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arboreal earthworms. We've better detailed nutrient cycling, reproductive strategies, and symbiotic associations among plant communities. We've also developed a systems view of tropical and temperate forests, seeing trees as part of a three-dimensional mosaic of vegetation stretching from the ground to the canopy/airspace interface. Several hundred researchers worldwide have established more than 100 permanent or semi-permanent access sites across the globe to study forest canopy ecology. International expeditions, symposia, conferences, and publications are now important components of a global network for this emerging discipline. On a daily basis, canopy ecologists solve aerial puzzles and communicate this knowledge quickly to colleagues around the world.

Presently, there is an urgency to quantify the world's treetops due to rapid species loss and habitat fragmentation. Foundations, universities, research centers, schools and museums, companies, scientists, and laypeople alike are investing millions of dollars into the field. As we move from qualitative to quantitative canopy studies, early signs suggest that we are losing a sense of wonder. It is especially noted in the field's battleground of terminology, the lexicon used to communicate recent discoveries and opportunities in the treetops, where prematurely entrenched viewpoints exclude or, at least, postpone, creativity and wonder.

In the early 20th century, British scientist J.B.S. Haldane penned his famous quote now brandished as an emblem of the scientific method: "Now, my own suspicion is that the universe is not only queerer than we suppose, but queerer than we can suppose" (Haldane 1928). Later in Possible Worlds, he echoed this theme by stating, "I suspect that there are more things in heaven and earth than are dreamed of, or can be dreamed of, in any philosophy." In a chapter on wonder, Heschel, too, embraced the incomprehensibility of human perception. "What fills us with a radical amazement is the reflection that in which everything is embedded but the fact that even the minimum of perception is a maximum of enigma. The most incomprehensible fact is the fact that we comprehend at all" (Heschel 1955). There are enough mysteries in the cosmos to stoke the fires of wonder indefinitely.

In the 1950s, the National Audubon Society published a wonderful but little-known book that speaks clearly about the hallmarks of leading naturalists. Entitled Homo sapiens audubonianus: A Tribute to Walter VanDyke Bingham, it lists 11 characteristics fundamental to this rare subspecies of human (National Audubon Society 1953), including a strong preference for the outdoors, an absorbing curiosity for nature, excellence in observation and description, a contagious enthusiasm, and a sensitivity to the beauty and worth of different forms of life. But, above all these, the Society listed the capability of retaining, in the presence of nature, an attitude of wonder as that enduring feature to separate leading naturalists from middling ones.

All these characteristics are probably common among canopy ecologists worldwide. Like their brethren in other emerging sciences, they are marked by their absorbing curiosity, skills at observation and intuition, and knack for putting physical discomfort and challenges into their proper places. In just over two decades, canopy ecologists have integrated a number of sub-disciplines and perspectives into their devoted work. The field of canopy ecology, newly emerged, is now answering questions about forest organisms and processes heretofore unknown. Let us hope that these remarkable scientists will retain in their endeavors, above all other attributes fundamental to leading naturalists, an attitude of wonder in the presence of nature.

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3 Walter VanDyke Bingham (1880-1952) was a prominent cognitive psychologist who supported nature studies, particularly the conservation efforts of the National Audubon Society.
on humble fruit flies in the early 1900s? Or, more apropos to this discussion, who could have guessed the windows of opportunity that would open when Donald Perry first climbed into the rainforest canopy of Costa Rica in the 1970s? Nevertheless, space exploration, marine biology, electron microscopy, and now canopy and soil studies have all been labeled recently as “final frontiers.” From Star Trek’s embellished overture ("Space... the final frontier") to Smithsonian researcher Carole Baldwin’s cinematic hyperbole about deep-sea trenches as the final frontier for biologists, scientists who make these assertions confuse the public andetter further discovery. History has taught time and again that such statements are, indubitably, false prophecies.

In recent literature, forest canopies and forest soils have been labeled final frontiers by their enthusiasts as if no discoveries await us beyond dotting the i’s and crossing the t’s of these still-developing fields of research. Terry Erwin, entomologist at the National Museum of Natural History, did not equivocate when he called tropical forest canopies “the last biotic frontier” (Erwin 1983). Andrew Mitchell, British naturalist and television producer, subtitled his 1986 book on rainforest canopies as a “journey of discovery to the last unexplored frontier, the roof of the world’s rainforests.” Further, in the final paragraph of the text, Mitchell wrote: “The discovery that nature’s last frontier is richer than was ever before dreamed is a message of hope, a gift for us to enjoy, and use wisely” (Mitchell 1986). Though an otherwise lovely, wonder-filled passage, its assertion that canopy ecology is a last frontier of discovery easily distracts from Mitchell’s message of conservation. Edward O. Wilson, Pulitzer-prize-winning scientist and professor emeritus at Harvard University, wrote in his foreword to Mark Moffett’s 1993 book, The High Frontier: “And within the rainforests, the canopy is the remote outland, the final frontier.” Though poetic and engaging, such hyperbole diminishes a sense of wonder in the field. If the canopy is considered as the entire biological column in forests, then all the biodiversity and ecological processes from the treetops to bedrock are linked together closely and offer endless discovery and opportunity for the scientific community.

Nadkarni (1995) appropriately admonished the scientific community in the conclusion of her historical overview of canopy ecology: “And so a long climb awaits. The last biotic frontier is dead. Long live the next one.” As long as humankind remains inquisitive, there will always be frontiers in science. And, as long as we are able to enter the treetops of the world’s forests, there will always be discoveries awaiting the prepared—and wonder-filled—minds.

The forest canopy is a frontier for exploration and discovery; however, like all other frontiers, it is far from being the final frontier for biology or for any other aspect of human study. André et al. (1994), of course, subtitled their pivotal article about soils “the other last biotic frontier” as a playful rebuke for canopy ecologists working at the top end of the forest’s bio-column. Yet soil ecologists have also employed such incautious embellishments in recent literature. For example, Coleman and Crossley (1996) called soil “one of the last great frontiers in biological and ecological research.” From the tops of forests to their soils, scientists move like faces in carnival mirrors, deeper and deeper into discovery. Time and again, throughout the history of science, we learn that no intellectual cul-de-sacs occur along its frontier borders.

**Summary: Reintegration of Wonder into the Emerging Science of Canopy Ecology**

Collectively, the world’s treetops are often referred to as a leafy eighth continent filled with undescribed species and ecological processes. Such phenomena are life’s riddles, arranged like nested boxes to lead scientists deeper and deeper into living mystery. Since the pre-access days of canopy ecology, scientists have described many new kinds of plants and animals. We’ve found canopy roots (also called aboveground adventitious roots; see Coxson and Nadkarni 1995) and
GLOBAL CANOPY PROGRAMME: A WORLDWIDE ALLIANCE FOR FOREST STUDIES—cont’d

References

Big Canopy Database website: http://www.canopy.evergreen.edu/bcd
CanopyLIFE website: http://www.globalcanopy.org/core/
Canopy Training School website: http://www.globalcanopy.org/core/
CanopyWorld: Global Canopy Programme website: http://www.globalcanopy.org

When scientists espouse a hard-edged attitude toward definitions, they hound out a sense of wonder for the natural world. Insistence that epiphytes cannot simultaneously be parasites is a manifest disregard for nature’s spectrum of diversity and also contravenes future discovery and opportunity by incarcerating our minds’ creativity. If we are convinced that there are no parasitic epiphytes, then we will not look for, nor will we expect to find, parasitic epiphytes. The workings of nature are best seen in the exception rather than in the rule. We are more likely to foster our sense of wonder about the natural world and our place in it if we accept as a training motto the dictum of Pasteur (1822–1895), who noted: “In the field of observation, chance favors the prepared mind.”

Finally, a Word about the “Final Frontier”

Long ago, Old Testament prophets counseled us: “Beware lest we say, we have found wisdom” (Job 32:13). Aldo Leopold (1887–1948), in his classic Sand County Almanac, echoed this theme for modernity when he warned that “We all strive for safety, prosperity, comfort, long life, and dullness” (Leopold 1966). He continued with an important reference to Henry David Thoreau.

Perhaps this [peace in our time] is behind Thoreau’s dictum: In wilderness is the salvation of the world. Perhaps this is the hidden meaning in the howl of the wolf, long known among mountains, but seldom perceived among men (Leopold 1966).

Perhaps we can now amend Thoreau’s proverb without offense to the Master Naturalist by stating plainly that the salvation of a human-filled world lies in our sense of wonder. From the Inca Trail in the Peruvian High Andes to the summit of Mount Sinai, from the oceanic trenches off the shores of the Galápagos Islands to the subarctic coastline of Labrador, from the dark forest floor of Cameroon to the sunny treetops of Amazonia, humanity’s ecological footprint is irrefutable and all pervading. Yet we discern new worlds ceaselessly—whether on a molecular or microscopic echelon or on a macroscopic scale. Nature is continuous, and so are our observations and discoveries.

It is, therefore, baffling that a modern scientist should point to any technical field and label it as a “last” or a “final” frontier. The history of science is jam-packed with innovative exploration and discovery in the natural world, even in areas studied exhaustively. For example, who could have guessed the far-reaching benefits of T.H. Morgan’s meticulous genetics experiments on humble fruit flies suggested the window on the rainforest canopy or electron microscopy’s frontiers.” From Swedish researcher Carole B. L. Hallqvist, biologists, scientists History has taught us.

In recent literature, enthusiasts as if not developing fields of History, did not emerge (Ervin 1983). And on rainforest canopy, world’s rainforests. It is nature’s last frontier that we can enjoy, and use its assertion that can be the message of conservation at Harvard Frontier: “And with that on.

Though poetic and the canopy is considered an ecological process of discovery and experience, Nadkarni (1995) points her historical evidence that the canopy is dead. Long ago, always be frontiers in forests, there. The forest canopies, it is far from being a playfield. Yet soil ecologists: example, Celery Bog, as the ecological and ecological in carnival minis tery of science.

Summary:

Collectively, the work described species and their new boxes to lead us into canopy ecology, of canopy roots also.
Kyoto Protocol focused attention on the role of forest canopies in sequestering carbon from the atmosphere. Whether forests act as a sink or a source of carbon remains uncertain. How the mechanism works at the canopy atmosphere interface remains unclear. We do not know the economic value of canopy biodiversity or ecological services, the value of its products for human health, or its ecotourism potential for local communities. The GCP seeks to create a significant new international effort in support of the Convention on Biological Diversity, calling for research on forest canopies. The canopy–atmosphere interface is a critical environment for interrogating future models of global change (Ozanne et al 2003).

Information will be made available on-line to the public, policy-makers, and scientists through the state-of-the-art Big Canopy Database currently being developed with funds from the U.S. National Science Foundation. A Canopy Training School will offer capacity building courses for scientists, forest managers, and conservationists in biodiversity-rich nations that need extra skills to inspire new leadership in canopy science and conservation. A CanopyLIFE biodiversity rapid assessment program is in development to assess the value of the myriad life forms in different forested environments. CanopyWorld, an interactive virtual rainforest website, is planned for schools. A number of pilot projects on biodiversity and LIDAR laser scanning of canopy structure are already underway to demonstrate the comparative and collaborative capabilities of the GCP and the benefits they could bring. The Global Canopy Handbook (Mitchell et al. 2002) was compiled by using the expertise and experience of over 40 leading canopy researchers from around the world. It covers the who, what, and where of all current techniques and projects available for investigation of forest canopies.

Figure 1  Installation of the Lambri Hills Canopy Crane, Sarawak, Malaysia. Photograph courtesy of Tohru Nakashizuka.

Continued
evidence for the suppression of host vigor from heavy Tillandsia infestations (see Benzing 1978). They have neither direct nor indirect connection to their hosts’ living tissue; however, they are not parasites, although they can be considered nutritional pirates (Benzing 1978, 1979), not just competitors, for their sustenance.

Orchids, on the other hand, are much more diverse in numbers of species and in their ecological strategies for acquiring water and nutrients. With such diversity in an ancient group of plants (a family between 100 and 110 million years old, according to Chase 2001), orchids show a “nature is continuous” fidelity that should not surprise us. There are numerous achorophyllous orchids where heterotrophism, utilizing a kind of indirect parasitism, is clearly essential for their survival (e.g., see Campbell 1963; Furman and Trappe 1971; Leake 1994; Richardson and Currah 1995; Cuttings et al. 1996; Szendrak and Read 1997; Yoder et al. 2000; International Orchid Conservation Congress 2001). In fact, over millions of years of evolution, orchids have become extraordinarily adept at solving disparate environmental challenges with unusually malleable morphology. The environmental heterogeneity among and within orchid habitats, especially forest canopies, doubtless explains the remarkable diversity of this large family of angiosperms. “Orchidaceae probably has more of the appropriate character combinations for life in tree crowns than does any other family . . .” (Benzing 1986). With so many species adrift in a lofty ocean of vegetation, far removed from ground-level nutrients and near to their hosts’ tissues, can we really say with certainty that orchids cannot ever be parasitic? The theme “nature is continuous” is fully embodied in this diverse group of flowering plants. Orchids are icons of change for the natural world.

GLOBAL CANOPY PROGRAMME: A WORLDWIDE ALLIANCE FOR FOREST STUDIES

Andrew Mitchell and Katherine Secoy

The Global Canopy Programme (GCP) is a global alliance that links studies of forest canopies worldwide into a collaborative program of research, education, and conservation to address biodiversity, climate change, and poverty alleviation. Its mission is to integrate forest studies across the world into a 10-year program focused on understanding the critical role of forest canopies in biodiversity and climate change. It also aims to identify cultural benefits from forest canopies and to transmit information to key stakeholders. This initiative evolved from a European Science Foundation/National Science Foundation-funded International Canopy Science Workshop in Oxford held in November 1999 in collaboration with the International Canopy Network (ICAN). At the workshop, 29 international experts from 10 countries produced a template for the GCP. They concluded that, by working together, canopy researchers can leverage more funding for a major collaborative natural science project to investigate one of nature’s last biotic frontiers. They also called for significant new funding on the scale of large physical science projects to undertake this pioneering task.

Such a program is now urgently needed to plug major gaps in our knowledge (Mitchell 2001). The structure, function, and resilience of the world’s forest canopy environment are unknown. Almost half of all terrestrial life-forms exist in forest canopies, but only a small fraction has been documented. The influence of forest canopies on climate change and their role in maintaining the earth’s biological diversity are based on very limited data. These roles are directly connected between the canopy interface with the atmosphere. The

Kyoto Protocol, the atmosphere needs technical means to determine how these products for human consumption may be obtained from the world’s forests. The Biological Diversity Convention, which seeks to create a global network of protected areas, is one of the mechanisms that will try to harmonize the interests of local populations with the threats to biodiversity. A Canopy Enquiry, or collaborative process, will test how best to use the virtual rainforest in order to gain access to the information and knowledge that can be gleaned from the study of the canopy interface.
mon ways of living usually share key qualities that set them apart from other vegetation. Occurrence on similar substrata under similar climate fosters evolutionary convergence. Yet approximately 25,000 epiphytic species (mistletoes included) exhibit little obvious unifying basis; no growth form, seed type, kind of pollen vector, water-carbon balance regimen, nutrient source, or resource procurement mechanism is shared by all (Benzing 1990). Later in his text, Benzing presented a classification of epiphytes based on their relationships to host plants. Epiphytes can be autotrophic, i.e., supported by woody vegetation without extracting nutrients from host vascular. This group includes accidental, facultative, and hemi-epiphytic plants such as stranglers. Epiphytes can also be heterotrophic, i.e., subsisting on xylem contents and sometimes receiving a substantial part of their carbon supply from a host. This type of epiphyte includes parasites such as mistletoes. In addition to classification schema, Benzing provided a photographic series of epiphytes in his book, among them a native Florida orchid (Dendrobium teneiss), a South Florida strangler fig (Ficus aurea), and a Kentucky mistletoe (Phoradendron flavescens), all captioned as “selected epiphyte types.” Interestingly, both Moffett and Nadkarni et al. referenced Benzing’s text in their essays. Yet they clearly promulgated the viewpoint that epiphytes are not parasites, whereas Benzing acknowledged that epiphytes are found in a muddled spectrum of relationships with the host plant: mutualism, commensalism, and parasitism. Benzing’s position, of course, agrees with Allen and Hoekstra’s stance that nature is continuous. The dissimilarity proffered by Moffett, Nadkarni, and others is a common but unnecessary, and unconvincing, distinction. Living things manifest a fuzzy and idiosyncratic nature that repeatedly defies our nomenclature. The term “epiphyte” is laden with semantic issues because life itself, particularly among these so-called air plants, is ambiguous—often continuous, rarely dualistic. Perhaps we should avoid altogether terms such as mutualistic, commensal, and parasitic (see Margulis 1990) and use only the moniker “symbiotic” to describe the ecological relationship between two species. Further, we should recognize that this relation can be positive, neutral, or negative for the partners in surprising and wonder-filled ways (Figure 26-1).

Epiphytes include thousands of orchid and bromeliad species. Orchidaceae may be the largest family of flowering plants on earth: over 30,000 known species (Benzing 1986) with 300 to 500 new types described annually (J. Becker and W. Higgins, pers. comm.). Bromeliaceae is a smaller family by an order of magnitude: 3,000 known species with approximately 40 new species annually. Though both families have terrestrial species, most known orchids and bromeliads are epiphytes (Benzing 1986) inhabiting tropical rainforests and montane cloud forests. As canopy plants, they are “uncoupled from soil” (Benzing 1985) and have evolved fascinating methods to obtain their nutrient and water needs in the treetops.

The trichomes and tank architecture of bromeliads act as efficient traps for non-soil nutrients, intercepting canopy litter and leachates from foliage (see Richardson et al. 2000a, 2000b). In spite of their close association with host vegetation, bromeliads have developed nonparasitic, alternative morphological features to tap the organic resources of their arboreal habitats. There is anecdotal

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**A Symbiosis Spectrum**

| Predation (+/-) | Commensalism (+0) | Mutualism (++) |

**Figure 26-1** An epiphyte defined through a spectrum of symbiosis: is its ecological role static or dynamic, immutable or evolving? Predation includes a symbiosis subset called parasitism. “+” identifies a positive impact for one of the species involved in the symbiotic relationship; “−” associates a negative impact; and “0” signals no apparent impact, positive or negative.
meaning. On the other hand, words too narrowly defined can throttle creative endeavor. Vocabulary for an emerging science needs to be a middle-ground affair—not too vague, not too specific—to ensure its lasting contribution to society, growing and changing as the application of the science suggests.

Words are also artificial constructs that have little or nothing to do with the natural world. They are human devices to help us organize our perceptions and experience. Allen and Hockstra wrote evocatively that a definition is a formal description of a discontinuity that makes it easy to assign subsequent experience to the definition. After experiencing the world, an observer decides whether or not the experiences fit the definition.

For all we know, _nature is continuous_ [italics added], but to describe change, we must use definitions to slice the world into sectors. The world either fits into our definitions or not. Either way, all definitions are human devices, not parts of nature independent of human activity (Allen and Hockstra 1992).

Nature is continuous. We have trouble with continuities, however, so we pigeonhole and divide for intellectual comfort and practical worldview. Words are verbal expressions of an ancient survival technique: scan the immediate environment, focus on a few facts, and make operational generalities about the world at large. It is a primitive and limiting (incarcerating, to borrow from Margulis) practice; but, historically, it has worked well for our clannish survival.

As one of the first-generation canopy ecologists, Mark Moffett (2000) attempted to unify the otherwise muddled lexicon of this frontier science. He proposed a unique précis on the basic terms of the field, attempting to address inconsistency and confusion with a standard set of terminology and definitions. In his introductory passage, Moffett bemoaned exactly some of the necessary qualities for an emerging science: inconsistency, misuse, inadequacy, and confusion. Rather than lamentable traits, these are early signs of illumination and right thought that can foster a sense of wonder. So long as individual authors clearly express the meanings of their technical vocabulary, discrepancies—even disagreements—with other authors can serve to advance the science, especially in its infancy. Discrepancies can also retain wonder in the foreground for its practitioners by highlighting ambiguities and calling attention to areas that require more scrutiny.

Epiphyte: A Divisive Definition

There is one seemingly impervious term among botanists, foresters, horticulturists, and canopy ecologists whose definition is incontrovertible: epiphyte. Or is it? Even a casual glance at the word's etiology reveals substantial disagreement among biologists about its meaning, yet some inaccurately connotes a water tight definition. In his recent critique of canopy terminology, Moffett defined epiphyte as a “plant, fungus, or microbe sustained entirely by nutrients and water received nonparasitically from within the canopy in which it resides” (Moffett 2000). In the same article, however, he pointed out that “every definition of this term I have seen contains serious discrepancies with actual usage.” Later Moffett admitted that “epiphyte is a term laden with semantic issues.” Continuing the emphasis on the nonparasitic nature of this group of organisms, Nadkarni et al. wrote in the new _Encyclopedia of Biodiversity_: an epiphyte is a “nonparasitic plant that uses another plant as mechanical support but does not derive nutrients or water from its host” (Nadkarni et al. 2001). Historically, in the spectrum of ecological interrelationships called symbiosis, epiphytes were viewed by many biologists as mutualistic or commensal with their host plants but never parasitic.

David Benzing, one of the world’s scientific authorities on vascular epiphytes, shunned such either/or distinctions and underscored the obvious ambiguities of epiphytism. “Plants with com-

Figure 28-1

or evolving? Predation or involved in the spread negative.
Two other first-generation canopy ecologists, Andrew Mitchell and Mark Moffett, also expressed their poetic zeal about the high frontier. For Mitchell, the canopy is a frontier of hope: The discovery that nature's last frontier is richer than was ever before dreamed is a message of hope, a gift for us to enjoy, and use wisely” (Mitchell 1986). For Moffett, the treetops are a triumph of biodiversity where “[T]here is more feasting, more famine, more courtship and sex, more tender care of the young and of home, more combat and more cooperation in this arboreal realm than anywhere else on the globe. The tropical rainforest tapestry has only begun to capture our imagination” (Moffett 1993). Like Beebe, these scientists seemed convinced about the incontrovertible lessons of conservation and interconnection to be learned in the treetops.

These excerpts from pivotal texts represented the underpinnings of wonder for the defining decade of canopy ecology. Then the inevitable occurred for nearly every emerging science—a concerted movement from qualitative to quantitative study. Another volume, published in the mid-1990s, symbolized this movement in the tiny community of treetop scientists: Lowman and Nadkarni’s *Forest Canopies* (First Edition). As a watershed text, it represented a fundamental shift in the scientific community toward analysis and synthesis. Thomas E. Lovejoy, author of the book’s foreword, predicted its central nature: “There is no better evidence than canopy biology that the age of exploration is not over. We can anticipate a diverse panoply of discoveries emanating from this field. Some will be of serious practical benefit to ourselves as living organisms. Others will illuminate aspects of biology never before dreamed of. Yet others will astound with their beauty or be intrinsically fascinating. In all cases it will be clear that canopy biology, as a recognized field of intellectual endeavor, began with this book.” (Lowman and Nadkarni 1995). Certainly, there were numerous articles in the scientific and popular presses, along with symposia and documentaries, throughout the 1980s and 1990s and into the 21st century that furthered the message of canopy ecology. But textbooks, as secondary or even tertiary summations of the state of affairs for science, can have far-reaching and long-lasting impact for an emerging field. Mitchell and Moffett’s books made their way to coffee tables, while *Forest Canopies* quickly found a place in university libraries, research facilities, science classrooms, and offices of field biologists around the globe. First-generation canopy ecologists who contributed to the text went beyond the metaphorical, beyond the descriptive, beyond the “intricate minuet of wonder and curiosity” toward the much needed, but bittersweet, quantification of the High Frontier. Even the founders of the science quickly emptied their latest writings of their early testimonials to radical amazement and then crammed the *Forest Canopies* pages with exacting prose common to other biological sciences. Tables, equations, and graphs proliferated in the literature, but—for some—the childlike expression of wonder became almost gauche and unscientific.

The Battleground of Terminology

The lexicon of an emerging science is largely experimental. Old words can find new applications. New words can materialize as epithets for new concepts. But the lexicon for a new scientific field can also suppress a sense of wonder among its supporters if it sets too quickly. As a frontier science develops into an established discipline, vocabulary can become a battleground. Societies close ranks, individuals stake out personal territories, and practitioners attempt to standardize the profession. Inevitably, something surfaces from the mêlée that acts as an overseer, much like the French Academy in Paris or the Royal Academy of La Língua in Madrid. Praised as “high courts of letters and rallying points for educated opinion” (Le Bars 1999), these learned academies have also been accused of hampering, even crushing, originality in their attempts to purify the language. As a clear warning to her colleagues against such insularity, Margulis noted that “our minds are incarcerated by our words” (Margulis 1990). Ill-defined words muddle an author’s
So, too, has this diminution occurred time after time in the sciences. Thomas Aquinas, the great Dominican apologist for the medieval Church, wrote in his *Summa contra gentiles*, that "[T]he astronomer does not wonder when he sees an eclipse of the sun, for he knows its cause, but the person who is ignorant of this science must wonder, for he ignores the cause. And so, a certain event is wondrous [mirum] to one person, but not so to another" (in Daston and Park 1998). What Aquinas seems to have overlooked in his erudition is that, for the sciences, a mystery solved is a wonder gained. In other words, the explanation of natural phenomena leads endlessly to more questions and more uncertainties about the universe. Like circus mirrors, this "intricate mietit of wonder and curiosity" (Daston and Park 1998) channels scientists into deeper and deeper mystery. Astronomers may understand eclipses, but then what do they know about solar flares and black holes and, after these, the expansion of the cosmos? Science is an indefatigable engine for wonder.

Forest biologists have always been curious about processes in the treetops. Yet, until the 1970s, they seemed to be content with *ex situ* investigations: collecting a beetle or a bird here, examining a fallen branch there that happened to be loaded with lofty epiphytes. *In situ* canopy studies began a quarter-century ago, especially with Donald Perry’s canopy web in Costa Rica for which he later earned a Rolex Award and front-page coverage in *Scientific American* (Perry 1984). Because early canopy biology focused on access techniques and descriptive documentation of poorly known arboreal flora and fauna, many academics viewed the field as a "Tarzan and Jane" frill or a throwback to 19th-century descriptive biology (Nadkarni 1995), similar to the deprecating accusations by Rutherford (1871–1937) about biologists and postage-stamp collecting (see Mayr 1988). The 1990s, however, represented the defining decade for treetops ecology (Nadkarni 1995; Rinker et al. 1995). Scientists discovered new species and new processes. A plethora of access techniques, the gathering of comparative datasets via widely accepted protocols, the generation of rigorously tested hypotheses, and the launch of a global communication network (including two international canopy symposia and a newsletter) promptly helped to define and organize the science. Unfortunately, with the movement from qualitative to quantitative science, canopy ecology forfeited some of the wonder so effortlessly expressed in its early literature.

Capturing the pre-access speculation about the wonders of treetop ecology, William Beebe’s words quoted earlier in this chapter helped to rally the attention—and courage—of intrepid investigators. Decades later, Donald Perry forged an intellectual path with his tropical canopy web and associated writings. His book, *Life Above the Jungle Floor*, became a tour de force that popularized the field, while the scientific community scrutinized his technical works. One excerpt from the text highlights Perry’s arboreal poetry:

Twenty million years from now, long after the planet has crawled with billions of the hopelessly starving, long after man has driven nearly all other species to extinction, and beyond when we see to the depths of our despondent spirits and intellect, and past the stage when we judge ourselves incompetent to live and rule by using poisonous and morbid tools of destruction, then and only then will tropical forests again raise their crowns in luxury, to feast in the warm sun. In that canopy there will be arboreal beasts, and I do not doubt that some will descend from the trees to cross our clever course. Perhaps one will stoop to wonder over fossilized remains and discover that another bipedal species had preceded it from the trees. And just maybe it will be a marvelous creature that takes a higher step in the mental plane and treats the planet and its inhabitants in a manner about which we have only talked (Perry 1984).

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1 On 1 September 2000, the National Science Foundation and Marie Selby Botanical Gardens funded two of these symposia for four years, both related to the effects of forest canopy herbivory on soil processes in temperate and tropical forests.

2 A third international symposium was held in Cairns, Australia, from 23 to 28 June 2002 for 250 delegates.
review of material that goes into such programs (e.g., Heroes of the High Frontier, National Geographic Society).

Although the mission of the ICAN as described in the bylaws does not include political activities, members have carried out programs to heighten awareness among politicians and other non-scientists on the importance of canopy biota and processes. For example, in 1997, the ICAN spearheaded an effort to get the signature of the Governor of Washington State on a Proclamation to declare July 17-24 as “Washington Forest Canopy Week.” Similar symbolic efforts to link the canopy with applied issues to the general public have also been carried out, such as the “Legislators Aloft Program” in 2002, in which ICAN members taught 12 Washington State members of congress to climb into canopy-level platforms and discussed forest management and conservation.

The Board of Directors of ICAN consists of eight members who represent the constituent fields of research, education, conservation, and arboriculture. The Directors meet annually to provide oversight on short- and long-term directions. The Scientific Advisory Council, which consists of 15 members, takes part in decisions on an ad hoc basis.

ICAN is a self-supporting organization, funded by subscriber dues, donations, and grants. For more information on the ICAN, contact Nalini Nadkarni at nadkarniN@evergreen.edu.

Reference


what makes us “Stand still and consider” (Job 37:14). The opposite of wonder is the indifference that emerges from habituation to the laws governing one’s world picture: “The reason why the adult no longer wonders is not because he has solved the riddle of life, but because he has grown accustomed to the laws governing his world picture. But the problem of why these particular laws and no others hold, remains for him just as amazing and inexplicable as for the child” (Max Planck in Heschel 1955). Solar eclipses and blood circulation may no longer be mysteries to 21st century society, but for most scientists—theists, agnostics, and atheists alike—they are still wonder-filled phenomena because of their sublime beauty and their connection to still other mysteries. Indifference to these phenomena is stifling, irrational, and shallow.

Many contemporary authors have decried the attenuation of wonder that often occurs in the aging of both individuals and societies. For example, Rachel Carson (1907–1964), a prophet for the modern environmental movement, noted this sad change as young people grow up: “A child’s world is fresh and new and beautiful, full of wonder and excitement. It is our misfortune that for most of us that clear-eyed vision, that true instinct for what is beautiful and awe-inspiring, is dimmed and even lost before we reach adulthood” (Brooks 1972). Abraham Joshua Heschel, internationally recognized Jewish scholar and theologian, observed the same diminution in society at large: “As civilization advances, the sense of wonder declines. Such decline is an alarming symptom of our state of mind. Mankind will not perish for want of information; but only for want of appreciation. The beginning of our happiness lies in the understanding that life without wonder is not worth living. What we lack is not a will to believe but a will to wonder” (Heschel 1955). Rather than a necessary precursor to maturity, the diminution of wonder, whether in individuals or society at large, may actually be a vestige of our immaturity as we advance.
THE INTERNATIONAL CANOPY NETWORK

Nalini M. Nadkarni

The International Canopy Network (ICAN) was established as a non-profit in 1994 to enhance communication among individuals and institutions concerned with research, education, and conservation of organisms and interactions in forest canopies. ICAN was formed in response to a perceived need to bring together the diverse group of people who were dedicating themselves to the emerging field of studies and conservation about the then little-known part of forest ecosystems (Nadkarni et al. 1995). A small cadre of international scientists and students created a tax-exempt corporation with 501(c)(3) status and the networking capacity of electronic media. Although the initial focus was on bringing together canopy researchers in academia, its interests have included outreach, education, and conservation.

One of the first core activities of ICAN was to facilitate rapid communication by establishing and maintaining an electronic mail bulletin board. The logistics have been handled by the Network Office of the Long-Term Ecological Research Program, sponsored by the National Science Foundation. In 2003, its subscriberhip was over 750 people, living in 62 countries. The bulletin board is used to circulate information about meetings, job openings, new research findings, and recent publications of concern to canopy researchers. It has also been used for information exchange (e.g., on equipment and canopy access methods) and for lively debates (e.g., on the definitions of canopy-related terminology).

The ICAN also publishes a quarterly newsletter (titled “What’s Up?”) to members. Prior to publication of each issue, the editor calls for articles and items of interest. Occasionally, the newsletter publishes sets of research abstracts from recent projects. Conservation and education programs are also featured. One of the most critical features of each issue is a list of recent scientific citations from ecological and environmental journals. Because canopy research is scattered throughout the literature, this provides a focal ground for researchers to easily keep in touch with current work. ICAN also organizes and co-sponsors scientific symposia, usually in conjunction with larger ecological meetings, using the email bulletin board and newsletter as a springboard for efficient communication.

Another major activity of the ICAN office is the maintenance of a website. A key feature is the bibliographic database of scientific and popular aspects of canopy science. In 2003, over 4,500 keyworded citations were listed, searchable by 18 categories. The website also contains a growing images library; electronic images can be downloaded directly. Other parts of the website include a canopy researcher directory, information on safe methods of canopy access and canopy sampling methods, and interpretive materials for school children.

Because of the pressing need to conserve forest canopy biota beyond the current generation, the ICAN has instituted a number of children’s programs. Staff members write articles about canopy plants and animals for children’s magazines and give talks to school groups, with a focus on 8- to 10-year-olds. In 1998, the ICAN initiated the “Ask Dr. Canopy!” program, in which children are invited to write or email questions about the canopy or forests in general to Dr. Canopy. They get responses to their queries from the “collective persona” of six volunteer canopy researchers.

Other outreach efforts to the general public have involved writing numerous articles for popular magazines (e.g., Natural History, National Geographic, Audubon, Glamour) and newspapers. An extremely important function of ICAN is consulting to the media and press. The topic of rainforest canopies has been a highly appealing one for television documentaries, and the ICAN has made strong efforts to provide scientifically sound information and

review of materials. Geographic Society.

Although the activities, members, and other non-scientific groups. In 1997, the ICAN State on a Public Call. Similar symbols, also been classified, and members taught forms and disciplines.

The Board of Trustees meets annually to present the Council, which charges ICAN with four grants. For more information, see green.edu.

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what makes us human? That adult no longer accustomed to the city and no others have.

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dimmed and even internationally less at large: the symptomatic of our.” And, according to the want of appreciation and wonder is not for all, 1955). Rather than individuals or society
universe is to look at it from as many different points of view as possible” (Haldane 1928). Whether by rope, walkway, or crane, a canopy scientist—rising vertically through the vegetation—sees the forest from the perspectives of bird and biped, as Alexander Skutch (1992) encouraged us more than a quarter-century ago: “To know the forest, we must study it in all aspects, birds soaring above its roof, as earth-bound bipeds creeping slowly over its roots.” Such an effort sweeps away some of the mystery, but not the wonder, of our temperate and tropical woodlands to bring them fully within the devoted scrutiny of modern science.

Until recently, research on forest ecology was primarily ground-based and uninformed about canopy processes. Only during the past 25 years has our understanding of treetop ecology expanded substantially beyond this bipedal bias, due in large part to the dauntless efforts of a handful of tropical biologists working from ropes, walkways, airships, cranes, canopy webs, and swarms sometimes 30 or 40 m off the forest floor (Rinker et al. 1995). These access systems now permit researchers to study forests from top to bottom, seeing them as integrated living systems, not as an illustrated series of discrete vegetative strata too often simplified in general biology textbooks.

The metaphors in the early scientific literature for the forest canopy were resplendent, atypically poetic, and capture some of our childlike intrigue with this borderland of science (Rinker 2000, 2001): tropical air castles, canopy oceans, hanging gardens, green mansions, aerial continents, highways in the trees, the eighth continent. Up there we were explorers in the roof of the world’s forests and—until we could observe, quantify, replicate, and collect in this leafy realm—we waxed romantic, unsure about the outcomes of our enquiry but convinced of its merits. Often noted in the early canopy literature was an observation from William Beebe’s Tropical Wild Life of British Guiana (Beebe et al. 1917): “Yet another continent of life remains to be discovered, not upon the earth, but one or two hundred feet above it, extending over thousands of square miles. . . . There awaits a rich harvest for the naturalist who overcomes the obstacles—gravitation, ants, horns, rotten trunks—and mounts to the summits of the jungle trees.” A rallying cry for canopy scientists, Beebe’s prose compressed all the reasons for canopy research into two poignant words: discovery and opportunity. These words registered on the heartstrings of every biologist, teacher, and student fortunate enough to enter the forest canopy. The canopy was a New World for us—or, more accurately, an Old World that our remote ancestors left behind millions of years ago. The treetops seem a siren song for our genetic memory. Now we return to the forest canopy, this time as researchers with probes, microscopes, and notebooks, but not so much an invasive return to our homeland as it is a search for our ancestral roots in the trees. This aerial eighth continent as much to teach about our primeval selves.

The 1990s represented the defining decade for canopy ecology, though, arguably, the science little more than a quarter-century old. In its early days, the literature was filled with poetic metaphors in order to capture some of our intrigue with this borderland of science. We also used this language of wonder to attract the attention and imagination of readers around the world. Since then, and especially since the 1990s, we have removed much of the poetry and replaced language typical of established biological fields. In this chapter, we argue that wonder can be reintegrated into canopy ecology without jeopardizing its legitimacy or rigor in order to promote discovery and opportunity in the treetops.

A Sense of Wonder in the Treetops

Wonder is a rational response to the sublime. To borrow from the medievals, it is sensum scientiae, the seed of knowledge (see Heschel 1955). It is, however, more than just a precursor to knowledge; it is a form of thinking, an unceasing attitude toward the immediately unknowable. It is
CHAPTER 26

Reintegration of Wonder into the Emerging Science of Canopy Ecology

H. Bruce Rinker and David M. Jarzen

No illumination can sweep all mystery out of the world. After the departed darkness the shadows remain.

Introduction: A View from the Treetops

The word “canopy” is historically a botanical term and, for this chapter, refers to all aboveground vegetation in a plant community (Nadkarni 1995; Parker 1995; Moffett 2000). According to scientists in the field, each plant community has a canopy (Seastedt and Crossley 1984). Individual trees can have canopies (see Lowman 1995b; Reynolds and Crossley 1997; Sillett and van Pelt 2000) even though, in normal usage, trees have crowns and forests have canopies. A temperate forest and a tropical forest each have canopies. Technically speaking, an orchard, a lawn, a golf course, and a kelp forest have canopies. This systems-wide term includes plants and all their aboveground associations. Contrast this with the word “crown” which, in the parlance of professional forestry, refers exclusively to the upper part of a tree, not to its attending flora— including epiphytes and lianas—and fauna (Winters 1977) and to its ecological processes. The term “canopy” denotes community architecture as well as species composition, nutrient cycling, energy transfer, plant-animal interactions, and conservation issues from the ground to the community-atmosphere interface for all plant assemblages. For the purposes of this chapter, canopy refers specifically to forest ecosystems.

Why study the canopy ecosystem? It is an unexplored frontier for scientific research and education. It is also a living laboratory. Most of the world’s estimated 30 million species live in the treetops because the canopy is also that layer of forest containing most of its productive tissue. Like gigantic stands of lollipops, temperate and tropical forests are sugar factories that have the bulk of photosynthetically active foliage and biomass high off the ground. Sugar in the treetops means the presence of sugar-eaters, too, along with their predators, parasites, decomposers, and most of the forest biota. To study the canopy ecosystem is to enter a leafy frontier for discovery and opportunity.

Researching the treetops is also vital for forest conservation. “Understanding the canopy as part of whole-ecosystem processes is an obvious priority if we are to responsibly manage and conserve forests in the future” (Nadkarni 1995). A view from the treetops provides us with a much more integrated perception of forest ecology than a ground-based view. In fact, the study of life in the canopy is a key to the whole of forest ecology (Nadkarni 1995). A treetops vista is a stunning reordering of spatial and temporal perspectives on the workings of the forest community. The late British ecologist J.B.S. Haldane once wrote, “Our only hope of understanding the universe is to know it.” Whether by reparation—sees the function aged us more than as birds soaring through effort sweeps away lands to bring them

Until recently, our canopy processes, a handful of tropical towers sometimes permit researchers not as an illuminated books.
The metaphors of poetry, in 2000, 2001; terrains, highways in the world’s forests and we waxed romantic, quoted in the book in British Grantham upon the earth... There awaits a thorns, rotten trees, scientists, Beecher's discovery and student fortunes; more accurately, the treetops seem a time as research to our homeland, has much to teach.
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Wonder is a name or seed of knowledge; it is a form...