discrepancies between disposal/improper disposal by healthcare workers operating in hospital and other medical facilities as compared with members of the general public. Most jurisdictions prioritize PPE use in medical settings. As a result, a greater percentage of mask consumption in a given jurisdiction may be used in medical settings. Masks disposed of in these settings are likely to have lower rates of environmental escape because medical facilities tend to have waste management systems in place to address PPE. Depending on the available data and context, masks used in medical settings could be excluded from calculations, or the very conservative 1% loss rate can substituted.[223]

The 3% overall loss rate, as expressed by the literature, includes marine litter from land and marine-based sources. The UNEP estimates that 80% of marine litter globally came from land-based sources, with the remaining 20% from marine sources.[224] This could suggest that using 3% as the overall number of masks entering the marine environment might be high, as the original loss number includes plastic pollution from maritime sources. Despite this, we have opted to use this number as the loss rate, recognizing that the increased use of PPE has resulted in increased disposal which has overwhelmed many waste management systems, and that loss rates are likely to be much higher in jurisdictions with non-existent to poor waste management systems.

We assumed the dry weight of an individual mask as between 3g – 4g. There is considerable variation in design, weight, and use of single-use plastic masks, hence this range has been selected as a rough median weight. At one end of the weight range we have the typical single-use plastic surgical mask which Allison *et al*. note weighs approximately 2.68g.[225] When we weighed a typical blue surgical masks, a 'PA 2 Layer Disposable Mask' widely sold in boxes of 50, we calculated its weight at 3.4g.[226] Weighing a second mask, this one a 3M model 1835 level 3 surgical mask, yielded a weight of 3.6g.[227] At the heavier end of the range, masks such as the N95 manufactured by 3M, weights approximately 9.92g (0.53oz).[228] Given that the use of these masks by members of the public appears to be less common than surgical masks, allowed this number to conservatively increase the upper threshold of our range to 4g. We recognize that the formula can be easily updated in light of more reliable data on the public use of various types of masks.

Case Study: Hong Kong

People in Hong Kong are well informed regarding pandemic prevention measures and are accustomed to wearing face masks when they are ill. In the early stages of the pandemic, the proportion of people in Hong Kong wearing masks in public, by some estimates, was close to 98%.[229]

The government also helped to supply people with masks. In early May 2020, the government of Hong Kong announced that it would be distributing reusable masks to the cities 7.5 million residents, and later in June, that it would distribute packs of 10 single-use plastic masks to every household (totalling over 30 million masks).[230]

Writing in June, 2020, Sun Yajing noted that conservative estimates from the Hong Kong Environmental Protection Agency suggested that people in Hong Kong were consuming 4 to 6 million masks daily, and that the number of masks that had been discarded in Hong Kong (since COVID-19 had reached the city in late January) was likely in excess of 500 million.[231]

Thus, if Hong Kongers are disposing of 150 million masks per month, this would equate to 450 to 600 metric tonnes of plastic waste, entering the waste supply chain, on a monthly basis. This volume of masks appears to have overwhelmed the waste management system; a significant number of these masks have been transported to landfills and have escaped into the environment, and many have been incorrectly disposed of (littered) and thereby also entered the environment. Using our formula, we can expect to see as many as 3 million of these masks littering Hong Kong streets (9-12 tonnes), and 4.5 million masks entering the environment (13.5-18 tonnes) per month.

Samples from Around the World

Here we have compiled a table using relatively reliable numbers of mask consumption, with when the data was reported, and the location it covers. Estimations as to actual need have been included in order to contextualize the potential scale of the issue.

Lost masks by number and weight given monthly consumption levels.

Date	Location	Masks/ month (million)	Loss Rate (3%) (million)	Weight (tonnes)	Source
18/04/20	Thailand	45	1.35	4.05 – 5.40	TEI[232]
11/07/20	Switzerland	105	3.15	9.45 – 12.60	FOPH[233]
26/06/20	Hong Kong	150	4.50	13.50 – 18.00	Yajing[234]
31/03/20	France	160	4.80	14.40 – 19.20	France 24[235]
29/05/20	South Korea	362	10.86	32.58 – 43.44	MDPI[236]
19/05/20	Japan	400	12.00	36.00 – 48.00	METI Japan[237]
23/09/20	UK	1,600	48.00	144.00 – 192.00	EJ[238]
00/06/20	Est. Global Supply 2020	4,333	129.99	389.97 – 519.96	AAI[239]
11/09/20	Est. Global Need 2020	129,000	3870.00	11,610 – 15,480	AAAS[240]

Two sets of data were not included in the above table but bear mentioning. First, we have masks used by healthcare workers, caregivers, and patients. In May, the OECD estimated that the global monthly demand for masks for healthcare workers was 840 million, and 360 million for caregivers and patients.[241] When the more conservative 1% loss rate was applied, a combined total of 12.0 million masks were calculated to be entering our oceans from this source, accounting for 36.00 – 48.00 tonnes of plastic.

In addition, it was difficult to identify reliable mask consumption numbers for many countries, particularly low- and middle-income countries (LICs and MICs). While there are no accurate consumption numbers, UNICEF estimated, in May, that the demand for PPE in LICs and MICs would reach "reach 2.2 billion surgical masks, 1.1 billion gloves, 13 million goggles, and 8.8 million face shields" through 2020.[242] Given these numbers and our formula, we could expect that if this demand were properly met, 5.50 million masks (16.50 – 22.00 tonnes) will enter our oceans from these countries. On one hand, many of these countries have less effective waste management systems, which would make this estimate low, on the other hand, this level of demand is not currently being met. In absence of reliable consumption numbers, this estimate has been included to provide additional context.

The number of masks entering the environment as a result of the COVID-19 pandemic is staggering. From the global production projection of 52 billion masks for 2020,[243] we estimate that 1.56 billion masks will enter our oceans in 2020, amounting to between 4,680 and 6,240 tonnes of plastic pollution. These masks will take as long as 450 years to break down, and all the while serve as a source of micro plastic, and negatively impact marine wildlife and ecosystems.

In a 2019 study *Marine Pollution Bulletin*, Beaumont *et al*. calculated that every tonne of plastic negatively impacts ecosystem services by as much as $33,000 USD.[244] As a result, the impact of these 1.56 billion face masks, in terms of reduced marine natural capital, could amount to between $154.4 and $205.9 million USD.

Given these staggering numbers and the serious and negative impact that plastic pollution has on our oceans, action is needed. Action is required at every level, from individual citizens changing their behaviours, to designers innovating reusable masks and those made from more sustainable materials, to changes in national laws and policies, to adherence to international laws and agreements. With regards to plastic pollution, and specifically plastic pollution resulting from COVID-19, there is no single solution, but rather a wide range of actions that need to be taken concurrently.[245]

Individual Action

"Choose Re-usable!"

Face masks are a key tool for the prevention of the spread of the SARS-CoV-2 coronavirus and other viruses.[246] While they may not be appropriate in medical settings,[247] reusable cloth face masks have been found to be an effective means of preventing the spread of the virus.[248] As one study noted, "cloth masks may be used to prevent community spread of infections by sick or asymptomatically infected persons, and the public should be educated about their correct use."[249] Individuals should be encouraged to wear reusable masks whenever possible.

When choosing reusable cloth masks, people should follow government recommendations concerning the design, materials used, and the fit of their mask.[250] Not only will this help reduce plastic pollution, but such efforts will also allow more disposable masks for frontline healthcare workers, those in hospital settings, and those who need them. Given shortages, the Centers for Disease Control and Prevention (CDC) has been obligated to ask people not to use masks intended for healthcare workers, such as N95 respirators.[251]

A recent working paper from the Plastic Waste Innovation Hub at UCL estimated that the annual demand for face masks in the UK was 24.7 billion. This number could drop to 136 million if only reusable masks were used.[252]

Discard Responsibly

There are still some circumstances where using a single-use mask may be necessary or unavoidable. In these instances, people should consider biodegradable options that are starting to become available (see 'Technological Solutions' below). All masks – single-use or reusable – should be discarded responsibly. Even a reusable or biodegradable mask will become pollution if incorrectly discarded.

Individuals should check with local authorities for guidance on proper disposal in their jurisdiction, as various protocols exist, depending on the local waste management system. Proper disposal of single-use masks will not only help keep them from entering the environment, but will also protect others from potentially contaminated PPE.

Take Action

There is also room on the part of member of the public to be proactive. They can encourage others to wear reusable and sustainable masks, and can encourage their governments to press forward with efforts to reduce plastic pollution. In addition to reusable face masks, there are sustainable and reusable alternatives for most single-use plastic items. Individuals should strive to reduce their consumption of unnecessary single-use plastic, purchase from companies that offer these alternatives, and encourage other companies to reduce their use of plastic.

A recent study in *Nature*, noted that by 2040, "current government and corporate commitments will only reduce the amount of plastic flowing into the ocean by 7 percent," and the in order "to cut the flow of ocean plastic by 80%, paper or compostable alternatives to single-use plastic would be needed and packaging should be redesigned to more than double the share of recyclable material."[253]

Individuals can also participate in beach cleanups. It is encouraging to see people around the world getting involved in these efforts. For example, the Ocean Conservancy reported that since 1986, 16.5 million volunteers have collected 154,000 tonnes of trash from beaches worldwide.[254] These efforts will help remove plastic from our beaches, but to avoid this becoming a Sisyphean ordeal we must ultimately stop the flow of plastic entering our oceans.

As a recent study recommended, "the most straightforward way to reduce environmental inputs of plastic waste is to produce less, especially waste that is not practicably or economically recyclable, readily escapes to the environment, or is unnecessary. [255]

Technological Solutions

While many solutions require a change in individual behaviour and consumption practices, these changes can be facilitated by the increased availability of sustainable alternatives, with technological and design solutions helping to reduce plastic pollution.

As the pandemic has progressed and mask wearing become increasingly widespread (and in many jurisdictions mandated) an extensive range of innovative mask designs have emerged. Many of these new designs were developed to reduce the need to rely on single-use plastic masks, designed to ease effective disposal, are made with more sustainable materials, or are designed for reuse. Solutions include:

- **Self-cleaning mask**: Israeli researchers, led by Technion University Professor Yair Ein-Eli developed a mask that can disinfect itself. Plugging the mask into a USB outlet for 30 minutes heats up carbon fibres inside the mask to temperatures sufficient to kill viruses.[256] Air/R Health Devices, France, recently received EU funding to design a mask with a similar ‘plug in and disinfect’ design, this one relying on a “graphene substrate and other nanoparticules which capture biological and chemical pollutants.” The company claims that “one simple charge decontaminates the filter in less than 10 minutes and allows for 12 hours of use.”[257] US-based LIGC proposed a design operating on similar principles.[258]

The Czech company ‘är’ has incorporated a coating of ViralOff into its self-cleaning masks. ViralOff, a substance designed by Sweden-based Polygiene, which contains “a reaction mass of titanium dioxide (TiO_2) and silver chloride (AgCl),” makes masks “self-cleaning over two hours.” [259] A number of companies and projects have proposed masks that similarly rely on chemical reactions for cleaning.[260]

- **Sustainable materials**: A number of designers have developed disposable and reusable masks using sustainable materials. In addition to a wide range of conventional fabrics such as cotton and linen, reusable masks have been made from bamboo fabric,[261] recovered marine plastic,[262] and recycled materials.[263] A number of compostable/biodegradable masks made from natural fibres have become available to members of the public, including masks made from hemp,[264] abaca tree fibre (a tree related to the banana),[265] wood fibre,[266] coffee yarn,[267] and sugar cane bagasse (waste plant fibre).[268]

  A research collaboration between the Swiss Federal Laboratories for Materials Testing and Research (EMPA) and École polytechnique fédérale de Lausanne (EPFL) are currently developing a transparent surgical mask made almost entirely of a ‘biomass derivative.’ The ‘Hello Mask’ is reported to be bio-degradable, and allow patients to see the mouths and expressions of doctors, a particular benefit to patients for whom a mask may be a major obstacle to communication, such as children, the elderly and the hearing impaired.[269]

- **Innovations for disposal**: While most single-use plastic masks discarded by members of the public end up in conventional household waste streams, a number of sources, including India’s University of Petroleum and Energy Studies, have proposed that these items be converted into biofuel.[270] A French firm, Plaxtil, is developing methods to recycle used masks.[271] In addition to the potential for contamination, one factor frustrating possible recycling efforts is the fact that many masks are manufactured from “multiple layers of different materials or polymers.”[272] As such, many experts are calling for the development of face masks from a single polymer, in order to facilitate recycling.[273]

NCD Corporation, a company that focuses on manufacturing biodegradable and compostable products, has developed a water-soluble mask. Made from polyvinyl alcohol (PVOH or PVA), NCD Corporation claims that this mask will dissolve instantly in hot water (60°C and 90°C depending on the product) and be converted into water and carbon dioxide.[274] In a landfill, the manufacturer claims that these masks "decompose within 180 days thanks to the liquids and microorganisms found in the garbage."[275] The manufacturer estimates that these masks would dissolve/degrade in 4 to 5 months if they were to enter sea water.[276] Research suggests that PVOH is "one of the very few vinyl polymers soluble in water also susceptible of ultimate biodegradation in the presence of suitably acclimated microorganisms.[277]

- **Extending use of single-use PPE**: Studies into the reuse and sterilization of single-use N95 respirators have been conducted,[278] and the CDC, in the face of shortages, has released guidelines for decontaminating N95 respirators.[279] Many jurisdictions with PPE shortages have resorted to these methods.

- **Developing recycling programs**: A number of companies have begun offering mask recycling services. For example, one company, TerraCycle offers targeted recycling services for items like coffee capsules, plastic packaging, and even action figures, corks, and eyewear. They have begun offering a 'ZeroWaste' box for facemasks. Customers order a box, fill it with the specific item, and ship it back to the company.[280] A small box for face masks (11" x 11" x 20") costs $86 USD, while a large box (15" x 15" x 37") costs $219 USD. The company notes that these boxes are not intended for medical waste – "materials contaminated with blood or bodily fluids that originate from health care facilities…"[281] The masks in returned boxes are sorted at the company's headquarters in New Jersey, USA, metal nose strips are removed, and "then, the piles are melted down and shredded into a mulch-like material that can be molded into things like railroad ties and shipping pallets.[282] This process is not cheap and there are additional environmental impacts involved in the transportation of the masks. The French company Plaxtil has also launched a mask recycling program, which shreds and decontaminates masks before using the materials to manufacture a range of plastic products.[283]

If they become litter, or are incorrectly disposed of, reusable and biodegradable masks can become harmful pieces of marine plastic pollution, as such, technological fixes are only part of the solution. Individuals must adopt new technologies and change their behaviour.

Government Policy

Governments have a central role to play in efforts to reduce single-use plastic. There are a wide range of policy instruments that can be implemented, which include measures designed to change consumer behaviour, market-based instruments, legislation designed to hold producers accountable, and incentive and support programs. There is much to be done and every possible type of policy intervention should be explored. Here we will briefly survey those measures which touch upon PPE specifically, but we encourage those in government to consider the wide range of measures proposed by other civil society actors.[284]

With respect to individual action, governments can implement policies designed to encourage the use of reusable masks and reduce the consumption of single-use plastic. Releasing guidelines regarding the proper manufacture and use of cloth masks is a good starting point.[285] Governments should work to make it as easy as possible to correctly dispose of PPE, such as by providing secure, visible, and easily accessible public trash bins with hygienic opening mechanisms.[286]

Members of the public can be further encouraged to properly dispose of PPE through instructional and motivational messaging, tailored to specific targeted audiences.[287] One editorial noted that an effective component of messaging is “emphasizing individual’s obligation to guard frontline employees.”[288] Furthermore, government officials, politicians, and public figures should model recommended prosocial behaviour.[289]

As an example, McKinsey, a management consultancy, recommends the use of the ‘influence model,’ which contains four general practices that are interrelated and designed to help change people’s behaviour and mindsets: “offering clear and consistent messaging to foster better understanding of the coronavirus, using formal mechanisms to shape safe behavior, teaching practical skills to instill confidence, and leveraging role models who reinforce new norms”[290]

Removing barriers to safe disposal, and educational policies and messages can be paired with punitive measures, such as increasing fines for littering. Many jurisdictions, faced with extensive littering of PPE, have already adopted these measures.[291] For example, in France, fines for littering have been increased as a means of reducing PPE litter. Fines for littering were raised from €68 to €135, which can increase to as much as €375 for late payment, and higher in some circumstances.[292]

Despite setbacks, legislative efforts to reduce the use of single-use plastics must continue and be accelerated as countries develop their COVID-19 recovery plans. Recycling and reuse rates for plastic are worrying low, with studies concluding that only 9% of plastic is recycled.[293] Prior to the pandemic, efforts were being undertaken to reduce consumption of single-use plastic, but many of these efforts have been paused or rolled back.[294]

Policy-makers face a pivotal decision point in a post-COVID-19 world: press forward with efforts to reduce single-use plastic items, or allow plastic pollution to continue to pile up and fill our oceans. In May, "the global market for packaging was projected to grow by 5.5 per cent during the pandemic, led by plastic," and demand for products such as single-use cups and single-use plastic cutlery is in high demand.[295] Governments must curtail the resurgence of single-use plastic items resulting from the pandemic and revive efforts that have been derailed or paused. Governments must adopt further measures aimed at significantly reducing single-use plastics. They should aggressively pursue measures such as "special environmental taxes, waste disposal fees or charges, and extended producer responsibility measures (e.g., deposit-refund, take-back schemes)."[296]

For example, despite the pandemic, a number of countries have pressed forward on legislation to ban single-use plastics. In early October, 2020, the Canadian government announced a nation-wide ban on single-use plastic by the end of 2021 as part of this countries plans to achieve zero plastic waste by 2030.[297] After banning plastic bags in 2016, Mauritius recently announced plans to ban all single-use plastic products by January 15, 2021.[298]

By some estimates, "replacing inadequate regulation, changing business models and introducing incentives leading to the reduced production of plastics" could help reduce plastic pollution by as much as 80%, particularly when coupled with packaging and product design aimed at facilitating recycling, and improved waste collection.[299] Efforts to establish and improve household waste collection and waste supply chains, particularly in low income countries, will have a lasting positive effect. The loss of PPE from existing collection systems could also serve as a means to identify weaknesses in those systems, and such, help facilitate improvements.

Governments should also support and encourage innovation and the development of reusable and biodegradable alternatives (for examples see 'Technological Solutions' above). [300] Incentive programs, grants, and other instruments can help promote "non-toxic, biodegradable or easily recyclable alternatives, such as natural fibres, rice husk, and natural rubber."[301] In addition to helping reduce the environmental impact of PPE, supporting the development of industries specific to these products could benefit local economics, particularly those in lower income countries.

Implementing policies supporting, and investing in research and development into the conversion of plastics into energy also appears promising. One example of such a policy, albeit as part of an effort at tackling ghost gear, is Hawaii's 'Nets to Energy' program, where the authorities provide no-cost disposal of derelict fishing gear, which is then burned to generate electricity.[302] After the success of this program, the 'Fishing for Energy' project was set up across 12 US states, and has helped keep over 1,814 tonnes (4 million pounds) of fishing gear from becoming deadly marine debris.[303]

Masks to Energy

Race for Water, a marine conservation foundation, proposed a similar program "using decentralised energy recovery units to transform plastic waste into energy, through a high-temperature pyrolysis process."[304] These compact units are ideal for remote communities, such as island communities, and help these communities to become self-sufficient in managing their waste and energy production. This program can use "income generated by the sale of electricity… to pay street collectors, or reduce waste management costs.[305]

While incineration for energy generation as a means of reducing plastic pollution has been criticized,[306] and does not address over production, consumption, and improper disposal, it may offer a short-term solution to the issue of increased plastic pollutions resulting from the COVID-19 pandemic. Likewise, it may serve as a solution in locations where recycling or disposal in a landfill may be impossible or unacceptable, such as remote islands.

Overall, the issue of plastic pollution is a serious one, and we strongly encourage all manner of policy innovation and experimentation.

International Agreements

Policy innovation should not be limited to the domestic arena, with international cooperation playing a critical role in efforts to reduce marine plastic pollution. As noted by the United Nations Conference on Trade and Development (UNCTAD), "global trade policies also have an important role to play in reducing pollution."[307] While many countries have, or are in the process of developing domestic policies (COVID-19 notwithstanding), the global nature of marine plastic pollution demands international solutions.

In this arena, a number of instruments can be employed. Downstream countries may find it beneficial to enter into bilateral support and capacity building arrangements with upstream countries. Riparian countries may wish to foster regional cooperation agreements to reduce pollution flowing into a particular river. Intergovernmental trade organizations will benefit from amending and improving standards to reduce unnecessary plastic pollution, such as standards regulating packaging. Existing international agreements and treaties can be adhered to and strengthened and new agreements developed to address emerging issues.

The regulation of plastics through international agreements has historically been of a lower priority as compared to other global pollutants. The first significant international agreement including provisions relating to the dumping of plastic pollution at sea was MARPOL, which came into effect in 1988.[308] While MARPOL covers dumping from vessels, it does not address plastic pollution entering the oceans from land-based sources, which as we have seen, account for as much as 80% of marine plastic.[309]

In addition to MARPOL, a number of other existing treaties, conventions, agreements, and partnerships touch upon marine plastic pollution. These include:

- The *United Nations Convention on the Law of the Sea* (UNCLOS), which was adopted and signed in 1982, contains a number of articles touching on marine pollution. Article 192, for example, declares that "states have the obligation to protect and preserve the marine environment." The Convention generally calls on states to take all measures necessary "necessary to prevent, reduce and control pollution of the marine environment from any source."[310]
- The *Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection* (GESAMP) was established in 1969 to advise the UN system on scientific issues relating the marine environment and its protection.[311]
- The *United Nations Global Partnership on Marine Litter* (GPLM) was launched at the UN Conference on Sustainable Development (Rio+20) in June 2012. It focuses on information sharing and creating connections between a wide range of actors with the goal of addressing the levels and impacts of litter, debris, and solid waste on the marine environment. It is principally an information, knowledge, and expertise sharing platform.[312]
- The *Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal* (Basel Convention) which seeks to protect the environment from a number of hazardous substances.[313] It was amended in May 2019 to include plastic waste under its provisions, with the goal of making "global trade in plastic waste more transparent and better regulated, whilst also ensuring that its management is safer for human health and the environment."[314] The amendments were supported by 187 countries (excluding the USA and Haiti which have not ratified the Basel Convention), and becomes effective on January 1, 2021.[315]
- The *Pacific Marine Litter Action Plan* (MLAP) is a regional plan of action for Pacific Island Countries and Territories, and focuses primarily on marine sourced litter, and to a lesser extent marine litter from terrestrial sources. At its core, this plan seeks to build on existing policy and regulatory frameworks for addressing marine litter, and to support the development of national legislation and cross-compliance codes in a region acutely impacted by marine plastic pollution.[316]

The gaps left by this patchwork of agreements fuelled calls for a binding international agreement dedicated to marine plastic pollution.[317] A number of recent efforts have attempted to answer this call. The United States National Oceanic and Atmospheric Administration (NOAA) and UNEP initiated the *Honolulu Strategy* in 2011. This framework document is intended to serve as a:

- Planning tool for developing or refining spatially or sector-specific marine debris programs and projects.
- Common frame of reference for collaboration and sharing of best practices and lessons learned.
- Monitoring tool to measure progress across multiple programs and projects.[318]

In February 2017, the UNEP launched Clean Seas, a campaign to serve as a catalyst for action, engaging a number of actors (governments, the public, and the private sector) in combating marine plastic pollution, with a focus on non-recoverable and single-use plastic.[319] Clean Seas contributes to the GPML, and has seen some success with individuals, governments, and companies in a number of countries pledging to eliminate various plastic products over the next few years.[320] This includes India pledging to eliminate all single-use plastic by 2022, and Kenya implementing what has been described as the world's strictest plastic bag ban, which includes steep fines (as high as ~$40,000 USD) or custodial sentences.[321] Clean Seas has also partnered with companies like Volvo, who have committed to reducing their use of single-use plastic and increasing the amount of recycled plastic in their products.[322]

The G20 has taken a number of steps in recent years to address marine plastic pollution. It drafted an action plan at its 2017 meeting.[323] The implementation plan adopted at the G20 meeting in 2019 included members committing to reducing marine plastic pollution in line with UNEP goals.[324]

Assuming the meeting is not impacted by COVID-19, the fifth session of the UNEP in February 2021 will include a discussion concerning the possibility of creating a global plastic treaty.[325] This meeting will mark a critical juncture in the path to a global plastic treaty – members will have to decide whether or not they wish to press forward with such a convention or treaty.

Conclusion

The additional plastic pollution created by the COVID-19 pandemic is but part of a much larger problem. Our oceans are filling with plastic pollution, and they have been doing so since the first piece of Bakelite incorrectly discarded. While this problem is not new, the urgency of the call to action grows louder as the plastic piles up.

As many as 1.56 billion face masks that will enter our oceans in 2020. These plastic masks will entangle, poison, and kill marine wildlife, and damage and destroy marine ecosystems, and they will do so for centuries to come. While the 4,680 to 6,240 tonnes of plastic these masks will add to our oceans represents a fraction of the estimated 8 to 12 million tonnes of plastic that enter our oceans annually, their addition to the marine environment is significant.

When we find marine plastic pollution on the beach it is often difficult identify its origins and to determine how long it may have been in the water. Because a plastic bottle can take as long as 450 years to break down, a bottle you find on the beach could have been tossed out a car window in 1977, blown out of an open air landfill in 1995, or washed into the ocean in a storm in 2018.[326]

The facemasks we are finding on beaches today have almost certainly entered the ocean after the COVID-19 pandemic began. For example, we did not start finding significant numbers of masks washing up on Hong Kong beaches until about 6 weeks after the onset of the pandemic. In this way, face masks serve as an indicator, revealing that the plastic threat facing our oceans is only growing. Masks on the beach are evidence that there are still serious weaknesses in our waste management systems, and that people are continuing to dispose of their plastic waste irresponsibly. Masks on the beach demonstrate that we must redouble our efforts to end our addiction to single-use plastic.

End Notes & Photo Credits

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