METHODS IN FOREST CANOPY RESEARCH

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(3) using canopy access for ecotourism and local income generation, (4) harvesting sustainable canopy products, and (5) using canopy science to inspire science education.

QUANTIFYING ECOSYSTEM SERVICES FROM FOREST CANOPIES

Several aspects of ecosystem services (reviewed in White et al. 2010) have emerged that prioritize canopy conservation. As rain forests continue to decline, the urgency of surveying their biodiversity becomes imperative. Reputedly, many small organisms dwelling in the treetops such as orchids as well as their resident invertebrates and other neighboring epiphytes, may have gone undetected simply because our ability to survey tree crowns has been limited to date. The wealth of biodiversity in the forest canopy is estimated at nearly half of the species on the planet (Wilson 1992), with no clear sense of absolute numbers, since canopy research is relatively new. Over the past 150 years, biologists have gradually expanded their knowledge of biodiversity as plant exploration became more extensive. The original estimates of 800,000 species made by Charles Darwin have been replaced by speculations ranging upward to 100 million (Wilson 1992); although estimates of perhaps 10–30 million are more frequently cited (Table 3.1). Our increasing knowledge of biodiversity on Earth has in great part been a consequence of tropical forest canopy exploration. Not only is the canopy important for species diversity; the types of species living in tropical treetops likely include important medicinal plants as well as genetic stock that may provide new sources of food, fabric, or other economic products.

BOX 8.1: THE ROLE OF PARAECOLOGISTS IN TWENTY-FIRST-CENTURY TROPICAL FOREST RESEARCH

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Tropical forests, comprising numerous species interacting in complex ways, are just as challenging to study as genomes, with their complex interactions among numerous genes. The progress in genomics has been substantial over the past 50 years, as our ability to read and process digital information, including DNA sequences, has grown exponentially. The same cannot be said about the methods available for the study of tropical ecosystems. For example, most entomologists studying tropical insects today employ almost the same field methods and numbers of assistants as Alfred Wallace 150 years ago (Wallace 1869). Accordingly, our knowledge of tropical forest ecology has not progressed according to Moore's law. We have not cataloged all the species in any tropical forest ecosystem or mapped their interactions, and tropical biodiversity estimates remain uncertain (Hamilton et al. 2010).

More substantial progress in tropical ecology can be achieved either by developing new methods of ecosystem inventory and analysis or by applying existing methods more intensely. Both approaches are essential. The key methodological improvements in tropical ecology are coming mostly from molecular biology, which is at last becoming useful in ecological studies. Large-scale DNA sequencing programs improve species description and recognition (Hebert et al. 2004; Miller 2007), while molecular methods are becoming increasingly useful in mapping species interactions, including predation and parasitism (Greenstone 2006; King et al. 2008).

Tropical forest studies are often limited by inadequate sampling and the failures to record many species and interactions (Novotny and Basset 2000). Increasing sampling effort by one to three orders of magnitude would improve the situation, as illustrated by advances in understanding tropical forest dynamics based on detailed inventories of large forest plots. The first plot, established in 1982 on Barro Colorado Island (Hubbell and Foster 1983), mapped 240,000 stems less than 1 centimeter in diameter in 50 hectares of tropical forest. This represented a three-hundred-fold increase in sampling effort compared to the then standard protocol of mapping stems fewer than 5 centimeters in diameter in 1-hectare plots. Large plots have become the standard for tropical forest research across a global network of plots coordinated by the Center for Tropical Forest Science (CTFS; http://www.ctfs.si.edu). Arguably, similar increase in sampling is needed to advance our understanding of animals, particularly insects, in tropical forest ecosystems. This could be achieved by increasing research budgets or, more realistically, outsourcing fieldwork from academic professionals to paraecologists.

Paraecologists are essentially technicians supporting ecological research. They can efficiently organize field work; use various sampling methods; sort, preserve, document, and database specimens; and prepare samples for molecular analysis (Basset et al. 2000; Basset et al. 2004; Janzen 2004). Paraecologists, and research technicians in general, are able to develop specialized knowledge of research protocols, local ecosystems, or particular taxa over many years. They work well in synergy with postgraduate students, who lack comparably long-term work experience but can give paraecologists a broader and a more conceptual perspective on research.

In our experience, mostly in Papua New Guinea (PNG), the best paraecologists recruit either (1) from forest-dwelling communities, where they spent their formative years in the forest and acquired extensive traditional knowledge of plants and animals but typically had limited access to formal education, or (2) among secondary school or university graduates with interests in biology and the potential to become professional biologists. Some paraecologists move on to pursue graduate education and research careers and others seek long-term employment in their technical role.

Paraecologists are particularly efficient in large-scale or long-term sampling programs,

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BOX 8.1, FIGURE 1. Parataxonomists created a "money tree" with their earnings from work on New Guinea's insect fauna.

in remote field conditions, and for sorting and processing large numbers of samples and specimens. For instance, eight paraecologists in PNG staged eight expeditions to remote rain forests over three years, during which they sampled and reared 75,000 caterpillars from 370 species. Their field work was sufficiently important to merit coauthorship of the resulting paper (Novotny et al. 2007). Likewise, our team of 18 paraecologists sampled 200,000 individual herbivores from 1,500 species and 11 guilds, feeding on more than 200 species of plants. This study documented almost 7,000 trophic interactions between particular plant and herbivore species. Although it required more than 50 person-years of work by paraecologists and additional 50 person-years by locally recruited field assistants, the study still suffered from insufficient sample size, as it documented less than 20 percent of the local plant–herbivore food web in the studied rain forest (Novotny et al. 2010).

The concept of paraecology was initially developed by Dan Janzen (Janzen 1992; Janzen 2004). In addition to Janzen's team in Costa Rica and ours in PNG, paraecologists contributed, for instance, to surveys on the arthropods of La Selva (http://viceroy.eeb.uconn.edu/ALAS/ALAS.html) and diversitas in the Western Pacific and Asia (Darnaedi and Noerdjito 2008). They are employed at INBio (the National Biodiversity Institute of Costa Rica; http://www.inbio.ac.cr/en/default.html) and throughout the CTFS 50-hectare plot network, including our plot in PNG. Paraecologists make key contributions to some of the largest data sets available for tropical ecosystems.

In spite of their success, few research projects involve paraecologists in a significant way. Whereas many business activities are increasingly outsourced from developed countries to developing countries where labor is cheap, ecological research continues to import a work force of students and researchers from developed countries to locations where fieldwork could be conducted more efficiently by paraecologists with local knowledge of biological, political, and social circumstances. Significant and ongoing investment of time and resources in paraecologist training is required to increase efficiency, however.

The investment required means that paraecologist teams become cost-effective only above a certain size and over longer periods of time. Five paraecologists working over five years might represent a minimum threshold; although this of course depends on the particulars of the project. For instance, Janzen's team in Costa Rica includes thirty paraecologists and has been active for thirty years, whereas our team in PNG includes twenty paraecologists and has been active for fifteen years. Few research institutions or projects are prepared to make such commitment. A team of paraecologists has much in common with other large-scale research programs: it is difficult to set up, expensive to maintain, and takes a long time to pay off, but it significantly increases productivity. Paraecologists have an important role to play in supporting the kind of large-scale and long-term research that is needed to understand ecosystems as complex as tropical forests.

Canopy processes provide additional ecosystem services that are becoming recognized at a global scale. The storage of carbon by trees, as part of their productivity, has been measured and valued in tropical forest ecosystems. REDD (Reduction of Emissions from Deforestation and Degradation) has achieved global recognition in climate change talks and by the Intergovernmental Panel on Climate Change (IPCC), as warming temperatures threaten the lives of millions of people and also threaten the integrity of many ecosystems (reviewed in Lovejoy and Hanna 2005). Epiphytes and their inhabitants are integral to the maintenance of rain forest ecosystems and have sometimes been referred to as the "canary in the coalmines" for tropical forest health (Benzing 1990). The processes of nutrient cycling, energy production, water filtration, and many other essential functions of rain forests are of global importance to the maintenance of life on our planet. Canopy processes drive many of the ecosystem services provided by forests—water conservation, climate control, productivity, carbon storage, and other invaluable benefits that forests provide to humans.