Now you see them...

IF YOU fill a jar with seawater and peer at it, you probably won't see much. Filter some through a very fine net and take a look with a microscope, though, and a whole world of plants and animals appears. This invisible world is absolutely vital to life on Earth.

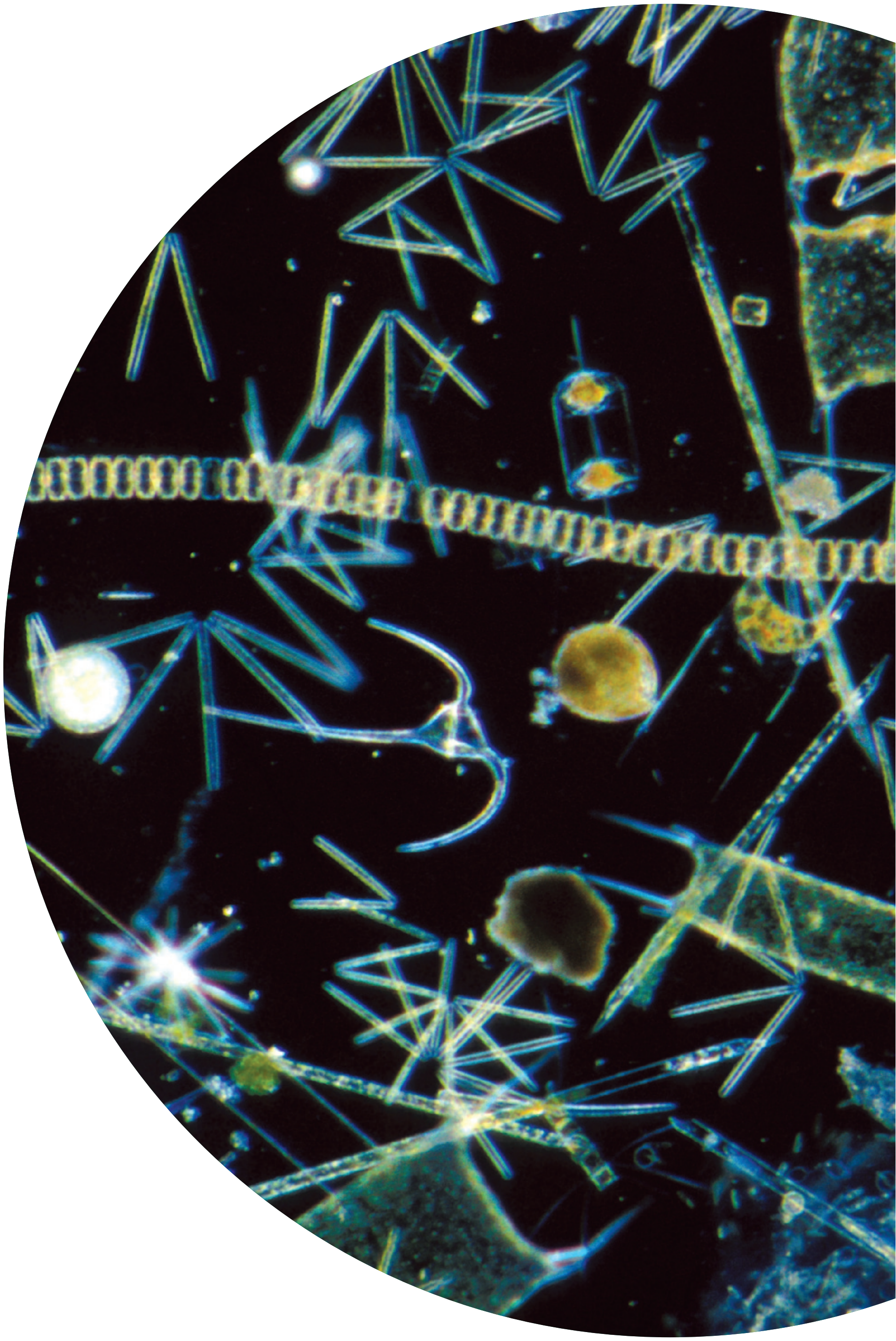
Most of the oxygen you are breathing was made by minuscule algae and bacteria. These plants, known as phytoplankton, provide half of the food on which all the animals on this planet depend. From the puniest shrimp to the mightiest whale, almost every creature living in the oceans ultimately relies on phytoplankton, as do many land-dwellers – including us. Three billion people depend in part on seafood for protein, and the livelihoods of nearly a tenth of the world's population are linked to fisheries.

Phytoplankton, in short, help make the world go round. "It's a big part of the planet's life-support system. If phytoplankton decline, it threatens the food base of a vast part of the biosphere," says marine biologist Boris Worm. "There's less fuel in the tank of the machinery of life, and you just don't get as far."

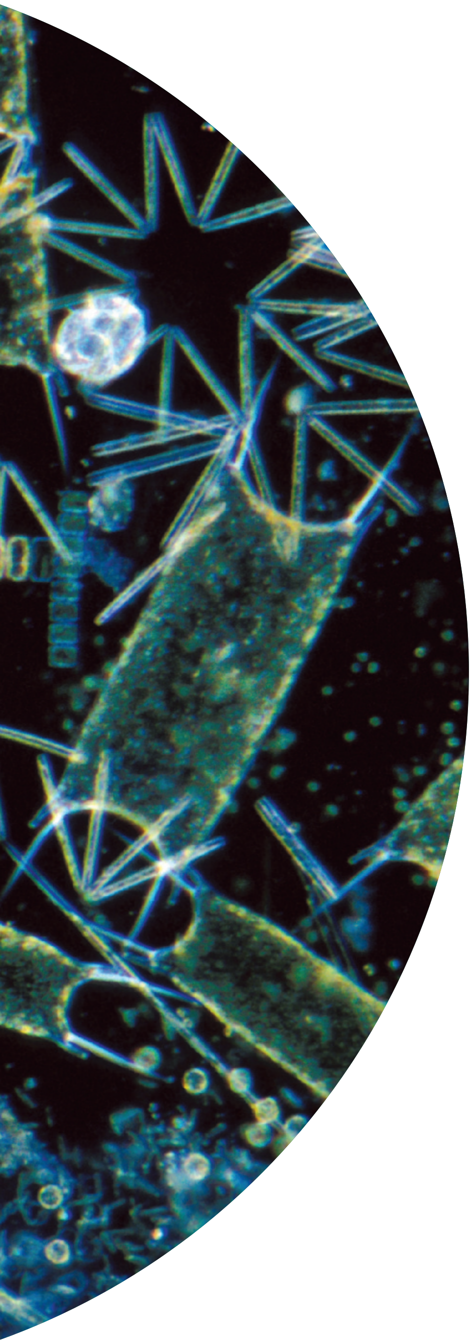
This is dramatically illustrated during El Niño events, when plankton levels plummet in the eastern Pacific, with huge consequences for the rest of the ecosystem. "When you go to the Galapagos during an El Niño, it's a totally different place," says Worm. "All the fur seals are skinny and there are a lot of dead birds."

That's why many people were stunned when a team led by Worm announced in 2010 that the same thing is occurring on a global scale, albeit far more gradually. Phytoplankton levels have dropped by almost 40 per cent since the 1940s, they concluded.

Some researchers weren't just dubious about the claim, they were incredulous. After all, Worm was saying that phytoplankton levels had crashed without anybody noticing. In this age of satellite observations, could we really have missed such a huge change for so long? And if phytoplankton levels really have plummeted, what has caused this decline – and will it continue?



Tiny plants in the ocean help feed the world, but we could be witnessing a dramatic decline. Bob Holmes investigates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You might think it would be easy to tell how productive the oceans are, but the question is surprisingly hard to answer. It is not like studying rainforests or grasslands, where plant growth is relatively easy to measure. Many phytoplankton species are so small they are hard to see even under a microscope. Instead, everyone relies on the fact that the stuff inside them that actually captures the sun's energy – chlorophyll – is green. The greener the water, the more tiny plants there are in it.

Nowadays, satellites can measure the ocean's greenness directly. But the first satellite that could do this went into orbit in 1979, and there is an uninterrupted satellite record only from 1997. This is not nearly enough time to spot a long-term trend. The only way to look further into the past is to turn to data collected the old-fashioned way, from a ship. From the 1940s onward, that has usually meant taking water samples and measuring their greenness with a spectrophotometer.

Murky depths

Before that, oceanographers mostly relied on one of the lowest-tech scientific devices ever invented, the Secchi disc: a weighted disc on a string, usually painted black and white. Dropping the disc over the side and recording the depth at which it vanishes from view reveals how murky the water is. Away from muddy coastal waters, this depends on how much phytoplankton there is. "It's a really good measurement. Surprisingly so," says Marlon Lewis, a colleague of Worm's at Dalhousie University in Halifax, Canada, and part of his team.

Another team member, graduate student Daniel Boyce, delved into the archives to compile as much of the colour and Secchi data as he could. "He's a new generation of oceanographer," says Lewis. "Halfway through the study, I said 'Dan, have you ever actually been on a boat?' And he said no. He's mining the rich data sets that we have accumulated over the years." Altogether, Boyce found nearly half a million observations spanning the world's oceans.

Then the team had to make sense of it. First they tossed out near-shore measurements, where the Secchi disc readings would be affected by sediment. Then they controlled for the fact that phytoplankton are much more common in some parts of the ocean, and during some seasons, than in others. Only after they had stripped out all this noise would any long-term trend appear.

And there it was: in 8 out of 10 ocean regions, phytoplankton levels have been falling (*Nature*, vol 466, p 591). Sure, numbers were up in some places and down in others, but on average, the decline was about 1 per cent per year over the last 40 years. "It's very shocking," says Boyce. "If I hadn't seen the results, I wouldn't have believed it." In fact, at first he didn't believe it. He and his colleagues checked and rechecked their analysis, but couldn't find a flaw.

What could be causing this decline? Phytoplankton levels are determined by the balance between how fast these cells grow and divide, and how quickly they get eaten by tiny animals or killed by viruses. Changes higher up in the food chain can cascade down. Fewer small fish, for instance, will lead to more phytoplankton-gobbling zooplankton. In theory, then, fishing could be affecting phytoplankton, but these kinds of ecological effects are very difficult to study in the ocean.

What we do know is that in many parts of the oceans, phytoplankton growth is limited by a lack of "fertiliser" – vital nutrients such as nitrate, phosphate and iron. Rivers and dust-laden winds supply some, and life itself may also play a big role in fertilising surface waters (*New Scientist*, 9 July 2011, p 36). In most oceans, however, the upwelling of deeper water is the main source. Big storms that stir up the sea and bring lots of nutrient-rich water to the sunlit surface layer, for instance, lead to bumper catches of fish in later years, while the reduced upwelling during El Niño events ›

> "Phytoplankton are a big part of the planet's life-support system. If they decline, it threatens the food base of a vast part of the biosphere"

causes plankton levels to plummet.

These factors explain why phytoplankton growth varies so wildly from year to year in any given area. Across the planet these fluctuations tend to balance out, so overall phytoplankton productivity doesn't change that much. What makes Worm's decline so scary is that it seems to be happening worldwide at the same time.

The obvious suspect is global warming. More than 90 per cent of the heat retained by Earth as a result of rising greenhouse gases ends up in the sea. Plankton do grow faster in warmer conditions, but warming has a far less desirable effect, too. As surface waters warm, they become less dense and this makes it harder for cold, nutrient-rich water to rise to the surface. Less mixing means less fertiliser, and if phytoplankton run out of nutrients they cannot grow however warm the water is. So on balance, warmer waters are expected to reduce phytoplankton growth, and this is just what Worm's team found. Apart from in the Arctic and Southern oceans, there was a strong link between higher sea surface temperatures and lower phytoplankton levels.

Oceanographers almost all agree that warming will lead to a decline in phytoplankton, but most expected only a small fall over the coming decades. And while there have already been dramatic falls in fish catches in many parts of the world, these have been attributed to overfishing rather than falling phytoplankton.

So the response to the claim that phytoplankton levels have nearly halved already was swift, and mostly negative. "I don't know of any phytoplankton ecologist that believes this," says Paul Falkowski, an oceanographer at Rutgers University in New Brunswick, New Jersey.

"When I read it I said, 'Wow, that's the opposite of what we see'," says Abigail McQuatters-Gollop of the Sir Alister Hardy Foundation for Ocean Science in Plymouth, UK, and the lead author of one of three scathing critiques published in *Nature*.

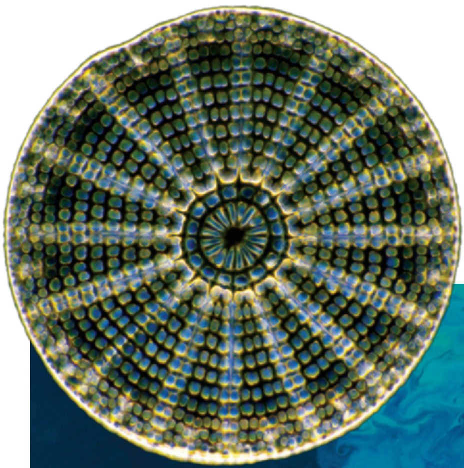
For the past 80 years, the foundation has been measuring phytoplankton in the Atlantic using the Continuous Plankton Recorder – a device towed behind a ship that filters seawater through the exposed part of a slowly moving silk "tape". The roll of silk is preserved and sent back to Plymouth, where technicians assess plankton abundance. The results, based on more than a quarter of a million samples, suggest phytoplankton biomass has gone up in the North Atlantic (*Nature*, vol 472, p E6) – the opposite of what Worm's team found.

A cruder method of estimating phytoplankton levels, called the Forel-Ule assay, is to match the colour of seawater against a series of reference samples. Marcel Wernand of the Royal Netherlands Institute for Sea Research in Texel has compiled more than 250,000 Forel-Ule readings since 1899, and finds these, too, contradict Worm's results. "The North Atlantic is greening, the Mediterranean is greening. We see more plankton there," he says. Several other regional data sets also show increases in plankton.

So a number of teams have set out to measure the same thing and come up with completely different results. Part of the reason, of course, is that each group has used a different method, each with its own flaws and biases. The relatively coarse mesh of the Continuous Plankton Recorder, for example, traps more large phytoplankton than small, so it gives a skewed picture. Each analysis also has its own way of correcting for seasonal and regional trends. "The other folks were getting different measures from different areas at different seasons," says Lewis. "We were all kind of blind men feeling different parts of the elephant."

Worm's study suffers from problems, too, not least because it combines Secchi disc readings with spectrophotometer measurements. Secchi readings tend to slightly overestimate phytoplankton concentrations, so since Secchi observations predominate early in the 20th century and colour estimates predominate later, this could give the appearance of decline where none exists (*Nature*, vol 472, p E5). "The amount of bias they show is as large as the trend they report over time," says Ryan Rykaczewski of Princeton University.

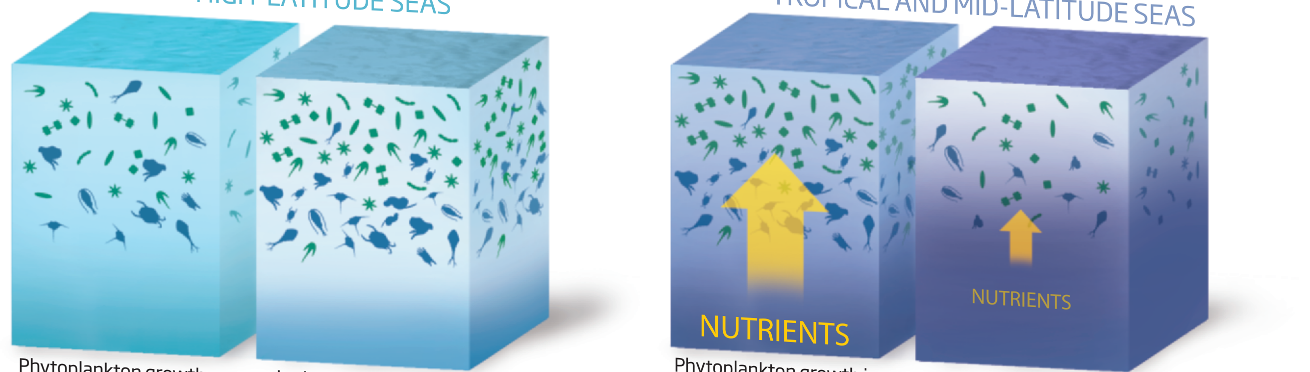
To iron out these issues, Worm and his team went back to their original data, carefully



MAIN: NASA/CORBIS. INSET: FRANK FOX/SCIENCE PHOTO LIBRARY

The famished ocean

Warming can boost phytoplankton growth in some parts of the sea, but its overall effect is negative



cross-calibrating Secchi, satellite and shipboard colour measurements, and correcting statistically for any differences. They also broadened their sweep to include Forel-Ule observations, and plan to add the Continuous Plankton Recorder data as well. They hope this improved, enlarged data set will help settle the controversy. The initial results still point to a worldwide decline of somewhere between 20 and 70 per cent.

"From everything we have done so far, we're seeing a decline," says Worm. "No matter what we include or exclude, we are always seeing a decline. The magnitude of the decline, and the regional detail, is still in question – but that there is a decline, I have very little doubt."

Worm has yet to convince McQuatters-Gollop and Wernand, but he does have some supporters. Scott Doney of Woods Hole Oceanographic Institution in Massachusetts, for instance, says that several climate models predict declines in phytoplankton. "[Worm's results] are certainly in line with what some of the models are suggesting," he says.

David Siegel of the University of California at Santa Barbara agrees that the effect may be real, but thinks more work needs to be done to confirm its magnitude. His unpublished analysis of 13 years of satellite colour data suggests warming leads to clear declines in phytoplankton in the tropics, with a more mixed response in temperate waters.

Phytoplankton make up for their diminutive size with stupendous numbers

Winners and losers

A similar study in 2006 came to much the same conclusions. "What we see in the satellite record, very clearly, is there is a very strong relation between climate-driven changes in the surface temperature and the plankton," says team member Michael Behrenfeld of Oregon State University in Corvallis.

So while the debate about whether phytoplankton levels have fallen already is far from settled, there is strong evidence that they will fall in the future as the oceans warm. What does this mean for us? Well, for starters, there are big regional differences and there will be winners as well as losers. Although Worm's team found a steep overall decline, their results still suggest phytoplankton levels rose in two-fifths of the ocean.

The bad news is that even in areas where productivity rises, there will not necessarily be more fish in the sea. In temperate regions, the phytoplankton tends to consist of large cells that are eaten by large zooplankton, such as copepods, and then by fish. Phytoplankton in the tropics, in contrast, tend to be tiny cyanobacteria, which are eaten by tiny zooplankton, which are eaten by slightly larger ones and so on. There are several more links in the food chain – and 90 per cent of the energy is lost at each link. This is part of the reason why tropical waters tend to support fewer fish, and thus less vigorous fisheries, than cold waters.

As the oceans get warmer, some cold-water regions are shifting towards the longer-food-chain regime. In the North Atlantic, the boundary between the two types of food chain has already shifted 1000 kilometres northward in recent decades.

Throw in overfishing, pollution, ocean acidification due to rising carbon dioxide levels and ocean deoxygenation due to warmer water, and it is really difficult to predict the fate of the world's fisheries, and ocean life more generally. To have any chance, we really need long-term, reliable monitoring of phytoplankton abundance. Yet the satellites that do the best job are coming to the end of their lives, and no replacements are in sight.

The bottom line is while the debate about Worm's results continues, we really could have missed a massive decline in phytoplankton – and if we are not careful, we won't be able to spot future declines either. ■

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