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OPINION

Life in the treetops—An overview of forest canopy science and its future directions

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Societal Impact Statement

Forests are currently under global threat from human activities, despite the fact that recent findings confirm trees are critical for the health of humans as well as for the entire planet. Advances in *whole forest* research, which includes the upper reaches and not just the forest floor, are providing critical information about carbon storage, biodiversity, water cycles, and other essential ecosystem services provided by trees. The methods to study forest canopies are relatively new and vastly underfunded, despite our growing recognition of the global importance of trees. In addition to advancing exploration of the treetops, the forest canopy toolkit is also proving instrumental to jumpstart innovative actions to conserve forest ecosystems.

Summary

Forest canopies are home to an estimated 50% of terrestrial biodiversity but remain relatively unexplored until just four decades ago. As one of the first global arbornauts, I share an abbreviated history of canopy science, and how treetop access has inspired forest conservation, especially in the tropics where forests remain relatively unexplored. The arboreal toolkit of ropes and harnesses, canopy walkways, dirigible and inflatable rafts, construction cranes, drones, and LIght Detection And Ranging (LIDAR) has revealed that forests provide many important ecosystem services, essential for life on earth. Yet despite millions of research dollars, extensive time, and extraordinary intellectual capital, the degradation of tropical rain forests is accelerating and does not correlate with the extent of scientific investments. A few case studies illustrate how canopy access methods can inspire innovative approaches to conservation, especially in tropical forests where deforestation is rampant: (a) Use treetop walkways for education and ecotourism, not just research, so that indigenous communities can earn sustainable income without logging; (b) Incorporate citizen scientists into forest field research through BioBlitzes or virtual technologies that are now relatively inexpensive and far-reaching; (c) Inspire girls, especially in low-income countries, to become stewards of their local forests; and (d) Seek diverse stakeholders in forest conservation actions, including religious and corporate leaders. I summarize how treetop exploration can inspire a renaissance in botany, engaging the public about the importance of trees, especially tropical forests and their biodiversity.

KEYWORDS
arbornauts, conservation, forest canopy, treetops, tropical rain forests, walkways

1 | SHORT HISTORY OF THE CANOPY RESEARCH TOOLKIT

A few early biologists, including Peter Ashton and Kamal Bawa, created rudimentary methods to study pollinators and flowering in Asian tropical canopies, but their techniques were not easy to replicate in multiple sites (reviewed in Lowman, Schowalter, & Franklin, 2012). The methods to explore the treetops in an affordable and replicable fashion were not well developed until the 1980s, making canopy biology a very infant science (Lowman & Rinker, 2004). Whereas astronauts study outer space, arbornauts explore the canopy. It seems extraordinary that the tops of trees, which exist commonly in backyards and streetscapes around the world, were not part of forestry research until the last few decades. The development of a rudimentary toolkit including single rope techniques (SRT) and canopy walkways allowed forest scientists to engage in whole forest research, instead of a narrow focus on the forest floor. Over the past several decades, new canopy access tools have facilitated whole-tree research. Concurrent with this chronology, a few seminal studies catapulted the world of canopy research, in particular the ground-based work of Terry Erwin, Smithsonian entomologist, who fogged tropical trees in Panama, causing insects to fall to the forest floor, and generated his astounding estimate of over 30 million species in the world (Erwin, 1982). Those numbers were challenged by Edward O. Wilson, biologist at Harvard University, who has claimed that biodiversity will likely approach 100 million species when organisms in forest canopies and soil are calculated (reviewed in Lowman & Rinker, 2004).

For over 100 years, most American foresters walked through the forest and essentially based all their findings on a narrow view at ground level. Occasionally, a tree was cut down that offered a chance for observations of its upper reaches, but more likely the

FIGURE 1 Single rope techniques (SRT) was the first generally used canopy access technique, beginning in the 1980s. (Credit: Anthony Ambrose)

entire trunk was harvested for profit. Several rudimentary canopy explorations were made during the mid-20th century, including walkways built for Operation Drake from Oxford, England or a few medical towers used to study insect vectors in Asian tropical forests (Mitchell, Secoy, & Jackson, 2002).

The first efficient, affordable, and easy-to-replicate method of SRT to study whole forests came into practice in 1979. At that time, I started asking questions about leaf longevity in the rain forests of Australia, but a half a world away in Costa Rica another student from San Jose State University, California named Don Perry was also studying tropical forest ecology. We both independently determined that accurate tropical forest research required access into the whole tree, not just the forest floor. Don purchased some climbing equipment from American recreational outlets, while I sewed and constructed my own harness because Australia did not have access to those types of gear. In Australia, I also welded a slingshot in the university shop, which ultimately required a permit to maintain and operate. Because there was no internet at that time, neither Don nor I learned about one another until we both published our methods and findings some 3 years later (Lowman, 1984; Perry, 1986). He went on to teach SRT to a handful of neotropical forest students, and I trained a bevy of researchers in the Austral-Asian forest ecosystems. The use of SRT spread quickly around the planet, and became a widely used, inexpensive tool to access the tops of almost any trees. (Figure 1). This led to amazing discoveries about the critical importance of forests that were not accurately measured from ground level (Lowman & Moffett, 1993; Lowman et al., 2012).

The first canopy walkway for permanent education and research access was opened in Queensland, Australia during 1985. The owner of an ecotourist lodge and I designed this walkway both to educate visitors and as a safer option than training volunteers in vertical rope ascent. This first walkway was constructed in Lamington National Park, but within several months another was completed in Lambir National Park, Malaysia by Maryland engineer, Ilar Muul. These two walkways, ours with pole construction and Muul's using cabled necklaces strung around tall trees, set the stage for future construction of walkways throughout the world. Both designs are useful in different situations, depending on topography, tree height, visitors, and diversity of uses. Increasingly, walkways provide sustainable income from ecotourism to indigenous people who serve as naturalists, boat operators, and lodge operators, instead of earning short-term income from logging (Lowman, 2009). The proliferation of walkways has advanced research in three ways: (a) Allow teams of scientists to work together in the treetops; (b) Facilitate safe observations in the dark or during inclement weather, and (c) Create long-term observations using devices such as camera traps, permanently marked leaves or epiphytes, and executing repeat transects (Figure 2).

FIGURE 2 Canopy walkways facilitate team research and long-term monitoring, as well as to foster conservation by providing income to indigenous people through ecotourism

FIGURE 3 Drones offer easy access to flowering/leafing phenology, or mapping the canopy in this image of a new walkway in Quechee, Vermont. (credit: Vermont Institute of Natural Sciences)

In the early 1990s, Alan Smith of the Smithsonian Institution placed a construction crane amidst tall trees in Panama's tropical forests. This new technique was expensive (approximately a million dollars to establish, plus additional costs for a unionized crane driver), but offered detailed access to every leaf, insect, or reptile found within reach of a crane arm (Parker, Smith, & Hogan, 1992). Cranes now exist in approximately 10 locations around the world but require a significant budget to operate beyond the scope of most students and researchers. Three cranes are forthcoming in China's tropical forests, Panama still houses two, one in Australia, and Europe has several in temperate forests; while Venezuela and Oregon have dismantled their cranes.

A fourth, and perhaps the most innovative canopy access tool, involves inflatables. A team under the direction of Frances Halle of the Institut de Botanique in Montpelier, France pioneered *Radeau des Cimes* (raft on the roof of the world) (Hallé & Pascal, 1991). This includes a combination of canopy raft, hot-air balloon, and sled to facilitate canopy sampling. The inflatables also require approximately a million dollars (US) of funding to launch an expedition, but they historically have hosted approximately 50 scientists to collaborate as a team throughout one expedition. Over time, the inflatables have surveyed the rain forests of Cameroon, Panama, Brazil, Gabon, and Australia (reviewed in Lowman et al., 2012).

Some of the newest canopy access technologies include drones and LIght Detection And Ranging (LIDAR). While drones are still in pilot stages, and illegal in some regions, they offer relatively inexpensive overviews of forests, including the documentation of flowering phenologies, mapping of tree species, or detection of illegal logging. (Figure 3). LIDAR is a sophisticated aerial reconnaissance apparatus that requires a dedicated camera and airplane beyond the budget of most researchers, but offers extraordinary information on canopy health, growth history, and physiology (Asner, Martin, Anderson, & Knapp, 2016). Arizona State University, USA currently houses a major center for LIDAR under the leadership of Greg Asner and Roberta Martin, where they have combined LIDAR with high-fidelity imaging spectroscopy (HiFIS), to quantify the California drought through overflights that accurately calculated tree mortality (Asner et al., 2015). Applications of LIDAR and related aerial imagery almost supersede the need for ground truthing (aka climbing), but not quite. Recent research on redwood transpiration was most successful using a combination of LIDAR and climbing (Ambrose, Baxter, Martin, Francis, Asner, Nydick & Dawson, 2018), where they calculated these tall trees transpire up to 500–800 liters of water daily.

2 | APPLICATIONS OF CANOPY ACCESS TO FOREST CONSERVATION

The ability to study whole forests from bottom to top not only expanded our understanding of trees, but canopy access has more recently inspired innovative approaches to conservation. One important effort is the application of canopy walkways to create income for indigenous people through ecotourism instead of logging. One example is the Amazon Center for Tropical Studies (ACTS) canopy walkway, located in Amazonian Peru on a tributary of the Napo River, that includes 12 bridges and 13 platforms over a quarter of a mile. This structure provides research access to over 100 species of trees, epiphytes and vines, but perhaps more importantly, employs over 100 families who make a sustainable living from ecotourism. The existing conservation reserve of 4,000 acres has expanded to over one million acres, with indigenous people serving as excellent stewards who prevent poaching because they recognize the importance of keeping the forest intact. Similar links between walkways and local economies exist in other tropical forests, offering an effective bottom-up conservation solution (Lowman, 2009; Tallis et al., 2014).

Other ways to ensure more effective conservation is to engage a broad array of citizens in field science. By educating the public about the importance of forests, successful citizen actions to sustain these ecosystems are more likely to follow. The Jason Project, developed by Bob Ballard of Titanic fame, reached millions of middle school youth who virtually visited different marine and terrestrial landscapes (www.jasonlearning.org). I hosted three seasons of virtual canopy exploration with the Jason project, and still hear from young people who ultimately pursued a career in field biology as a result of these school programs (see also Lasky, 1997). Community-driven engagement via BioBlitzes or expedition travel for aspiring scientists also provide effective public conservation education about forests. Educating the public about the importance of big trees and saving forests can also lead to more sustainable consumption from industrialized countries whose citizens inadvertently buy palm oil, soy, or tropical timber without any knowledge of its source. The engagement of girls, especially in low-income countries where they are often the stewards of pollinators, fresh water and firewood, is especially important; and local conservation benefits by empowering women as stakeholders (Tallis et al., 2014).

In Ethiopia, the Orthodox priests are the stewards of their last remaining primary forests, called church forests (Lowman et al., 2012). By partnering with the religious leaders, I was able to implement effective conservation of the last remaining church forests by building simple conservation walls with the priests' blessing. These walls exclude cattle and goats from eating the seedlings, reduce firewood collection, and keep the farmers from plowing too close to the forest edges. Unique collaborations of community members, such as a partnership of religion and science to conserve local forests, provides more effective bottom-up conservation than the conventional notion of top-down leadership activities (Lowman & Pallaty 2017).

3 | FUTURE OPPORTUNITIES

Canopy research is still in its infant stages, but the arbornaut's toolkit of SRT, walkways, cranes, inflatables, and aerial imaging is now adequate to explore the whole forest, not just the forest floor. Due in part to the last three decades offering new modes of access to the entire tree, forest scientists have quantified the critical importance of forests to global health. This has led to heightened awareness of the importance of big trees, and especially tropical forests. In summary, trees are now recognized for their role in global carbon storage, controlling rainfall patterns through foliage transpiration, impacts on climate control, soil conservation through healthy root systems, important homes for a large swathe of terrestrial biodiversity, and major hubs of primary productivity. Many forests, especially in the tropics, are currently disappearing at rapid rates, and before scientists can fully explore their canopies or monitor their ecosystem services to provide context for the importance of their conservation. With additional resources, forest canopy access will undoubtedly lead to more discoveries of cryptic biodiversity and quantify the resiliency of tree species with impending climate change. Simple ways to engage locals in bottom-up conservation of global forests include the construction of canopy walkways for ecotourism, the engagement of all ages (and especially girls) in canopy research, which in turn educates them about the value of trees, and conservation partnerships between scientists and diverse stakeholders.

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