Algal blooms, like this one in the Barents Sea, may look beautiful, but they can choke other marine species

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The godfather of pollution

The damage wrought by nitrogen fouling our land, water and air is terrible and underappreciated. At last, the global fightback is starting, says **Andrew Zaleski**

THERE is an invisible gas in Earth's atmosphere that is feeding an environmental crisis. The damage gets worse every year. If things are left unchecked, we are heading for a global disaster. And here is the most worrying thing about this gas: it isn't carbon dioxide.

Nitrogen is normally thought of as inoffensive stuff; after all, this colourless substance makes up 78 per cent of Earth's atmosphere. When you feel a refreshing breeze on your cheeks, it is mostly nitrogen molecules swishing past. Our ecosystems naturally cycle nitrogen from the air in and out of our soils, where it forms an essential nutrient for plants. The trouble is, this cycle is now dangerously out of whack because of human activity. The result is nitrogen in harmful forms swamping the wider environment.

Some of the effects of this crisis have been obvious for ages. We have long known, for instance, that pollution from nitrogen-bearing compounds prompts algal blooms that choke waterways. But other effects are now coming ›

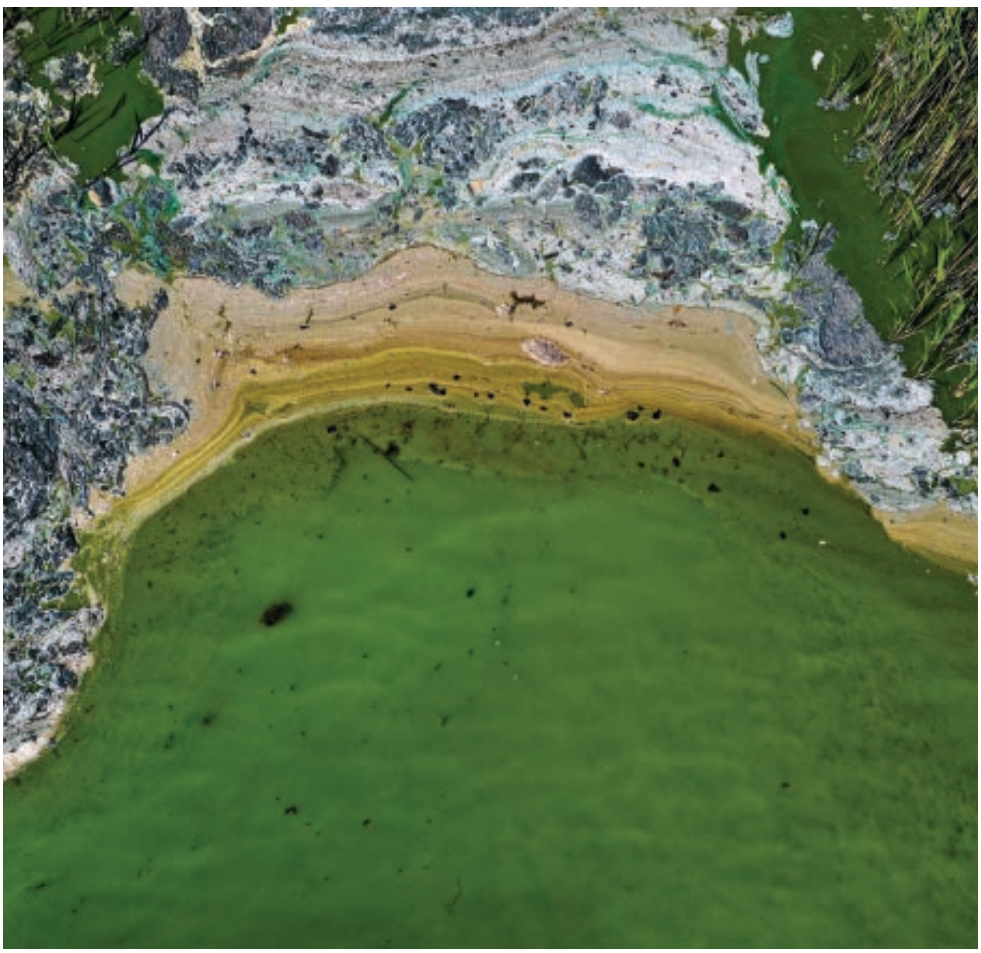
Five ways nitrogen is harming our planet

1. Ocean dead zones

Rain can wash nitrates into watercourses and oceans. This nitrogen-based pollution feeds algal blooms that suck up oxygen as they decompose, choking aquatic life. The result is a watery "dead zone", of which there are more than 400 in the world's oceans, including a huge one in the Gulf of Mexico.

2. Air pollution

Cars and power plants emit nitrogen oxides, which are one of the principal precursors to a type of air pollution called particulate matter. These tiny particles can be breathed into our lungs, where they cause tissue damage associated with a range of health problems.



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into focus too, like the way nitrogen pollution is killing peat bogs. Compounds of nitrogen are also damaging the delicate balance of the atmosphere.

A United Nations panel set up to assess the problem has revealed just how bad things have become. In fact, nitrogen pollution is one of the most dire crises we face. Fortunately, there are ways that we can dig ourselves out of this hole – but they will involve wholesale changes to how we grow our crops.

All life on Earth depends on nitrogen. Most of the crucial chemical components of our bodies, from the proteins in our nails to the DNA at the heart of every cell, incorporate this element. But even though nitrogen gas is all around us, it isn't useful as a raw material for living things in that form. Nitrogen molecules in the atmosphere consist of two nitrogen atoms joined by an extremely strong triple bond, making it tough to chemically manipulate.

Life requires its nitrogen in a more reactive form, sandwiched into compounds with weaker bonds. Animals get these compounds in their food, but they initially enter the food chain on land through two main natural processes. The first involves bacteria living in association with the roots of leguminous plants such as peas. These microorganisms take in nitrogen molecules from the air and use special biochemical machinery to prise apart that triple bond. Then they combine the resulting nitrogen atoms with hydrogen to form ammonia in a process called nitrogen fixation. Other bacteria then convert the ammonia into nitrate ions, which plants can absorb. The only other natural process with the necessary heft to fix nitrogen is a lightning bolt.

This is one half of the nitrogen cycle. Meanwhile, other bacteria carry out the process in reverse, breaking down nitrogen-

"Nitrogen is normally thought of as inoffensive; after all, it makes up 78 per cent of the atmosphere"

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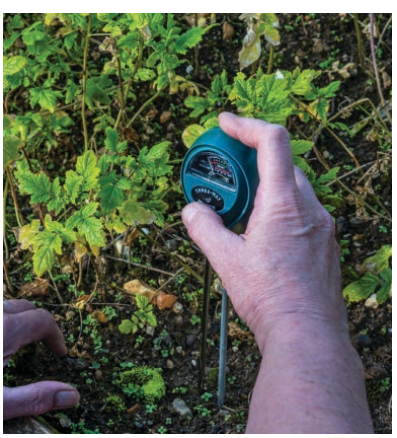
Nitrogen-based pollution degrades the environment in various ways. It can contribute to algal blooms in Sweden (far left), smog in Baoding, China (left), and soil with higher acidity (below left)

3. Soil acidification

The same nitrate that can sneak into waterways can also pull key nutrients out of the soil, including magnesium and calcium. This can make soil too acidic, such that plants are unable to take up nutrients properly.



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containing compounds in dead plants and animals and releasing nitrogen gas back to the atmosphere. In a world without human meddling, it is thought that the cycle should roughly balance out.

For centuries, farmers have observed that plants generally tend to grow better if the soil has been prepared with lots of nutrient-rich manure. So they forked in this natural fertiliser and grew legumes, with their symbiotic nitrogen-fixing bacteria, in rotation with other crops.

The trouble began in the early 1900s, when the German scientists Fritz Haber and Carl Bosch devised an industrial means of plucking nitrogen gas from the air and converting it to ammonia. Modern synthetic fertiliser was born. This was originally heralded as a success story because of all the extra food it helped us grow. Today, adding nitrogen-based fertilisers to poor soil allows us to feed 2 billion people who would otherwise go hungry.

But the Haber process, as the chemistry is called, has big downsides when carried out on industrial scales. The conditions required are punishing – a temperature of 450°C and a pressure about 200 times that at Earth's surface. This swallows huge amounts of power: worldwide, the Haber process is responsible for 1 per cent of human CO_2 emissions, about the same as the entire UK.

Worse, all the extra ammonia being produced has tipped the nitrogen cycle wildly out of balance. To see just how bad it is, it helps to think in terms of a concept called planetary boundaries. The idea is that nine crucial environmental systems – for example, fresh water and the ozone layer – can't be degraded too much before presenting an existential risk to humanity. The nitrogen cycle is one of these systems and the best estimates suggest there should be no more than 62 million tonnes of nitrogen a year fixed on land to remain within the safe boundary. Admittedly, there is a good deal of uncertainty about how much nitrogen is fixed by nature. Still, it is clear that we have smashed through the planetary boundary: today, at least about 300 million tonnes of nitrogen are fixed each year through both natural and artificial processes (see diagram, page 45). "We've completely disrupted the balance of where these nutrients sit and what life forms they are accessible to," says biogeochemist Penny Johnes at the University of Bristol, UK.

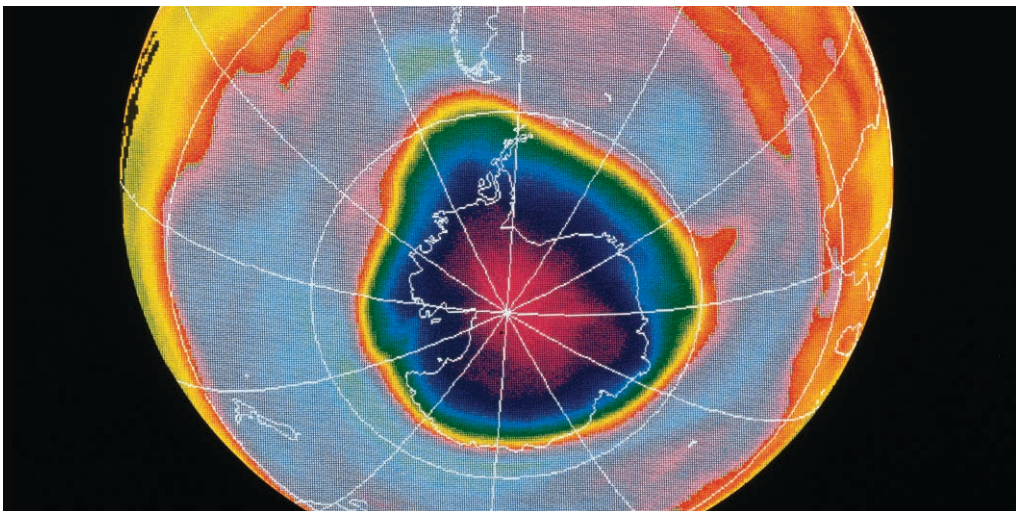
Need a fix

Few know this better than Mark Sutton at the UK Centre for Ecology and Hydrology, who has been studying nitrogen pollution for decades. In 2011, the United Nations Environment Programme asked him to undertake the first global assessment of the problem, to determine how bad it was, what to expect in future and how to fix it. A few years later, Sutton became the head of a UN-backed project aiming to develop an International Nitrogen Management System (INMS).

The aim was to do for nitrogen what the Intergovernmental Panel on Climate Change (IPCC) had done for CO_2. Sutton and his team are drawing on the existing research to chart the full extent of well-documented problems like fertiliser pollution being washed into our oceans. They have also highlighted some previously unknown issues (see: "Five ways nitrogen is harming our planet", left). "The INMS doesn't have to prove the existence of nitrogen pollution," says Sutton. "Rather, it's got to say how we get the world scientific community to work together."

The IPCC has set a recognised goal of limiting global warming to 1.5°C by 2100 compared with pre-industrial temperatures. Sutton and his team wanted a similar rallying call for nitrogen use, but knew it would be politically tricky. He recalls one meeting at New York University in 2018, where he sat with a handful of nitrogen experts discussing what target they should set.

They realised that asking the world to cut nitrogen use in agriculture would meet a lot of resistance, notably from the powerful fertiliser industry. In the end, the scientists decided to call for nitrogen waste to be cut instead – after all, up to 58 per cent of the nitrogen in fertiliser isn't taken up by crops. It was an easier sell, they thought; who could object to cutting waste? And it was much needed. Research by ›



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4. Ozone depletion

Excess nitrate can be converted by bacteria into nitrous oxide gas. At high altitudes, this reacts with ultraviolet light and eats away at the ozone layer that shields us from UV rays. The damage is tough to undo, because nitrous oxide has a lifespan of 120 years.

5. Alkaline air

Rising levels of ammonia pollution are decreasing the acidity of the air. Certain habitats, such as peat bogs, rely on the air being slightly acidic. In Northern Ireland, this problem is causing the degradation of sphagnum peat moss bogs, a major store of carbon dioxide.

Nitrogen pollution can damage the ozone layer (a map of which is shown, top) and kill peat bogs in Northern Ireland (bottom)

Xin Zhang, now at the University of Maryland, and her colleagues shows that nitrogen use efficiency has fallen from 50 per cent in 1961 to 42 per cent today.

In October 2019, the UN held a meeting in Colombo, Sri Lanka, to discuss the nitrogen problem. Just beforehand, Sutton and 150 colleagues wrote to the UN secretary-general urging that their idea for a waste-cutting target was taken up.

It worked. The meeting adopted the Colombo Declaration, a road map for halving nitrogen waste by 2030. But with only 14 nations so far signed up, nitrogen remains a fledgling cause on the international stage. "It feels like the Paris Agreement is a massive 500-year oak tree and the Colombo Declaration is a little sapling," says Sutton.

"If we don't deal with nitrogen, then dealing with any other environmental challenge gets a lot harder"

That isn't to say that climate change and nitrogen woes can be treated separately. Nitrogen pollution makes a swathe of other environmental problems worse, from pollution of drinking water to smog in cities. "If we don't deal with our nitrogen challenge, then dealing with pretty much any other environmental or human health challenge becomes significantly harder," says David Kanter, vice-chair of the International Nitrogen Initiative.

Take nitrous oxide, a gaseous by-product of denitrification carried out by soil bacteria. It is a greenhouse gas with about 300 times the warming impact of CO_2. More and more of it is being produced as we cram too much fertiliser into soils. Kanter says it simply won't

be possible to keep global warming below the IPCC's target of 1.5°C unless we do something about the nitrogen problem.

The way out of this mess begins with more intelligent management of fertilisers, by far the worst source of nitrogen pollution. Many farmers blanket their fields in fertiliser several times each growing season. This guarantees a great yield – but also a lot of nitrogen waste.

Better options already exist. Take the "smart nitrogen" fertiliser produced by businesses such as Nutrien. This comes as pellets of nitrogen encased in a polymer. Water leaches into the pellet, dissolves the nitrogen, which then seeps out gradually. This drip-feeds crops with a gradual supply, ensuring more gets absorbed and less runs into streams and so on.

Smart fertilisers are too expensive for most farmers, though, so some people are trying a low-tech equivalent called urea deep placement. Urea is a widely used and cheap nitrogen fertiliser. Its disadvantage is that once applied, it converts quickly to ammonia, creating such a build-up in the soil that ammonia gas escapes into the air.

The deep placement approach involves pushing granules of urea much further into the soil. This means that as urea turns into ammonia, it is already close to the roots and can be absorbed more readily. The International Fertilizer Development Center (IFDC), a global non-profit organisation, is conducting field trials of the strategy in countries including Ghana, India, Rwanda and Vietnam. Its researchers say the farmers in the trials are achieving nitrogen use efficiencies as high as 80 per cent. "The single most important thing that can enhance nutrient efficiency is controlling nitrogen," says Latha Nagarajan at the IFDC.

In wealthier places, a precision agriculture revolution promises even greater rewards. The idea is to use satellites, drones and remote sensors to get an up-to-the-minute picture of how crops and soils are faring. Does this corner of a field need an extra few grams of nitrogen? Would that stretch benefit from a little more water? Armed with this information, farmers can give each area exactly what it needs. In its ultimate realisation, robots fed with the data will do the farming while humans monitor from afar. This could be a game changer for nitrogen pollution, says Johnes.

One US company, PrecisionHawk, uses drones for overhead crop inspection. These have cameras to spot signs of blight or stress, an indication that more fertiliser is needed. The firm found that during the 2016 growing season, corn farmers using the system saved $4 a hectare on nitrogen fertiliser, meaning they were buying, and applying, less.

Perhaps the most ambitious solution is to reimagine what Haber and Bosch did all those years ago. Rather than extract nitrogen from the air in industrial quantities and slather it on fields, might we be able to convert nitrogen gas to ammonia where and when plants need it? A slew of biotech start-ups are starting to show that the answer is yes.

Root of the problem

Regular nitrogen fixing bacteria can only form symbiotic relationships with certain plants, like soya beans and legumes. But firms such as Pivot Bio in California are re-engineering these bacteria so they can nuzzle up to other crops, like wheat. Farmers spray the bacteria onto seeds before planting. After germination, the bacteria live symbiotically with plant roots and fix nitrogen into nutrients the roots can absorb. The firm carried out field trials of its system in 2018 across 47 US states, comparing the harvest from fields treated with their product and ordinary synthetic fertiliser. This showed that the bacteria-treated fields yielded about 480 kilograms more crop per hectare than those treated with ordinary fertiliser.

It is the symbiotic relationship between the bacteria and the roots that seems to be crucial. "Our data shows that the microbes are producing nitrogen right around the time that the corn is calling for that nitrogen," says Richard Broglie at Pivot Bio. The upshot is that the nitrogen gets absorbed from the soil more quickly, leaving less scope for it to escape into watercourses or the air. Several other US start-ups are working in this space, such as Joyn Bio in Boston and Intrinsyx Bio in Silicon Valley.

All these methods will go some way to reducing nitrogen pollution. The INMS is pushing 76 ideas for reducing nitrogen waste in a UN report published in December. But the mix of measures that will be most feasible and effective in any given place isn't yet known; the soil type and many other factors all make a difference. For now, it is up to farmers and governments to decide the best methods.

Meanwhile, Sutton is keen to rally support for the goal of halving nitrogen waste by 2030. Whether it is achievable will depend largely on the buy-in the INMS secures from countries by 2022, when its UN funding ends. By then, the hope is to have what Sutton calls the "godfather of pollution" firmly on the global agenda. ▮

Andrew Zaleski is a writer based near Washington DC