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Good-bye, Tarzan

The Science of Life in the Treetops Gets Down to Business

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Notes from the Underground

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GOOD-BYE, TARZAN

For studies of life in the forest canopy, the swashbuckling is over. The science has just begun.

BY NALINI NADKARNI

Yet another continent of life remains to be discovered, not upon the earth, but one to two hundred feet above it. . . . There awaits a rich harvest for the naturalist who overcomes the obstacles—gravitation, ants, thorns, rotten trunks—and mounts to the summits of the jungle trees.

TO THOSE OF US WHO REMEMBER THE FIRST forays into the forest canopy, a mere twenty years ago, it seems astonishing that the trenchant observation quoted above was made almost eighty years ago, by the naturalist and explorer William Beebe. I certainly recall my first day in a tropical rain forest, where low-hanging clouds and lush trees rarely allow the sun to penetrate, when I finally realized what Beebe had meant. Every surface of branch and trunk was covered with mosses and flowering plants, but my eyes were drawn to the treetops. I wanted to climb up, out of the damp stillness of the forest floor.

A month later, in a lowland Costa Rican forest, I got my wish. The tree I chose was an emergent one, a tree that towers over its neighbors. With a powerful slingshot my coworkers and I launched a weighted fishing line over a branch 125 feet up. We tied the line to the end of a nylon climbing rope, pulled the rope over the branch and secured one end of the rope to the base of the tree. Then, with simple but elegant techniques adapted from mountain climbers and cavers, I began to scale my first tropical rain forest tree. A climbing harness kept me roughly upright, and ascending devices, which move only one way along the rope, enabled me to shift my attachment to the main rope alternately between my feet and my torso as I climbed the tree much like an inchworm.

From thirty feet up I could readily see my companions and the shorter trees and bushes below. After another sixty feet I was warmer, partly from the effort of pulling myself up, but also from the sunlight, no longer being filtered by the cover of leaves. Wind rustled through the trees, a sound rarely heard on the forest floor. And I could see at once, firsthand, that the leaves do not grow randomly, the way they look from the ground, but in a spiral pattern that maximizes the surface area exposed to the sun.

I realized I was in the canopy—the treetop region—which is a different world, with its own weather, smells, sounds and life. Far below were the dampness and gloom of the forest. Around me now, as I neared the top of my rope, were wheeling birds, brightly colored insects and sky. From my perch I could see for miles around over the tree crowns of the forest, and I began to yell with excitement, a response I have since heard many times from people first entering the canopy. Questions bloomed in my brain. How do the plants survive in this environment? Without root connections to the earth, where do their nutrients and water come from? What role do the organisms of the canopy play in the larger environment of the forest? No textbook had ever answered or asked such questions. I knew I would be back soon.

A FEW YEARS PREVIOUS, AS A RECENT GRADUate of Brown University, I had had to choose between careers in bioloby and dance. After nine-month trial stints collecting beetles in New Guinea and dancing in Paris, I chose biology. But in a sense, I never entirely gave up dance: every forest is a kind of dance. Its organic material and the environmental conditions it influences stretch from the deepest tips of its roots, twenty-five feet underground, to its topmost leaves, 300 feet above the forest floor. Throughout that volume is abundant life and constant change, but its richest parts are in its upper level, the forest canopy. The canopy may account for 50 percent of the biodiversity in the biosphere, for thousands of undescribed species live arboreally. The consumption of leaves by canopy-dwelling insects and monkeys is a critical stage in the nutrient cycles, the pathways whereby resources are stored and exchanged through rain, leaf litter and foraging animals. The huge surface area created by canopy leaves enhances the interception and storage of nutrients borne by the atmosphere. The structure of the canopy affects wind speed, pollutant concentrations and the water balance of the entire landscape, and it essentially controls the sunlight, weather and temperature on the forest floor.

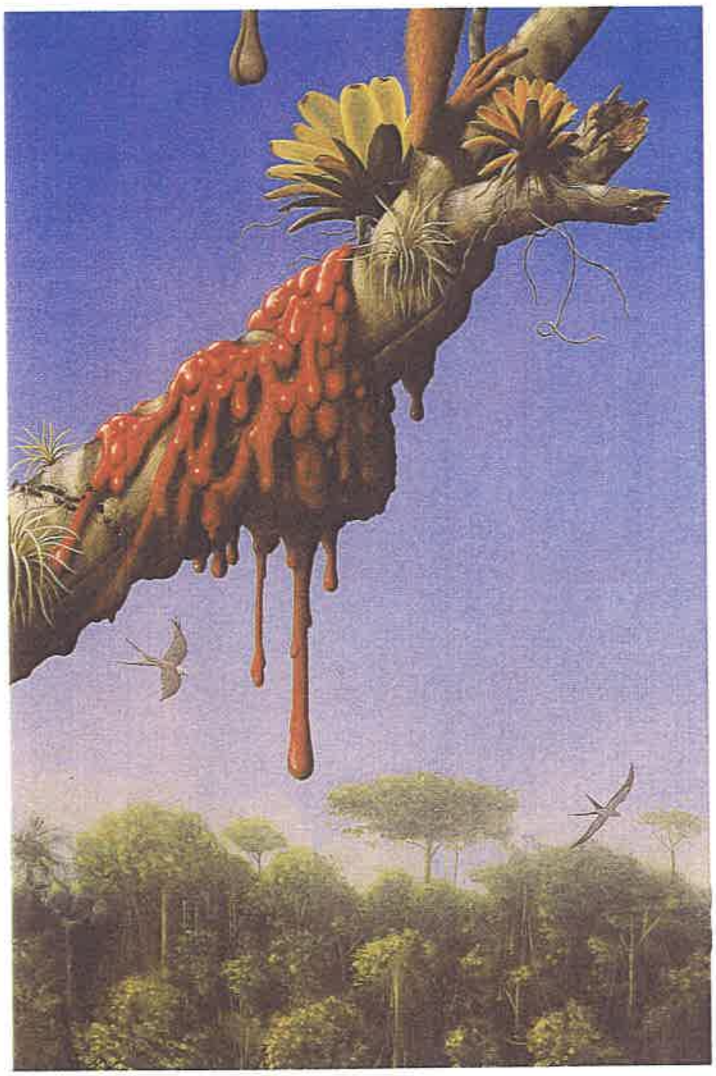
Yet, traditionally, forest ecologists have measured and studied complex ecosystems without leaving the ground. They estimated the growth rates of trees, for instance, by measuring trunk diameters each year at their own shoulder height, then calculating the change in wood volume from year to

Alexis Rockman, Bromeliad, Kaieteur Falls, *1994* year. They estimated the productivity of the forest by sampling leaf litter in known areas, then extrapolating the results to the rest of the forest. They prepared inventories of resident organisms from evidence compiled from traps placed on the forest floor. Biologists who wanted to study arboreal flora and fauna relied on specimens gathered from fallen trees.

Thus until quite recently the canopy had not been studied in situ. The treetops remained an unexplored world. Even among forest ecologists who had an interest in exploring them—and such people were by no means in the majority—there was the undeniable problem of access. Then, in the early 1970s, a small cadre of investigators penetrated the canopy and began documenting the organisms and interactions of the treetop world. Their findings fundamentally altered the notion of what a forest is.

Initial work in the canopy was focused almost exclusively on access. In the early 1970s Oregon workers modified caving and mountain-climbing techniques for use in trees to study the nutrient pools and cycles in old-growth Douglas fir forests. Those inexpensive methods made climbing trees safe for both tree and climber, and soon canopy biologists began to be depicted on television as rope-swinging Tarzans, or Janes: muscled, fearless explorers penetrating an unknown and dangerous world with machetes, crossbows, ropes, spikes and ultralight aircraft. Not for nothing was the entomologist Terry L. Erwin of the Smithsonian Institution moved, in 1982, to call the forest canopy "the last biological frontier."

Historically, a frontier was land that could be claimed by anyone willing to live the often dangerous but independent life of the pioneer. The presence—and subsequent closing—of the American frontier profoundly shaped life in the country. Similarly, the pioneers of canopy research risked their lives climbing high trees in remote field locations, resisted the indifference and ridicule of their ground-based colleagues and worked with little or no background information on their field. But each climb also meant new possibilities, perhaps the discovery of an unnamed species or a ringside seat for some exotic interaction.



Alexis Rockman, Tree Branch, *1994*

Not long ago, while writing the summary chapter for a collection of papers on the canopy, I had one of those minor epiphanies that come rarely but sweetly to academics: the canopy frontier has finally closed. In the past few years it became clear that a distinct field was coalescing, and a few established investigators from other fields joined the canopy pioneers. Now it is no longer necessary always to don climbing boots to reach the habitat of interest; cranes, cables and hot-air balloons extend the biologist's reach and make the journey safer. And those of us who study the canopy are no longer pioneers seeking to occupy a space virtually untouched by other human beings. Ardent young arboreal ecologists may argue that thousands of new species remain to be named and described and that many processes are still to be quantified and explained. But we are now, I believe, settling in. The time has come to take stock of where the discipline has come from and where it may be going.

AFTER THAT first ascent into the treetops, I charged back to my graduate committee and explained the need to pursue canopy biology. I was convinced the study of life in the treetops was the key to the whole of forest ecology. The canopy is defined by ecologists as the aggregate—including air and space—of every tree crown in a forest: foliage, twigs, fine branches and, perhaps most significant, epiphytes, plants that grow on other plants. In my proposal I wrote that I would study epiphytes and their roles in the ecological workings of a forest.

My committee of terrestrial ecologists was skeptical. Were there no scientifically important questions that could be more easily addressed from the forest floor? Tree climbing seemed like too much fun to be real science. But ultimately they acquiesced, and for my dissertation I compared the ecological roles of canopy plants in a temperate rain forest in Washington State with a tropical cloud forest in Costa Rica.

I spent the next two years climbing trees, clipping patches of epiphytes from branches and hauling them to the laboratory to process and analyze. Although epiphytes grow on other plants, they are not parasitic organisms, as mistletoe is, because they do not rely on their hosts for water or nutrients. Epiphytes merely perch on the trees, and if pulled off their host, they will often survive. If a canopy epiphyte falls to the forest floor, though, it will eventually die, presumably from lack of sunlight.

I learned that in temperate rain forests the amount of plant material embodied in epiphytes is four times greater than that of their host trees. In tropical cloud forests the epiphyte nutrients make up about half the nutrients of the tree foliage. I also learned that nearly half the organic material that makes up the thick mats in the tree crowns of the rain forest is dead; it becomes "crown humus," or true soil, formed when epiphytes die and decompose in place. That organic matter supports self-contained mini-ecosystems high above the forest floor, complete with arboreal earthworms, beetles, ants, plants and pollinating birds. Because that soil is nearly ten times as acidic as the soil on the ground, much of the life it supports is quite different from the life on the forest floor.

While scrambling and clipping epiphytes from branches, I made a discovery that explains one way the canopy community nourishes itself. Certain trees send out roots from their own branches and trunks, and those roots snake down into the mats of crown humus. Tracing the root systems revealed that they are a shortcut in nutrient transfer. Trees supporting epiphytes can obtain nutrients without depending solely on their own root systems a hundred feet below. The strategy is not restricted to a single location or taxonomic group of trees but occurs in rain forests as far away from Costa Rica as Chile, Papua New Guinea and New Zealand. Although rain forests appear to be lush and able to support huge amounts of life, in many cases the soil is poor, because constant rain leaches out many of the nutrients. The root shortcuts into epiphyte-generated soil help explain how there can be nutrient conservation in such regions.

Intrigued by the roles canopy-dwelling plants play in the context of the entire forest, my colleagues and I set out to examine the use of epiphytes by birds and other vertebrates. Most studies of the relations between tropical birds and plants tended to focus on resources from trees and understory shrubs. And aside from work done on groups such as hummingbirds, few field studies mentioned the importance of epiphytes for birds.

In 1985 I embarked on a study of epiphytes and birds in a Costa Rican rain forest. With Teri J. Matelson—a highly experienced, sharp-eyed bird-watcher—and my undergraduate student Greg Keyes, I set up fourteen treetop observation arenas in old-growth areas and in younger ones. From sunrise until sunset we sat on suspended portable platforms in six-hour, staggered shifts and recorded the number and behaviors of foraging birds. From close range we watched our subjects probe flowers for nectar, water or insects; pluck and eat fruit; hover at nectar deposits; pick at moss mats and crown humus for insects; or sip water from pools in artichoke-like bromeliads.

Of the fifty-six bird species foraging in our sites, 60 percent hunted in epiphytes. Overall, a third of foraging visits involved epiphytes. In fact, several species seemed to specialize in epiphytic resources. In nine out of every ten visits, the ochraceous wren foraged in crown humus, and the purple-throated mountain-gem sipped nectar from epiphytic shrubs in the blueberry family. The most popular epiphyte, the woody shrub *Norantea,* was a veritable smorgasbord for many bird species. Slate-throated redstarts picked insects off its foliage; silver-throated tanagers and emerald toucanets ate its red fruits; stripe-tailed hummingbirds and purple-throated mountain-gems sipped its nectar; and prong-billed barbets scavenged insects from its branches.

Epiphyte use by animals is not unknown. Birds gather epiphytic mosses and lichens to weave, pad or camouflage their nests, and they bathe in the pools of water that collect in bromeliads. White-faced monkeys pluck and peel back the leaves of tank bromeliads in search of insects. I have seen tree snakes slither along branches and pause at each pool—seeking to feast on a squatting frog or a bathing bird—then move on to the next pool like a teenager cruising fast-food restaurants on Main Street. A diverse assemblage of creatures depend on epiphytes for food, water and shelter, and the community swells the canopy resource pool well beyond what can be created by the host trees. Seasonal differences between epiphytes and their hosts make resources available at different times of the year.

> Tree snakes slither *along branches and pause at each pool, seeking to feast on a squatting frog or a bathing bird.*

Such discoveries were truly frontier science. The canopy root systems had been waiting forever under epiphyic mats for any mildly observant biologist with a plant clipper to scramble around and make the connection. Likewise, birds, monkeys and snakes had long been flourishing, courtesy of the canopy's epiphyte community, and needed only three biologists with a convenient perch and time on their hands to be discovered. Just as in 1848, when the first pioneers who arrived at Sutter's Mill, California, stumbled over gold nuggets, the riches were there for the taking. Later arrivals would have it harder, needing equipment and patience to tease the more obscure bits of gold from dirt.

After publishing my results in scientific journals, I continued my research in the Costa Rican canopies. Not all was clear sailing; the National Science Foundation, dubious about the scientific validity of canopy work, turned down my grant requests on three consecutive occasions. But within a few years, more canopy-science papers were published, and an international symposium devoted to epiphytes convened in 1986. The field began to gain legitimacy and to flourish.

As interest in forest canopies grew, so did the means of access and measurement. Antenna tower systems were erected to study meteorology from the forest floor to above the canopy. The "canopy raft," a magnificent—and costly—hexagonal net, was created by the French biologist Francis Hallé of the Laboratoire de Botanique in Montpellier, France, and gently deposited by hot-air balloon on top of a Cameroon rain forest canopy in the mid-1980s. The use of large construction cranes has dramatically enlarged the range and ease of data collection, enabling a pair of biologists to sit comfortably in a gondola that can be raised and lowered mechanically to nearly any location within a seven-and-a-half-acre area.

With that kind of access, data can be gathered easily, repeatedly and not only from the trees but also from the spaces between them. Even the biologists on the ground have joined in the canopy gold rush, shooting insecticidal fog into the canopy with a motor-driven blower to harvest canopy-dwelling arthropods. Satellite remote sensing, based on the differential reflectances from surfaces of vegetation, can show the canopy on a far larger scale than can be perceived by a single tree-clinging biologist. Such techniques have given workers the time, once spent brooding about how to work safely in the treetops, to analyze and interpret the data they collect. Ironically, the future canopy biologist may not even need to move away from a computer screen and modem to do treetop biology.

How will a Daniel Boone fare when he is taken from his log cabin *and deposited in a suburban ranch house?*

THE TOOLS HAVE BROUGHT WITH THEM AN explosion of interest and advances in the field disproportionate to the pace of general biology. Funding for canopy projects is finally flowing, including a million-dollar U.S. congressional allocation to purchase and maintain a construction crane for study of old-growth forest canopies in the Pacific Northwest. Thus a large—albeit uneven—body of information on the canopy of tropical, temperate and boreal forests now exists. The frontier has closed, and in the wake of the pioneers have come the farmers, the settlers and the burden of society.

Other scientific disciplines have been here before. For marine biology the invention of the Aqua-Lung opened the bottom of the ocean to study and marked the beginning of the field's professionalization. Canopy scientists are in the midst of a similar transition—from biotic frontier to terra cognita—and face the problem of how a Daniel Boone will fare when he finds himself taken from his log cabin and deposited in a suburban ranch house. What new challenges await workers in a field now swamped with newcomers itching to gather the fruits that only a decade ago belonged to the intrepid few?

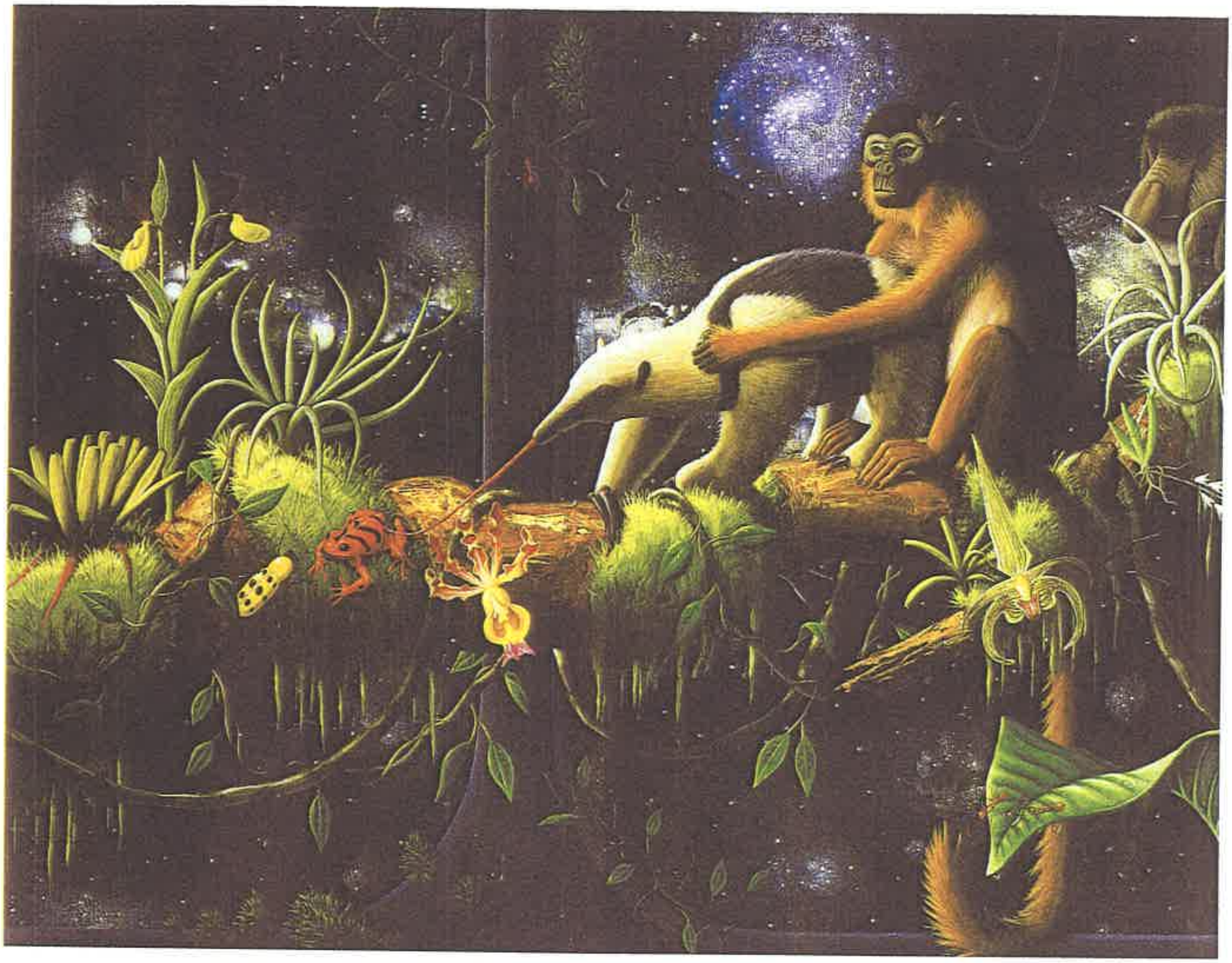
Ecologists are still grappling with the dynamic three-dimensional data that a forest yields. The scientific value of mapping and analyzing the spatial distributions of relations between organisms in two dimensions is already clear. For example, because desert plants compete for water, their spatial distribution is regular. Other plants, which might depend on each other for pollination, reflect that interdependence in their patterns on the ground. Such spatial studies have led to insights about the chemical and biological processes that underlie plant interactions.

But in the canopy—a three-dimensional ecological system par excellence—the spatial patterns have not yet been identified, mostly because of their complexity. Methods that yield sound field statistics, as well as reliable estimates of population distributions of canopy inhabitants, do not yet exist. Part of the reason for such a lack of information is that the methods of collecting, storing and analyzing data have been notoriously independent and often idiosyncratic. Rope climbing traditionally encourages investigators to work singly or in small groups, and so they produce small sets of data.

NOW THAT THE PROBLEMS OF ACCESS AND perceived legitimacy have been solved, canopy workers must find ways of deriving results accessible to many people. For example, Hallé's canopy raft was conceived as an independent project, but a raft expedition now being planned will be a coordinated effort by many teams working on complementary projects. Investigators will study such phenomena as leaf nutrients and insect diversity across a common canopy structure. Similarly, the canopy crane to be erected in the Pacific Northwest will enable investigators to study questions ranging from tree architecture to the effects of air pollution on canopy lichens. Those investigators will require spatial information on the underlying substrate—tree trunks, branches and foliage—to coordinate their data.

Data from the canopy will be valuable to geographers and land-use managers, among others. Conversely, information from those fields can aid canopy ecologists. Such reciprocal use of information demands that one think in advance about how the data should be organized, to ensure that it will be available to workers in other specialties. To address that issue, Geoffrey Parker of the Smithsonian Environmental Research Center in Edgewater, Maryland, and I were awarded a planning grant from the National Science Foundation to bring together forest canopy investigators and workers from many other fields to develop methods of dealing with three-dimensional data. Of course, some tools could be borrowed from other disciplines, such as oceanography, electrical engineering, astronomy, hydrology, and medicine, especially computerized tomography. One approach is to visualize the canopy as a collection of many small volumes of air, leaves or wood. In that way, the numbers of each kind of volume can be summed, and thus the entire space determined. There are also ways of reconstructing two-dimensional images into three-dimensional ones.

Another urgent task for the new science of the canopy is



Alexis Rockman, Biosphere, *1992*

to characterize its community of scientists. How can canopy investigators communicate—and capitalize on one another's work—given the vast range of subjects that inform their research? No single journal or regular meeting is devoted to their work, yet some seventy-four journals have printed articles related to the canopy. Last year alone canopy biologists and ecologists attended seventeen professional meetings. Perhaps most telling is that there is still no consensus about the software that canopy workers ought to use, a fact that severely limits the exchange of data.

What emerges is a fragmented picture of canopy science. Although a wide range of tools is available—both for access and data analysis—few avenues exist for formal communication and synthesis among disciplines. Interests, backgrounds, perceived problems and ways of overcoming them are as broadly scattered as is the roster of a university. The approaches are both qualitative and quantitative, and the tools range from the simple to the highly technical. Many workers strongly sense the need to exchange information and tools. Many of the primary issues described by canopy ecologists require an understanding of—or at least data on—structural and physical aspects of the canopy. Conversely, workers who undertake remote sensing are eager to validate their results with information obtained in the field, which would perhaps reveal the biological and physiological underpinnings of their images.

CANOPY SCIENCE NO LONGER BELONGS TO mountain climbers and gymnasts. Indeed, the tasks of moving into the three-dimensional space of the canopy and creating the corresponding three-dimensional pictures of it are easy, at least compared with the daunting task of standardizing the methods of data collection and organization. Canopy biologists have had to be fiercely independent for a long time; for some the idea of setting standard protocols for accurate comparative work may be more formidable than scaling a giant redwood tree. Shifting research activities from forest to computer does not come easily to one accustomed to long days hanging hundreds of feet above the earth, and the skills of the pioneer may not be the strengths of the settler.

And so a long climb awaits. The last biotic frontier is dead. Long live the next one. ●

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