Yale Environment 360

A man collects snails amid a nitrogen-fueled algae bloom in China's eastern Jiangsu province. LIU JIN/AFP/GETTY IMAGES

Can the World Find Solutions to the Nitrogen Pollution Crisis?

More and more nitrogen keeps pouring into waterways, unleashing algal blooms and creating dead zones. To prevent the problem from worsening, scientists warn, the world must drastically cut back on synthetic fertilizers and double the efficiency of the nitrogen used on farms.

BY FRED PEARCE · FEBRUARY 6, 2018

The world is using nitrogen fertilizer less and less efficiently. A greater proportion than ever before is washing into rivers and oceans. An environmental catastrophe looms, nitrogen scientists say, and the world urgently needs to develop strategies to prevent it.

Post-war physicists fearing nuclear apocalypse came up with the Doomsday Clock. In the 1980s, biologists contemplating ecological meltdown began talking about "biodiversity" loss as a way to tag and measure the crisis. Soon after, climate scientists recast concern over global warming with a warning that within a century it would lead to temperatures greater than any in human history.

Now, it is nitrogen's turn.

Last month, in a seminar room at New York University, a score of nitrogen experts from around the world began drawing up scenarios of what a future nitrogen-soaked

planet might look like – and to devise simple metrics for encouraging a global effort to head off disaster.

They met as part of the International Nitrogen Management System, a five-year, $60-million research project from the UN Environment Programme and the Global Environment Facility, that is intended, says its chief Mark Sutton, as nitrogen's equivalent to the Intergovernmental Panel on Climate Change.

The bottom line, many there concluded, was that we must halve the amount of nitrogen we dump into the environment by mid-century or our ecosystems will face epidemics of toxic tides, lifeless rivers, and dead oceans. And that to do that will require, among other things, almost doubling the efficiency of nitrogen use on the world's farms.

In the past half-century, humans have increased the amount of nitrogen in the environment more than any other major element. Sewage, livestock waste, fossil-fuel burning, and especially our use of synthetic fertilizer have all contributed to a doubling of nitrogen flows. Half the world's crops today are grown with the aid of fertilizer made by capturing inert nitrogen from the air.

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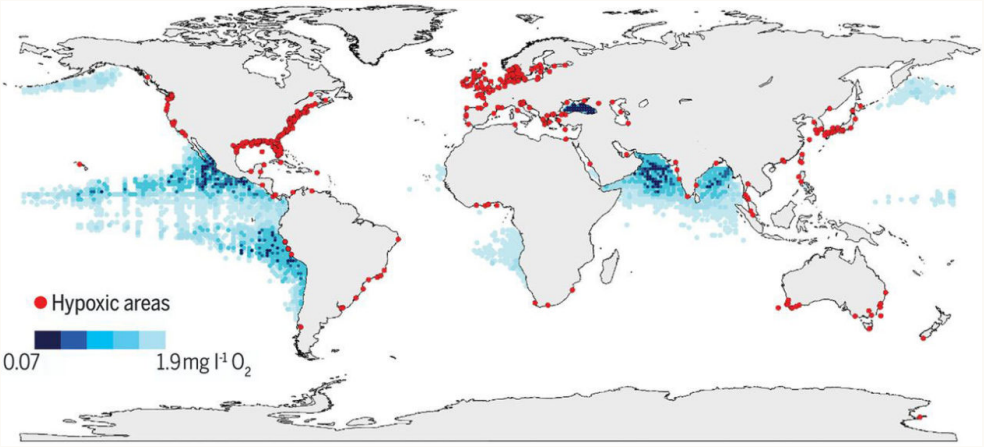
Earth system scientists say nitrogen is the major factor in biogeochemical pollution, one of four "planetary boundaries" that we have exceeded, risking "irreversible and abrupt environmental change." The world is attempting to address the other three: climate change, deforestation, and biodiversity loss. But, says Sutton, a British researcher at the Centre for Ecology and Hydrology in Edinburgh, nitrogen pollution is a largely ignored environmental story, with no international agreement or UN agency to galvanize action.

The New York meeting was part of an effort to change that. The focus was on agriculture, which is responsible for about two-thirds of global nitrogen pollution. "We've done pretty well feeding the world," says Sutton. "But now we have to address the fallout from that."

That fallout is all around us. In the United States, it is being felt in virtually all parts of the country – unleashing algal blooms in rivers from the Ohio to the Klamath in California; poisoning underground water reserves in California; leaving fish gasping for oxygen in Chesapeake Bay; and creating toxic "red tides" off the shores of Florida.

The Gulf of Mexico has a regular "dead zone," where excess nitrogen stimulates so much aquatic plant growth that its eventual rotting consumes all the available oxygen, suffocating most other marine life. The zone arises from nitrogen pouring down the Mississippi from the grain fields of the Midwest. It typically extends each summer for 5,300 square miles. Last summer's reached 8,800 square miles, the largest ever.

All told, there are more than 400 dead zones in the world's oceans, covering an area four times as great as in 1950. The largest, in the partially enclosed Baltic Sea in Europe, often covers more than 20,000 square miles.



A map showing coastal sites where anthropogenic nutrients, such as nitrogen from fertilizers, have exacerbated or caused low oxygen levels in the water, leading to dead zones (red dots). BREITBURG ET AL, SCIENCE 2018

The largest cause of this ecological mayhem is the 120 million tons of synthetic nitrogen used globally in agriculture each year. That is twice the amount of nitrogen reaching fields from organic sources such as animal manure, crop waste, and leguminous plants that fix their own nitrogen.

But the most shocking statistic is that less and less of the nitrogen poured onto fields is being incorporated into crops; more than half is washing from fields into rivers. The nitrogen-use efficiency (NUE) of the world's farmers has slipped from more than 50 percent in 1961 to about 42 percent today, according to Xin Zhang, an environmental scientist at the University of Maryland.

While most of the world's natural resources are being used with increasing efficiency, fertilizer is being used with evermore abandon. As a result, more than half of all the synthetic fertilizer ever produced has been applied to farmland in the past 30 years.

Asian countries are doing the worst. In India, where fertilizer application has doubled in 20 years, NUE has slipped from 40 percent to 30 percent, Zhang said. But the absolute worst case is China, which has gone from an average NUE of more than 60 percent in 1961 to just 25 percent today.

This compares with modest efficiency improvements seen in many developed nations, including the U.S., which is at 68 percent. Half a century ago, China's NUE was similar to that of the U.S; now it is little more than a third as good.

Chinese ecosystems are under siege as a result. Nitrogen kills fish in huge numbers from the Yellow River in the north to the Pearl River in the south. Algal blooms are reported in a third of the country's lakes. Massive "red tides" of toxic algae spread from river estuaries across the East China Sea.

Chinese farmers typically put twice as much nitrogen onto their fields as their European counterparts.

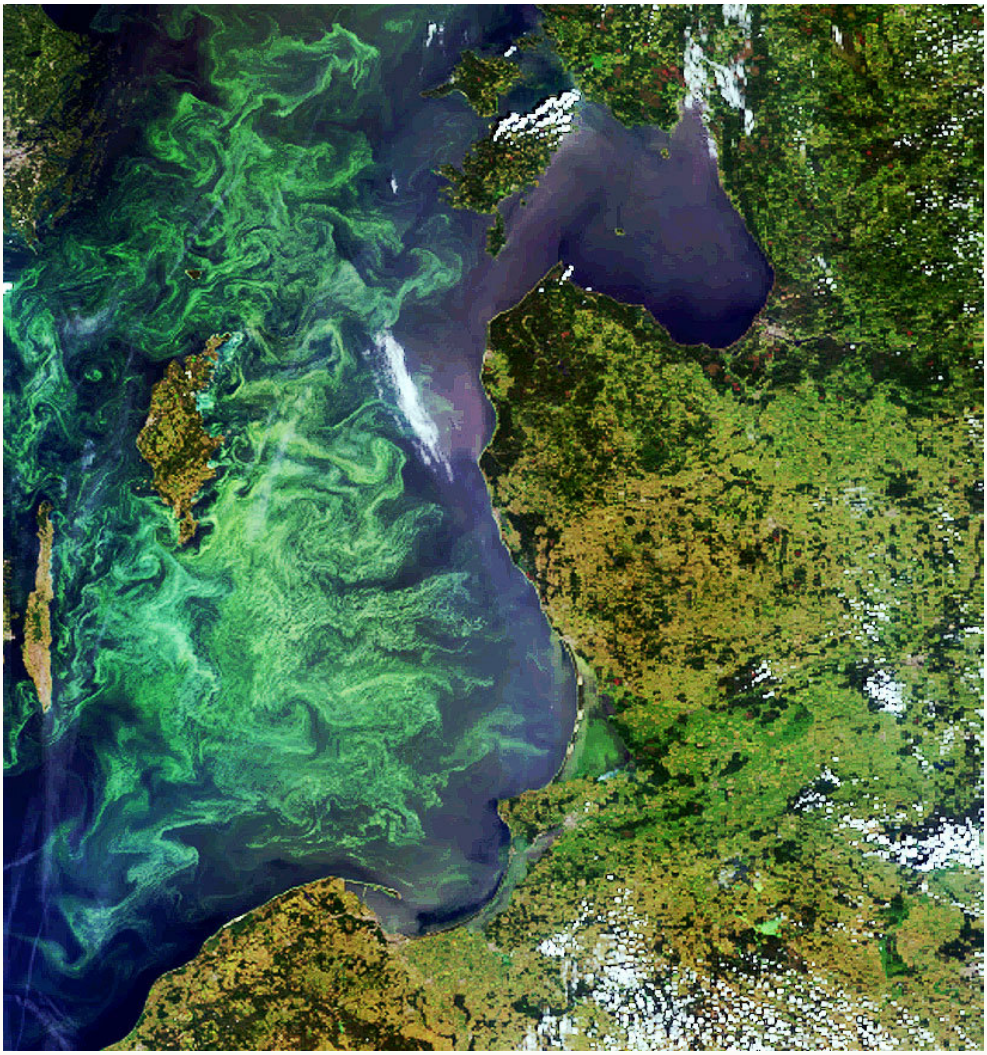
There are two main reasons for the dramatic decline in NUE in Asia: cheap fertilizer prices and the genetic makeup of the "green revolution" crops developed half a century ago to feed fast-rising populations in a hungry world.

In the mid-20th century, plant breeders, such as Nobel Prize winner Norman Borlaug, produced varieties of grain crops such as corn and rice that responded exceptionally well to additional fertilizer. To grow more, farmers simply have to pour on more fertilizer.

At high applications, there is a law of diminishing returns. Extra nitrogen has a diminishing effect on yield. Farmers make a judgment about how much more is worth pouring on – usually based on economic rather than ecological reasons. When fertilizer is cheap, it makes sense to keep on pouring. As a consequence, Chinese farmers typically put twice as much nitrogen onto their fields as their European counterparts.

The scariest result from Zhang's analysis is the prospect of Africa following the path taken by China. At present, most African farmers apply only small amounts of fertilizer. Supplies are sporadic and many farmers poor. As a result, Africa's average grain yields are not much more than one ton per hectare, compared to three tons in most of Asia and seven tons in Europe and North America. But what fertilizer African farmers do use is readily taken up by nutrient-starved crops. So Africa's average NUE is currently the highest in the world, at 72 percent.

But as it tries to grow more to feed itself – the African green revolution called for by everyone from the World Bank to the Gates Foundation – the law of diminishing returns will kick in here too. In future decades, we can expect a rapid rise in the amount of fertilizer run-off across the continent, says Zhang.



Annual phytoplankton blooms in the Baltic Sea, such as this one in 2005, create dead zones that often stretch more than 20,000 square miles. EUROPEAN SPACE AGENCY

Her data show a clear sign of what economists call the environmental Kuznets curve. The Russian-American, Nobel Prize-winning economist Simon Kuznets argued that as countries industrialize and grow wealthy, the efficiency with which they use natural resources shows a common pattern. They begin in a cheap-and-dirty way, with terrible resource efficiency. But gradually, as pollution and other downsides of this inefficiency increase, they invest in doing things better. Eventually, at least for some materials, efficiency gains exceed rising demand for the products being produced. At that point, economies can start to "dematerialize," as Rockefeller University futurologist Jesse Ausubel has put it.

In most rich countries, use of agricultural nitrogen shows this curve. The NUE of American and European farms deteriorated until around 1970, as farmers poured on more fertilizer. But after that, it began to improve. Since 2001, the U.S. has been getting higher yields despite putting on less fertilizer, says Zhang.

But in developing countries, there is so far little sign of similar tipping points. The crops bred by the green revolution in effect optimize the cheap-and-dirty approach. With heavily subsidized fertilizer prices in countries like China and India, there are no

incentives for farmers to use less. That is why so many nations – and the world's farmers as a whole – remain stuck on the wrong side of the Kuznets curve, says Zhang.

So what to do? The huge NUE discrepancies between countries mean that the world could cut nitrogen losses simply by rearranging where crops are grown. Ecologist Nathaniel Mueller, of Harvard University, reported recently that the world emits 69 percent more nitrogen from fields than it would if crops were grown in places with optimum nitrogen-use efficiency. But such a global rearrangement of crops sounds unlikely.

So how can we reconcile feeding a world of 9 billion people by mid-century with slaying the nitrogen dragon?

Zhang suggests the world should aim to reduce nitrogen runoff from crop fields from the current roughly 100 million tons to 50 million tons by 2050. That, she says, will likely require raising average agricultural NUE from the current 42 percent to about 70 percent. To achieve that might involve getting Europe and North America to 75 percent, and China and the rest of Asia to 60 percent, while finding ways to keep Africa from dropping below 70 percent.

Plant breeders may come up with high-yielding grains that can fix their own nitrogen from the air.

How to achieve that is the big question. Economics suggests that a big hike in the price of fertilizer would help, by discouraging over-fertilizing when the yield benefits are marginal. But should the hungry, especially in Africa, be sacrificed to optimize nitrogen production? A better way is needed. Perhaps technical solutions can accelerate Asian countries on the upside of the Kuznets curve, and help Africa leapfrog the cheap-and-dirty phase.

Plant breeders may come up with high-yielding grains that fix their own nitrogen from the air. But, with or without such a boon, the smart money now is on finding better ways to make sure fertilizer is only applied when and where it will actually get to plant roots. Low-tech ideas include fertilizer granules that can be planted in soils close to plant roots. This is labor-intensive, but is already being tried in Bangladesh.

A high-tech approach would involve what is becoming known as precision agriculture. This involves using algorithms that analyze plant health and local soil and climate conditions to provide a bespoke program for the amount and timing of fertilizer applications, which are then carried out with pinpoint accuracy, often using GPS-guided equipment.

Fixing the fertilizer failings of modern farming is only part of the solution to the nitrogen problem, of course. When it produces its final report in late 2021, the International Nitrogen Management System is also likely to push for global efforts to

recycle livestock manure, to turn more treated human sewage into fertilizer, to reduce food waste, and even to encourage changes to our diets.

The group's report may also suggest that environmentally aware citizens start checking their nitrogen footprint with as much concern as their carbon footprint. (An average American has a nitrogen footprint of about 41 kilograms a year, compared to 24 kilograms for an average person in the Netherlands, says Allison Leach of the University of New Hampshire, a footprint pioneer.)

There may be environmental trade-offs along the way. Those gathered in New York last month were spooked by the impacts of the push to grow biofuels as a solution to climate change. By mid-century, biofuels could become the biggest source of nitrogen in the environment.

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But the bottom line is that the scandalously inefficient use of nitrogen fertilizer, the biggest source of surplus nitrogen in the environment, has to be tackled head on. Should every nation be given a nitrogen use efficiency target? Or should, as Sutton suggested, the world agree to adopt a target of halving nitrogen waste by 2050 – the nitrogen equivalent of the 2-degree temperature target set by the Paris Accord on climate change? Even that, those at the New York meeting thought, might not bring total emissions below the planetary boundary for nitrogen. But, like the 2-degree target for climate, it might avoid the worst.

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