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The Collection and Preservation of Plant Material from the Tropical Forest Canopy

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From all over the earth—tundra, desert, steppe, mountain, ocean island, and lake—we gather the threads of plant life on land, and we trace them in the canopy of the forest, which first fitted plants for their life in the desert and on the mountain. . . . Too little is known of these places . . .
—E. J. H. Corner, "The Life of Plants" (1964, p. 284)

I. Introduction

The forest canopy harbors a diverse assemblage of plants of many different growth habits. The reproductive parts of tall trees, many epiphytes, and lianas may exist only in the upper canopy. Access to these upper regions is essential to identify canopy plants and to collect and document voucher specimens for a particular forest region. The majority of botanists, however, have relied on collecting techniques that are opportunistic (i.e., "reach and grab") rather than on methodically conducting more comprehensive samples of forest composition. Reproductive parts (essential materials for proper identification and botanical study) and leaves from the upper canopy (whose physical and physiological structure may differ strikingly between the canopy and understory) are not accurately represented in herbaria because collection of these specimens has historically posed an insurmountable challenge. This limits our ability to classify forest plants and our understanding of their taxonomy and ecology.

Why collect plant material from the canopy when it is more easily obtained from the understory? Fallen branches and entire treefalls sometimes enable a botanist to collect canopy specimens with ease, but information associated with the plant's specific habitat is often lost in a tangle of broken branches. Collecting an identifiable plant fragment may be sufficient for the botanist who is interested only in recording the presence of a certain species in a region, but data on plant habit and environment are necessary for ecological and taxonomic treatments. Systematic surveys should be assessed not only in terms of their breadth of taxa, but also in terms of their inclusion of both canopy and understory materials that are essential for an accurate description of whole forests.

In this chapter, we review the most commonly used methods for collecting plants from tropical forest canopies, discuss collection techniques necessary for different plant groups, give information on collecting and preserving specimens from the canopy, and summarize the coverage of canopy plant material in herbaria throughout the world.

II. Collecting Methods

A. Collecting Methods Used in Early Expeditions

Plant collecting became popular as both a hobby and a vocation over two hundred years ago. Although early plant collectors contributed a great deal to the scientific record, some also inadvertently contributed to the demise of canopy species (e.g., orchids). To the "plant hunters" of the eighteenth, nineteenth, and early twentieth centuries, tropical forests represented an endless bounty of exotics available for collection. Tropical plants were sought for both their scientific curiosity and horticultural value. Many species, especially colorful epiphytic orchids, were collected and transported by ship to plant fanciers in England and Europe, where they were grown in greenhouses or Wardian cases (large terrariums).

Three methods were used by Europeans to collect plants from tropical forest tree canopies prior to the 1920s: collecting from fallen limbs, hiring indigenous forest-dwelling people to climb, and cutting down trees. Botanical expeditions were typically very elaborate affairs. Among Joseph Hooker's entourage for collecting plants in India were "an attentive valet, coolies, seed gatherers, runners, cooks, tree climbers, plant dryers and pressers, an instrument mender and taxidermist, and, naturally, sepoys to guard the lot" (Whittle, 1970). Albert Millican's (1891) adventures in the Colombian Andes were typical of many who sought out canopy plants for the commercial trade: "After two months' work we had secured about ten thousand plants (of *Odontoglossum crispum*), cutting down to obtain these some four thousand trees, moving our camp as the plants became exhausted in the vicinity" (p. 151).

The chronicles of early botanical collectors illustrate a wealth of innovative, sometimes amusing, techniques for sampling plants from forest canopies. For example, good fortune played a role for the Czech collector Benedict Roezl in South America in 1871. While canoeing down a swollen river with a local guide after an unsuccessful expedition on the Pacific slope of the Andes, he came upon a large tree floating downstream. The recently fallen tree was "festooned . . . with epiphytic orchids, ferns and mosses of every shade of green." Roezl and his guide, taking advantage of this rare opportunity, "moored themselves to the tree and collected plants from its branches as they traveled downriver." Their "rich haul" offset the previous disappointments of the collecting trip (Whittle, 1970).

It was not until the Oxford University Expedition in 1929 to former British Guiana (now Guyana) that a Western botanist ascended into the rain forest canopy (described in Mitchell, 1986). Ladders were placed in the canopy of a huge "morubukea" tree by two local tribesmen, and then an armchair was hoisted up using ropes and pulleys. Since then, both simpler and more elaborate methods have been used to reach the upper forest canopy (Lowman and Moffett, 1993; Chapter 1).

B. Collecting Techniques Currently Used

Early methods of free-climbing and felling trees are still used by modern plant collectors, though less frequently than in the past. However, the free-climbing expertise of local inhabitants, chicleros, and other intrepid individuals should not be underestimated. In Peru, while two botanists were preparing to climb, their Bora assistant ascended a tree and cut specimens from branches 25 m high before they had their spikes ready (B. Bennett, personal communication). In Sarawak, Asah Amak Unyang free-climbed into the canopy and spent most of the day making collections from 35 canopy-level trees (P. Ashton, personal communication).

Technological advances in the twentieth century have led to improved climbing techniques that cause less tree damage from the sampling process (Chapter 1). Felling trees for specimen collection should be confined to those trees that are in imminent danger of destruction from road-building crews, dam projects, and other human activities. Conservation priorities make nondestructive collecting techniques essential for future maintenance of many forest regions.

We conducted a survey of contemporary field botanists to quantify which methods are used most often to collect canopy-level plants in tropical rain forests (the forest type considered most complex and subsequently most challenging for botanical surveys). We sent an eight-question survey to 39 botanists in nine countries; respondents' experience comprised 606 collective years of fieldwork and 437,000 collection numbers. Our questions related to their collection of canopy plant material: trees, epiphytes, heramong naturally fallen trees and limbs was the most common technique, followed by the use of a pruning pole and searching along road cuts (mainly used for facultative epiphytes). Seventy percent of respondents had collected "canopy" material from boats (Table I). Approximately two-thirds of those surveyed had collected specimens from trees recently felled by road crews, and most of the collectors had followed crews specifically for the purpose of making plant collections.

Despite their common use, ground-based methods do not enable the collector to make comprehensive surveys of upper-canopy plants. Collection of material that has fallen to the forest floor is opportunistic and often does not provide important ecological information, for example, it is often impossible to ascertain the height and environment from which a specimen originated. Ground-based sampling creates three shortcomings for herbarium collections: (1) inaccurate depiction of the canopy foliage of tall trees with polymorphic leaves where collectors harvest predominantly understory leaves; (2) inadequate classification of plant specimens (as well as undiscovered species) from the upper canopy levels; and (3) bias toward understory species and plant material, which may cause disproportionate representation of forest canopy structure and diversity.

Canopy-based methods described by respondents include climbing trees with single-rope techniques (Fig. 1); ladders, the peconha method (climbing with a loop of webbing held around the trunk), and tree grippers/Swiss "tree bicycles" (Fig. 2); climbing irons with spikes/*patas de loro* (Fig. 3), or freehand; cherry pickers, booms, platforms or walkways (Fig. 4); and innovative methods such as cranes, dirigibles, and the canopy raft (Chapter 1). The collection of plants from tree canopies requires a greater investment in time and equipment than from the forest floor, but the use of both canopy-based and ground-based techniques results in a more accurate and complete depiction of the flora.

Several botanists reported the discovery of unexpected plants in the canopy after climbing into trees. One advantage of using canopy-based techniques is the potential discovery of flowers, fruits, and even foliage that is not visible from the ground. Another advantage is to facilitate more comprehensive sampling through the vertical stratification of forests. Just as SCUBA diving enhances one's understanding of coral reef life below the ocean surface, the view from above the ground gives the botanist a better perception of forests and their canopy components.

Although canopy-based methods are more comprehensive than ground-based sampling, they have limitations in terms of suitability for certain types of fieldwork. For example, French climbing spikes are only useful for ascending trunks with a diameter between 10 and 50 cm (Mori and Prance, 1987). Spikes will damage trees after frequent, long-term use, but probably baceous vines/woody lianas, and other. The respondents addressed two topics:

1. field methods that were used most commonly for plants of different habits (some botanists also related stories of special interest owing to the idiosyncracies of their collecting techniques) and
2. ranking of herbaria according to quality and usefulness of collections of the six major groups of canopy plants.

Field methods were separated into the categories of ground-based and canopy-based sampling. The more conventional techniques of ground-based collection reported by the respondents included searching through natural treefalls, using a fishing line with a weight to pull down vegetation, and clipping branches with extendible pole-pruners (Table I). Unconventional ground-based techniques have included harassing monkeys so they would retaliate by breaking branches (R. Foster, personal communication) and collecting foliage that was strewn on the forest floor by raucous gangs of galahs (M. Lowman, personal communication). The use of boats to collect plants overhanging water was included with ground-based collecting methods.

Ground-based techniques were used approximately twice as often as canopy-based sampling methods. The ground-based technique of searching

Table I Ground-Based Collecting Techniques and Their Proportional Use by Field Botanists

	Percentage class for those surveyed who used method for:[a]			
Collection method	Trees	Epiphytes	Vines	Unspecified
Using naturally fallen trees and branches	3	4	4	1
Searching along road cuts	2	4	3	0
Pruning pole	3	4	3	0
Rope or line with weighted end	2	2	2	0
Rope with pruning saw	1	2	1	0
Throwing stones	1	2	1	0
Using a boat to reach plants over water	3	3	3	2
Using "legally" felled trees	0	0	0	3
Rifle to shoot branches down	0	0	0	1
Felling trees	0	0	0	1
Using stick to knock plant down	0	1	0	0

[a] Classes 0–4 correspond to the percentage of time this field technique was employed by botanists surveyed: 0 = never; 1 = 1–25%; 2 = 26–50%; 3 = 51–75%; 4 = 76–100%.

Figure 1 Karen Ferrell-Ingram using Jumar ascenders and climbing rope in Costa Rica. (Photo by Stephen Ingram).

do little damage to trees climbed only once or several times (S. Mori, personal communication). Hence, they are more suitable for floristic than for ecological studies. Swiss "tree bicycles" can be used for ascending trees with diameters of 18 to 72 cm that are free of most lianas, epiphytes, and climbing plants (Mori, 1984), but their design makes it awkward to move onto branches (T. Croat, personal communication). Single-rope techniques offer access primarily to a vertical transect near the rope, where most foliage is beyond reach. However, a "web" of ropes or nylon webbing secured to branches increases access within the canopy (Perry, 1986).

Combinations of several canopy-based methods (Tables I and II) offer

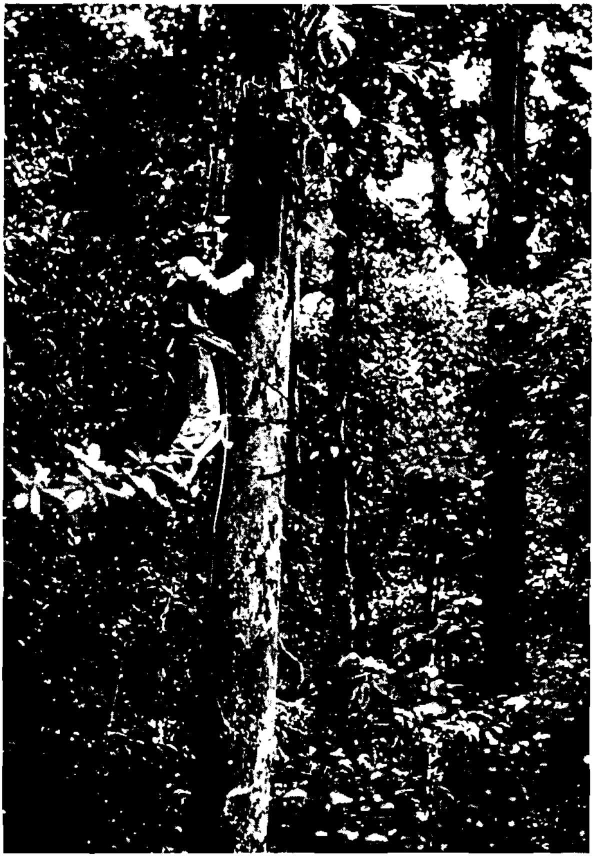

Figure 2 Scott Mori using Swiss "tree bicycles" in French Guiana. (Photo courtesy of Scott Mori, New York Botanical Garden.)

the most comprehensive sampling opportunities. For example, single-rope techniques plus the use of an extendible pruning pole are a good combination, especially with the help of an assistant on the ground. Extendible pruning poles, typically considered a ground-based method (Table I), may also be used from canopy walkways, platforms, or the canopy raft. Ascending suitably sized neighboring trees with either climbing spikes or tree bicycles and an extendible pruner can be very effective for collecting from the canopy of large-diameter trees (S. Mori, personal communication). Relative costs and ease of different canopy access techniques are summarized in Chapter 1.

Figure 3 Scott Mori collecting tree canopy material with the use of French climbing spikes (also called *patas de loro* or "parrot feet") and extendible pruner in French Guiana. (Photo by Carol Gracie, New York Botanical Garden.)

General safety precautions are necessary for any tree-climbing technique, and specific precautions may be necessary for certain techniques. In general, one should check knots and equipment on the ground, avoid climbing partially dead trees, climb with a spotter on the ground, wear a hardhat, and climb only when fully alert. Make sure the rope and branch will support the full weight of at least two people before ascending via single-rope techniques or arborist techniques. One needs to be alert to the potential dangers of wasps, biting ants, and venomous snakes, especially in low- and middle-elevation tropical forests. Dripping sap and plant spines are nuisances that are best avoided.

Figure 4 Meg Lowman using walkway constructed to access forest canopy in Belize.

C. Biological Differences between Canopy and Understory Plant Material

One of the greatest shortcomings of early herbarium specimens of canopy plants was the lack of information about the habitat of the collections. Information on the height, light conditions, and identity of the supporting host plant (for epiphytes and vines) was often omitted, in part because such information was not known for specimens collected opportunistically from fallen branches. Identification of tropical host trees in many regions did and still does pose a difficult challenge.

Canopy and understory plant material exhibit physical and biological differences, which makes each important to collect. Some epiphyte species are limited to a certain vertical range in the forest (Johansson, 1974; Kelly, 1985; S. Ingram, K. Ferrell-Ingram, and N. Nadkarni, unpublished data). Sampling among different crown heights may yield ecological information about the canopy processes of a forest (Lowman, 1984). The size differ-

Table II Canopy-Based Collecting Techniques and Their Proportional Use by Field Botanists

	Percentage class for those surveyed who used method for:[a]			
Collection method	Trees	Epiphytes	Vines	Unspecified
Climbing/scrambling to 4 m	2	4	3	0
Free-climbing higher than 4 m (or asking someone else to do so)	3	3	2	0
Using climbing irons/spikes/tree grippers	2	1	1	0
Using tree-climbing ladders	1	1	1	0
Climbing ropes with Jumar ascenders or similar gear	1	1	1	0
Permanently rigged cable and basket system	1	1	1	0
Semipermanent platforms or canopy walkway	1	1	1	0
Canopy raft	1	1	1	0

[a]Classes 0–4 correspond to the percentage of time this field technique was employed by botanists surveyed: 0 = never; 1 = 1–25%; 2 = 26–50%; 3 = 51–75%; 4 = 76–100%.

ences between understory and canopy foliage may vary by 10-fold; leaf area, toughness, longevity, chemistry, photosynthetic capacity, and other physical attributes differ significantly throughout the canopies of many tree species (Lowman, 1992).

III. Application of Methods for the Collection of Canopy Plants

A. General Flora Surveys

When plant collectors make general surveys, such as for a regional flora, they usually begin with opportunistic collecting. For example, branches overhanging rivers may have fertile material that can be collected from boats (Table II); recent treefalls may provide flowering lianas, epiphytes, and foliage from the host tree; low-growing branches and epiphytes can often be reached along forest trails or ridges. Many species of lianas that inhabit the upper crowns of mature forests also occur in gaps and forest edges (Putz, 1984), where they may be easier to observe and collect. If an area has been collected over many decades, then opportunistic sampling will probably produce an adequate (although incomplete) description of the canopy flora. The addition of canopy-based techniques to collect plants may yield previously undocumented lianas, epiphytes, and trees.

B. Canopy-Level Trees

Several methods can be used for collecting specimens in the crown after opportunistic approaches are exhausted. Shotguns or rifles are used to harvest branches of tall trees (although the specimens may be damaged from their descent to the ground and the foliage may be riddled with shot). A slingshot used with nylon line can snag a branch up to 25 m high (depending on the amount of foliage interference), and a crossbow can shoot a line as high as 45 m (Perry, 1986). It may then be possible to cut limbs using a rope with a pruning saw or chainsaw blade attached, or to cut some foliage by tugging on the line, but such tasks are time-consuming and often unproductive. The advantages of these ground-based methods are their relatively low costs, light weight for field transport, and ability for even an acrophobe to collect canopy flora. Some botanists prefer collecting tree specimens with the rope-and-saw method instead of using more bulky and expensive climbing gear (M. Grayum, personal communication), and others prefer the relatively lightweight, inexpensive French climbing spikes, also called *patas de loro* (A. Gentry, S. Mori, and M. Nuñez-Vargas, personal communication).

One of us (M.D.L.) spent 15 years collecting and measuring ecological attributes of canopy foliage in rain forests. Leaves in the upper canopy were significantly tougher, smaller, thicker, and more sclerophyllous, and differed in their levels of tannins and phenolics. For example, the leaves of *Doryphora sassafras* in the understory of a subtropical rain forest in Australia were up to 4 times longer in length, 10 times greater in surface area, and 25 times softer, and an average of up to 26% surface area was defoliated (as compared to an average of 7% in the understory) (Lowman, 1992). In lowland tropical rain forests of Cameroon, the leaves of *Sacoglottis gabonensis* were 2 times longer and 4 times greater in surface area in the understory than in the upper canopy, and suffered 25 times the level of herbivory, 0.5% versus 12.9% (M. Lowman, M. Moffett, and B. Rinker, unpublished data).

The challenges of conducting statistically replicable ecological sampling throughout different crown regions of the forests in this study were daunting, and even most canopy-based techniques were inadequate for comprehensive ecological canopy research. To measure a canopy process such as herbivory, two types of canopy measurements were made that used a range of access techniques. "Long-term measurements" involved frequent access for monthly measurements of foliage over many years, without harvesting foliage (Lowman, 1984). A second method, called "discrete measurements," involved destructive sampling of multiple branches from measured heights and light environments in the crown. Almost every type of canopy-based and ground-based sampling was used to measure herbivory as a canopy process: single-rope techniques (sometimes combined with pole-pruners and/or swinging across on horizontal vines), shotguns, rifles, slingshots, treefalls and branchfalls, following behind logging operations, exploiting destructive galahs who broke off leaves, cherry pickers, leaning over cliffs and edges, trams, ladders, canopy raft, dirigible and sled, canopy crane, scaffolding, platforms, and walkways. Although these methods vary in effectiveness, it was necessary to use many techniques to accumulate adequate ecological information about canopy foliage.

C. Lianas and Vines

Lianas are the most undercollected major plant group (Gentry, 1991). Because lianas often grow between trees, they do not tend to descend with treefalls as readily as epiphytes do, and serendipity becomes a more important factor in their collection. Their flowers and fruits may be found on the ground, but foliage and branches from lianas of mature forest canopies are often impossible to observe or obtain, except by canopy cranes or other costly methods. In Panama, the canopy crane erected by the Smithsonian Tropical Research Institute was used to survey vines on over 80 trees within several days (M. Lowman, unpublished data). With any other method of access, such efforts would require several months.

Canopy-based techniques may enable a collector to reach vines in the upper canopy, although even ropes are not successful in reaching the outer crown, where vines tend to congregate. More intrepid botanists in our surveys confessed to free-climbing upward or outward while anchored to the tree with nylon webbing, despite obvious dangers. Using extendible pruning poles from a secure perch in the canopy is probably the safest low-cost method for collecting vines from the outer canopy. One innovative ground-based technique involved the use of a hand winch to literally wind vines back down to ground level (Putz, 1990). We predict that using a combination of ground-based and canopy-based techniques for studies of vine abundance and diversity in tropical forests would be more successful than ground-based techniques alone (e.g., Putz, 1984).

D. Epiphytes

At The Marie Selby Botanical Gardens, where the herbarium collection contains predominantly epiphytes, fewer than 10% of specimen labels include information about habitats or host trees. Labels indicate that most collectors have obtained specimens opportunistically from the ground, although others have used single-rope techniques (e.g., Ingram and Nadkarni, 1993). Ecologists who collect and study epiphytes most commonly use felled trees (e.g., Kelly, 1985), ladders with extendible pruners (Bøgh, 1992), rope ladders (Hofstede *et al.*, 1993), and single-rope techniques (e.g., Wolf, 1992).

One of us (S.W.I.) compared ground-based with canopy-based collection techniques to calculate the percentage of a known local vascular epiphyte flora via these two collecting methods. Canopy-based collection techniques for this ecological and floristic study were crucial for two reasons: (1) accurate information about the type of microhabitat occupied by each epiphyte species was quantified and (2) a more complete epiphyte flora could be found by including single-rope climbing techniques. Another advantage of single-rope techniques was the ability to repeatedly climb individual trees at different seasons to collect canopy plants in flower. Eighty-five percent of the nearly 250 epiphyte species from a 4-ha site in Monteverde, Costa Rica, were collected using ground-based techniques (i.e., from fallen trees, branches, and lower tree trunks). Although ultimately 15% of the epiphyte flora was collected with canopy-based methods only, the inclusion of these 38 species made the final checklist more comprehensive and valuable (S. Ingram, K. Ferrell-Ingram, and N. Nadkarni, unpublished data). In addition, the specimens made from standing tree canopies have more useful habitat information than those from fallen branches. As with lianas and foliage from canopy trees, we advocate a combination of ground-based and canopy-based collection techniques to survey vascular epiphytes.

IV. Preservation of Field Collections

The accession of plant specimens from tropical forests, whether ground-based or canopy-based access techniques are used, requires three steps: (1) collecting and numbering specimens, (2) recording data, and (3) processing the specimens. Plant collections should be fairly representative of the local population and should contain as much information as possible. The ultimate goal is to make a more or less two-dimensional representation of a three-dimensional part with associated information.

The plant itself is the botanist's most important source of data, but recording collection information is crucial for a useful specimen. Each collection should be given an unambiguous number. Ideally, the final specimen with the label should provide information regarding the plant species' important anatomical features, its habitat, associated species or vegetation, relative abundance, geographical location and elevation, date of collection, and collector(s) name and number. Ephemeral characteristics, such as flower color and odor, should be noted at the time of collection and included with the basic collection data. Plant parts of certain taxonomic groups (such as some orchid flowers) should be preserved separately in a solution of alcohol, water, and glycerin. Recording certain features of the live plant, and making specific preparations before pressing specimens, is necessary for identification of some plant families (Bridson and Forman, 1992).

The preservation method used for plant collections depends on the climate, available resources for drying, and the preferences of the collector. The specimens can either be dried in the field or kept saturated in alcohol within plastic bags (the Schweinfurth method). In the humid tropics, most vascular plants will grow mold within several days if not dried sufficiently. Pressed plants can be suspended over kerosene lanterns to dry; a bed of hot embers is a more effective heat source. The greatest advantage of field-drying is that the dried specimens keep their color and do not become as brittle as when they are dried after being stored in alcohol. The Schweinfurth method is advantageous where mold presents a threat, or during collecting trips with continuous travel. This method requires less material, takes less time, and requires no further care for weeks until specimens are ready to dry (Bridson and Forman, 1992).

V. Herbaria with Important Collections of Canopy Plant Material

We surveyed botanists to identify herbaria with good representations of canopy material in six major plant groups (see Section II, B). Most botanists listed the herbaria they were most familiar with as being among the herbaria with the most useful collections. Most of the herbaria listed in Table III can be considered to belong to either of two groups: large or

Table III Plant Groups and Herbaria, in Alphabetical Order, with Notable Collections of Canopy Plants[a]

Epiphytes: AMES, B, BR, COL, CR, F, G, HNT, K, MO, NY, SEL, U, US, W
Hemiepiphytes: A, GH, MICH, MO, NY, S
Herbaceous vines/climbers: K, MO, NY, SEL, US
Woody vines (lianas): CR, F, K, KEP, MO, NY, P, U, US
Paleotropical forest trees: A, BM, DUKE, F, K, L, MO, P, US, W, WAG
Neotropical forest trees: A, AAU, CUZ, F, GH, K, MO, NY, P, QCA, UC, US

[a]Key to abbreviations of herbaria (Holmgren *et al.* 1990): **A,** Herbarium, Arnold Arboretum (Harvard University Herbaria), MA, U.S.A.; **AAU,** Herbarium Jutlandicum, University of Aarhus, Denmark; **AMES,** Orchid Herbarium of Oakes Ames (Harvard University Herbaria), MA, U.S.A.; **B,** Herbarium, Botanischer Garten und Botanisches Museum Berlin-Dahlem, Berlin, Germany; **BM,** Herbarium, The Natural History Museum, London, England; **BR,** Herbarium, Nationale Plantentuin van Belgïe, Meise, Belgium; **COL,** Herbario Nacional Colombiano, Bogotá, Colombia; **CR,** Herbario Nacional de Costa Rica, San José, Costa Rica; **CUZ,** Herbario Vargas, Universidad Nacional San Antonio Abad del Cusco, Cuzco, Peru; **DUKE,** Herbarium, Duke University, NC, U.S.A.; **F,** Herbarium, Field Museum of Natural History, IL, U.S.A.; **G,** Herbarium, Conservatoire et Jardin botaniques de la Ville de Genève, Genève, Switzerland; **GH,** Harvard University Herbaria, MA, U.S.A.; **HNT,** Herbarium, Huntington Botanical Gardens, CA, U.S.A.; **K,** Herbarium, Royal Botanic Gardens, Kew, England; **KEP,** Herbarium, Forest Research Institute of Malaysia, Kuala Lampur, Malaysia; **L,** Rijksherbarium, Leiden, Netherlands; **MICH,** Herbarium, University of Michigan, MI, U.S.A.; **MO,** Herbarium, Missouri Botanical Garden, MO, U.S.A.; **NY,** Herbarium, New York Botanical Garden, NY, U.S.A.; **P,** Herbier, Muséum National d'Histoire Naturelle, Paris, France; **QCA,** Herbario, Pontificia Universidad Católica del Ecuador, Quito, Ecuador; **S,** Herbarium, Swedish Museum of Natural History, Stockholm, Sweden; **SEL,** Herbarium, Marie Selby Botanical Gardens, FL, U.S.A.; **U,** Herbarium, State University of Utrecht, Utrecht, Netherlands; **UC,** University Herbarium, University of California (Berkeley), CA, U.S.A.; **US,** United States National Herbarium, Smithsonian Institution, Washington, DC, U.S.A.; **W,** Herbarium, Naturhistorisches Museum Wien, Wien, Austria; **WAG,** Herbarium Vadense, Agricultural University, Wageningen, Netherlands.

specialized. Herbaria in North America and Europe with large collections (more than two million specimens, such as BM, F, G, GH, K, L, MO, NY, S, US, and W) were recommended by respondents for their large, representative collections of most of the six plant groups listed in Table III (abbreviations follow Holmgren *et al.*, 1990; Table III). Herbaria that are not large (fewer than one million specimens) often have specialized collections of certain plant taxonomic groups, ecological growth habits, or regions. For example, herbaria in Bogotá, Colombia; San Jose, Costa Rica; and Quito, Ecuador, have significant collections of different plant groups from their respective countries.

The herbaria listed indicate that the most useful collections are housed at large herbaria. However, there are hundreds of small herbaria around the world with extensive collections from the local flora (e.g., Cuzco, Peru) or from other regional floras (e.g., the University of Aarhus' Ecuadorian collections). Large collections of nonvascular Neotropical epiphytes can be found in Bogotá, the University of Florida (Gainesville), and the State University of Utrecht, The Netherlands. Significant collections of vascular Neotropical epiphytes of several families are housed at Selby Botanical Gardens and Huntington Botanical Gardens, in addition to the larger herbaria cited in Table III.

VI. Future Directions in Plant-Collecting Methodology

The goals of specific research projects and resources available will dictate, to a large extent, the collection methods that field botanists use. For example, the collection and observational methods used by Conservation International's Rapid Assessment Program (RAP) team are aimed at the quick evaluation of an area's biodiversity (Parker and Carr, 1992). Because of the urgency and magnitude of their field work, RAP botanists collect juvenile lianas and canopy-level trees from branches or sucker shoots at ground level, note observations of canopy species out of reach, and rely on their knowledge of plants to assess the species diversity of certain tropical forests (R. Foster, personal communication). If complete habitat data are essential for canopy vine or epiphyte collections, or for ecological studies of canopy vegetation, then it is imperative to use one or more canopy-based techniques. If the goal of a project is a complete florula over the time span of a short funding period, then it is advisable to employ both canopy-based and ground-based collecting methods. Although the most cost-effective approach depends on the goals of the project and funds available, in most cases a combination of ground-based and canopy-based methods yields more complete results than either method alone. For ecological studies, or for returning to a certain tree repeatedly, single-rope techniques or ladders are probably best. For floristic studies, or for collection of canopy-level trees, climbing spikes probably offer the easiest, least-expensive access (at least in forests without lush epiphytic vegetation).

We advocate more comprehensive collection of canopy plants with careful documentation of their taxonomic and ecological attributes. With the current rapid destruction of tropical rain forests at the rate of 142,000 square kilometers per year (Wilson, 1992), the description of canopy plant species becomes more urgent to implement conservation strategies.

VII. Summary

We reviewed the methods used for the taxonomic collection of forest canopy plants. Collectors from a range of institutions were surveyed to quantify the diversity of collecting techniques. The most commonly used methods for the collection of herbarium plant specimens are ground based, such as opportunistically gathering epiphytes from fallen trees or cutting tree foliage with extendible pruners. However, canopy-based methods offer better information about the plant's environment and, in many cases, offer the only access to plant reproductive parts. For more careful documentation of the taxonomic and ecological characteristics of different canopy plants, and for more comprehensive floral surveys of different forest regions, we encourage the combined efforts of both canopy-based and ground-based collection techniques.

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