Traveling across the treetops
A crane’s-eye-view of Panama’s forest canopy yields biological surprises

The cagelike, steel gondola lofted by a construction crane swings slowly next to the 30-meter-high crown of an Anacardium excelsum tree. Purple flowers from an immense network of vines cover the bright green crown. The flowers teem with colorful animals: bees, hummingbirds, butterflies, beetles, and day-flying moths. A meter-long iguana creeps along a nearby branch.

All around the A. excelsum are other species of trees, also draped with vines, known as lianas. The plants come in a wide variety of sizes, shapes, and orientations that aid them in their competition for light.

“This is a frontier of discovery,” says Stephen S. Mulkey, a plant ecologist with the University of Missouri at St. Louis and a research associate of the Smithsonian Tropical Research Institute (STRI) in Panama. “It makes you wonder why we spent so much time in the understory, when the action is up here.”

S. Joseph Wright, an STRI research biologist, stands next to Mulkey in the gondola, noting the crane’s ability to put researchers face-to-face with canopy plants and insects. “Previously, we’d basically been standing on the floor, looking up, or just ignoring what’s up here,” says Wright.

For six years, the STRI biologists have conducted crane-based research on what they refer to as “the business end of the tropical forest”—the upper canopy. This top layer of leaves and branches is a living boundary between the atmosphere and a sea of diverse life. It is a boundary where heat, oxygen, water vapor, and carbon dioxide are interchanged between the biosphere and the atmosphere. The extremes of sunlight here drive photosynthesis at rates well beyond those of the understory, pumping energy into a complex system of leaves, flowers, fruits, and animals.

One goal of the crane studies is to uncover the biological details of this system. A longer-term goal is to incorporate findings about plant physiology at various levels—leaf, tree, stand, and landscape—into models of regional gas exchange. Such models could be crucial to understanding how tropical forests affect the global atmosphere, including its carbon balance.

The STRI crane (BioScience 42: 664-670) was the first crane put to use in canopy research. The idea for the crane crane was hatched in the late 1980s by Alan P. Smith, former assistant director for terrestrial research at STRI, who died in 1993. The 38-meter-tall original crane was erected in 1990 in the semideciduous forest of Panama City’s Parque Natural Metropolitano (PNM) as part of a feasibility study. Decommissioned in April 1992, it was replaced with a crane 4 meters taller. The cranes have led the way in a blossoming of research in forest canopies.

In a relatively short length of time, biologists at the Panama site have delivered an impressive array of findings, assisted both by the crane and by advances in portable analytical equipment. So far, researchers from 14 countries have conducted projects that have ranged from studies of insect biodiversity to sampling the ways that plants respond to changes in microclimate and carbon dioxide concentration.

“The forest canopy access system has proved to be feasible, and its immediate success in supporting research has exceeded our expectations,” says Ira Rubinoff, director of STRI. Advances are coming along so quickly that STRI and the United Nations Environment Programme (UNEP) have organized a Tropical Forest Canopy Conference, which is to be held in March 1997 on the STRI campus in Panama.

Up to the canopy

Only in the past few years have researchers begun to give much attention to the upper canopy, where an estimated 90% of all tropical forest organisms live. Much of the delay was because it is so hard to reach. Biologists learned to climb trees, build walkways, and even lower an inflatable raft from a dirigible. These techniques proved less than ideal.

When researchers could not get up the trees, they managed to bring down what they needed and, in the process, ruined opportunities for long-term study. Plant ecophysiologists, for instance, used to study gas exchange in these tall canopies by shooting a branch down with a shotgun and quickly clamping on a gas analyzer. “This is where the crane is so powerful,” says Mulkey. “You can come back repeatedly and sample any site in the canopy in a nondestructive way—throughout the lives of the leaves.”

With a horizontal jib of 51 meters, the crane currently in use in Panama gives researchers access to 8000 square meters of upper canopy surface and 28,000 cubic meters of for-
est volume, including approximately 140 individual canopy trees.

The crane research, a cooperative effort of STRI, PNM, and UNEP, has received funding from the Smithsonian Institution; the governments of Finland, Norway, and Germany; the Andrew W. Mellon Foundation; the US National Science Foundation; the German Space Agency; and the Norwegian Institute for Nature Research. Its success has inspired other groups. A canopy crane project led by the Austrian Academy of Sciences began work in late 1995 in a rain forest along the upper Orinoco River in Venezuela. US researchers began work in 1994 in a canopy crane in the old-growth coniferous forest of the Thomas Munger Reserve in Washington State. This crane, named the Wind River Crane, is maintained by the University of Washington and the US Forest Service’s Pacific Northwest Research Station and Gifford Pinchot National Forest.

A world record

Among the broadest advances made using the STRI crane has been in understanding plant physiology in the upper canopy. Here, leaves are exposed to windier, drier, and brighter conditions than in the strata of forest below. Changes in temperature and humidity are greater on top—both daily and seasonally.

The mid-day temperature in the upper canopy can be 5°–8°C higher than on the forest floor, and the relative humidity is often 30% lower than near the ground. The upper-canopy plants at the crane site get no rain during the extremely arid dry season, yet they must face up to 1,500 millimeters of rain in the rainy season.

The researchers have found that different plants respond to these dynamic changes by varying leaf carbon exchange rates, canopy photosynthesis, and water management. At the PNM site, Wright, Mulkey, and their colleagues found that light intensity generally drops 90% or more just beneath the canopy surface, and that leaves in this shaded sub-canopy have gas exchange rates characteristic of leaves of shade-acclimated understory plants.

STRI’s Klaus Winter and his colleagues discovered a world record of sorts: a fig tree, Ficus insipida, was found to have the highest photosynthetic rate of any tree species yet studied—it takes up carbon dioxide six and a half times faster than some other tropical forest canopy species. The high photosynthetic rate for F. insipida was not surprising, because this species colonizes forest gaps—a habitat known for high light intensity. It has adapted to live its entire lifetime in intense light.

The biologists note that despite the world record, F. insipida is likely to turn out to be just an also-ran, because few canopy species have been sampled so far. These data will be useful not for record books, but in

The use of cranes to travel into the upper reaches of the forest has opened up research possibilities that were unheard of when scientists had to climb the trees themselves. Stephen S. Mulkey (left) and S. Joseph Wright visit the treetops in the Smithsonian Tropical Research Institute’s crane to understand the workings of the forest canopy in Panama. Photo: Kaoru Kitajima.

Most scientists who study the canopy consider the crane invaluable because it gives them the ability to evaluate forest spaces with volumes on the order of 28,000 cubic meters, without harming trees. Photo: Antonio Montaner, Smithsonian Institution.
This crane tower is self-erecting. A pneumatic pump raises it to a height of 42 meters, pushing it above the 30-meter-tall canopy. Photo: Antonio Montaner, Smithsonian Institution.

establishing carbon gain and other characteristics of plants for use in, among other applications, regional carbon exchange models.

So, too, will be data from a study by Catherine Lovelock, a post-doctoral researcher at STRI, and Winter. They showed that the carbon gaining capacity of trees may be limited by the ability of branches to use extra carbon. By exposing individual branches to a doubling of carbon dioxide, the researchers found that the extra sugars produced in the branch may have been used locally and apparently did not affect growth in the rest of the tree.

After some time under carbon dioxide fertilization, the photosynthesis rate in these branches declined, approaching its original level, despite the availability of additional carbon dioxide. One implication of this finding is that predicting an increased growth response in an environment higher in carbon dioxide may not be as simple as some scientists thought.

Making optimal leaves

To deal with the environmental extremes in the upper canopy, plants must make tradeoffs. They invest their resources in different ways than they do in other layers of the forest, and this determines the types of leaves they produce. For instance, a thick, drought-resistant leaf loses less water during the dry season than does a thinner leaf. However, such thick leaves are inefficient at sunlight capture under the cloudy skies of the rainy season. Put simply, one of the questions addressed by the crane researchers is: Which leaf is better for the tree and at what time of year?

The answer, they discovered, is that plants have evolved many ways to solve this problem of tradeoffs. Kaoru Kitajima, an STRI post-doctoral researcher working with Mulkey and Wright, found that some canopy species, such as Luehea seemannii, produce two kinds of leaves in one year—a drought-resistant leaf with high photosynthetic capacity for the sunny dry season and a thinner, more slowly photosynthesizing leaf for the wet season.

Interestingly, this dry-season leaf is produced near the end of the seven-month rainy season, when water is abundant. Mulkey and Wright suspect that this switch just before the end of the rainy season is a general phenomenon in the tropical canopy. These leaves take advantage of the opportunity for carbon gain before water stress sets in but while clear skies enable more photosynthesis.

Just as intriguing, Mulkey and Wright have discovered that trees maintain their maximal leaf area for only a short time—approximately three to four months, corresponding to the period just before flowering. They censused more than 39,000 leaves of nine tree and liana species and found that total leaf area changed by 50% to 300% within the wet season, depending on the species.

The finding is important for global climate models. Some models assume that leaf area remains constant during the wet season and declines in the dry season. Nature is not nearly that simple.

Another surprise was a strategy used by A. excelsum to deal with the problem of maximizing carbon gain and minimizing water loss in the upper canopy's harsh environment. Frederick Meinzer and Guillermo Goldstein, biologists from the University of Hawaii, found that the tree's complex whorls of leaves create considerable dead air space, so that when stomata release water vapor during photosynthesis, the moisture tends to hang in the dead air and buffer leaves from the surrounding dryness. This strategy, combined with stomata that readily close in response to a drop in humidity, allows A. excelsum to avoid significant drought stress during the dry season.

"It's really a remarkable organism," Mulkey says. "We had no idea it had these features until we got into the crane."
Canopy research network blossoms

As canopy research has blossomed, so has a new organization aimed at aiding communication among people and institutions involved in canopy research, education, and conservation. The International Canopy Network (ICAN), a nonprofit group, was founded in 1994 when the Canopy Research Network and the Canopy Institute united. The network had included mainly canopy researchers; the institute promoted conservation through interpretation of canopy research to nonscientists.

"By including researchers, educators, conservationists, and arborists under one 'crown,' links among these groups can be more easily forged," says Nalini Nadkarni, president of ICAN and a canopy biologist with The Evergreen State College, Olympia, Washington. ICAN is funded by subscriber dues, donations, and grants. More than 800 members in 51 countries pay a $30 annual fee and gain access to a quarterly newsletter, a directory of ICAN members, and a bibliographic database on both scientific and popular aspects of canopy science. The group sponsors an electronic mail bulletin board and World Wide Web page (http://esnet.edu/ican) and organizes scientific symposia and meetings. It plans to start a library of color slides and videos and create interpretive materials for school children. —WA

Crowded with insects

As biologists strive to document biodiversity against a backdrop of global habitat destruction, they are acutely aware that the tropical forest canopy may hold the largest reservoir of yet-to-be-documented species. A controversy ensued in 1982 when Terry Erwin of the Smithsonian Institution in Washington, DC, published an estimate that tropical forest canopies are home to 30 million undescribed arthropod species. Only 1.8 million species of animals and plants—in or out of the canopy—have been described.

Part of the controversy involves a method for estimating numbers of species in tree crowns. That method—broadcasting insecticide and counting species that drop—fails to distinguish between arthropods specific to the host tree and those simply passing through. The beauty of examining live insects and related organisms is that researchers can directly observe their life histories and sort out host specificity. "With the crane, we can look at the behavior of insects," says Wright. "We're not stuck with dead bodies."

Working in the crane, Milton Garcia, a graduate student at Universidad de Santa Maria Antigua, in Panama City, found that fewer than 150 beetle species inhabit L. seemannii. That is nearly an order of magnitude fewer beetle species than Erwin had estimated for the same tree species. On the other hand, Frode Odegaard, a predoctoral student from the University of Trondheim, in Norway, found 70 species of weevils and leaf beetles that survive by scraping the tendrils of the lianas that weave through the canopy. Moreover, Odegaard discovered more than 1100 species in these two beetle families in the canopy beneath the crane, and the rate of discovery of new species was undiminished after 600 hours of censusing.

These numbers and the observed level of host plant specificity are surprisingly compatible with Erwin's original estimates. The STRI researchers say more work using the crane in different types of tropical forest and at different times of day and night will be crucial. "The bottom line is that this new information may help settle this debate," says Wright.

The future

Such comparative studies are about to begin. A new crane, financed by a contribution from the Danish government to the STRI/UNEP canopy biology program, arrived in April and was scheduled to be erected by the end of 1996 in a site on the Atlantic side of Panama within the US Army's Fort Sherman. At press time, the STRI researchers were planning to move the canopy crane at PNM in March 1997 to a well-developed dry forest on the Pacific side within a second US military reservation. Says Mulkey, "The comparisons that will be possible between this site and the Fort Sherman site on the Atlantic side will be very exciting."

The wider range of habitats will not only provide a broader perspective on the arthropod biodiversity question, but also will allow researchers to learn more about environmental variation within individual tree crowns and physiological processes within and among tree branches. Canopy studies also may lead to satellite remote sensing of forest dynamics, if researchers can establish reliable measures of the light reflected by leaves as they execute their various strategies. Another area of keen interest is the role that lianas, epiphytes, and other canopy-dwelling plants play in moving carbon, water, and nutrients within the forest ecosystem. Such are the details needed to improve the accuracy of models for what occurs at the boundary between the atmosphere and the business end of the forest.

William H. Allen is a science writer for the St. Louis Post-Dispatch and a 1996-1997 Knight Science Journalism Fellow at the Massachusetts Institute of Technology.

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