ON THE EDGE

Ecologist Marten Scheffer became a leader in the science of tipping points by studying lakes. Now he's making waves in many other fields

By **Gabriel Popkin**

It was a murky problem. In the late 1980s, scientists in the Netherlands were struggling to reverse an outbreak of cloudy lakes. The source of the scourge was no mystery: Nutrients were running off farm fields and leaking from sewage treatment plants, fueling algae blooms that turned once-clear waters a sickly green.

But researchers had discovered that just cutting off the flow of nutrients often wasn't enough to restore clarity; some lakes and ponds seemed to have tipped into a new, persistently turbid condition. To clear the water, the scientists discovered they needed to give the ecosystems an extra jolt, which they could sometimes do by removing certain kinds of fish. Nobody had a clear theoretical conception of why such "shock therapy" worked.

Marten Scheffer, however, saw something in the gloomy water. The math-savvy ecologist had just arrived at a Dutch environmental agency and had been assigned to study the troubled lakes. He realized they were demonstrating a phenomenon known as bistability—the lakes had two stable states and could abruptly tip from one to the other as a result of a small external nudge. The equations describing such shifts had been around since the 1960s—and even depicted in paintings by Salvador Dalí—but they had found few real-world applications. In the Netherlands, however, Scheffer and his colleagues put them to use, conducting increasingly sophisticated experiments that demonstrated how a better understanding of tipping points could have very practical applications.

That work led in 1993 to a now-classic paper in *Trends in Ecology & Evolution* that has

PHOTO: MANON BRUININGA

Before diving into science, Marten Scheffer studied music. He's recorded 15 albums.

helped make Scheffer a leading, and sometimes unorthodox, thinker on the science of tipping points. Now, at 56, the Wageningen University ecologist has crossed a threshold of his own: Flush with funding, he's become the intellectual hub for a global network of scholars who meet for freewheeling discussions, often at a retreat center he built on his family farm in the Netherlands. The collaborations are carrying Scheffer far from the rural lakes where he started, to efforts to identify tipping points in tropical forests, global climate, and communities of gut microbes, and even in the onset of migraine headaches and depression.

Scheffer has become "the social glue … the chief networker in some ways" for a growing community of tipping point researchers, says climate scientist Tim Lenton of the University of Exeter in the United Kingdom. Along the way, he's won hefty science prizes, and his key papers have tallied some 10,000 citations.

Some researchers, however, worry that Scheffer might be moving too far, too fast with his ideas, and that tipping point models, while elegant, are sometimes too rudimentary to be very practical. Still, few question his scientific acumen or skill at shattering disciplinary barriers. Scheffer's "independence is his trademark," says ecologist Wolf Mooij, a colleague at Wageningen University and the Netherlands Institute of Ecology.

THAT AUTONOMY WAS ON DISPLAY in 2009, when Scheffer received the Spinoza Prize, a €2.5 million award that is the Netherlands' most prestigious science honor. Winners typically give a predictable speech. Scheffer, an accomplished musician, instead pulled out a guitar and played an original acoustic composition from *Transitions*, one of 15 albums he has recorded.

Once, Scheffer thought he might play music for a living. Raised in the Dutch countryside by parents who played classical flute and piano, young Scheffer was asked what instrument he wanted to learn. "It was not really a question" of whether he would take lessons, he notes, so "I picked [an instrument] they did not play," the violin, and studied it seriously, well into his college years.

When it came time to choose a career, however, Scheffer tipped toward science. ("I would never be able to be a [classical] violin player," he says, given his eclectic musical tastes.) After earning an undergraduate degree in ecology from Utrecht University, he eventually landed at the Netherlands' Institute for Inland Water Management and Waste Water Treatment.

Soon, Scheffer was wading into the murky lake problem, putting him squarely within a long scientific tradition. Some historians argue that modern ecology itself was launched by the publication of "The Lake as a Microcosm," an 1887 paper by American ecologist Stephen Alfred Forbes. Lakes hit a sweet spot, Scheffer says: ecosystems that are self-contained and experimentally tractable yet intricate enough to yield profound insights. "They're really complex systems but … we understand them relatively well, and can actually manipulate them," he says. And in wet, table-flat Netherlands, Scheffer and his colleagues had plenty of lakes within reach.

Most notably, they showed that clear lakes with plentiful vegetation are resilient to moderate nutrient influxes, whereas murky lakes lacking such vegetation cannot easily return to clarity. The scientists also learned why "shock therapy"—removing bottom-feeding fish—can work. They found that the fish stir up sediment, releasing stored nutrients that keep lakes murky even after external flows are stanched. Once the fish are removed, the water clears enough for aquatic plants to grow; the plants then help hold bottom sediments in place, even if the fish return.

The fish removal method is now used in restoration projects around the world. And the lake experiments helped generate enough high-profile publications for Scheffer that, in 1992, Utrecht University awarded him a Ph.D., despite the fact that he never bothered to formally enroll in graduate classes.

"Marten really formulated very clear, testable theories about shallow lakes," says Stephen Carpenter, a limnologist at the University of Wisconsin, Madison, who studies transitions in North American lakes.

To illustrate the findings, Scheffer introduced a type of graphic that has become a hallmark of his work. It shows a ball rolling across a simple 2D hill-and-valley landscape (see p. 1554). A deep valley represents a resilient, stable state, such as a clear lake with plentiful vegetation and few nutrient inputs. When the ball sits in such a valley, it is difficult to move; if nudged, it quickly rolls back to equilibrium on the valley floor. But if a lake becomes overfertilized, the system resembles a valley with shallow slopes; a slight nudge can push the ball into the next valley—which represents a new stable state like a turbid lake. Restoring clarity means finding ways to lower the hill and reverse the ball's path—such as cutting off nutrients and removing bottom fish.

Such graphics have been invaluable in communicating Scheffer's ideas to policymakers and field workers, who don't typically dabble in complex mathematics. "The ball in a cup pictures really helped get the idea into the minds of managers, and now they're using it all the time," he says. Scheffer "really bridged the gap between the deep theory and the application," Mooij says. "He was very effective in communicating this for both scientific and applied audiences." (In contrast, Dalí's 1983 effort to depict tipping point theory met with less success; the painting, part of his "Catastrophe Series," was his last and is little known.)

SCHEFFER'S CAREER has had its tipping points, each carrying him further from his home in limnology. In the mid-1990s, his lake work helped persuade the more senior Carpenter to invite Scheffer to join the Resilience Alliance, an eclectic confederation of scientists who study what makes some systems stable in the face of change. Scheffer recalls that at his first meeting, in 1997 in the bush in Zimbabwe, the group sat around nightly campfires, trading ideas. "It was very inspiring," he says.

Four years later, he and a group that included several participants in the Zimbabwe retreat published a *Nature* paper that aimed to bring the concept of ecological tipping

Scheffer's varied interests include showing off pond life to his children and a colleague.

points into the mainstream. Drawing on studies of lakes, coral reefs, forests, deserts, and oceans, the team argued that ecosystems can often shift abruptly in response to gradual changes, and that managers need to recognize when such "forcings" could cause a catastrophic loss of resilience. The paper has since garnered some 3000 citations.

By the time the *Nature* paper appeared, Scheffer had become head of Wageningen University's Aquatic Ecology and Water Quality Management group. His work over the next decade ranged far beyond aquatic ecosystems, however. He modeled tipping points in climate and other natural and human systems and wandered into fierce ecological debates, including the question of why so many species exist. To advance his brand of freeform transdisciplinary collaboration, Scheffer and a colleague conceived the South American Institute for Resilience and Sustainability Studies, a research center that is now partly funded and under construction in Uruguay.

Scheffer also began wondering whether, with the right kind of data and methods, researchers could detect warning signs that a system was about to tip. Hints of such forecasting methods had appeared in journals as far back as the 1980s, but they received renewed attention after Scheffer and colleagues published a 2009 review paper in *Nature*. One promising statistical signal, they noted, is "critical slowing down," in which an ecosystem or population approaching a tipping point takes longer to recover from a perturbation. To use the ball and valley analogy, when a ball is slower to roll back to the valley floor, that's a sign it is becoming easier to push it into a new stable state.

On the strength of such work, Scheffer won three major awards in 2009 and 2010 that allowed him to do what other scientists dream of: jump off the grants treadmill and pursue his wide-ranging interests. First came the Spinoza Prize, then a €2.5 million European Research Council Advanced Grant (to study early warning signals in a variety of systems), and finally a €2.1 million grant from the Dutch Ministry of Education, Culture and Science (part of a larger project to study climate tipping points).

SCHEFFER WASTED NO TIME in putting his new financial independence to use. Waiting for the Spinoza Prize ceremony to begin, he and his co-awardees, University of Twente physicist Albert van den Berg and Leiden University neurologist Michel Ferrari, began discussing whether tipping point theory could help predict and possibly prevent migraines. The three soon began a joint project, and in 2013 they sketched out a hypothesis in *PLOS ONE*. They are now gathering data to identify neuronal activity patterns that might reliably predict migraine attacks.

Meanwhile, other experimental demonstrations of early warning signals have begun to appear. Scheffer's team, for instance, has used increasing amounts of light to stress laboratory algae and show that populations fluctuate in a recognizable way before crashing. Jeff Gore, a physicist at the Massachusetts Institute of Technology in Cambridge, has achieved a similar result in experiments that stress populations of laboratory yeast. And in a real-world demonstration, Carpenter and colleagues reported in 2011 that they were able to detect early warnings of a food web transition in a lake in northern Wisconsin by tracking signals in fish and plankton populations.

But some researchers urge caution in generalizing from a few results. "My view is that in many cases, the early warning signals [Scheffer] has worked on will be too simplistic to apply to the real world," says Jef Huisman, a microbiologist at the University of Amsterdam and a sometime collaborator with Scheffer. And two psychopathologists from the University of Groningen have challenged a venture Scheffer took into psychiatry, published earlier this year in the *Proceedings of the National Academy of Sciences*. Scheffer and collaborators suggested that signs of "critical slowing down"—and impending depression—may be found in self-reported mood data. The critics were unconvinced, though one of them, Elisabeth Bos, finds the idea exciting. "If you can prove that there's a subset of individuals who really show these critical transitions," she says, "that would be a great tool to use in clinical psychiatry."

Others worry that by trying to apply his ideas too broadly, Scheffer risks creating the kind of hype and blowback that crippled an earlier effort to develop tipping point models, also known as catastrophe theory. "One has to be careful not to kill the baby with the bath water, not to do what happened with elementary catastrophe theory and say it's the solution to everything," says theoretical ecologist Simon Levin of Princeton University.

Scheffer embraces such warnings. He has invited critics to workshops, which often take place at Scheffer's retreat center, built to look like an old Dutch farmhouse. Guests stay in a nearby hotel and bike to the farm. After a morning of heady talk, they might adjourn to pick apples or swim in a nearby lake—in no danger of turning cloudy.

The experience is "very intense yet quite relaxed," says one participant, psychiatrist Kenneth Kendler of Virginia Commonwealth University in Richmond. It's Scheffer's way of nudging his colleagues toward yet another intellectual tipping point. ■

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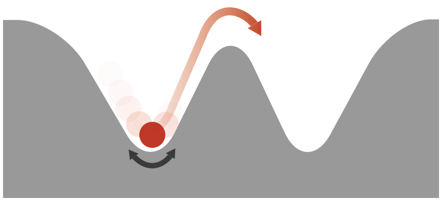
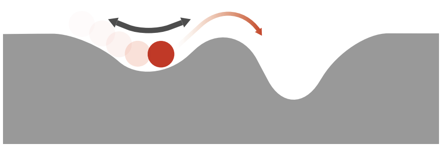
Nudge science

Scheffer uses accessible diagrams to illustrate tipping point concepts.

A resilient system returns to equilibrium quickly after a small push (**black**). It takes a major push (**red**) to tip the system into a new stable state.



A less resilient system recovers more slowly from small pushes (**black**). This "critical slowing down" can be a warning sign that the system could easily tip into a new state (**red**).



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