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Lars Hedin
Featured Scientist Interview

*Recently, an analysis of Essential Science Indicators*SM *from Thomson Reuters recognized the work of Dr. Lars Hedin as having the highest percent increase in total citations in the field of Environment & Ecology. Currently, in this field, his citation record includes 15 papers cited a total of 518 times between January 1, 1999 and December 31, 2009.*

Dr. Hedin is Professor of Terrestrial Biogeochemistry in the Department of Ecology and Evolutionary Biology and Princeton Environmental Institute at Princeton University.

In the interview below, he talks with* ScienceWatch.com *correspondent Gary Taubes about his highly cited work.

SW: What initially prompted your research on forests and nutrient cycling?

I started with this innate fascination for natural systems. I've always been attracted to the question of how the natural world works. I then moved toward the kind of questions that are more are important for understanding how humans are affecting natural systems.

That's a path toward studying complex ecological systems, and then you almost have to choose whether to have your feet wet or dry. By that I mean, I started out studying water systems and then slowly moved up onto dry land.

Then if you're interested in climate change, as I was, you very quickly figure out that tropical forests, like in the Amazon or Central America, are especially important in the earth's climate system. Plus, they're just terrifically fascinating, complex, diverse, and they're highly sensitive to human activities.

SW: Since the 1990s, you've specialized in unpolluted tropical and temperate forests. What's the importance of these unpolluted forests?

We started off studying temperate forests, trying to understand the frame of reference for a natural temperate forest. Most studies before us had looked at polluted temperate forests, and they'd describe essential processes—cycling of nitrogen or other nutrients—and the observation was always that these ecosystems were highly perturbed by human disturbance. European forests, North American forests, the answer was always human disturbance.

But nobody had a frame of reference for a temperate forest that hadn't been disturbed by humans. So we had the idea to travel back in time, before the industrial revolution. We did this by going to the most unpolluted temperate forest we could find in the world, in Southern Chile.

We tried to characterize how such truly natural forests work, to derive a kind of baseline for natural forests. And our results changed how people think of the nutrient cycles that sustain these forests, and how pre-industrial conditions are understood and characterized in climate models.

Once we did this with temperate forests, we decided to compare them to tropical forests, which appear to work completely differently. And so we began studying tropical forests around the world.

"We want to reduce our understanding to mathematical expressions that can then go into these models and allow us to better forecast how nutrients control the carbon cycle."

SW: When did you publish the work on temperate forests in southern Chile, and how was it received?

That was in 1995 (Hedin LO, Armesto JJ, Johnson AH, "Patterns of nutrient loss from unpolluted, old-growth temperate forests—evaluation of biogeochemical theory," *Ecology* 76[2]: 493-509, March 1995), and received widespread attention (including an award from the Ecological Society of America). The work showed that we had not previously understood how the unpolluted nitrogen cycle works in these natural forests.

We spent about five years studying these pristine, undisturbed forests, and we ended up learning entirely unexpected things about the nitrogen cycle. For example, our findings helped resolve some long-standing paradoxes and problems for which we hadn't had solutions.

One paradox was the question of why so many forests in the world are limited by nitrogen. We found that nitrogen limitation can be generated in a quite unexpected way—by the slow leak of organic forms of nitrogen from the soil.

SW: Could you fill us in on the importance of the nitrogen cycle in forests, since it's so critical to your work and to this concept of nutrient cycle?

Nitrogen is the key nutrient that controls the machinery of photosynthesis. That's why you use nitrogen to fertilize the tomatoes you grow in your garden. Nitrogen allows the photosynthetic machinery to be built and to function. Nitrogen cycles in natural ecosystems; it goes from the plant to the soil and back up to the plant. It can be plentiful or it can be extremely scarce, depending on the local soil conditions. So nitrogen is perhaps the most important nutrient controlling plant growth in the world.

If you want to understand how plants work, how forests work in the climate system, you need to understand the nitrogen cycle—how an abundant or scarce nitrogen defines exactly how the forests respond to the greenhouse gas carbon dioxide in the atmosphere, whether it can be taken up and stored, or not. Such knowledge defines how we think of these systems as productive or unproductive, and how to manage them in the face of human perturbations such as climate change.

SW: Do human pollutants affect the availability of nitrogen?

That's the point. In disturbed parts of the world, in the parts with a lot of humans and a lot of pollutants, there are large amounts of nitrogen pollutants. That's why we wanted to get away from them in our work on unpolluted Chilean forests.

In our 2002 *Nature* paper, "Nitrogen loss from unpolluted South American forests mainly via dissolved organic compounds (Perakis SS, Hedin LO, 415[6870]: 416-9, 24 January 2002), we pointed out that almost all the studies that had been done previously to determine how human pollutants worked in these systems didn't show how the systems worked naturally. And because of that, they didn't have a baseline against which they could compare and judge the extent of human disturbance.

SW: Did you expect that paper to be so highly cited?

I suspected it might. The original paper in 1995 on temperate forests was highly cited and this one put the earlier findings in a broader context.

SW: How has your research evolved in the years since that 2002 *Nature* paper?

Since then we've realized that the nitrogen and phosphorous cycles in tropical forests behave very differently from what the traditional models suggest. The traditional models come from temperate systems, and we have to develop a whole new set of rules and theories for tropical environments. And that's been very exciting. We have some major findings on that.

SW: Can you tell us about those?

I may be complicating this too much, but let me try to explain. It's well known that tropical forests are major sinks for carbon dioxide, which is, of course, a greenhouse gas. There's no question that the nitrogen cycle will limit how much carbon dioxide can be taken up in tropical forests, and in particular a part of the nitrogen cycle called nitrogen fixation.

If plants run out of nitrogen, they can fix it from the atmosphere. It's a fantastic process, a symbiosis between plants and microbes that are housed within nodules that are attached to the plant root that can bring in lots of fertilizer nitrogen naturally. We are beginning to think that this process is essential for allowing tropical forests store carbon over time.

What we found in tropical forests that we study in Panama was a big surprise: the factor that controls this process of nitrogen fixation is not phosphorous, a major nutrient, as everyone had thought, but instead a trace metal, molybdenum. Molybdenum is a part of the enzyme nitrogenase, which is responsible for nitrogen fixation, and it depends on molybdenum. It has molybdenum atoms in its active site. And what we found is that molybdenum is the factor that controls whether fixation can happen or not in these soils.

"...nitrogen is perhaps the most important nutrient controlling plant growth in the world."

It was kind of breathtaking. That's the first time that was ever shown in highly productive tropical forests. We published that last year in *Nature Geoscience*. The first author, Alexander Barron, was a student of mine (Barron AR, *et al*., "Molybdenum limitation of asymbiotic nitrogen fixation in tropical forest soils," 2[1]: 42-5, January 2009).

SW: Were there any unexpected or serendipitous events in your research—moments when your findings were determined as much by luck as anything else?

Many times. I'll give you two examples. The first was the work in Chile. As a graduate student I realized that the work on nutrient cycles in temperate forests was almost entirely done in polluted areas of the northern hemisphere, but if we wanted to actually learn about natural systems and how those are organized, we would have to do it in the far southern hemisphere. As we said, those were the most unpolluted in the world.

Within a week of thinking about that, I had a South American faculty member walk into my office, and he said, "Hi, I'm Juan Armesto and I study forests in Southern Chile." We collaborated for 10 years after that.

Another example is on the molybdenum finding on nitrogen fixation. As it turns out somebody in Panama was running an eight-year experiment testing different kinds of fertilizers to see how the forest responded to them. We were fortunate to be able to take advantage of that experiment. But we were also fortunate because one of the experimental treatments was a mixture of trace metals, which is not usually done. People tend to add nitrogen and phosphorous and that's it, but they'd also added trace metals.

And the curious thing—this is really beautiful—was that when phosphorous fertilizer was added to this forest, we still found an increase in nitrogen fixation in those plots. That went with the traditional model that phosphorous is the primary governing factor on fixation in tropical soils. But then, when we looked at the trace metal treatment, we found the same response. That was very curious. You wouldn't expect the same response from both phosphorous and trace metals.

Here's the serendipity. We realized that molybdenum was the most likely trace metal that influenced fixation, and in phosphorous fertilizer there's often contamination by trace metals. Guess what that was? Molybdenum, at about one ten-thousandth the concentration of the phosphorous itself. We went back and did the experiment again but this time using super-clean, pure phosphorous, and we added that to the forest and we got no response. That was the key experiment that pointed to the sole influence by molybdenum.

That means that in this system, and we're still working to generalize this, but in this system, it was molybdenum that was controlling the fixation. That was serendipity, but we had to have an open mind to really appreciate it.

SW: Did you find that some researchers were reluctant to accept such a radical finding?

First of all there's certainly been a lot of interest from all over the world. We have gotten emails from China, Africa, Brazil, and a lot of other tropical countries. We have gotten supportive comments about how beautiful it was to be able to separate out the effects of molybdenum verses phosphorous. Others maybe misunderstood our findings by thinking that we were arguing that phosphorous is never important, which we did not.

Our current view is that in some environments maybe it's molybdenum and in some maybe it's phosphorous. It just points to how poorly we know tropical forests even though they're really central to our climate systems.

SW: Does this uncertainty about tropical forests affect the modeling of climate systems worldwide?

This becomes a very important question. There are things we know about tropical forests and things we don't. We know they're an important sink for carbon dioxide, but we don't know how nutrients will affect the ability of forests in the future to continue taking up carbon dioxide. Will this carbon sink persist over time or will it become saturated? That's where these nutrients come in and they're absolutely critical. It's a fundamental challenge.

There's a very complex chain of reasoning for why we care about these nutrients, and when we put them into state-of-the-art models, the nutrients really make a difference. Yet there are so many unknowns—how the nutrients affect the forests, how the forests store the carbon, and how the storage of carbon affects the climate system.

SW: If you increase molybdenum concentration further will it continue to increase nitrogen fixation?

That's one question that came up a lot after we published these findings. And the answer is, we don't know that and I hesitate to go there. I'd just be speculating. Right now we're doing some experiments that will get at that, or partly get at that.

SW: How would you describe the ultimate goal of your research?

Ultimately what want to do is build a set of rules for how nutrients govern these highly complex ecosystems, and build them into what's called earth system models. We want to reduce our understanding to mathematical expressions that can then go into these models and allow us to better forecast how nutrients control the carbon cycle.

The carbon cycle on land, which is what we're studying, is the most poorly known part of the global carbon cycle. We're behind the people who study it in oceans in many ways.

SW: What would you like to convey to the general public about your work?

That with global climate change and the human influence on the environment, we now live in a time when we have to learn to manage our environment. In doing so, we have to understand how the environment works as a complex system. We can't take shortcuts. Instead we really need to understand how it works at a deep, fundamental level. That's what we're trying to do.

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Lars Hedin's current most-cited paper in *Essential Science Indicators*, with 269 cites:

Chadwick OA, *et al*., "Changing sources of nutrients during four million years of ecosystem development," *Nature* 397(6719): 491-7, 11 February 1999. Source: *Essential Science Indicators* from Thomson Reuters.

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