Where is all our plastic?

Whales and fulmars have plastic in their stomachs and even earthworms ingest plastic particles. Researchers know more and more about how our plastic waste gets into the environment and its effects on nature. Yet we still don’t know where the bulk of it goes.

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Plastic garbage gets everywhere, from tropical beaches to the polar seas, and varies from loose fishing nets that strangle marine animals to plastic fragments in the stomachs of whales. Marine biologist Jan Andries van Franeker of IMARES Wageningen UR has been doing research on plastic in northern fulmars for 30 years. 'Almost all the fulmars we study have plastic in their stomachs. In a few cases the quantity is such that it was obviously the cause of death, from constipation for instance. I am worried about other possible effects of plastic on the remaining fulmars. On their physical condition, for instance, as we know they cannot eat as well if their stomachs are full.'
Fulmars are present in large numbers and can do something that is not feasible for scientists: take continuous samples of the surface seawater in the northern hemisphere. Except during the brooding season, tens of millions of fulmars live continuously on the open sea, swallowing bits of plastic which they mistake for food.
When the birds die and wash up on the shore, whatever the reason, researchers can learn a lot about the pollution in a marine zone from the contents of their stomachs. So they saw the increase in the amount of plastic we use reflected in a huge increase in the amount of plastic in bird stomachs around the North Sea, from an average of two pieces in the 1970s to ten in the 1980s. The birds found along European mainland coasts carry more plastic than those found on sparsely populated Spitsbergen beaches. Bird stomach examinations reveal shifts too: 30 years ago a large proportion of the plastic took the form of pellets used to make all sorts of packaging and utensils. This proportion has gone down by three quarters, whereas the proportion of consumer plastics has gone up. What floats in the sea now is mainly large or small fragments of plastic bags, bottles, bottle tops and other packaging waste.

> **'Just because you don't see the plastic anymore, it doesn't mean it's gone'**

STEADY INFLUX

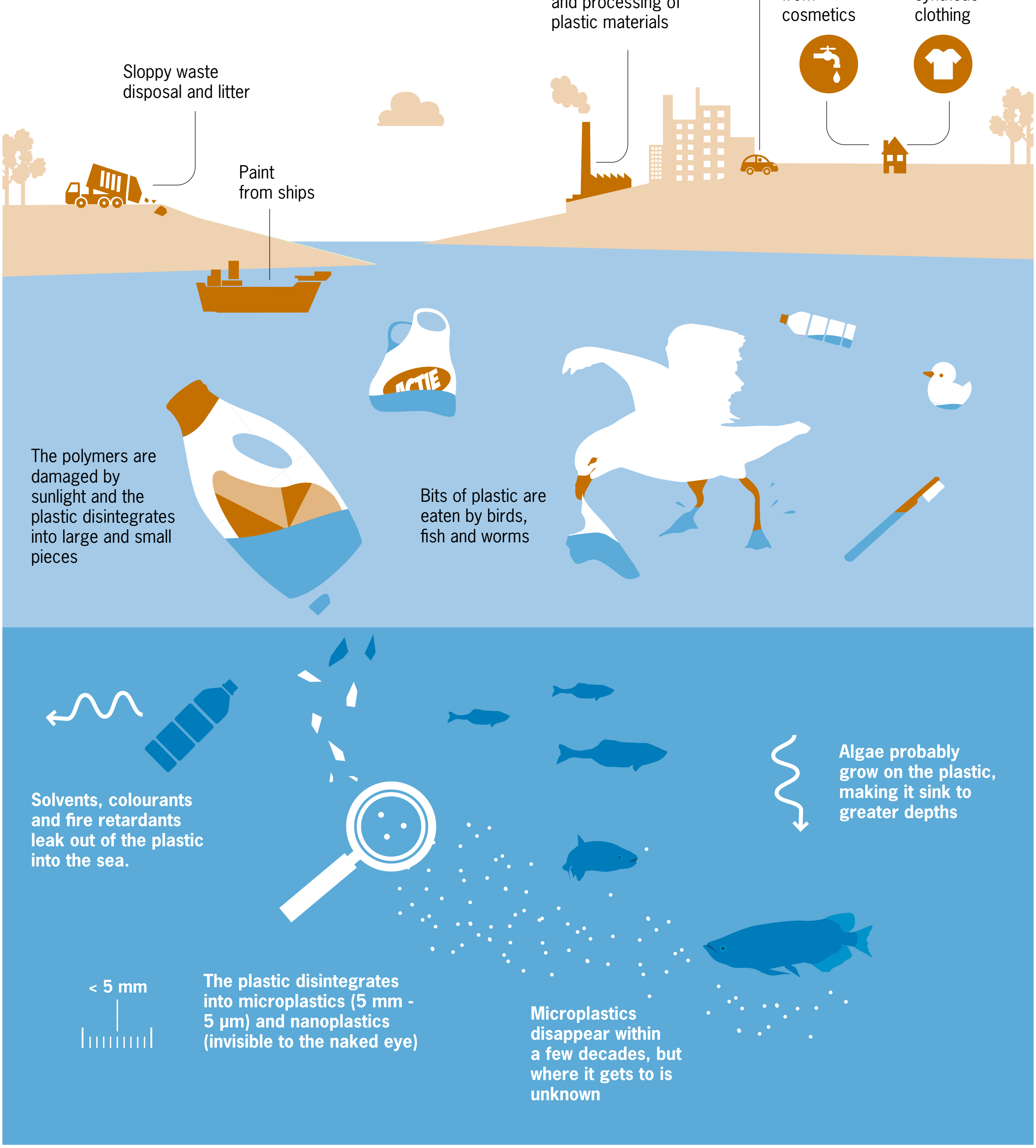
The reduction in quantities of industrial plastic pellets on the ocean surface, thanks to better regulation and agreements in the plastic industry, took place within the space of a few years. This shows that there is a steady influx of new plastic waste in the sea, says Van Franeker. 'If the influx of certain types of waste decreases, that is reflected in the composition of the plastic particles in the sea. That is how we know that if we take radical steps from today to stop plastic getting into the sea, it will have disappeared from the North Sea in 20 years' time,' says Van Franeker. 'But where it then ends up remains a big mystery.'
The plastic waste is steadily replaced in the Pacific, Atlantic and Indian Oceans too. There, far from the continents, circular currents cause the formation of plastic islands. These islands cover a surface as big as France, although their mass is less compact than the word 'island' might suggest. They generally contain less than ten small plastic particles per cubic metre of water, which comes to a few kilos of plastic per square kilometre of sea surface.
Van Franeker explains that increasingly detailed calculations have been made in recent years of how much plastic ends up in the sea through badly organized waste disposal and litter. In countries such as Nigeria and China, this adds up to many millions of kilos. But there are many other sources too, such as wear and tear on car tyres, plastics in cosmetics and litter (see box). Researchers estimate the total amount of plastic landing in the sea worldwide at about eight billion kilos each year. But only a fraction of this is visible: when scientists collate all the data, they arrive at a total of 250 million kilos of plastic floating on or just under the surface of the world's oceans. In short, then, scientists 'see' no more than a small percentage of the total amount of plastic that end up in the sea. The rest has disappeared. Perhaps some of it washes up on shorelines; perhaps it sinks to the seabed. But what is currently found on beaches or seen by divers on the seabed cannot account for the missing billions of kilos of plastic. This has partly to do with the enormous depth and breadth of the oceans, of course. Research ships can only take reliable samples from the top layer of water. What is more, the nets they use to fish for plastic have a mesh size of 0.3 millimetres, so smaller plastic particles are not captured, and no one knows what is floating around in the dark depths of the sea.

CARRIER BAG

It is not easy for scientists to keep track of plastics in the environment because they deteriorate and falls apart. If you hang a plastic carrier bag on a clothesline in the sea for a year and then dry and weigh it, you will find that the material has got lighter and smaller. The additives in it, such as solvents and colouring agents, have leached into the seawater.
The plastic itself deteriorates too. Sunlight damages the polymer chains, rendering the material brittle. As the water wears them down, bags, bottles and bottle tops disintegrate into ever smaller fragments and specks. Creatures such as fulmars mistake >

PLASTIC POLLUTION

Of the 8 billion kilos of plastic that end up in the environment worldwide, most of it ends up in the sea, brought there by wind, sewers and waterways. But only a fraction of it – 250 million kilos – ever gets located. It is hard to find out where the rest goes as the oceans are deep and the plastic decays and disintegrates.



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SOURCES OF PLASTIC POLLUTION

It is not an exact science, but governments and researchers are finding out more and more about the various sources of plastic pollution. For the plastic in the sea, the 50-kilometer-wide coastal strip is crucial. Worldwide, that is where most people live and it is their plastic waste that is likely to end up in the sea. A major source is badly processed household waste and litter on streets and roadsides that is carried to the sea by the wind, sewers, rivers and other waterways. Alongside this obvious source of plastic pollution, consumers and industry produce a lot more plastic particles, some of which end up in the sea. In 2014, the Norwegian ministry of the Environment calculated the contributions of various sources of microplastics. Norway's five million inhabitants wash about 600 tons of plastic fibres into the sewer system by washing synthetic clothing, and 450 tons in the form of dust from their homes. Roads are another big source of plastic particles: road markings and tyres, release 320 and 4500 tons of plastic particles respectively.

this plastic for food and it gets ground down in their stomachs to even tinier sand-like particles.

This is known as 'microplastic'. It measures between five millimetres and five micrometres (the thickness of a human hair) and it appears everywhere. It is coming in for plenty of attention because of its small size: tiny plastic particles can easily come loose and get ingested by fish, birds and worms. Microplastics can also absorb toxins from the environment, such as PCBs and DDT. These 'persistent organic substances' have chemical properties that make them adhere readily to plastic surfaces.

This means that organisms that eat microplastic can easily be exposed to toxic substances, says Wageningen professor of water and sediment quality Bart Koelmans. In recent years, his group has concentrated on research into the effects of clean and polluted microplastic on fulmars, lugworms, mussels, water fleas and algae.

Koelmans' group looked at effects of plastic pollution in saltwater and freshwater environments, by exposing organisms to higher and higher concentrations of microscopically small particles of polystyrene. In algae this limits growth, and water fleas not only stay smaller but also reproduce less successfully. Sandworms, which live on the seabed, become thin if there are a lot of polystyrene balls in the sand. When the seabed is polluted, with PCBs for instance, they ingest a lot more of this.

In this kind of study, researchers often decide to magnify the conditions by using high concentrations of the toxic substances and adding a lot of additional plastic, says Koelmans. 'Then you certainly do see a negative impact on growth and reproduction, but that doesn't tell you what the situation is in the ocean.'

CUMULATIVE

The consequences in the ocean depend on the quantities of PCBs already present in an animal, thinks Koelmans, as well as on how badly polluted its food is. 'If a toxin is binding to plastic, that substance must already be in the water and in the algae and other small creatures too. So an organism is already coming into contact with PCBs anyway through water and food, and the effect is cumulative. You can use model calculations to show that the contribution of plastic remains negligible in comparison with the amounts already being absorbed.'

With that nuance in mind, it becomes clear that observing an effect of microplastic and the toxic substances it carries in the natural world is very tricky indeed, says Koelmans. 'If you do field research you deal with a lot of biological variation in the data you are trying to measure. The effect of absorption of toxic substances from plastic falls roughly within that variation. So we shall probably never be able to detect big effects of toxic substances in microplastic from the field data.'

But that is not the end of the matter. Koelmans is very keen to find out more about the effects of even more finely ground plastic particles, the ones which are not visible to the naked eye. Laboratory tests have shown that these 'nanoplastics', as they are called, can pass through biological membranes and thus permeate the gut lining and get inside cells.

COSMETICS

There is even less knowledge available about the effects of plastic on land, a topic on which there are hardly any academic publications. 'I think that is because in the sea and on the beaches the problem is highly visible,' says Violette Geissen of the Soil Physics and Land Management chair group at Wageningen UR. 'Also, the biggest problems with plastics in the soil are in developing countries and southern Europe. No research is being done on it there yet.'

It is not at all clear how much plastic waste ends up in the soil, says Geissen. It gets into the soil through garbage dumping, litter or sewer sludge containing microplastics from plastic fibres in clothing in the washing machine, and even from cosmetics.

Geissen is a pioneer in this uncharted terri-

> **'If we stop plastic getting into the sea from today, it will have disappeared from the North Sea in 20 years'**

tory. One of her research areas is China, where for a number of years now, thousands of hectares of farmland have been covered with a transparent foil called plastic mulch. This restricts evaporation but the foil disintegrates when it is removed and little bits of plastic get ploughed deeper and deeper into the soil. Geissen: 'In some agricultural soils we find between 0.5 and 1 percent microplastic. That is an awful lot.'
Soil fauna eat microplastics, as Geissen showed in a recently published experiment with earthworms living in soil with varying quantities of microplastic. 'Worms dig, so they concentrate the microplastic in their poo and transport it up to half a metre deep. We don't know whether it gets broken down and how much risk there is of it getting washed out into the groundwater. Another interesting question is whether microplastics attract agricultural pesticides. We want to find out whether microplastic has an influence on the transport and breakdown of herbicides.'

LITTLE BREAKDOWN

'I think most plastics hardly break down at all,' says Van Franeker. 'Just because you no longer see the plastic, it doesn't mean it's gone. Microplastic in the sea disappears in a few decades, but where it gets to and what form it takes, goodness knows. Some kinds of breakdown of plastics by fungi and bacteria have been described but we don't know how fast that goes and where it happens. Nor do those studies tell us what is left in terms of plastic residues. Many plastic materials are toxic and they can include fire retardants and solvents. And even if the plastic does get broken down completely, with plastic waste we dump all kinds of toxic substances into the environment. That's another reason to stop doing it.'
It is not easy for scientists to keep track of microplastic and the even smaller variant, nanoplastic, says Van Franeker. Microplastic is just visible with the naked eye but once it has broken down further into nanoplastic, you need a microscope. 'You have to try to measure plastic particles whose presence in the environment is very hard to demonstrate. Because how do you find nanoparticles of plastic in a sea full of biological nanoparticles?'
Koelmans' guess is that microplastic floating just beneath the waves in the ocean disappears from view because the surface of the particle gets overgrown with a layer of bacteria and algae. The particles then become so heavy that they slowly sink to depths of hundreds of metres or more. The visible plastic islands are the tip of the iceberg, with masses of floating plastic confetti below them at greater depths. Koelmans' group is currently working on model studies which describe the process of breakdown into microplastic and sinking to the depths of the ocean, in the hope of learning more about what happens to the plastic. 'It is difficult to get a grasp of the biological process involved as the plastic gets overgrown and then sinks,' says Koelmans. 'But when researchers take measurements on the ocean, their scope is restricted. The plastic research at sea primarily looks just under the surface. We cannot be sure how much plastic is floating around two to three thousand metres below the surface. And you cannot recreate the ocean in the lab.'

PREVENTING TRAGEDIES

Van Franeker: 'It might sound worrying that we don't yet know where the microplastic goes to, but if the effects were really dramatic we would probably have noticed them by now. Because certain regions would have become completely lifeless, for example, or because of all sorts of inexplicable diseases affecting marine animals. My hope is that the plastic problem will not be too overwhelming, and that if we cut down on plastic waste now, we can prevent real tragedies. But that's just a feeling, not science. Based on that feeling I do think we should be careful. And without crying wolf we should call people to action.'
The question of to what extent plastics have an ecological impact is still not easy to answer, notes Van Franeker. Species respond in very different ways. 'We are looking at fulmars because they are very common birds. In spite of the plastic in their stomachs, that species has increased in numbers over recent decades. More recently they've not been doing so well here and there, but can you prove that's because of plastic? You can't make a watertight case for that. Perhaps plastic causes some extra deaths among fulmars, which you only notice when there is a shortage of food. I say: use your common sense and make sure we don't get yet more microplastics in the environment. Policymakers shouldn't wait until there is conclusive scientific evidence that species are dying out.' ■

www.wageningenur.nl/en/plasticinwater