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Enhancement of forest canopy research, education, and conservation in the new millennium

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Abstract

Study of the forest canopy has reached a critical stage in its development from a young 'frontier' area of study to a vibrant and coalescing field of investigation and communication. Many current environmental and social issues at global scales (e.g., environmental change, acid deposition, loss of biodiversity) are related directly to our knowledge of forest canopies. I present six activities that are needed to help the vibrant and growing field of forest canopy studies progress efficiently. Enabling canopy researchers to communicate with each other and with those outside our field is an important element to address these issues. The establishment of a graduate-level training program is also a high priority to generate and maintain a healthy discipline. Formal procedures to identify particular forest sites of critical concern should be initiated, and these should include communication of prioritized sites to conservation groups and policy makers. Instilling a sense of wonder and appreciation for organisms and interactions in non-scientists is another important avenue for forest canopy conservation.

Introduction

The forest canopy has been termed 'the last biotic frontier', and is one of the richest but most poorly studied habitats in the biosphere (Lowman & Nadkarni 1995). Canopy study is becoming a data-rich discipline that bears on many fields of science and environmental issues. Canopy-dwelling plants (epiphytes) constitute up to half the total plant diversity of some wet tropical forests and provide crucial resources for a host of arboreal birds and mammals (Nadkarni & Matelson 1988). Recent research from numerous tropical and temperate canopies document that canopy invertebrates exhibit a tremendous amount of diversity and 'endemism' in the canopy (Winchester 1993; Basset 1993; Stork et al. 1997; Fagan & Winchester 1997). Canopy structural elements such as foliage and twigs account for a tremendous 'sieving' effect of fog in some forests, causing wind-borne precipitation and its accompanying nutrients and pollutants to be deposited locally (Coxson & Nadkarni 1995). Because canopy organisms dwell at the atmosphere-forest interface, they can serve as indicator organisms to monitor changes in global climate and atmospheric conditions (Lugo & Scatena 1992; Benzing 1998). The bulk of the photosynthetic machinery of the biosphere is located within forest canopies, so understanding their physiology and interactions has tremendous importance on issues relating to global carbon budgets and global environmental change.

Studies from multiple scientific disciplines constitute the field of canopy research: e.g., forest ecology, meteorology, zoology, geography, and conservation biology. Recent technological applications for access to the canopy such as the 'canopy raft' and the canopy crane, have allowed researchers to record and interpret larger amounts of meaningful canopy data. In the last decade, a burgeoning of scientific and popular interest in the canopy has occurred (Parker et al. 1992; Nadkarni & Lowman 1995). Interdisciplinary research groups are just now coalescing to approach canopy questions from new and different spatial scales. Heightened public interest in biodiversity, global climate change, and tropical deforestation has generated books, symposia, popular articles, and films about the canopy.

Both the types and amounts of canopy structure data are changing rapidly. In the past, scientists working alone with simple rope-climbing techniques generated studies that produced fairly small data sets. However, recent access innovations permit multiple teams of scientists to work within the same volume of the canopy. Canopy scientists have to deal with more data, new kinds of data, and the need to share data. Data collected by canopy research teams will be useful to other scientists (e.g., geographers, land use managers), just as data emanating from allied fields could aid forest canopy researchers.

Historically, canopy scientists have been notorious for independent ways of taking, storing, analyzing data and communicating their results in ways that are not conducive to comparative studies. As a first step to increase the capacity of canopy researchers to improve this situation, my colleagues and I carried out a survey of canopy researchers (Nadkarni & Parker 1994; Stork & Best 1994) to identify the major obstacles impeding forest canopy research. The surveys indicated that the field is developing rapidly but is fragmented, due to the multidisciplinary nature of the field and the historically isolated nature of the researchers. Three major obstacles were identified: dearth of communication networks among canopy researchers, lack of formal training for future canopy researchers, and problems with data management. More specifically, the latter obstacle involved the lack of uniformity in collecting, processing, and analyzing canopy data, the dearth of data archives, and the inability to link data for comparative research.

In this paper, I outline the dynamics of the field as it has developed and discuss six ways in which canopy researchers might make the pathway of development of this emerging field more efficient and useful to themselves, science, and society. I place the development of training programs, tools for analysis, and pathways of communication for canopy scientists in the context of other emerging and interdisciplinary scientific fields.

Progression of development of scientific fields and canopy studies

Scientific fields go through stages of maturity, as do societies, people, and plants. A scientific field in its infancy is typified by descriptive studies by individual scientists who identify phenomena and document patterns. As a field matures, investigations involve multiple researchers who address process-oriented questions to explain the observed patterns. A sign of maturity for a field is when its scientists can validate predictive models and relate findings to those of other fields. At that stage, scientists can respond to the 'what if' questions about pressing societal concerns posed by policy-makers (Figure 1).

At the turn of the 20th century, canopy science is at an early stage of development. It has been characterized by isolation of researchers, lack of harmonized methods, and the perception that questions addressed are 'obscure'. In the last decade, however, canopy studies have developed rapidly due to six activities:

1. establishment of formal and informal networks within and outside canopy research (e.g., the International Canopy Network (Nadkarni et al. 1997), the European Science Foundation's Tropical Canopy Research Programme);
2. growing realization that canopy studies yield important insights into issues of global environmental issues such as climate change, maintenance of biodiversity, and the creation of sustainable forest management practices;
3. a growing information base from which to draw theory and synthetic works,
4. increased use of experimental approaches to research;
5. active collaborations among canopy scientists and database and informatics scientists to better visualize, process, and archive canopy datasets;
6. heightened awareness of the general public to the excitement and importance of canopy studies due to efforts of educators and media attention.

Recommendations for enhancement of forest canopy activities

Canopy researchers should take advantage of these growth-promoting elements to further their own field, enhance other fields of science, and contribute to environmental issues facing our society. I propose and describe six actions that will address these obstacles and enhance the role of canopy studies in global and political realms.

1. *Strengthen formal and informal communication networks within canopy studies and to allied fields*

In response to the 1994 canopy survey, which identified lack of communication networks as a major

Relevance to Compelling Social Questions ↓	Stage	Types of Studies	Data Characteristics	Logistics
	YOUNG	Descriptive	Few datasets, individually designed	Personal, individual communication
	↓			Technological tools Informal networks
	MATURING	Process-oriented	Use of database models & technology	Formal communications Courses Graduate programs
	↓ MATURE ↓	Predictive	Linked, harmonized, knowledge base with connectivity to many datasets	Jointly funded programs

Figure 1. Costs and benefits of database development and use by different scales and approaches of scientific projects. See text for explanation of categories.

obstacle to canopy studies, The International Canopy Network (ICAN) organization was created in 1994 to facilitate communication among individuals and institutions concerned with research, education, and conservation of organisms in tree crowns and forest canopies. Core activities of ICAN include maintenance of an electronic mail bulletin board, circulation of a quarterly newsletter and member directory, organization of canopy symposia, circulation of a membership directory, maintenance of a citations bibliographic database, and creation of instructional materials about forest canopies for children. The group was originally supported by research funds from the National Science Foundation, but was subsequently incorporated as a non-profit organization, an arrangement that enables it to continue beyond the life of the supporting short-lived grant. These actions have enhanced communication and promoted the efficiency of canopy research and thus largely solved a substantial impediment to the development of our field.

2. *Develop an international graduate program in canopy studies to ease the way for future canopy researchers*

The survey of canopy researchers highlighted the condition that forest canopy study lacks any formal graduate training program. Students need a program that trains them in a variety of disciplines, effectively crosses disciplines, and provides contact with the worldwide community of canopy scientists. Because of the relative youth of canopy studies, canopy researchers are often isolated in their institutions. This contrasts to colleagues in more established disciplines (e.g., marine biology, soil science), who have colleagues 'down the hall' with whom to confer and collaborate. Thus, a student wishing to gather the tools to become a successful researcher in forest canopy science must either rely upon a single mentor who works on the canopy or jump from one institution to another to gain his/her background. The result is a background that is either too narrow for the breadth of background that canopy studies demands, or a program that is fragmented and inefficient.

Goals for a formal graduate training program are to train scientists who can work across traditional disciplinary fields to understand the complex factors that explain forest canopies and their associated abiotic and biotic attributes. My colleagues and I recommend certain characteristics and components for such a program (Table 1). The program we envision consists of a multi-tiered institutional structure, trainees will matriculate at one of the several resident institutions. They would have periodic, structured access to a group (ca. 20–30) of 'Canopy Research Advisors' at other

MODE OF RESEARCH	USE OF DATABASE TOOLS	COST OF USE TO INDIVIDUAL	COST OF NON-USE	BENEFIT TO INDIVIDUAL	BENEFIT TO SCIENCE
[illegible]	OPTIONAL	HIGH	LOW	LOW	LOW
[illegible]	OPTIONAL	HIGH	LOW	LOW	HIGH
[illegible]	INTEGRAL	HIGH	FATAL	HIGH	HIGH
[illegible]	INTEGRAL	LOW	FATAL	HIGH	HIGH

Figure 2. Progression of development for emerging scientific fields.

Table 1. Characteristics and components of recommended graduate training program in canopy studies.

1.	Commitment of one or more 'home institutions' for coursework, administration, and guidance
2.	Flexible academic curriculum to provide 'tailored' interdisciplinary course input
3.	Summer field program at canopy research sites
4.	'Canopy walkabout' for exchange of ideas, approaches, and protocols
5.	Virtual and real seminars and workshops
6.	Funding from private, agency, and university sources

institutions around the world who have agreed to serve as mentors in this 'university without walls'. The program has three parts: coursework, research training at field sites associated with the resident institutions, and the 'canopy walkabout'. The latter is a way to expose students to a variety of field situations and research approaches; during the summer walkabout, trainees will work directly with a subset of Canopy Research Advisors to broaden their field research experiences. This will have the positive consequence of knitting together the scattered canopy community by direct interchanges of research experiences.

3. *Actively develop ties with database and computer scientists in order to develop harmonized tools to share data, maintain a data and dataset archives, database of scientific references, and recognized research protocols*

The relative youth of the field – with its lack of entrenched methods, legacy datasets, and conflicting camps of competing groups – provides a unique opportunity for integrating data management and analysis tools into the research process. The sociology of the discipline is conducive to sharing data; forest canopy researchers appear openly communicative and supportive of each others' work. Thus, the forest canopy studies serve as an excellent arena to generate database tools that could also serve other fields of ecology and science (Linsenmair & Stork 1994).

Since 1994, my colleagues and I have developed a history of querying the canopy community about the need for and value of database tools. In September 1993, Geoffrey G. Parker and I convened a workshop on canopy studies, as part of the Long-Term Ecological Research All-Scientists' Meeting. Participants developed the framework presented below to study forest canopy structure-function studies. At a follow-up meeting in 1994, a group of database scientists from the H.J. Andrews Experimental Forest and elsewhere expressed interest in collaborating with canopy scientists. There was also excitement at 'reviving' some of the canopy datasets previously collected.

After these meetings, canopy scientists undertook several exploratory data management projects and evaluation, including our building some prototype database tools. At workshops we organized at international canopy meetings in 1998, the canopy research community came to consensus that a variety of obstacles to database use still exist. These include non-overlapping disciplinary focus, sizes of project, and conceptual differences concerning canopy structure and function. Because informatics activity ultimately reflects the science, we concluded that a database cannot become an effective integrative tool until the science itself is integrated. Paradoxically, the science cannot easily become integrated without the use of database tools. Our reviews of tools applicable to canopy science discovered a wealth of software tools used in other disciplines for displaying information about complex structures, processes, and datasets, but the best of these were not easily portable to other disciplines. To explore why has database use in canopy science has not been generally successful, we revisited how canopy research is done and found that different 'research modes' are differentially amenable to the successful use of databases (Figure 2). 'Individual projects' involve a single research question and a small, usually single-investigator project. 'Co-located research' is a collection of projects that share the same study site or organism, but different researchers focus on different questions. 'Comparative projects' take place at different locations but are driven by an emergent question that requires comparative data, though not necessarily collected in standardized ways. 'Collaborative projects' (often typified as 'big science'), involving multiple researchers on several sub-questions that relate to a single overarching theme. In Figure 2, each row shows a different mode of conducting canopy research (distinguished by the scale of the activity) and each column the general importance, and cost of implementing or neglecting database activities.

Generally, the importance of database structures and cost of non-implementation rises with the scope of the project, while costs to the individual researcher falls. For individual projects, a large investment in database tools is cost-ineffective. On the other extreme, in collaborative projects, database activities are integral to the activities involved, so database tools are included from the inception, with the cost borne by the project as a whole, thus reducing the load on individual participants. Between these extremes are cases where the introduction of suitable database technology could have relatively high benefit and low cost. This analysis suggests that the case of co-located and especially comparative canopy studies could benefit from an investment in database activities. Canopy researchers have agreed that additional effort is warranted for efforts to produce a database for such intermediate cases.

4. *Establish specific criteria for standards that will help conservationists in decision-making on priorities for protected areas*

Although research projects, education/outreach programs, and communication networks serve important functions in forest conservation, activities that directly contribute to conservation of specific pieces of land are also needed. The ICAN has outlined a procedure which may serve this function (Table 2). The 'Adopt-a-Canopy' concept enlists the input of forest canopy researchers to identify critical sites (termed 'canopies of international significance', CIS), who base the listing of sites on ecologically sound criteria (e.g., the presence of endangered or endemic species, high beta diversity, indiginous human cultures). A committee then ranks these by conservation priority and makes recommendations for the amount and types of support needed to preserve or maintain the CIS. This may involve the establishment or maintenance of a research field station, the salary of field support staff, or installation of a canopy crane or computer system. An important step in this process is to communicate with established conservation groups (e.g., World Wildlife Fund, The Nature Conservancy) about these priorities. This committee should also work to raise funds through foundations, individuals, and agencies. Policy makers must then be contacted and convinced to implement the purchase and protection of these sites.

5. *Nurture contacts with policy makers to provide scientifically sound input to land use and environmental issues*

Links between scientists and policy makers are notoriously weak and sporadic. Because canopy research has direct bearing on a number of extremely important issues of environmental and social concern, many policy makers are interested in input from forest canopy researchers; a few communication pathways between canopy researchers and policy makers now exist. For example, an organization called the Union for Concerned Scientists (UCS, Cambridge, Massachusetts), has as its goal the bringing together of policy-makers and scientists to better resolve issues requiring scientifically sound input. One of the projects of the UCS is the Sound Science Initiative. In this program, a consortium of scientists from diverse disciplines and geographical areas and policy makers approach complex environmental problems. Their current topics include biodiversity and climate change, both of which relate directly to forest canopy studies.

Table 2. Recommended steps to initiate the 'Adopt-a-Canopy' concept, a practical program to effect forest canopy conservation.

1.	Assemble a committee of forest canopy researchers to develop criteria for canopies of international significance (CIS) (e.g., high beta diversity, endangered species, 'keynote' functions, protected status, indiginous human cultures)
2.	Solicit CIS nominations from the canopy researcher community; gather documentation for sites that meet stated criteria
3.	Select and prioritize sites, and make recommendations for appropriate support needed at each site
4.	Seek corporate, agency, and individual sponsors
5.	Communicate and collaborate with conservationists and policy makers

6. *Foster the imagination and support of the general public by providing educators and the media with sound information in accessible forms*

The world of the forest canopy holds such great biodiversity and such intriguing and little-known interactions that tremendous interest exists about canopy studies among scientists and non-scientists. In the last five years, a large number of articles, television programs, and films have been produced about forest canopy researchers and their research. Interest comes from a wide range of age groups, particularly children, who have a natural love of climbing trees and exploring little-known places.

Canopy researchers must take the time from their project work to provide information in accessible forms so that the general public can understand more about forest canopies and the importance of the interactions and organisms that live there. This could take the form of writing popular articles for childrens' magazines or a publication for lay adults, giving an informal talk at a local naturalist or bird-watching club or a class of students in a local elementary school, or providing expertise on local environmental issues that relate to forest canopies to politicians or land managers. Such 'indirect' activities, though rarely rewarded in the traditional academic system, are fundamental to improving societal attitudes about research and conservation, and will ultimately produce more support for forest canopy work.

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