Views from the Top: The Evolution of Forest Canopy Studies©

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In any area of science, the field progresses from being a young field to a maturing field, and finally becomes mature. The field of astronomy, for example, could be considered a very mature field. It started out with people who have an object of interest, such as the moon or other celestial body. There is usually some sort of technological discovery or breakthrough—in that case, a telescope—that allows them to get closer to their object of interest. There also has to be a pulling together of a large number of people, so they can gather the resources they need in order to explore their object of interest further. When there are enough resources, enough interest, enough technology, and enough scholarship, they actually get to go to that object of interest and explore it even more deeply.

When I was in graduate school, the study of forest canopies was at a very young stage of development. People had not climbed into forest canopies—they knew different plant and animal species lived up there, but they did not consider it as a field of science worthy of formal study. The first thing they needed (just as astronomers needed a telescope) was the technological means to get up to the forest canopy. Until about 20 years ago, the only way to climb up there was the childhood method of shinnying up the tree, which is not very safe and is rather restrictive. Over the last two decades, people have been very clever in the way they have gotten into the canopy. They have built towers to study the microclimate of the canopy. They have built catwalks in order to catch arboreal insects that pass through the forest canopy.

They have also applied mountain climbing techniques to trees—which is my method of choice. We shoot lines into trees, we pull up ropes, and then using simple mountain climbing equipment, which costs less than $300, we haul ourselves into the canopy. Don Perry, for example, ties three cables together so he can move up and down and occupy that three-dimensional volume below him. There are more elaborate and more expensive techniques, such as hot air balloons. The “canopy raft” was developed by a group of Frenchmen at the University of Montpellier. This raft is lowered gently on the top of tropical rain forest trees, and people can collect samples from the tops of these trees.

The most important and amazing development in terms of the technology of getting into trees is the use of canopy cranes. These are off-the-shelf construction cranes we put into rainforests. One example is the Wind River Canopy Crane Research Facility, in a temperate coniferous forest in Washington State where I do some of my work. This crane was used to build the San Francisco Public Library before we bought it. We painted it green and put it in the forest. The jib is 290 ft above the forest floor, and circles around 360 degrees. The jib goes in and out and up and down, so it can get to the three-dimensional volume of the forest canopy. One of my colleagues, Geoffrey Parker, for example, can measure the photosynthetic capacity of a single leaf that he measured the year before. For the first time, we can now understand the effects of aging and time on leaf development and carbon production—a fantastic part of our toolbox of ways to understand the forest canopy.

I will now discuss the development of scientific processes and the progression of science with regard to canopy studies. Having learned how to get into canopies. We can now ask the question, "What type of studies do we do as our research progresses?" In general, when you start out in a young field of science, you tend to do studies about patterns—basically descriptive studies—asking what is there: What's there on the moon?, What's there in the treetops? As your field matures, you are able to do experimental work. This lets you ask process-oriented questions such as "Why is this here?, Why isn't that there?" Finally, in a very mature field, you have enough information from pattern and process studies to get to predictive questions.

The early canopy researchers, including me, started out with basic descriptive studies. We went up into the canopy and we found plants and animals that had not been documented or even named before. We had opportunities to observe camouflage. It was wonderful to climb into trees and see examples of this sort of interaction. Many of the early studies were pure natural history studies. Neil Rettig, for example, spent 6 months in French Guinea in the top of a tree, a *Ceiba* tree, documenting the life history of the harpy eagle, the largest predatory bird in the world. He followed the life cycle from egg to chick to adult. This kind of work would not have been possible if he had remained on the forest floor.

There are many plants that live exclusively in the canopy, and these have intrigued botanists for hundreds of years. They obtain their nutrients and their water not from putting their roots in the tree or their roots on the ground, but rather by gathering nutrients that are dissolved in rainwater and mist. It is these plants—the "epiphytes" (plants that grow on other plants)—and their ecological roles in the forest as a whole that I became very interested in as my own career developed. Some epiphytic plants are as large as whole trees; other species are so small they can grow on the surface of a single leaf. Imagine the life cycle of such a plant—they need to be speeded up in order to get their life over with before the host leaf falls—that can present some challenges in terms of life history. Many plant-animal interactions can be documented high in the canopy that cannot be seen on the forest floor. Processes that are absolutely fundamental to the maintenance and the reproduction of the forest, such as pollination and fruit dispersal, all could be observed by these early explorers of the forest canopy, in the canopy.

I have done my work in the Monteverde Cloud Forest, in Costa Rica, starting work on patterns, then process, and now predictive work. Every surface of the stems, the branches, and the trunks, are covered with epiphytic plants. Since 1983, my students, colleagues, and I have been describing the nutrient inputs to that canopy system, how nutrients are captured and moved around, and how they are moved to other parts of the ecosystem. We measure mist input with giant sieves that capture cloud input as it blows across the forest canopy. We climb into trees and cut off patches of mosses that occur on the inner branches of large mature trees. We take these branches and these moss mats down to the our lab and we analyze them. We spent 5 to 7 years simply describing this material. I am fascinated by them because they are little ecosystems unto themselves. They have all the ingredients of a full ecosystem, including vascular plants, non-vascular plants, dead organic matter that accumulates underneath those mosses, and even invertebrates—insects and earthworms.

In fact, one of the first studies on these arboreal ecosystems was done by my husband and me. My husband, Jack Longino, is also a tropical biologist—he studies insects. We extracted the invertebrates from the dead organic matter in the canopy and compared them to the insects that live on the forest floor. We found that although the overall density of invertebrates was much lower in the canopy, all the major groups of invertebrates existed in that forest canopy, including earthworms and slugs and species that you would normally expect to see crawling about on the forest floor.

In later work, one of the phenomena I discovered was that some of the host trees that support epiphytes and these dead organic matter mats actually put roots out from their own branches and trunks, snaking into that dead organic matter and taking up nutrients. This was a phenomenon that, although obvious when you pull back these mats of organic matter, had never been reported before. As a graduate student in 1981, I published this result on the cover of *Science*, one of the major journals of science. Suddenly, canopy work was not just Tarzan and Jane, swinging in the trees. It wasn't just finding a new species of some obscure orchid or earthworm. Rather there was something of deep scientific interest about the forest canopy, enough to warrant the cover page of *Science*.

It was at this time that we began to feel that canopy studies were beginning to mature. Studies that followed the *Science* article included going to that next level of maturity—the process-oriented studies. I mentioned that we cut off mats of epiphytes and I was curious as to how long it would take these mats to grow back. I presumed it would be very quick because epiphytes grow so well in a cloud forest like Monteverde. We put a little nail and marked where these bare patches were. I came back 6 months later and nothing had grown back. A year later, nothing had grown back. It was not until 8 years later that I recorded the first bits of re-colonizing epiphytes. They came back not from the side as I had expected, but rather from the bottom of the branch. There was a thin "scuzz" of moss and algae that grew from the bottom of the branch. I realized then that these epiphytes, once disturbed, are actually very fragile ecosystems. We have since done some experimental work where we take bits of colored moss and we drop them on branches (stripped branches and nonstripped branches) to try and understand the mechanism of why this process of recolonization is so slow.

We are now moving towards predictive studies. The advent of global climate change and its impacts provides a venue to investigate this. In cloud forests, it has been predicted that the cloud banks that bathe the cloud forests in mist and fog are going to move up the mountain because of the higher sea and land surface temperatures. Our recent studies show that epiphytes, which rely on this dense fog, are probably very good indicator species for global climate change—something that is very difficult to document quantitatively. Thus, our Monteverde work has progressed from pattern to process and now to predictive studies.

I now discuss this progression of science with respect to the types of data that canopy researchers pull together. Data are the currency of the scientific world. As a scientist in a young field of science, one tends to collect data idiosyncratically. I collect data in my little notebook and Geoffrey Parker collects data in his little notebook. Nobody can easily compare data. As the field matures, you can start making linked data sets that allow for comparative work. Finally in a mature field, such as human genetics, the whole field uses one giant linked data set which makes for a very efficient and productive way to do science.

Canopy studies is just now moving out of the single-researcher idiosyncratic stage. A survey of canopy researchers we conducted in 1994 indicated that what was holding back canopy studies was not access into the trees, which we have largely overcome with our technological tools. Rather, the major obstacle has been our inability to link data, share data, and to do comparative studies and to use and reuse canopy data that are actually difficult and expensive to get. We linked up with some computer database experts and got a grant from the National Science Foundation to start what we call the Canopy Database Project. We are combining efforts of forest canopy researchers with database scientists to create software tools that will help us manage, analyze, and disseminate data on forest canopies.

We decided to focus as a first step on forest canopy structure—something that is absolutely basic to understanding forest canopy function. Canopy structure has been the object of interest for many decades of forest ecology research. People have made "profile diagrams" based on real forest data. Now, computer scientists are experimenting with other means of visualizing structure with computer graphics. Other data, emanating from remote sensing and satellite imagery, now allow us to look at canopy structure at a much larger spatial scale than has ever been possible.

Because there are so many ways to look at and visualize forest structure, we were challenged when we tried to come up with standardized or harmonized ways that people could look at canopy structure together. Our canopy database team realized we could simplify the way people deal with tree structures. We recognize that there are a finite number of ways in which you can put trees together. If you measure trees as cylinders, or trees as sticks, you can match those up with the different ways of measuring tree branches and tree crowns. Now we are trying to put together databases in which people can say "I measure my trunks like this, but my foliage like that", and therefore they can put together data and compare them to other data very efficiently. We are also working on what we call the "Big Canopy Database", in which we pull together information that will be useful for canopy researchers ranging from safety plans to scientific citations to visualization programs. This will allow us to progress in our field of canopy studies more efficiently.

In our explorations of how to deal with canopy structure, I have realized that there are trees everywhere in our lives—not just botanical trees. In marine systems there are "trees" in the form of fan anemones. We can ask how marine biologists deal with tree-like structures. When I fly in an airplane and look over a river system, I realize that a river is nothing more than a tree that has fallen down, been flattened off, and filled with water. Thus, we might learn from hydrologists, and hydrologists might learn from us in terms of how to map and understand tree data. We have trees in our bodies: dendritic nerve systems, blood vessels in our muscles, and trachea in our lungs. Even when you look at road systems of suburbia from above, you realize that there are tree-like in form. So part of our exploration now is to go to other fields—allied fields and non-allied fields—and figure out how they deal with tree-like data.

We can also think about communications in terms of its way of developing in a scientific field. When canopy research was a young field, communication was very personal. I would call Jess Parker on the phone and ask him what he did about a particular data set he had collected, and he would call somebody else. Now we have been developing some informal networks. We have not yet created formal programs such as graduate programs, but we do have the International Canopy Network. This group was formed in 1994 by myself and a graduate student, Joel Clement. We created a nonprofit organization called the International Canopy Network, with the positive acronym of ICAN. The idea is to bring together researchers, educators, and conservationists who are concerned with forest canopies. Our primary desire is to provide multiple pathways of communication. We have an email bulletin board with about 750 people subscribed, a quarterly newsletter called "What's Up?", and a web page. We link people and information together.

We believe strongly that it is very important to inform the next generation of the importance of forest canopy biota and organisms. Given the generation time of trees, if we do not teach the saplings of *our* generation, those trees are not going to persist into the next one. We write articles for kids' magazines, such as, *Dragonfly, Highlights for Children,* and *Ranger Rick*. We give talks in schools, usually at the 4th to 6th grade levels. We have a program called "Ask Doctor Canopy!", where kids can write or email their questions about the canopy to a body of eight volunteer canopy researchers that responds to the children. This is important not only to transmit the information about forest canopies and how long a python is, but also the children understand that scientists are real people, and that they find it worth their while to actually communicate with kids.

We do not delve into politics or policy too much, but we try to spread the word about the forest canopy as broadly as possible. We enter the political realm for symbolic actions. For example, Governor Gary Locke of Washngton State signed a proclamation to announce that 17 July to the 24th is Forest Canopy Week in Washington State. This is a symbolic way to make people understand that forest canopies are indeed fundamental to many aspects of our lives.

One of our big activities is consulting to the media. We give scientifically sound information to media people, including "*Heroes of the High Frontier*". We attempt to keep sensationalism out of it — e.g., how many poisonous snakes have bitten you? Rather, we convey the importance of scientifically sound information about forest canopies through whatever means we can.

The final category I will discuss concerning the development of canopy science is the relevance to societal issues. Scientists in a young field start out with curiosity-driven questions, e.g., how many katydid species are there in the canopy? As the field matures, the questions that scientists come up with in that field tend to be more socially relevant. This is the case with forest canopy studies. We now realize that many of the pressing environmental issues that face our society today bear greatly on forest canopy research. Issues such as global warming and carbon storage, are relevant, as the major part of carbon storage occurs in forest canopies. The issue of the maintenance of biodiversity in our planet is also relevant, as the major part of biodiversity occurs *in* forest canopies. It has been estimated that over 50% of all of the species on our planet reside in tropical rain forest canopies. Thus, those who study canopies should have something to say about how these resources might be understood and managed. A third issue is the sustainability of forest products, and how we can maintain those in a healthy way. A group of forest ecologists and forest canopy researchers have recently formed the Global Canopy Program. They are obtaining funding from international agencies to link existing canopy field sites all over the world to answer questions about global climate issues, maintenance of biodiversity, and forest sustainability.

What I have described so far is that forest canopy studies have matured to some extent, but there is still a long way to go. I have been riding and driving that progression ever since my days as a graduate student, and I am wondering now, in my own stage of development as a more senior researcher, where do I go next? Do

I continue with these pattern and process studies and extend these to other forests?

I find that what is more important to me right now is to contribute to forest conservation. I hope to understand how I could apply what I know about forest canopies to conserve them. I realize that humans tend to preserve that which they know the values of. For example, we value Steinway pianos and therefore we take good care of them. We make sure they are in the right relative humidity; we tune them every 6 months. But we do not take very good care of the things that we don't value, or that we don't know the values of.

I am now trying to assess, integrate, and communicate what I can find out as to *all* the values of forest canopy organisms. These will include not just the ecological ones, but also the economic and aesthetic ones. This could be a valuable conservation tool. When you tell some people about the ecological values of forest canopies (e.g., their ability to capture atmospheric nutrients and store carbon, and preserve diversity), they listen and attend to those values. Other people are more interested in economic values—the timber that is harvested, the horticultural plants that are harvested from forest canopies, or the potential medicinal plants that indigenous people know about in forest canopies—or maybe even some economic values of which we may not be aware.

There are also aesthetic values—and those especially tend to be downplayed by scientists. I think, however, they can be extremely important tools in terms not only of conservation but also understanding trees. For centuries, trees and forests have been the object of aesthetic interest. We know that there is something about the forest that captures the spirit of human beings in a very positive way. Within that also is the concept of the spiritual. Trees and forests have been part of the tradition of many religious and spiritual traditions. Our own Christian tradition of the Garden of Eden rates as important the Tree of Life, and the apple tree. In the Talmud we read "…and the Lord God planted a Garden in Eden, and so you too, when you come to Israel, shall do nothing before you have planted…" This is true not only in the Judeo-Christian traditions, but also in the Eastern religions, where trees are thought to be places of serenity, places of reflection, places where we find ourselves. There are also many spiritual objects that are made out of objects that come from trees and forests, or concern organisms that live in trees in forests. This manifests the universality of the positive feelings humans have for trees—not restricted to a single culture or religion.

One of the activities that I will focus on in the future is to integrate ecological, economic, and aesthetic values about forest canopies. I recently received a grant from the National Geographic Society and a Guggenheim Fellowship to build platforms in trees. My idea is to invite ecologists, artists, and economists to literally sit together in the treetops. We will make our measurements, create our art, or do our analysis of the values of forests and trees. We will then try to weave these values together into some coherent whole that becomes a confluence of values and understandings.

One of the most effective ways of getting people aware, and valuing of forest canopies is to bring them up into the forest canopy itself. Over my career, I have taught over 500 people how to climb. I find that teaching people to climb the way that I do is often time-consuming, and I cannot teach everybody. One of the efforts I'm making is to help promote the building of canopy walkway systems. In particular, I am involved with one on the Evergreen State College campus, where I am a member of the faculty. We are blessed with 1000 acres of forested woodland around our buildings. We brought in a structural engineer to build a walkway system that connects our Library Building with the patch of forest behind it. The Library Building represents, in many ways, how humans store, and use information—in our library, our computer center, our art galleries, and administrative offices, all of which are contained in this building. But the forest also contains information—in the species that live there, and their interactions with each other and their environment. By directly connecting the library to the forest, we make a symbolic link between these two ways of understanding the three-dimensional forest from a different perspective.

Thus, forest canopy studies have been going through a rapid evolution in the types of studies that are carried out, the forms of data being collected and shared, the pathways of communication, and the relevance to societal issues. However, the field retains a youthful exuberance and openness to all who are interested in forest ecosystems.

Propagation of *Begonia hiemalis* at Klem's Greenhouse, Inc.©

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ROOTING BEGONIA CUTTINGS

Rooting *Begonia hiemalis* tip cuttings is quite easy and there are many different methods used by different growers. Some use propagation tents, some use mist, and some don't use either. We root our cuttings in a double-layer system with mist. The cuttings start on a warm heated floor for 2 weeks where they receive just enough mist to keep them from stress. On tray tables just above this crop is a crop 2 weeks older. The cuttings receive minimal light, provided by fluorescent lamps, under the tray tables. After 2 weeks the cuttings are moved up onto the tables and the floors are cleaned and disinfected in preparation for a new crop of cuttings. A new crop of cuttings is put under mist in the same process that takes the 2-week-old crop out of the mist. The table that is emptied into the just-cleaned space is immediately filled with the next 36 flats of 2-week-old cuttings, and the process repeats until all of the 2-week-old cuttings are up on tables and the new cuttings are on the floor underneath them. At 2 weeks most of the cuttings have small roots. Up on the tables conditions are much dryer and brighter, and during the warmer months spritzing the cuttings is necessary for the transition. At 4½ weeks most of the cuttings are well rooted and ready for shipping.

There are many rooting media that work well for rooting hiemalis begonias. The medium needs to be light and well drained. Artificial media like oasis and rock wool can be challenging because they dry out too fast and the cuttings don't transition to bigger pots well. We have historically had best results using peat-based media. A direct-stick program works very well where only one cutting per pot is required.

We now root our cuttings in a 35-mm Jiffy pellet. The Jiffy Corporation designed a tray to meet our specifications. The tray gives the cuttings just enough space to