Brian Enquist

Forests Around the Globe Follow Same Biological 'Scaling' Laws, UA Ecologist Reports in April 5 Nature

Thursday, 05 April 2001

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Continuing on from an earlier breakthrough that plants scale along similar lines as animals, University of Arizona ecologist Brian Enquist and a colleague now have succeeded in applying the scaling technique to entire forests.

In an article published today (April 5) in Nature, Enquist of the UA's Ecology and Evolutionary Biology Department and Karl J. Niklas of Cornell University report tree populations in closed-canopy forests follow the same allometric trends globally, whether the forest is located in the Amazon or in Canada.

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Allometry refers to the study of how attributes of organisms change with their size.

"That's actually quite unexpected, that across all the complexity that you see, there are these underlying scaling rules," Enquist said. "Now it appears that we can follow the allometric signal all the way from individuals to ecosystems. We find allometry critically influences the structure of plant communities across the globe in a very predictable and regular way."

To apply allometric concepts to a plant community, Enquist and Niklas used a data set of 226 closed-canopy forests, where the trees grows so well that little light reaches the ground. In a pattern echoed throughout the world, the trees fill in the area to capture resources as efficiently as possible while at the same time spacing themselves out as much as they can.

As a result, the number of individual trees in a community can be predicted by knowing the size of the average tree. Many small trees could use the same area and resources as a few large trees, with the number of individual trees scaling to the minus three-fourths power of body mass.

Although few non-mathematicians enjoy thinking in terms of exponents, the three-fourths power rule is one worth considering because it consistently turns up in the study of life forms.

Biologists have long known that animal metabolism does not increase on a 1-to-1 ratio as size increases. Rather, larger animals have slower metabolisms -- and it turns out these rates, as well as many other physiological traits, are predictable using allometry.

For instance, while a typical elephant weighs 220,000 times greater than that of a typical mouse, the three-fourths power rule for how metabolism changes with an animal's size correctly predicts than the elephant needs only 10,000 times as many calories to sustain its great bulk. Other physiological and life-history traits also scale to size, including life span, population density, blood circulation, heart rate and reproduction rate.

"It's always been one of the big mysteries of life, why this happens," Enquist noted.

This mystery captured his attention so much that he decided to pursue graduate study at the University of New Mexico so he could work with Jim Brown, a biologist known for applying scaling principles to animals.

When Enquist asked, "What about plants?" he found that many physiological characteristics in plants, from microscopic algae to giant redwoods, scaled along the same three-quarter power rule that governs animals. This launched a collaboration that came to encompass Geoffrey

West, a physicist at Los Alamos National Laboratory who had been concentrating on scaling issues among subatomic particles. Working together at the Santa Fe Institute in the late 1990s, the trio developed a unifying theory that provides a good reason for the observed trend.

"I think the important insight is that all these allometric relationships that we see in biology appear to be interconnected," Enquist said. "They share a common explanation. It has to do with how organisms have evolved to transport resources from the environment through efficient vascular networks. These networks dictate the rate and timing of all these movements. Allometric relationships merely reflect the constraints of vascular networks."

In a field like biology, where practitioners tend to focus on differences among species and ecosystems, an overarching theory that highlights a "universal" principle seemed destined to create a stir. This it did, and their 1999 results were described in publications such as the New York Times and New Scientist as well as scientific journals like Science and Nature.

Every life form, whether plant or animal, must obtain resources from the environment to support cellular metabolism. They use vascular networks to distribute these resources. In animals, these vascular networks start with major veins and arteries and end in capillaries that nourish individual cells. In plants, the networks carry water and nutrients through the xylem of the trunk to increasing smaller tubes until it reaches the miniscule vessels in the leaves. A mirror image of this network occurs underground ending in the fine roots.

"You can consider the plant itself as a series of individual bundles or cables," he said. The laws of physics apparently dictate the size of these cables, as well as resistance from friction, with the eventual end result being the predictability of scaling by the three-fourths power rule.

"Ultimately, life is a 'tree'," he added. "If you take out your lung, and if you cut down a tree, and you measure the length and width of the branching, mathematically these networks are the same."

Enquist and his colleagues liken the evolution of vascular networks in biology to effectively filling an additional dimension. The networks branch so they fill in the available volume -- which has three dimensions -- in the most efficient way possible. He sees the theory as working well with one of evolutionary biology's classics: natural selection, more popularly if less accurately known as survival of the fittest.

"Because resources are transported across surface area -- lung surface area, leaf surface area, root surface area -- natural selection has acted to maximize those areas. But at the same time, the internal transportation distances over time is minimized. The result has been the evolution of biological diversity that follow the same allometric rules," he said.