BOB DAEMMRICH/POLARIS/EYEVINE

THE PLASTIC OCEAN

SCIENTISTS KNOW THAT THERE IS A COLOSSAL AMOUNT OF PLASTIC IN THE OCEANS. BUT THEY DON'T KNOW WHERE IT ALL IS, WHAT IT LOOKS LIKE OR WHAT DAMAGE IT DOES.

BY DANIEL CRESSEY

Kamilo beach, on the tip of Hawaii's Big Island, is a remote tropical shore. It has white sand, powerful waves and cannot be reached by road. It has, in fact, much that an idyllic tropical beach should have. But there is one inescapable issue: it is regularly carpeted with plastic.

Bottles, fishing nets, ropes, shoes and toothbrushes are among the tons of waste washed up here, thanks to a combination of ocean currents and local eddies. A study in 2011 reported that the top sand layer could be up to 30% plastic by weight[1]. It has been called the dirtiest beach in the world, and is a startling and visible demonstration of how much plastic detritus humanity has dumped into the world's oceans.

From Arctic to Antarctic, from surface to sediment, in every marine environment where scientists have looked, they have found plastic. Other human-generated debris rots or rusts away, but plastics can persist for years, killing animals, polluting the environment and blighting coastlines. By some estimates, plastics comprise 50–80% of the litter in the oceans. "There are places where you don't find plastic," says Kara Lavender Law, an oceanographer at the Sea Education Association in Woods Hole, Massachusetts. "But in terms of the different marine reservoirs, we've found plastic in all of them. We know it's pervasive."

Newspapers tell stories of the 'Great Pacific garbage patch', a region of the central Pacific where plastic particles accumulate, and volunteers participate in beach clean-ups across the globe. But in many ways, research lags behind public concern. Scientists are still struggling to answer the most basic questions: how much plastic is in the oceans, where, in what form and what harm it's doing. That's because science at sea is hard, expensive and time-consuming. It is difficult to comprehensively survey vast oceans for small — sometimes microscopic — plastic fragments, and few researchers have made this their line of work.

But now interest is picking up. "There have been more publications in the last four years than the previous four decades," says Marcus Eriksen, director of research and co-founder of the 5 Gyres Institute in Santa Monica, California, which works to fight plastic pollution. Scientists and environmentalists know that there is a lot to do. Last May, the United Nations Environment Programme (UNEP) passed a resolution at its Nairobi meeting, stating that "the presence of plastic litter and microplastics in the marine environment is a rapidly increasing serious issue of global concern that needs an urgent global response".

WHERE DOES IT COME FROM?

In 2014, a team at the US marine park Papahānaumokuākea, off the northwest coast of Hawaii, removed a fishing net from the reserve that

weighed 11.5 tonnes — roughly equivalent to a London bus. Nets and other fishing equipment that have been lost or discarded at sea are thought to make up a large fraction of marine plastic. An estimate[2] from UNEP suggests that this 'ghost' fishing gear makes up 10% of all marine litter, or around 640,000 tonnes.

There is much more than that. Global production of plastics rises every year — it is now up to around 300 million tonnes — and much of it eventually ends up in the ocean. Plastic litter is left on beaches, and plastic bags blow into the sea. The vast quantities of plastics dumped as landfill can, if sites are not properly managed, easily wash or blow away. Some sources are less obvious: as tyres wear down, they leave tiny fragments on roads that leach into drains and on into the ocean.

In a 2014 paper, Eriksen and his team analysed data on the items found in a series of expeditions across the world's oceans and estimated that 87% by weight of floating plastic was greater than 4.75 millimetres in size[3]. The list included buoys, lines, nets, buckets, bottles and bags (see 'A sea of plastic'). But when the pieces were counted instead of weighed, large plastics made up just 7% of the total. Many plastic items break down under the onslaught of sunlight and waves until they eventually reach microscopic sizes, and other plastics are small from the start, such as the 'microbeads' that are added to face scrubs and other cosmetic products, and that go down the drain.

Concern about these microplastics has been growing ever since 2004, when Richard Thompson, who researches ocean plastic at Plymouth University in the United Kingdom, coined the term. (It is now often used to refer to pieces less than 5 millimetres across.) His team found microplastics in most of the samples it took from 18 British beaches, as well as in plankton samples collected from the North Sea as far back as the 1960s[4]. Since then, the number of papers using the term has rocketed, and researchers are attempting to answer questions ranging from how toxic the materials are, to how they are distributed around the world.

HOW MUCH IS OUT THERE?

If surveying the ocean for plastic is expensive and difficult at the surface, it's even harder below it: researchers lack samples from enormous areas of the deep sea that have never been explored. And even if they could survey all these regions, the concentration is typically so dilute that they would have to test huge volumes of water to get reliable results. Instead, they are forced to estimate and extrapolate.

In a paper published last year, a team led by Jenna Jambeck, who researches waste management at the University of Georgia in Athens, estimated how much waste coastal countries and territories generate, and how much of that could be plastic that ends up in the ocean[5]. The group reached a figure of 4.8 million to 12.7 million tonnes every year — very roughly equivalent to 500 billion plastic drinks bottles. But her estimate excluded the plastic that gets lost or dumped at sea, and all the plastic that is already there.

To get a handle on this, some researchers have gone trawling, using fine-meshed nets to see what plastic they can catch. Last year, oceanographer Erik van Sebille of Imperial College London and his colleagues published one of the largest collections of such data[6]. They combined information from 11,854 individual trawls, from every ocean except the Arctic, to produce a 'global inventory' of small plastic pieces floating at or near the surface.

They estimated that, in 2014, there were between 15 trillion and 51 trillion pieces of microplastic floating in the oceans, with a total weight of 93,000 to 236,000 tonnes. But these numbers present scientists with a problem. This estimate of total surface plastic is just a small fraction of what Jambeck estimated entered the ocean every year. So where is all the rest? "That's the big question," says Jambeck. "That's a tough one."

Researchers are trying to find answers. Jambeck is now working with a mobile-phone app called the Marine Debris Tracker, which offers a way to crowdsource vast amounts of data as users send in information about rubbish they encounter. She is also working on a project for UNEP to build a global database of marine-litter projects.

WHERE IS IT?

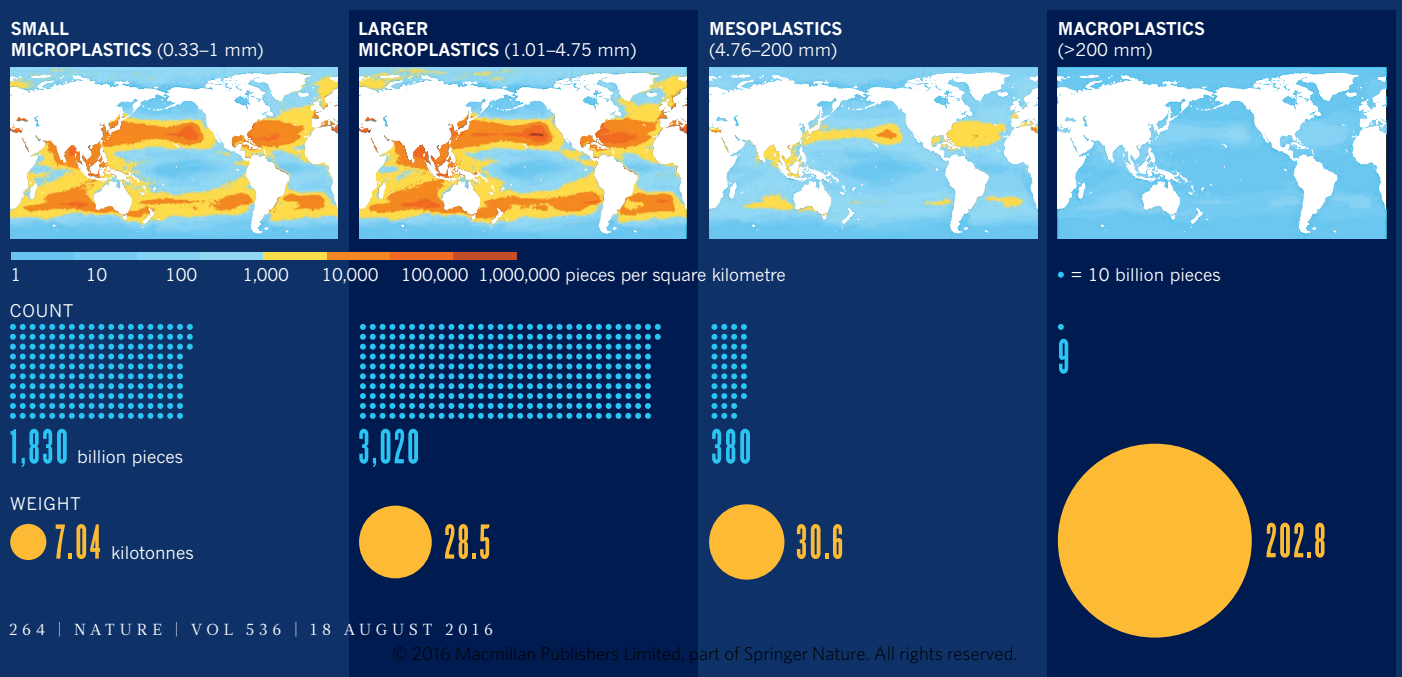
The mismatch between the estimated amount of plastic entering the oceans and the amount actually observed has come to be known as the 'missing plastic' problem. Adding to the puzzle, data from some locations do not show a clear increase in plastic concentrations over recent years, even though global production of the materials is soaring.

Public attention has focused on the Great Pacific garbage patch, where plastics collect thanks to an ocean current called a gyre. The name is something of a misnomer — visitors to the patch would not find piles of seaborne rubbish. A study from 2001 reported 334,271 pieces of plastic per square kilometre in the gyre[7]. This is the largest tally recorded in the Pacific Ocean, but still works out as roughly one small fragment for every three square metres.

Modelling by van Sebille and his colleagues suggest that concentrations could be several orders of magnitude higher in the Pacific garbage patch, and an equivalent zone in the North Atlantic, than elsewhere.

A SEA OF PLASTIC

A 2014 study[3] estimated that more than 5 trillion plastic pieces, weighing more than 250,000 tonnes, float on the surface of the world's oceans. Small pieces make up the majority by count, but large items account for the greatest weight. Currents cause plastics to accumulate in the North Pacific and North Atlantic 'garbage patches'.



But the plastic here is accounted for in surveys, whereas the missing plastic is, by definition, missing and therefore somewhere else.

Some of it is probably on the sea floor. Certain types of plastic sink, and even ones that start out floating can eventually become covered with marine organisms and be pulled down. Work from Thompson has shown microplastics in deep-ocean sediment — an under-studied zone that could be hiding some of the missing millions of tonnes[8]. Remotely operated vehicles also regularly find large plastic items among the litter that has sunk into the deepest ocean trenches.

A substantial portion of ocean plastic may simply end up on shorelines, and other plastic 'sinks' are uncovered all the time. In 2014, Thompson co-authored a paper showing that microplastics had accumulated in Arctic sea ice at concentrations several orders of magnitude greater than that found even in highly contaminated surface waters[9]. "We have a lot of educated guesses" about where the missing plastic is, says Law. "In my mind, we don't have the answer to that."

Thompson and others are now looking beyond microplastics to nanoplastics — ones less than 100 nanometres in size. "Nano-sized particles of plastic are being manufactured," says Thompson. "So it's highly likely that some will escape into the environment. There's also the fragmentation of larger items." But nanoplastics are proving hard to study. Researchers commonly use a type of spectroscopy to confirm whether fragments recovered from the sea are made of plastic, but the method does not work well on pieces below about 10 micrometres, Thompson says. He hopes to learn more as part of a UK-government-funded project called RealRiskNano, which will look at sources and pathways to the environment for these tiny fragments. "It wouldn't surprise me to find they do exist. But at the moment it's below the level of detection from an environmental sample."

WHAT HARM DOES IT DO?

Researchers know that marine plastic can harm animals. Ghost fishing gear has trapped and killed hundreds of animal species, from turtles to seals to birds. Many organisms also swallow pieces of plastic, which can accumulate in their digestive system. According to one often-quoted figure, around 90% of seabirds called fulmars washed ashore dead in the North Sea had plastic in their guts. What's less clear is whether this pollution has major impacts on populations.

Lab studies have demonstrated the toxicity of microplastics, but these often use concentrations that are much higher than those found in the oceans. In February this year, though, Arnaud Huvet, who studies invertebrates at France's national marine research agency (Ifremer) in Plouzané, published work in which he exposed Pacific oysters to microplastics at concentrations similar to those found in the sediment where the creatures live. Animals in the plastic-laced water had poorer-quality eggs and sperm and produced 41% fewer larvae than did those in a control group[10]. It was one of the first studies to show a direct link between plastic and fertility problems. "That made an impact," van Sebille says.

So did a study in June from fish ecologists Oona Lönnstedt and Peter Eklöv, in which they exposed perch larvae to 'environmentally relevant' concentrations of microplastics. The larvae ate the plastics — they even seemed to prefer them to actual food — which made them grow more slowly and fail to respond to the odour of predators. After 24 hours in a tank with a predator, 34% of plastic-dosed larvae survived, compared with 46% of those raised in clean water[11].

Lönnstedt, at Uppsala University in Sweden, was disturbed by photos of the transparent larvae clearly showing the small plastic spheres in their guts. "It's awful, so of course I feel strongly about it," she says. "People who say plastics won't be an issue in the oceans need to take a look at the evidence again."

But some scientists question the implications of the work. Alastair Grant, an ecologist at the University of East Anglia in Norwich, UK, says that the levels of plastic that gave adverse effects in Lönnstedt's paper — 10–80 particles per litre — are still orders of magnitude higher than the vast majority of field measurements. Most reports are less than 1 particle per litre, he says. "The evidence I can see at the moment suggests microplastics are probably within safe environmental limits in most places."

WHAT SHOULD WE DO?

Despite the lack of comprehensive data about ocean plastics, there is a broad consensus among researchers that humanity should not wait for more evidence before taking action. Then the question becomes, how?

One controversial project has been devised by The Ocean Cleanup, a non-profit group that by 2020 hopes to deploy a 100-kilometre-long floating barrier in the Great Pacific garbage patch. The group claims that the barrier will remove half of the surface plastic there.

But the project has met with scepticism from researchers. They say that plastic in the gyre is so dilute that it will be tough to scoop up, and they worry that the barrier will disturb fish populations and plankton. Boyan Slat, chief executive of The Ocean Cleanup, welcomes the criticism, but says that the barrier project is still in an early phase, with a prototype currently deployed off the Dutch coast. "We're using this test as a platform to investigate whether there's any negative consequences. The only way to find out is to go out and do it," he says.

In a paper published earlier this year[12], van Sebille and his colleague Peter Sherman showed that it would be much more effective to place clean-up equipment near the coasts of China and Indonesia, where much of the plastic pollution originates. "The closer to the plastic economy loop you intervene the better it is," van Sebille says. "We've got to stop it in the treatment plants, in the landfills. That is the point to intervene." Eriksen likens the situation to addressing air pollution, where people have long realized that filtering the air is not a long-term solution. Filtering the oceans seems similarly implausible, he says. "What we've seen worldwide is you go to the source." That means reducing the use of plastic, improving waste management and recycling the materials to stop them from reaching the water at all.

"WE'VE GOT TO STOP IT IN THE TREATMENT PLANTS. IN THE LANDFILLS. THAT IS THE POINT TO INTERVENE."

That's a lot to ask, considering how ubiquitous plastics are. But some scientists allow themselves to imagine a world where plastics have been brought under control. According to research by Law and Jan van Franeker, some types of floating plastic might disappear in just a few years[13]. Perhaps even Kamilo beach would eventually return to its unpolluted form.

But plastic will have left its mark, as layers of tiny particles embedded in sediment on the ocean floor. Over time, this plastic will become cemented into Earth — a legacy of the plastic era. "There will be this layer of rock around the world that is going to be plastic," Eriksen says. ■ SEE NEWS FEATURE P.266, AND BOOKS AND ARTS P.272

Daniel Cressey *is a senior reporter for* Nature *in London.*

1. Carson, H. S., Colbert, S. L., Kaylor, M. J. & McDermid, K. J. *Mar. Pollut. Bull.* **62,** 1708–1713 (2011).
2. Macfadyen, G., Huntington, T. & Cappell, R. *Abandoned, Lost or Otherwise Discarded Fishing Gear* (UNEP, 2009).
3. Eriksen, M. *et al. PLoS ONE* **9,** e111913 (2014).
4. Thompson, R. C. *et al. Science* **304,** 838 (2004).
5. Jambeck, J. R. *et al. Science* **347,** 768–771 (2015).
6. van Sebille, E. *et al. Environ. Res. Lett.* **10,** 124006 (2015).
7. Moore, C. J., Moore, S. L., Leecaster, M. K. & Weisberg, S. B. *Mar. Pollut. Bull.* **42,** 1297–1300 (2001).
8. Woodall, L. C. *et al. R. Soc. Open Sci.* **1,** 140317 (2014).
9. Obbard, R. W., Sadri, S., Wong, Y. Q., Khitun, A. A., Baker, I. & Thompson, R. C. *Earth's Future* **2,** 315–320 (2014).
10. Sussarellu, R. *et al. Proc. Natl Acad. Sci. USA* **113,** 2430–2435 (2016).
11. Lönnstedt, O. M. & Eklöv, P. *Science* **352,** 1213–1216 (2016).
12. Sherman, P. & van Sebille, E. *Environ. Res. Lett.* **11,** 041001 (2016).
13. van Franeker, J. A. & Law, K. L. *Environ. Pollut.* **203,** 89–96 (2015).