polarization measurements disturbed the system by only about half as much as Heisenberg's original formulation of the uncertainty principle dictates.

Ozawa says that Busch and his collaborators use the worst-case scenario, averaged over many quantum states, to define the disturbance caused by a measuring device. That may not reflect the actual conditions under which a particular quantum system in a particular quantum state is being examined. As a result, Ozawa says, the authors are overestimating measurement errors. But Busch and his colleagues argue that the definition of instrument error Ozawa uses is not universally valid, and therefore does not call into question Heisenberg's principle.

### CRYPTIC CLUES

The debate may sound esoteric, but quantifying by how much a measuring device can disturb the properties of a quantum system is crucial to the burgeoning field of quantum cryptography and computing. In principle, a quantum computer would be more secure than an ordinary computer because anyone trying to peer at the information would disturb it, leaving a telltale trace.

If Ozawa's 2004 work holds up, it would mean that a thief might be able to steal quantum data without anyone knowing, as the furtive measurements might barely disturb the system at all.

But what Busch and his collaborators have proved, says Uffink, is that if an eavesdropper has no control over the state of the quantum system in question — as will typically be the case for a data thief — then the eavesdropper will necessarily disturb the system in the way that the original version of the uncertainty principle predicts. "This is an important result that we did not have before," Uffink says.

Neither Uffink nor quantum theorist Howard Wiseman at Griffith University in Brisbane, Australia, are willing to say that Ozawa's approach is wrong, however. Indeed, it is possible that both results are correct, Wiseman notes.

He suspects that a strange quantum concept known as negative probability — negative dips in the probability distribution of a particle's location or momentum — could be at the heart of the issue. These dips may mean that a measuring device disturbs the system less than the uncertainty principle seems to allow. "The fact these two different definitions give you a different answer is telling you something about the weirdness of quantum mechanics," says Wiseman. ■


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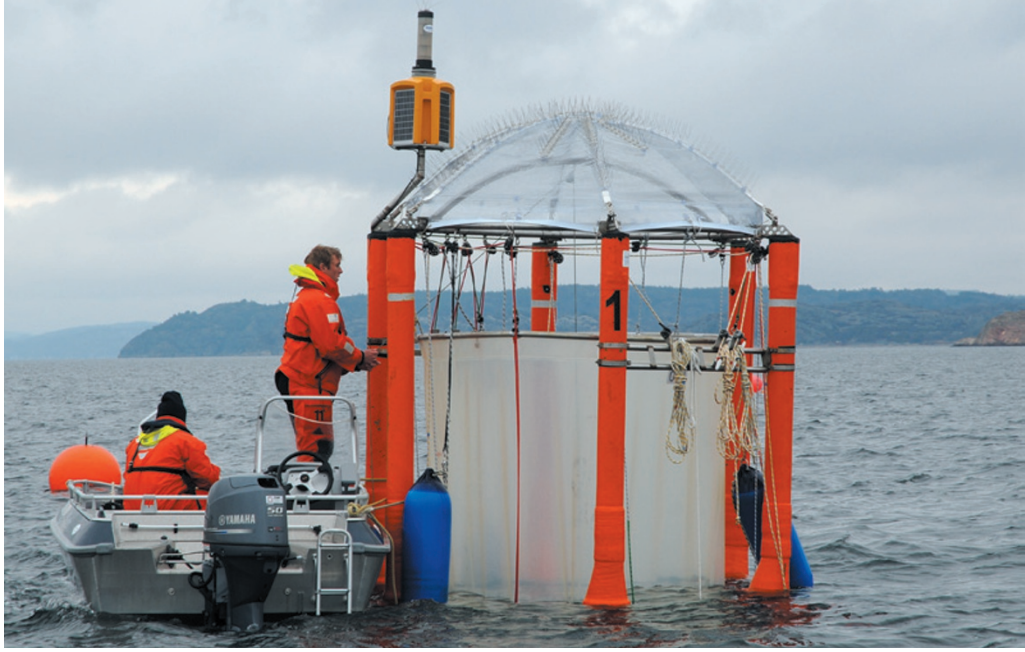

Researchers suspend 20-metre-tall sacs in a Swedish fjord to enclose entire ecosystems for study.

MAIKE NICOLAI/GEOMAR

MARINE ECOLOGY

# Floating tubes test sea-life sensitivity

*Ocean labs probe effects of ocean acidification on ecosystems.*

BY HRISTIO BOYTCHEV

Global warming is not the only worrying consequence of rising carbon emissions. As levels of carbon dioxide increase in the atmosphere, more of the gas dissolves into the oceans, making the water more acidic. Marine scientists fear that the conditions will disrupt ecosystems by, for example, inhibiting some organisms' ability to build shells. Yet the effects are unclear: in small-scale laboratory tests, certain species have proved surprisingly resilient, and some even flourish.

Marine biologist Ulf Riebesell says that these results tell only part of the story: scientists need to scale up and examine whole ecosystems. Lab studies of isolated species ignore variables such as competition, predation and disease, he says. Even minor effects of acidification on the fitness of individual species — especially small photosynthetic organisms such as phytoplankton — can upset food chains, eventually harming larger species. "If you only focus on the lab results, you are being misled," he says.

Riebesell and his colleagues at GEOMAR Helmholtz Centre for Ocean Research in Kiel, Germany, have developed innovative experimental environments — 20-metre-tall sacs suspended in the ocean, which enclose entire ecosystems and allow the effects of elevated $CO_2$ to be measured. The first results, published this year, suggest that some plankton thrive in acidic environments and can wreak havoc on food chains[1]. Another experiment will end in July, and preliminary evidence suggests that conches and sea urchins are vulnerable to acidification.

The project is inspired by analogues on land, in which swathes of forest are bathed in extra $CO_2$ to study the effects on plant life (see *Nature* **496,** 405–406; 2013). For the sea, Riebesell and his colleagues constructed 'mesocosms' — floating cylinders of thin plastic that function like giant test tubes[2]. When first put into the water, the sacs are left open at the top and bottom, allowing hundreds of small species to enter. After several days, they are closed and acidified water is pumped in (see 'Sea lab'). Over weeks or months, researchers measure how the ecosystems inside fare in comparison with those in untreated sacs.

Realizing this simple idea has been challenging. The scientists began in 2006 with a prototype, free-floating in the Baltic Sea, that floated too well: currents carried it along much faster than expected, and the scientists had to chase it in a research ship. After only two days they reached Swedish waters, for which they had no research permits. When they tried to recover the mesocosm, it broke.

The team conducted its first successful experiment in 2010, using a lighter design that was moored in place in the Norwegian Arctic archipelago of Svalbard. The researchers found that, compared with the

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controls, the acidic mesocosms produced less dimethyl sulphide[3] — a gas that helps to form clouds, which reflect sunlight and can counteract climate warming. Riebesell is not sure what causes the change; he thinks that the plankton in the mesocosm might be making less of the gas, or the acidic water could be affecting its stability.

Picophytoplankton, the smallest photosynthetic organisms, turned out to grow better in the acidic mesocosms[1]. But at the same time, diatoms — larger algae that are among the most important producers of ocean biomass — suffered. The change could mean that more nutrients are cycled among the picophytoplankton rather than reaching larger animals such as fish. Indeed, preliminary results from the latest experimental run indicate that larvae of sea urchins and Strombidae conches are barely surviving in the acidic mesocosms. However, the scientists think that food quality may not be the main reason for their demise; pathogens and problems making shells could also have a role.

Adina Paytan, an oceanographer at the University of California, Santa Cruz, says that Riebesell's work "fills an important niche between lab work and field studies" and has "advanced the field considerably". She takes a different systems approach to acidification, studying 'natural mesocosms': underwater springs off Mexico that enrich zones in $CO_2$.

Riebesell says that these regions are a good lab for studying immobile seagrasses, but not organisms that can move freely. Paytan notes that there are problems with Riebesell's mesocosms: for example, the plastic walls filter out some ultraviolet light, removing a natural stressor for photosynthetic organisms. And the tubes are impermeable, so nutrients in the water become exhausted, and experiments last only a few months. Nevertheless, Paytan says, "we still learn a great lot from these experiments".

This year's run, in the Swedish Gullmar Fjord, uses five control mesocosms and five in which acidity is boosted to levels associated with the atmospheric $CO_2$ concentrations predicted for the year 2100. The experiment will end next month after a 6-month run — the longest yet — during which the researchers have monitored a natural plankton bloom.

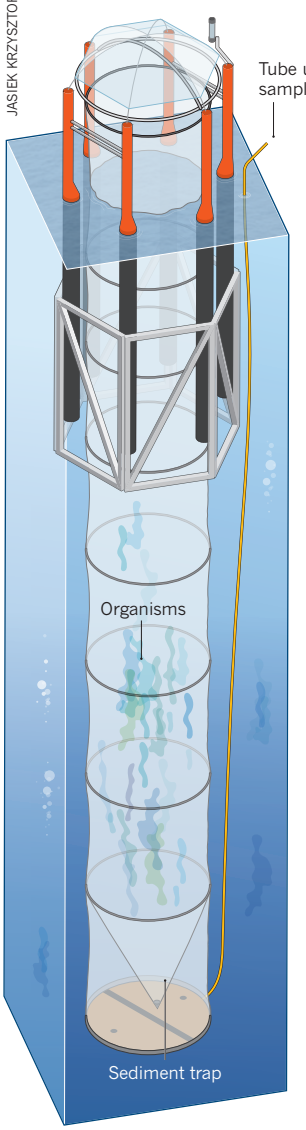
Riebesell and his team seem comfortable with using their mesocosms as a hybrid between a controlled laboratory environment and a natural one. They have introduced fish eggs into the ecosystems for the first time, and Matias Scheinin, a marine biologist at GEOMAR, is using the sacs to explore natural selection. By tracking the abundance of individual strains of diatoms — which can undergo hundreds of generations in a few months — he hopes to identify those that flourish in acidic environments. He will screen them for the genes responsible, to investigate rates and mechanisms of adaptation.

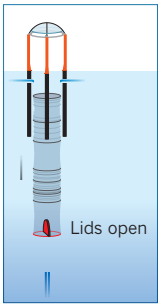
Oceans have gone through major acidification events during climate change in the ancient past. By accelerating evolution, Scheinin wants to get a glimpse of their future. "I have some hope that evolution can help marine life deal with acidification," he says. "It's not the first time it has had to go through it." ■ SEE COMMENT P.429


1. Brussaard, C. P. D. *et al. Biogeosciences* **10,** 719–731 (2013).
2. Riebesell, U. *et al. Biogeosciences* **10,** 1835–1847 (2013).
3. Archer, S. D. *et al. Biogeosciences* **10,** 1893–1908 (2013).

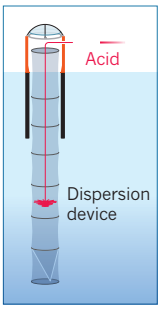

## SEA LAB

Scientists are testing the ecosystem-wide effects of ocean acidification in 55-cubic-metre plastic mesocosms.




**1 Filling the mesocosm**
The tube is left open at the top and bottom for two days, allowing organisms to fill the space — about the volume of a double-decker bus.




**2 Acid injection**
The mesocosm is closed and water enriched in carbon dioxide is added.

JASIEK KRZYSZTOFIAK/*NATURE*; SOURCE: REF. 2

### CORRECTION

The News story 'Space rovers in record race' (*Nature* **498,** 284–285; 2013) wrongly stated that the Russian scientists used laser mapping from the Lunar Reconnaissance Orbiter to make a three-dimensional representation of the Moon's topography. In fact, they used processed images from the orbiter's narrow-angle camera.