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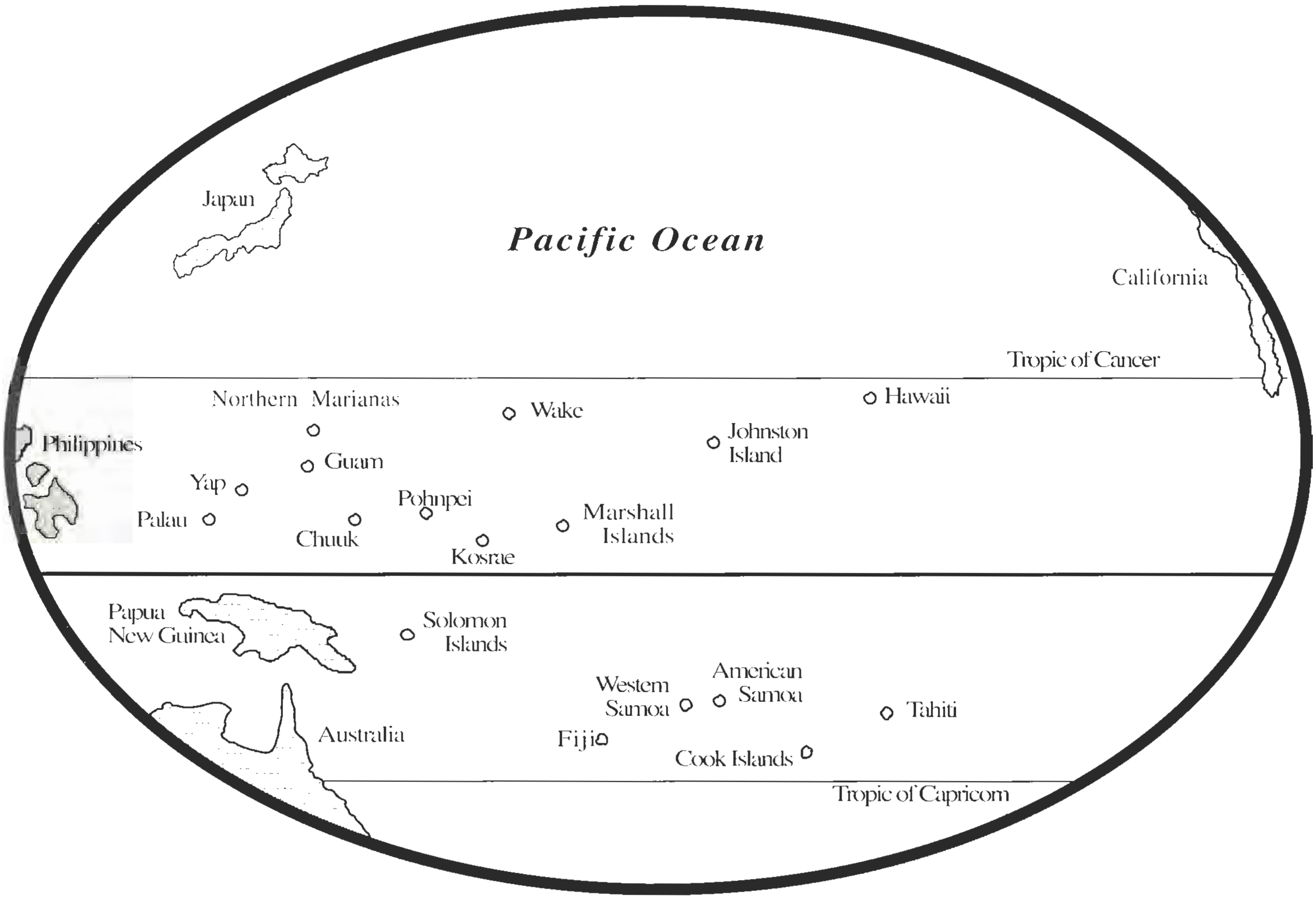

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The 17 papers in the Proceedings of the Session on Tropical Forestry for People of the Pacific cover the topics of the USDA Forest Service's tropical forestry research, forestry research in Asia and the Pacific, management of tropical forests for products and energy; forest and wildlife management, the South Pacific Forestry Development Programme, tropical rainforests of northern Australia, forest resources in New Guinea, management factors affecting forests, forests of East Kalimantan, forest biological diversity, hydrologic effects on forest management, fire management in Central America, soil taxonomy and land evaluation, tropical termites and cuticular hydrocarbons, natural regeneration of Hawaiian forest species, mangrove stands in Micronesia, and introduced weeds of native Hawaiian forests.

Retrieval Terms: tropical forestry, forestry research, resource management, biological diversity, natural regeneration, soil taxonomy, mangroves, tropical termites, weeds, wildlife management, Central America, East Kalimantan, Hawaii, Micronesia, northern Australia, New Guinea, South Pacific

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Preface

Tropical forestry for people of the Pacific is a major undertaking. The world's largest ocean is dotted with islands of all sizes, and all but the smallest are home to people. And most have forests of some kind. This Symposium offered a glimpse of the breadth of the values that the people in this huge expanse place on their forests and how they are addressing forest management issues.

What should be the role of forestry research in resolving problems and in meeting the expectations of the region? Tropical forestry in the United States, Australia, Papua New Guinea, The Federated States of Micronesia, Kalimantan, and Central America was the principal topic of this Symposium. The importance and difficulties of communication in this vast area was a topic of major concern.

On the day before the Symposium, a small group of participants met to discuss the needs of the forest environment and how to respond to those needs. A major concern was that various people and organizations coordinate with each other, to avoid duplication of work or possible destructive interference with each other or both. The organizers hoped that this group could identify some clear ideas for a resolution that could be supported by the participants of the symposium. The group agreed only that the difficulties in meeting the desires of people who live in the tropical Pacific are similar to those facing people everywhere. People everywhere want food, security, shelter, fresh water, and hope for the future of their children.

Experiences everywhere—but especially from the Pacific basin—are the best base of knowledge to meet the forestry challenge in the area. This Symposium is one way to begin the process. The papers provide the kind of broad spectrum needed as a base for action. The first five papers present an overview of research and management issues. The next two papers address issues related to the silviculture of tropical and subtropical forest resources. The relationship of different cultures to forest management is the subject of the next three papers. The remaining papers touch on a broad array of research issues. These include hydrology, fire management, soil taxonomy, insect taxonomy, forest species regeneration, classifying mangroves, and biological control of forest weeds.

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Tropical Forestry Research at the USDA Forest Service's Institute of Pacific Islands Forestry[1]

C. Eugene Conrad **Jerry A. Sesco**[2]

Abstract: Deforestation during the last decade has grown at an alarming rate, giving rise to concern for its potential adverse effects on global climate. The impetus for focusing greater emphasis on tropical forestry management and research was provided by the International Forestry Cooperation Act enacted into law in 1990. The Act enables the Forest Service to intensify its efforts to develop sustainable uses of forest lands, and to provide greater emphasis to managing tropical forests for non-woody, and non-consumptive products. Field centers for this research are the Institute of Pacific Islands Forestry in Hawaii, the Institute of Tropical Forestry in Puerto Rico, and the U.S. Forest Products Laboratory in Madison, Wisc. The Institute of Pacific Islands Forestry is responsible for carrying out the Pacific Southwest Research Station's tropical forestry research program in the tropical Pacific. The Institute is also responsible for carrying out the Pacific Southwest Region's State and Private Forestry support program for tropical forestry in the Pacific basin.

The subject of this symposium session—Tropical Forestry—is particularly timely. People all over the world have become alerted to the array of issues associated with forestry and the environment. During the 1980's, as tropical deforestation increased at an alarming rate, concern for the future of tropical forests grew to unparalleled worldwide proportions.

Wholesale deforestation is widely recognized as having global repercussion, including potentially injurious effects on global climate. When a forest is cut and not properly regenerated, a valuable ecosystem is changed. A little bit less oxygen is produced. Where the forest was, the daily range of temperature is changed. The exposed soil is more subject to erosion from direct impact of rain and often infiltration of rainwater is slowed. When the rains come, flooding below the former forest will probably increase.

When the forest does not regenerate, non-forest plants with fewer deep roots may become dominant. Often the plants that replace forest species store less carbon, live shorter lives, and more rapidly release their stored carbon back into the atmosphere. Different micro-organisms, insects, birds, and animals take over the land. When large areas of forest are converted to short-lived ground cover, the effects can cause changes in the world ecosystem.

We know that the world's environment is changing. We do not know how fast the change is occurring, but in the extreme it could threaten our very existence. Even now large areas of tropical forests are being affected by rapid deforestation. About 18 million hectares a year are being converted from forests to other uses, and only about 1 to 2 million are being satisfactorily reforested. Many hectares of forest land are being turned into farms and then abandoned because the land soon becomes degraded and unproductive.

Most people understand that the deforestation problem is not going to go away and that it will not be easily solved. Tropical forests are renewable, but often only with great difficulty. When former forest land is used for grazing and for growing vegetable crops, the soil can become degraded quickly. After the soil is degraded or lost, the land may not be capable of growing the forest that was once there.

In appraising tropical forestry management and research needs, managers face a full spectrum of questions: What specific research and management actions are needed? If forest ecosystem structure and functions are in balance, how can they be managed to provide for the needs of people and still maintain an acceptable balance? How can forests be managed to maintain their essential attributes? When forests are destroyed, how severe are the local and global effects? When forests are perturbed, what is their potential for restoration—to what degree of the pristine forest and at what costs?

This paper describes the roles of the U.S. Department of Agriculture's Forest Service and of its Pacific Southwest Research Station's program at the Institute of Pacific Islands Forestry for addressing the major questions and issues pertaining to tropical forestry research in the Pacific basin.

The Role of the Forest Service

For more than 70 years, the Forest Service has had a strong, active interest in tropical forestry. During the last dozen years, it has participated in studies that have lead to a series of widely distributed reports on tropical forestry:

In 1980, the U.S. Interagency Task Force recommended to the President of the United States that the nation should "seek to protect and manage U.S. tropical forests in exemplary fashion" and "conduct a strong domestic research program...to help...protect, and manage tropical forests" (U.S. Interagency Task Force 1980).

In 1984, the U.S. Congress' Office of Technology Assessment discussed various technologies to manage, protect, and sustain tropical forests and related resources (U.S. Congress, Office of Technology Assessment 1984).

In 1985, the United Nations' Food and Agriculture Organization (FAO) outlined steps to conserve and develop tropical forest resources on a long-term sustainable basis (United Nations Food and Agric. Orgn. 1985).

In 1989, the Forest Service demonstrated its commitment to the FAO plan by proposing an expanded and strengthened tropical forestry research and development program (U.S. Dep. Agric., Forest Serv. 1989).

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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Perhaps what might be termed the capstone of these efforts was the enactment into law of the International Forestry Cooperation Act of 1990, which provides for a greater role for the Forest Service in international forest conservation—a program especially targeted at tropical forestry. The Act...

- Allows the Forest Service to respond more fully to requests for technical expertise in sustainable tropical forest development. Although the Forest Service has for many years participated in forestry projects of the U.S. Agency for International Development and the U.S. Department of Agriculture's Office of International Cooperation and Development, the law now authorizes the agency to provide direct forestry assistance to countries not now receiving aid.
- Directs the Secretary of Agriculture to establish an Office of International Forestry in the Forest Service under a new official—the Deputy Chief—International Forestry—at agency headquarters in Washington, D.C.
- Specifies that funds to be spent on Forest Service international cooperation and assistance be identified in the President's budget submitted to the Congress of the United States.
- Directs the Secretary of Agriculture to establish an Institute of Tropical Forestry in Puerto Rico, and an Institute of Pacific Islands Forestry in Hawaii, to conduct research on tropical forestry management. This provision statutorily designates the Institute in Hawaii that had been established by the Secretary's order in 1967.

The Forest Service's field centers for research on tropical forestry are, therefore, the Institute of Pacific Islands Forestry, the Institute of Tropical Forestry, and the national U.S. Forest Products Laboratory at Madison, Wisc. The International Forestry Cooperation Act of 1990 enables the three field units to intensify their efforts to develop technology for sustainable uses of tropical forest lands. More emphasis will be given to managing tropical forests for non-woody and non-consumptive products. Such products include extractive reserves of natural rubber, oils, fruits, and nuts. Non-consumptive uses include environmental amenities that may not be compatible with intensive timber management and hardwood extraction. Particular attention will be given to avoiding land degradation and promoting sustainable development patterns that relieve pressure on remaining natural forests.

Role of the Institute of Pacific Islands Forestry

The Pacific Southwest Research Station research program at the Institute of Pacific Islands Forestry in Honolulu is carried out by two research work units. One is "Restoration of Tropical Island Forest Ecosystems" and the other is "American/Pacific Island Forestry Research." The two work units are headquartered in Honolulu but have personnel stationed in Hilo, Hawaii and on Yap island in the Federated States of Micronesia.

Direction for the Institute's tropical forestry research efforts is provided by the Forest Service's Tropical Forestry National Research Program and by the Station's long-range Strategic Plan that focuses on tropical forestry as one of the six major areas of research in the 1990's and beyond.

The Institute's research program uses a multi-disciplinary approach and calls upon the specialized skills of universities, cooperating agencies, and other organizations. Station scientists have become known for conducting research in Central and South America as well as in the tropical Pacific islands. Among the scientific disciplines needed are entomology, fire science, forest ecology, genetics, mensuration, meteorology, plant and insect pathology, range science, silviculture, social sciences, soil science, wildlife biology, and wood technology.

Cooperative Research

Experience in doing cooperative research provides the Pacific Southwest Station with the background needed to coordinate work among scientists. Within the agency, the Station links its work on tropical forestry with the Southern Station's Institute of Tropical Forestry and with the U.S. Forest Products Laboratory. The Institute's major land management cooperator in Hawaii is the Division of Forestry and Wildlife. The Division provides office and laboratory space as well as much of the forest land for carrying out research. Hawaii is the only State that is responsible for managing tropical forests.

National Programs

The national strategic plan for Forest Service Research calls for using our organizational strength to develop partnership teams. Universities, Federal and State agencies, private companies, and public organizations will be important members of these teams. The Plan directs more research toward problems related to environmental changes, multiple resource uses, and human valuation of natural resources. These are issues that are of paramount importance in dealing with the multiple aspects of tropical forestry.

Another national program—the Resources Program Assessment also highlights a global concern for the environment. The need is for greater attention to be directed toward conserving resource values for global benefit. The RPA focuses on National Forests and also recognizes a major Forest Service role in supporting the tropical forestry needs of our neighbors.

Agencies and Private Organizations

Private sector organizations as well as Federal and State agencies are important cooperators and supporters. Land owners such as farmers, ranchers, and foresters provide places to do critical research. The U.S. Department of the Interior's Fish and Wildlife Service is one of the important cooperators in Hawaii and other U.S. affiliated island nations and territories in the Pacific basin. The Service identifies and proposes the listing of threatened species as endangered. The roles of the Institute of Pacific Islands Forestry are to do appropriate forestry research and assist with developing recovery plans.

The Institute's project on biological control of forest weeds depends on the quarantine facility provided by the National Park Service at Hawaii Volcanoes National Park. Research on biological control of forest weeds has also received strong support from the States of Hawaii and Oregon. The new mangrove research in Pohnpei, Federated States of Micronesia, includes an Institute scientist and others from Oregon State University and the College of Micronesia. C. Brewer Co. Ltd., the U.S. Department of Energy, the State of Hawaii, and governments of other Pacific Islands have been cooperators with Forest Service scientists in research on growing biomass for fuel. The University of Hawaii, Hawaii Department of Land and Natural Resources, and the Weyerhaeuser Company have provided funds and other resources for research on field comparisons of tissue cultures of loblolly pine with seedling loblolly and Caribbean pine. This team has also done research comparing varieties of Hawaiian koa.

Need for Cooperative Research

Current and future research is based on interrelated components that have application in multiple ecosystems. Research on each of the components requires major effort by certain disciplines. If we are going to achieve success in providing the technical support needed to restore tropical forests, we must develop widespread commitments from the scientific community. Therefore, the need for cooperative research is urgent.

Even with the commitment of all Forest Service scientists, the research that is needed would still require even more scientists. Outside the Forest Service are current research projects in all phases of tropical forest ecosystems. Pacific Southwest Research Station scientists need to take part in these cooperative research efforts.

For the augmented program in tropical forestry research, many scientists at the Pacific Southwest and other Forest Service research stations will be needed. Most of them are interested, but other current and continuing research commitments limit the amount of time they can devote to tropical forestry. We need new scientists involved in the program. Science cooperators should come from universities, colleges, and government agencies everywhere. These science partnerships may be most important for achieving the best solutions to tropical forestry problems. Tropical forestry in the Pacific should receive special attention from scientists in the Pacific Basin. Scientists in developing countries, especially in those where tropical forests are found, should be key partners in the commitment for tropical forests.

To get more scientists involved, perhaps we should consider a **competitive cooperative grant program** that would be open to the best scientists regardless of affiliation. For example, a Forest Service scientist could cooperate with an appropriate outside scientist and enhance the products of both. This approach would enlarge the scientific community's commitment to achieving problem solutions. The urgency to begin delivering the needed technology from new research should be recognized in developing each cooperative grant. Competitive cooperative grant research on specific projects would be done over a period of a few months to a few years. The research would continue to be focused on the highest priority projects.

A strength of Forest Service research is our long-term work on forest ecosystems. Such research can sometimes cover decades and is crucial for testing and refining hypotheses that deal with organisms that live hundreds of years. We must build on our strengths as members of the scientific community. Forest Service scientists should provide long term continuity. Scientists from other organizations would provide critical knowledge when it is most needed. With these partnerships, solutions for the difficult problems in tropical forestry can be achieved in a timely manner.

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Forestry Research in Asia and Pacific[1]

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Abstract: Much research has been done in Asia and the Pacific that might help Pacific Island countries produce more biomass and better manage their natural resources. National forestry research institutes throughout the region have examined many important aspects of forestry. Not all research findings are directly transferable between countries, but research methods and results can help guide research and policy decisions. Trends in forestry research priorities over the previous decade are examined. National research findings are identified that may affect Pacific Island forestry. Research not affected by environmental conditions are included, and several mechanisms for accessing this information are examined.

Over the last decade, a large amount of resources, financial and human, have been expended on identifying and setting priorities for forestry research needs. Many meetings, studies, and reports have espoused the need to increase support for forestry research and develop the infrastructure to communicate research findings between countries. To begin to understand the complexities of the organization of research in this vast and culturally diverse region, it is necessary to review the major events affecting research policy and the research priorities of professionals in the region.

This paper reviews a sampling of major forestry research to illustrate the potential for research from continental and island Asia to address these research priorities, and suggests mechanisms to improve access to some forestry research. The examples given are only the "tip of the iceberg," but illustrate the infrastructure available to share information and improve national forestry research programs.

Trends Affecting Forestry Research

The major events affecting forestry research in Asia and the Pacific Islands during the decade of the 1980's were:

1981—World Bank and United Nations Food and Agriculture Organization issues their report on "Forestry Research Needs: Time for Appraisal."

1982—Directors of Forestry Research hold their first meeting, at East-West Center, Honolulu, Hawaii.

1982—Australia establishes its Centre for International Agricultural Research.

1983—International Union of Forestry Research Organizations sponsors regional workshop at Kandy, Sri Lanka.

1985—International Task Force on Forestry Research, made up of private and public sector members, proposes a Tropical Forestry Action Plan.

1986—Directors of Forestry Research hold their second meeting, at East-West Center, Honolulu, Hawaii.

1987—World Bank, FAO, and other organizations meet at Bellagio, Italy and organize a task force on tropical forestry research.

1988—World Bank, FAO, and other organizations meet again at Bellagio, and propose options to expand and coordinate forestry research.

1989—Asia and Pacific Regional Office of FAO convenes meetings of forestry research directors.

1989—Consultative Group of International Agricultural Research Board declares the need for a forestry institute.

1990—Asia-Pacific Forestry Commission holds its fourteenth meeting in Manila, Philippines.

1991—Institute of Pacific Islands Forestry, Pacific Southwest Research Station, USDA Forest Service, sponsors Forestry Research and Management Meeting in Honolulu, Hawaii.

The 1981 World Bank and United Nations Food and Agriculture Organization (FAO) report asserted the need to examine the forestry research needs of developing countries and to refocus resources to address new and prominent issues. The study acknowledged a shift in forestry programs to meet the basic needs of rural populations and attack the decline of natural ecosystems. It concluded that more resources and consideration should focus on three issues: rural development forestry, maximizing biomass production to meet expanding energy demands, and conservation of natural ecosystems (World Bank/FAO 1981).

The East-West Center organized two meetings of Directors of Forestry Research (1982 and 1986). At the first, the conferees declared the need for stronger coordination among national research institutes in the region. During the second workshop, the Center presented the results of a regional survey that examined the allocation of resources to forestry research within national forestry institutions (Lundgren 1986, Lundgren and others 1986).

The study concluded that over 50 percent of research efforts were directed to biological factors of forestry, including watershed management, forest hydrology and protection, wildlife, recreation and resource inventory. Twenty and 22 percent of the resources addressed forest products and plantation management research, respectively. Agroforestry and social forestry research accounted for less than 6 percent of the resources (Lundgren and others 1986).

In 1984, the International Union of Forestry Research Organizations (IUFRO) Special Programme for Developing Countries (SPDC) organized a regional workshop at Kandy, Sri Lanka. The workshop set priorities for forestry research and ranked

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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silviculture and management research as the greatest need. Other priorities included genetic improvement of multi-purpose trees, species selection, design of agroforestry systems, and pest management. Recommendations also included establishing 10 regional species research networks (Lundgren and others 1986).

An International Task Force on forestry research proposed a global research strategy for tropical forestry (Anon. 1988b). It accorded high priority to agroforestry research and set priorities in three categories: tree/crop interactions, especially hedgerow intercropping and the effect of shade; nitrogen fixation; and the effect of green leaf manure on crop yields. Other priority research included shelterbelts and farm fuelwood production.

The Bellagio I meeting (1987) acknowledged that the resources allocated to forestry research were severely deficient. Subsequent to the meeting, an international task force organized to examine tropical forestry research recommended increased research in five fields: agroforestry, natural forest management, tree improvement, wood utilization, and forest policy. It proposed seven institutional options to coordinate and expand forestry research that were deliberated during the Bellagio II (1988) meeting. That meeting endorsed the proposed option to expand the responsibilities of the Consultative Group for International Agricultural Research Board (CGIAR). At the 1989 meeting of the Board, this alternative was supported and a declaration to that effect was adopted. The governing body of CGIAR gave special importance to forest resources as essential to rural economies and energy (Anon. 1989).

In August 1989, the Asia and Pacific Regional Office of the FAO, convened an expert consultation of directors of forestry research institutions. A primary objective of the meeting was to identify research appropriate to neighboring countries. The consensus of the group was that considerable research was available to improve national programs, but that access to the results was a serious obstacle. Several mechanisms to improve the flow of information were discussed. Two were endorsed and acted upon—INFORM and FORSPA.

The fourteenth session of the Asia-Pacific Forestry Commission (APFC) met in March 1990 and endorsed the recommendations of the TFAP task force for increased forestry research in five fields. It urged the FAO to take actions similar to the CGIAR to improve forestry research and recommended that FORSPA be made operational (Anon. 1990).

Research Priorities in the Pacific Islands

To understand the potential for sharing forestry research between countries, it is important to appreciate the needs identified by the professionals in the region. For the purpose of the XVII Pacific Science Congress, research needs are limited to Pacific Island countries. This vast region, though included in the rhetoric, has been seriously neglected in regional and international forestry research programs. The priority research needs in Pacific Island countries as expressed and determined in recent endeavors are as follows (H = high; M = medium; L = low):

Heads of Forestry	USDA Forest Service
Plantation Benefit/Cost Analysis	Forest Policy and Legislation (H)
Regeneration of Degraded Sites	Erosion Control Methods (H)
Non-Wood Forest Products	Watershed Management & Protection (H)
Utilization of Coconut Wood	Natural Forest Management (H)
Wood Properties of Timber Species	Agroforestry Practices (H)
Forest Plantation Techniques	Forest Products Marketing (H)
Species & Provenance Trials	Pest Control (M)
Nursery Techniques	Nursery Management (M)
Forest Policy and Legislation	Tree Improvement (M)
Forest Plantation Techniques	Silviculture (rotation length) (M)
	Mensuration (growth and yield) (M)
	Mangrove Management (M)
	Stress Tolerance (wind, salt) (L)

The Heads of Forestry of eight Pacific Island countries met in Suva, Fiji, in November 1990 to, among other business, establish priorities for national and regional forestry programs (Anon. 1990). The assembly recognized many problems and issues that spanned the region, including increasing population growth, low priority for forestry in national policies, and lack of information on many forestry aspects. It identified various research needs that would improve national and regional programs. For example, high priority was placed on developing benefit/cost analysis of plantations as they relate to the preservation of natural forests. Regeneration techniques of logged and degraded sites were identified as the preferred research focus. The demand to identify and quantify the non-wood forest products used in each country has been strong.

The members observed that "most countries in the region have substantial unused coconut resources" and that "... little is known about the physical properties of many common tree species." (Report of Heads of Forestry Meeting 1990, draft). They recommended that increased resources be focused on researching the uses of coconut wood. Resources also should be allocated to test the physical properties of commercial and potentially commercial species. In addition, basic forest plantation research, species and provenance trials, nursery techniques, and spacing trials were recognized as priorities.

In 1990, The USDA Forest Service examined the forestry situation in Pacific Island countries. Their study's objectives included surveying forestry programs for the need to improve education, extension, and research facilities. The report identified numerous activities to improve national and regional programs. For example, high priority was placed on developing effective erosion control measures and agroforestry and community forestry practices. Medium priority was given to such research topics as pest control, nursery management, tree improvement, silviculture (e.g., rotation length), mensuration (e.g., growth and yield), and mangrove management. The survey placed low priority on stress tolerance (e.g., wind, salt, etc.) research and forestry on degraded sites (Booser 1990).

Forestry Research in the Pacific Islands

Except for Fiji and Papua New Guinea, it is not apparent that other Pacific Island countries have national forestry research programs. As of 1989 the Cook Islands had no forestry research center. Research in the Cook Islands was mostly done as part of reforestation programs, and their Forestry Department has relied on research results from other Pacific basin countries, most notably Fiji, Vanuatu, and New Zealand.

Forestry research conducted in other Pacific countries has not been coordinated by national programs. For example, a variety of research undertaken in Western Samoa and reported in the Nitrogen Fixing Tree Research Reports was performed by Peace Corps and other nongovernmental organizations. Kidd and Taogaga (1985) examined the effect of "green manure" on upland taro. Cable and others (1983), with the University of South Pacific, analyzed intercropping NFTs with taro. Research at the University of South Pacific also has examined growth and yield of fuelwood for many nitrogen fixing trees (Cable and others 1984).

In-depth case studies illustrate the social and ecological relationships of land use systems. They provide research managers basic information of the systems that research may affect. Kunzel (1988, 1989) described agroforestry in Tonga and the role of trees in traditional land use systems. The studies examined factors that support or inhibit agroforestry, and recommendations were made to improve the systems. Thaman (1989, 1990) described the role of trees in Pacific Island countries, most notably Kiribati and Fiji. The Richardsons (1986) described the environment and major components of agriculture systems in the Pacific Islands. Surveys provide an important foundation to advance research on specific components of agroforestry. They are typical of the research initially undertaken to understand and improve land use systems.

Research in Hawaii is an important resource for national and regional forestry research programs. The USDA Forest Service has been conducting forestry research for decades in Hawaii and much of this may be useful to other countries. In addition, the Forest Service's research program extends to Pacific Island countries, where it has direct benefits. The University of Hawaii is an important research facility and source of appropriate forestry information. For example, Raynor (1989) examined indigenous agroforestry systems in Pohnpei; Dudley (1990) analyzed the performance and management of fast-growing trees in a variety of ecological conditions; and MacDicken (1983) studied the growth rates of nitrogen fixing trees (NFTs).

In the 1930's the Department of Forestry in Fiji tested over 200 species for potential in reforestation. *Swietenia macrophylla* was selected as the "best" species, and until the mid 1970's was the species of choice. After a devastating attack by the Ambrosia Beetle, five other species were added to the forestry programs. The Ministry now uses seven species: *Swietenia macrophylla*, *Pinus caribaea, Anthocephalus chinensis, Maesopsis eminii, Cordia alilodora, Agathis vitiensis,* and *Endospermum macrophyllum* (Jiko 1989). The recent publication by the Timber Utilization Research Division, "A Guide to the Specifications of Local Timbers for Building Applications," has perhaps, the greatest potential benefit for neighboring countries to increase utilization of timber resources, especially that of lessor known species.

Forestry research institutes in Papua New Guinea (PNG) have much to offer neighboring countries. For example, a variety of species have been identified that are suitable for reforestation of logged areas. Forestry research institutes have also developed nursery and plantations techniques for other species. Over 40,000 forest insects have been identified, collected and stored in a national insectorium. The Papua New Guinea Forestry Research Institute (PNGFRI) recently published a book on micro-identification of all commercial timbers and has published more than 10 volumes on wood preservation and utilization of minor forest products.

Forestry Research in Asia

Most if not all Asian countries have national forestry research programs. Some, like the Philippines, India, and Thailand, are more developed and their results are easily accessible. Others, like Malaysia, may be well developed, but their research results are not readily available. Yet other countries have modest research programs (Myanmar and Bhutan) or their programs concentrate on supporting other countries. Japan's main priority is to promote international research and contribute to world forestry.

We summarize here only the major research programs in each country, providing examples of the primary research *(table 1)*. The lack of inclusion of other countries should not suggest that they are unimportant, or have nothing to offer. Rather, they are not included for lack of space or information on them.

All research programs have results, experience, and expertise to share, and research from all countries should be considered for its potential benefit to other programs. For example, the primary focus of Bhutan's forestry research program is fodder species. Perhaps the forestry research from China most appropriate to share with other countries focuses on management techniques for shelterbelts and intercropping to improve traditional farming systems. China also has performed comprehensive economic analysis of the effects of shelterbelts and intercropping on traditional systems.

Southeast Asia

The focus of research in Myanmar (Burma) may be relative to other national forestry research efforts. Tree improvement research on *Tectona grandis* and *Pterocarpus macrocarpus* might help improve the use of these species. Research on Pterocarpus has focused on clonal propagation and development of seed orchards. The national research program is examining growth performance and the control of pests of *Acacia auriculiformis* (Norbu 1989).

Other forestry research that may be applicable includes fuelwood production, social forestry planning, and agroforestry for erosion control. With the over dependence throughout the region on a few species for pulp production, the results of

Table 1—*Examples of primary forestry research in Asia*

India	
	Agroforestry Marketing
	Spacing Trials in Social Forestry
	Species Selection for Agroforestry & Degraded Sites
	Volume and Yield Tables for Social Forestry Species
Indonesia	
	Tree Improvement
	Seed Orchards
	Plantation Establishment Techniques
	Silviculture of Rattan Species
Myanmar	
	Tree Improvement
	Clonal Propagation & Seed Orchards
	Fuelwood Production
	Agroforestry for Erosion Control
	Growth, Yield & Pest Management of *Acacia auriculiformis*
Nepal	
	Fodder Trials
	Vegetative Propagation of Fodder Species
	Spacing Trials; Protection of Fodder Trees
	Coppice Management in Short Rotations
Pakistan	
	Stress Tolerance Trials —Waterlogged and Saline Conditions
Philippines	
	Species Selection for Reforestation
	Economics of Agroforestry
	Species Performance for Erosion Control
	Soil & Water Conservation Techniques
	Agroforestry Cropping Systems
	Traditional & Non-Traditional Uses of Mangroves
	Production of Mychorrhizal Tablets
	Silviculture of MPTS
	Propagation by Tissue Culture
	Artificial Regeneration — Assisted Natural Regeneration
	Species & Provenance Trials
	Wood Properties and Use of Coconut Lumber
Sri Lanka	
	Species Selection for Livestock Systems & Erosion Control
	Soil Fertility Rehabilitation with Green Leaf Manure
	Socio-economic Studies of Agroforestry
	Economics of Agroforestry
Thailand	
	Biomass Production
	Nutrient Cycling in Agroforestry Systems
	Benefit/Cost of Fuelwood Production
	Silviculture of Agroforestry Systems

research in Myanmar on species for pulpwood could greatly enhance planting programs. Like other countries, Myanmar is pursuing research on production and management of bamboo.

Nine Indonesian institutes and universities are active in forestry research, yet the primary institute is the Agency for Forestry Research and Development (AFRD). For many years, AFRD focused on the "genetic improvement" of *Pinus merkusii*, the main reforestation species. Increased research from AFRD and other institutions has resulted in the establishment of seed orchards of *Pinus merkusii, Eucalyptus urophylla, E. deglupta, Acacia mangium, Paraserianthes falcataria,* and *Leucaena* sp. (Agency for Forestry Research and Development 1989). AFRD also has important findings in establishment techniques of many of these species for industrial plantations. The institute is studying the silviculture of rattan species.

No less than 34 institutes are engaged in forestry research in the Philippines. Many have important and potentially pertinent research that is appropriate for neighboring countries. The Ecosystems Research and Development Bureau (ERDB) has identified eight multi-purpose tree species for reforestation: *Paraserianthes falcataria, Anthocephalus chinensis, Eucalyptus deglupta, Gmelina arborea, Endospermum peltatum, Ochrona phyamidale, Xylopia ferrugeni* and *Leucaena leucocephala* (Polisco and Natividad 1989). The ERDB also examines important aspects of agroforestry, including the economics of perennials under plantations, species performance for erosion control, soil and water conservation techniques, agroforestry cropping schemes, and extension strategies to enhance adoption of agroforestry. Recently, the ERDB analyzed traditional and non-traditional uses of mangroves.

The University of the Philippines at Los Banos (UPLB) has been doing forestry research for many decades. An example of important research here is the development of mychorrhizal tablets to increase pine and eucalyptus seedling performance in nurseries. UPLB has found that *P. falcataria* coppices profusely even when its stumps are over 30 cm in diameter. UPLB scientists found no substantial loss in survival when paraserianthes stems were cut flush with the ground, or at 15 cm or 30 cm above the ground (Polisco and Natividad 1989).

Other institutes are examining propagation by tissue culture, artificial regeneration and species and provenance trials. Using tissue cultures, researchers have developed plantlets of *Calamus ornatus* 25 days after placing the embryos in a planting medium. Philippine institutes have been able to decrease germination period from 120 to 2 days with almost 100 percent success (Polisco & Natividad 1989). They also are finding ways to regenerate Dipterocarpus species. Assisted Natural Regeneration (ANR), a promising form of wasteland reclamation, was developed and tested in the Philippines. Philippine institutions are also testing a variety of multi-purpose trees (mpts) for fuelwood production; *Leucaena leucocephala* and *Paraserianthes falcataria* had the highest survival rates in provenance trials of mpts.

The Philippines conducts forest products research that is important to neighboring countries. Examples include cocolumber processing, handmade rice paper, low-cost housing materials from wood excelsior, and small-scale charcoal production (Tesoro 1989).

The forestry research center in northeast Thailand has examined the effects of intercropping on biomass production of four fast growing species—*Acacia auriculiformis, Leucaena leucocephala, Eucalyptus camaldulensis* and *Peltophorum dasyrachis*—and several agricultural crops (Personal observation 1989). Similar experiments examined annual rates of nutrient cycling by tree crops in agroforestry systems. The cost-benefit analysis of fuelwood production in agroforestry has been examined. Other research includes studies of the optimal combination of trees and crops. Thinning and pruning studies are determining management practices to optimize crop and tree yields. On-station research is examining multi-storied mixed planting systems and coppicing ability of selected tree species.

South Asia

India has a long history of forestry research, the results of which may help improve forestry programs in other countries. National forestry research has focused on several important species: *Acacia catechu, Ailanthus excelsa, Anthocephalus chinensis,* bamboo species, *Bombax ceiba, Lagerstroemia parviflora, Melia azedarach,* and *Tetrameles nudiflora* (Singh 1989). Results from Indian studies on agroforestry marketing, development of volume and yield tables for social forestry species, species selection for degraded sites, and silvicultural treatments could help other national forest programs. The effect of trees on crop production and spacing trials in a social forestry context are research topics examined extensively by Indian research institutes.

Research in Nepal, especially that which focuses on the Terai, may be useful to other countries. Extensive fodder research has included species trials, intercropping multi-purpose trees with fodder grasses, methods of protecting fodder trees from grazing animals, and vegetative propagation of fodder species. Agroforestry/social forestry research includes methods to gain people's participation in forestry programs, propagation methods suitable for farmers, and on- farm mulch demonstrations. Coppice management on short rotations is another example of research that may prove useful. Bamboo propagation, cutting trials, and seed collection and storage studies might help improve bamboo production in other countries.

Important research findings from Pakistan include species for water-logged and saline areas, tree/crop relationships, sericulture, and agroforestry. Some of the species identified for water-logged and saline conditions are *Eucalyptus camaldulensis, Albizia procera,* and *Pithecellobium dulce* (Sheikh 1989). Results from agroforestry trials indicate a decrease in crop yields along shelterbelts but an overall increase in income from the sale of trees. Researchers in Pakistan have developed a disease-free F1 hybrid of mulberry and have found that one hectare of mulberry (planted 1 × 1) can yield 23 metric tons of utility leaves. Adding five bags of urea per ha. can increase yields 100 percent (Sheikh 1989). Agroforestry research in Pakistan has looked at the effects of single trees and boundary planting on crop yields, and the design of appropriate systems to meet social needs and biological (e.g., saline) conditions.

Forestry research in Sri Lanka has examined the effects of trees on crop yields, the performance of different combinations of species on biomass production, and species selection in tree/livestock systems. Research to improve productivity of systems includes the effect of leaf manure on soil fertility, and methods of using trees for erosion control; species selection for intercropping and improvement of pasture grasses. Socio-economic research in Sri Lanka includes the economics of hedgerow intercropping, development of models for mixed cropping systems, and economics of home gardens.

Mechanisms to Access Forestry Research

Much of the forestry research done in Asian and Pacific Island countries could benefit national programs in neighboring countries. But, access to these findings varies greatly with the subject and development of information networks. Published research results are obtainable only if national libraries can purchase or exchange documents and many lack basic current literature.

Research projects supported by international agencies such as work on rattan, bamboo and multi-purpose trees have well developed networks, and their documentation may be circulated throughout the region. For example, experts in rattan may know about similar research in other countries. Further, a member of the MPTS research network will know about colleagues' research in participating countries. Unfortunately, results of less popular or more recent research are difficult to obtain. For example, much work has been done throughout the region on growth and yield of agroforestry species, yet this information is not widely distributed. Though growth and yield varies between sites, this information could provide decision-makers general guidelines of expected yields and advance research efforts.

Mechanisms are needed to share basic research results. There are networks for specific research (e.g., multi-purpose trees, rattan, bamboo), but until recently no networks focused on collecting and sharing information on forestry in general. The FAO, with the Directors of national forestry research institutes initiated, two networks to enhance the flow of forestry information.

At the 1989 FAO consultation on forestry research for Asia and the Pacific, an Informal Network of Forestry Research Managers - Asia-Pacific Region (INFORM) was created. Its objectives are to promote: 1) regional cooperation and foster closer working relationships among the forestry research institutes (FRI's) of the region; 2) information-sharing and exchange of experiences among the FRI's for mutual benefit and collective self-reliance; 3) traditional IUFRO activities in the region. Periodic meetings are planned to increase the flow of materials.

The Forestry Research Support Programme for Asia-Pacific (FORSPA) was started in 1989, also during the consultation of Directors of Forestry Research Institutes (Anon. 1989c). Its primary objective is to improve forestry research capabilities in the region to respond more efficiently to the needs of participating countries. These include Bhutan, China, Fiji, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Sri Lanka, and Thailand.

Recognizing a need to coordinate agroforestry research and share results of this research, the FAO initiated a third mechanism in May 1991 to address this concern. The approach is to set up a participatory network of national forestry institutes for increased training, research, and extension of agroforestry activities and information. The project will set up demonstrations of successful agroforestry systems and provide a source of documentation of agroforestry information. Based in Jakarta, Indonesia, the geographic focus of the network are nine South and Southeast Asian countries. No reference is made in the operation plan to include Pacific Island countries.

Other international agencies are coordinating research on specific aspects of forestry. Examples of some are included below.

The Australian Centre for International Agricultural Research, established in 1982, encourages research aimed at identifying and finding solutions to agricultural problems in developing countries. ACIAR commissions research and communicate research results to individuals and institutions. The Centre works on a variety of issues common through the region, including smallholder agriculture development, tree improvement, forage crops, as well as marine problems. Its forestry research works to promote the use of Australian trees in developing countries. Participating institutes have established adaptability trials of about 50 species of eucalyptus, acacia and casuarina.

The International Development Research Center (IDRC) recognized the importance of bamboo and rattan and developed a network to support research on these species. The research seeks to find efficient ways to solve the problems of insufficient supplies of raw materials and other obstacles to provide greater employment opportunities for rural populations.

The Forestry/Fuelwood Research and Development (F/FRED) project, funded by USAID, responded to the fuelwood needs in the region. Its aim is to advance the research and research capabilities on multi-purpose trees in participating countries. After its initial funding cycle, the network includes over 30 institutions in 12 South and Southeast Asian countries. These institutes are examining the performance of select multi-purpose trees in three ecozones: humid, arid, and semi-arid. The project also supports three trials representing 25 provenances of *Acacia auriculiformis*. Other experiments supported by F/FRED are Leucaena psyllid trials, alley cropping, and feeding trials.

The Nitrogen Fixing Tree Association (NFTA) provides scientists a way to evaluate a variety of nitrogen fixing trees (NFTs) and select the most appropriate species for given conditions. The Cooperative Planting Program (CPP) is used by scientists throughout Asia and the Pacific to test NFTs. NFTA has over 240 trials with scientists at locales, throughout the region, including Fiji, Guam, Yap, American and Western Samoa, Tonga, and Papua New Guinea.

Conclusions

The amount of funds dumped into forestry research each year is having little, if any, effect on arresting the monumental degradation of our natural resources. An astronomical amount of monies support research that will provide little benefit to society. Until most recently, societal issues had little, if any priority in national forestry research programs. Over the last decade the focus of forestry research is shifting toward these issues. Most, if not all, national programs include social forestry in the rhetoric. Some even have research programs that address this critical issue. But, few allocate sufficient resources to understanding the diverse cultural factors of managing or growing a forest.

More attention and consideration must be given to the societal characteristics that complicate the technical aspects of forestry. The forestry community knows how to grow trees. We can calculate growth and yield and determine the "best" species for a particular climates. But, without a genuine understanding of different cultures and how their people view trees, technical "fixes" are ineffective at stopping deforestation.

A concerted effort is needed to collect and share the results of forestry research throughout the eastern hemisphere. This information must be readily available to forestry professionals in every country in the region.

The Pacific Island countries must be included in all phases of the evolution of international and regional forestry research programs. It is essential to the health of the region that the island countries no longer be viewed as " . . . and the Pacific." Research networks based outside the Pacific region are ineffective at coordinating the flow of information among the islands.

The forestry research community in the Pacific Islands would greatly benefit from a coordinated effort to gather and share research results. This must include information from continental as well as island countries. But, the coordinating body and the central repository for the information must be located within the Pacific Island countries. The information center must serve the needs of the people of the region, and their participation in the network is essential to its health. To gain this participation, it is critical that the network managers come from local communities, for they can better serve the needs of their people. But, we all have a vital role to play in sustaining the health of our global ecosystem.

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Management of Tropical Forests for Products and Energy[1]

John I. Zerbe[2]

Abstract: Tropical forests have always been sources for prized timbers, rubber, tannin, and other forest products for use worldwide. However, with the recent concern regarding global change, the importance of effective forest products management and utilization has increased significantly. The USDA Forest Service's Forest Products Laboratory at Madison, Wisconsin, has embarked on a new program on the utilization and identification of and research on tropical tree species. This new work will be centered at the Laboratory and at the Forest Service's Institute of Tropical Forestry in Puerto Rico.

The USDA Forest Service's Forest Products Laboratory, at Madison, Wisconsin, has started a new program in tropical forestry. This utilization program emphasizes the identification of wood decay fungi in the tropics, improved drying processes for tropical species, and improved sawing of difficult to process tropical species. We are also investigating new panel and molded products capable of being manufactured with tropical species and recycled wood and plastics. We have strengthened our research effort in identification of extractives from tropical species. In an effort to permit construction of affordable houses with local materials, we are studying construction techniques for the tropics.

Other important work that can lead to improved economic opportunities in the tropics includes determination of properties and uses of native species and modification of production processes for mixtures of tropical species, utilization of plantation species such as eucalyptus for products and energy, and protection of wood under severe exposure conditions such as extreme moisture and the Formosan termite.

This paper describes the new work in tropical forestry planned for the Forest Products Laboratory, and in the Forest Service's Institute of Tropical Forestry in Puerto Rico.

Forest Products for Energy

That the tropical forests are being destroyed at an alarming rate is widely known and accepted. This prompted President Bush and the other world leaders at the recent Economic Summit in Houston, Texas, to call for a global forest convention or agreement to curb deforestation in their July 11, 1990, communique.

The motivation behind tropical forest deforestation is not widely understood. Most studies estimate that less than 20 percent of the deforestation is due to logging for timber. Most of the deforestation occurs because of land clearing operations for conversion to other uses such as grazing or agriculture, commonly slash and burn agriculture which leads to short-term use followed by desertification. Perhaps some trees are removed and utilized, but most are felled and burned to clear the site.

Although the importance of tropical deforestation is widely recognized, the basic reasons behind it are more subtle. The root causes of deforestation are primarily social ones: abject poverty, population pressure, overwhelmed institutions, and uncontrolled development. As a result of these factors, the tropical forests are under pressure by indigenous peoples who are forced to resort to slash and burn agriculture, by developers who want to convert the forests to other uses such as ranching, and by loggers who remove but a few commercial species per acre and leave the bulk of the trees that are unmarketable to be felled and burned. It is important to the world economy that industry, infrastructure, and domestic markets be established in developing countries so that the wood currently being wasted may be used, and so that the productivity of forest lands be sustained.

Tropical forests can contribute to economic development only if they are used. Furthermore, it is important that these forests be used in an efficient and sustainable way, thus providing an economic incentive for their continued management. This is where the need for utilization research enters in.

Tropical forests have always been sources for prized timbers, rubber, tannin, and other forest products for use worldwide. However, with the recent concern regarding global change, the importance of effective forest products management and utilization has increased significantly. Generally, commodity products are the highest value use of the sustainable resource worldwide, but industrial usage for energy is becoming more important. Traditionally, energy from wood in the form of solid wood or charcoal has been the principal source of cooking fuel in the tropics, but this use was, and still is, extremely inefficient.

The reasons why this material is unused are primarily because of the problems associated with utilization. For many species, the wood and its properties and suitable methods for processing are unknown; consequently it has no value. Improved utilization through research, therefore, can play a key role in enhancing the value of the forest and improve its prospects for sustainable management.

Forest health, productivity, and diminishing fuel wood supplies are becoming issues of international concern in light of the perceived impacts of tropical deforestation on global climate change. To reverse these deforestation trends, forest resources need to be improved, managed, and used. Atmospheric carbon dioxide increase may be as much as 3.0 gigatonnes per year as a result of deforestation. This compares with 6.6 to 7.0 gigatonnes per year from consumption of fossil fuels. Sustainability of forests and increases in forest production instead of wasteful incineration could reduce carbon dioxide emissions to the atmosphere through reducing both fossil fuel use and land conversion. Developed countries such as the United States should assist in sharing expertise and experience in managing forests

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for sustainability and profitable use of production. As developing countries increase living standards and consume more raw materials and manufactured goods, the United States will face greater competition in supplying more goods on the world market. This condition requires more knowledge of demand, pricing, international markets and trade, and natural resource policies.

Needed Research

Most of the trees are left behind after commercial logging because of the many species found on the typical tropical site. The common practice is to harvest only the highest value material suitable for traditional products. The properties of wood from the remaining trees vary widely and in most cases are not known. Research is needed to determine the properties of these lesser-known species so that ones with similar properties and processing characteristics can be grouped to optimize their processing and use.

Most of the exported tropical timber is in log form or with very low levels of primary processing. This minimizes the favorable employment effect that would occur with additional domestic processing. Domestic processing and use within the originating country is limited because of the low recovery rates that are common in tropical areas; wastage is unacceptably high. Property and processing research are needed to improve recovery and lower degrade. Research can also lead to the processing of woods that are presently unused because of their high density and silica content.

Some tropical species such as rubberwood, coconut, eucalyptus, and teak are currently grown in plantations. These plantation-grown trees either do not have a long history of utilization for wood products, or have altered properties because of their plantation origins. Research is needed to determine the properties and optimize the processing and end use of these plantation species, thus helping to relieve some of the pressure on the natural tropical forests.

Adequate shelter is a critical need in the tropics, particularly after natural disasters. Tropical timbers could play a much more active role in providing this shelter if appropriate structural designs were available and if grades and standards were available to guide the appropriate use of these timbers. Also needed are ways of protecting these structures from biological deterioration, possibly by natural preservatives extracted from naturally durable tropical woods. The tropics furnish a fruitful field for insect and disease pests to operate. If some species of pests are destructive in the temperate zones, they are usually even more so in the tropics. And some species, such as the Formosan termite, are of concern only in the tropics and sub-tropics.

Finally, there is the question of domestic energy from wood and energy used in processing wood products. Fully a third of the world's population relies on wood for domestic fuel, and in some areas, such as Africa, this is a critical need. More efficient and appropriate cook stove designs and charcoaling techniques can help ease the demand if householders and colliers can be convinced of their effectiveness. As more lumber is processed at the points of origin, seasoning before shipment will also assume more importance. Seasoning of wood consumes considerable energy in lumber processing, and more efficient drying processes and alternative forms of energy are needed.

Planned Action

The Forest Products Laboratory is proceeding with plans to create a Tropical Woods Research Team at the Laboratory with some of the scientists located at the Forest Service's Institute of Tropical Forestry, in Puerto Rico. The unit is to be given a mission to conduct research on the utilization of tropical woods and the implementation of this research. The mission will extend beyond the utilization problems of the American tropics to include all tropical regions. However, initial emphasis will be given to the Caribbean and lowland landscapes of Latin America, particularly the Amazon basin.

The research team will focus on tropical wood utilization questions and provide vivid evidence of the Forest Service's commitment to the broader issues of tropical forest deforestation and economic development. It will be highly practical and applied and heavily slanted toward training and demonstration, possibly with support from the International Tropical Timber Organization Fellowships and Small Grants Program *(fig. 1)*. It will enable us to offer technical assistance, when needed, and will offer the advantage of a fast response, particularly in the case of responding to natural disasters. The team will also enhance opportunities for research monitoring within the Forest Health Monitoring Program/FIDR Initiative. Forest Health Monitoring is a focused Forest Service research effort with broad participation nationwide. The mycology work in the tropics could provide early indication of changing forest health that heretofore have been missed.

Areas of Emphasis

Research pertinent to tropical forest utilization includes the following areas which are anticipated to receive special attention.

Mycology

Initial efforts will survey the fungi present on the various sites. For the first time, we will have an organized study of the fungi found in the various tropical ecologies. This will provide background information for the selection and enhancement of fungi for site rehabilitation and for screening for biotechnological purposes. The expanded Center for Forest Mycology Research collection of wood rotting fungi, which will result, will serve as a resource for other scientists and industry who are attempting to employ fungi for biotechnological purposes.

Processing

Processing research would focus on methods of handling the large number of species that are difficult to process because of such characteristics as high density and the presence of silica *(fig. 2)*. Embodied in this work would be research on metallurgy and sawblade design. This would complement our ongoing efforts on sawtooth design and the effect of vibration on surface quality so it would be of interest to the domestic industry as well.

Figure 1—Training is critically needed in tropical institutes. At the USDA Forest Service's Forest Products Laboratory, a scientist from China learns how to use a universal testing machine from a Laboratory specialist.

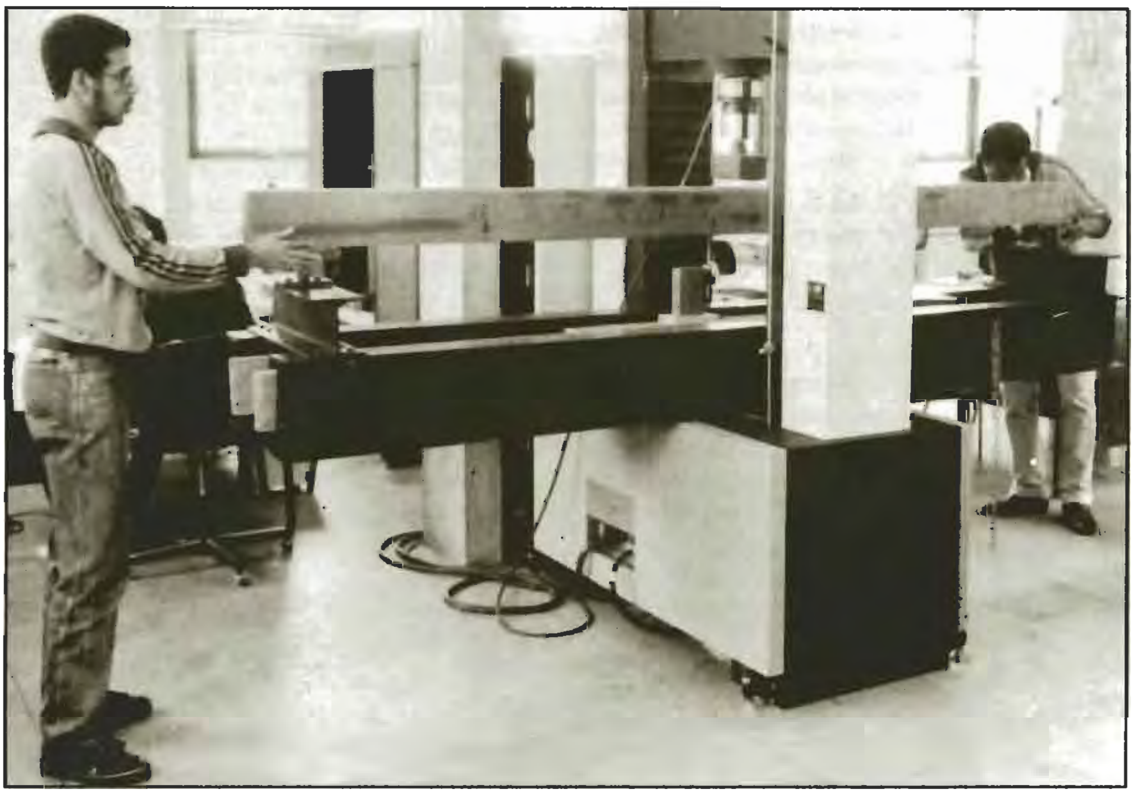

Figure 2—Timber is being readied for strength testing at an institute in Brazil. To optimize the processing and intended use of lesser-known tree species, research is needed on their properties.

Drying

Drying research will evaluate the utility of a variety of lumber dry kiln types and will develop proper kiln schedules and procedures. Species groupings will be evaluated as a presorting procedure to cope with the large number of species to be handled.

Composites

In the composites area, research will evaluate the feasibility of mixtures of tropical hardwoods as furnish for a variety of panel products and shaped sections for furniture and other local uses. Board investigations will include the feasibility of using mineral binders for producing a naturally durable panel for use in tropical applications. Also included here are evaluations of chemical modification of the fibers or particles so as to optimize the properties of the finished board or shaped product.

Wood Properties

Research will evaluate the anatomical and mechanical properties of the lesser known species to aid in their utilization. Additional research will evaluate other characteristics such as shrinkage, density, silica content, grain characteristics, appearance, and possible extractives from naturally durable trees that might be synthesized to produce protective compounds such as for sapstain control.

Grading

Alternative visual and automated grading systems will be developed to introduce species-independent grading. Such systems are necessary to handle the large numbers of species that will be handled at the typical small sawmill in the tropics. The development of alternative grading technology that is more suitable for a small sawmill would have domestic application as well.

Construction

Research here will focus on expanding the use of native species for much needed housing through the development of construction guidelines and design. Wood has natural advantages for such uses as in roof systems when we develop the appropriate truss designs. Also included here are designs and treatments to protect the structure.

Strength values are not critical for housing. But as strength values are determined for the various species or groups of species we can anticipate expanded use of these species in more engineered systems such as light industrial and commercial construction and timber bridges. Greater acceptance of wood in construction could expand the demand for domestic woods as well.

Economics

Overlaying all of this work is the need for economic feasibility analyses of new and emerging products and processes. Economic assistance is also needed to evaluate the domestic supply implications and international trade prospects as more of the lesser known species achieve commercial importance. We foresee a basis for effective trade and use of American wood products and processing equipment in tropical forest development and utilization.

Approach

We will start this new program through problem analysis or an integrated array of problem analyses on tropical wood utilization problems. As the work progresses it will probably involve outside researchers, especially those in the tropics. Tropical research institutions would undoubtedly have much to contribute.

The new unit for work on the problem at the Forest Products Laboratory will require the addition of three staff. Two of the positions will be located at the Institute of Tropical Forestry. They will probably consist of a Forest Mycologist and a Forest Products Technologist with a broad general background. The third position is that of the Tropical Forestry Manager, who will supervise the two positions located in Puerto Rico and provide day-to-day management of the entire team.

In all of this work, the need to respond to severe deforestation of lands throughout the tropics, and reverse serious adverse environmental impacts is the driving force. This is a long overdue step in the right direction.

Holistic Forest and Wildlife Management in Hawaii—Is It Possible?[1]

Michael G. Buck[2]

Abstract: Land management agencies face a highly introspective period. "New perspectives," "new forestry," and "holistic management" are all terms being used to "define" a different way of managing natural resources—a recognition that people are not satisfied with the status quo. As the population of Hawaii grows, the expectations of forest and wildlife resources are increasing. Along with this increase comes the management complexity generated by competing and often conflicting uses. What is holistic natural resource management? Is it possible in Hawaii? And how can we do it?

Holism is the principle that a part is understandable only in relationship to the whole. It is a very simple concept, but how can it be used to help better manage our forest and wildlife resources in Hawaii? Let us consider this opportunity in a series of four questions: (1) What is holistic management? (2) Is it possible to do in Hawaii? (3) Are we doing it now? and (4) What needs to happen? This paper seeks to answer these questions.

What Is It?

Land management agencies face a highly introspective period. "New perspectives," "new forestry," "holistic management" are all terms being used to "define" a different way of managing natural resources—a recognition that people are not satisfied with the status quo. The management of forest and wildlife resources has become a controversial subject, with much emotional and, at times, polarized debate. Special interest groups are numerous and vocal. Litigation has become a commonly used tool to influence government programs. Shifts in social values are calling for more responsive and aggressive natural resource management programs.

The forestry profession especially has been held up to public scrutiny. The Society of American Foresters, in its May 1991 issue, *Journal of Forestry*, introduced a "new" land ethic to deal with the changing times for its members to review. The new land ethic considered "entire forest *ecosystems*" rather than just forest land. It stressed "*maintenance* and *enhancement* of the *productivity* and *integrity* of forest land and associated resources *over time*." It also addressed "*sustainable* production of goods and other resource values." Well, all these warm, soft, and fuzzy buzzwords made me feel better about the concept of holistic management, but didn't exactly provide a road map for how to do it.

Looking for insight, I moved to the next article in the Journal on *sustainability*. "Ah ha," I said, "here will be the answer" — but lo and behold there were eight different types of sustainability. My heart dropped but I read on. The first four types were actually product mixes ranging from a dominant product to a global village concept with community and human benefit sustainability concepts sandwiched between. Following were four ecosystem sustainability concepts starting with self sufficient, then ecosystem type, and then ecosystem insurance. It ended at ecosystem-centered sustainability, which basically is a "live and let live but don't touch" concept. This all led to more confusion but brought clarity to the definition of what is holistic natural resource management?

I don't really know what holistic natural resource management is, but aren't we spending too much time trying to define it? I do know what it isn't and there are definitive symptoms that indicate when you are not on the right track. I also feel confident we'll know when we get there or at least moving in the right direction.

Is It Possible to Do It?

It is possible, and Hawaii has the potential to be a world leader. Hawaii, America's only tropical state, has the eighth largest State-owned forest and natural area reserve system in the United States. Within this system is a full range of tropical ecosystems, including lowland and montane rain forests, and some of the world's most unique examples of tropical biodiversity, much of it endangered. The State of Hawaii has historically recognized the importance of its tropical forest watersheds and is committed to managing them wisely. The Division of Forestry and Wildlife is one of the only integrated forest and wildlife agencies in the United States, bringing together managers of the species and the habitat. Cooperation and communication between Federal and State agencies has greatly improved, increasing effectiveness of limited resource management funds.

Private agencies such as the Nature Conservancy and the National Tropical Botanical Gardens are making significant contributions and commitment to Hawaii. Vehicles have been established for increased management of private lands with the passage of the Forest Stewardship and Natural Areas Partnership legislation, providing cost-sharing monies to private landowners who enter into long-term management agreements with the State. Finally, Hawaii's people are concerned with the future of the state's forest watersheds, which is reflected in increasing natural resource management budgets.

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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Are We Doing It Now?

We have made an excellent start and are improving, but still have a way to go. I won't list all our recent successes, which are many, but focus on some very disturbing symptoms that still exist:

- Communication is poor to non-existent between many special interests groups.
- Litigation is a way of life, wasting valuable resources that could be better used on the ground, not in the courts.
- Endangered species are still being lost. Some cannot be helped, based on historic loss of habitat and small gene pools, but new management paradigms could stem this trend.
- Natural resource productivity is still being degraded as the silt-flooded reefs of Molokai and the conversion of valuable koa forest land in Kona demonstrate.
- Private landowners are distrustful and becoming alienated by the process of public involvement in natural resource management issues.
- A renewable resource and sustained yield ethic is lacking. Many citizens and political leaders do not understand that natural resources, if managed wisely, can and need to be harvested to provide essential benefits.

What Needs to Happen?

Although the road map to holistic forestry and wildlife management in Hawaii is not completed, we will continue to move in the right direction if the following needs are addressed:

1. The battle for the budget dollar is the first major hurdle for any management agency. Holistic management would indicate that there should be a direct connection between the use of natural resources and the funds needed to manage and sustain those resources. Water has long been recognized as the most important resource of Hawaii's forest lands. Mountain watersheds are the source of water for the majority of the islands' developed urban, industrial, and agricultural areas. The monies available for watershed management dwarfs in relationship to the value of the product being used. Tourism is another example of where the use of and impact on forest and wildlife resources are not directly connected with the management of those resources. Beautiful landscapes, hiking, and other outdoor recreational opportunities attract many tourists who want to see the "real" Hawaii.

2. Holistic management should recognize the difference between public and private land and exploit it. Public and private land owners have different clienteles, time perspectives, and accountability concerns. At times, benefits for the public good will outweigh short-term economic concerns. Yet, availability of carrots (e.g., tax incentives, cost sharing programs) will have a longer lasting effect than the judicious use or threat of the stick (e.g., condemnation, law suits). Coercing people to comply with laws with penalties for non-compliance is a poor motivator of action. People do better when pulled by incentives rather than pushed by regulations or penalties. The amount and distribution of private land in Hawaii offers potential to create effective buffer zones and habitat corridors for public lands managed for native ecosystems.

3. More opportunities for Hawaii's people to participate in managing their own natural resources are needed. Meaningful volunteer programs need to be expanded. The University of Hawaii should develop a natural resource management curriculum so graduates can qualify for professional jobs in Hawaii. Holistic management recognizes that a sense of ownership is a powerful tool.

4. Applied research that is directly applicable to forestry and wildlife management must be accelerated. We need to work on the full spectrum of land uses ranging from agroforestry to koa silviculture to conservation biology. Holistic management recognizes that a little knowledge can be dangerous but better than none at all.

5. Holistic management recognizes that time and monies spent in court mean less time and money in the field. Better forums for communication, such as demonstration areas, town meetings, and newsletters, are needed to regain public trust and allow the professionals to get down to the business of managing land.

If America hopes to inspire the world to greater efforts to manage its tropical forest and wildlife resources, it must surely set a good example. Hawaii, America's only tropical state, could be a model for demonstrations of sustainable tropical land use systems, ranging from conservation biology to agroforestry, and provide a valuable training and extension resource for tropical land managers. The accomplishments over the last 10 years indicate we are on the right road and heading in the right direction. Let's continue and have the holistic accomplishments guide the holistic rhetoric.

The South Pacific Forestry Development Programme[1]

Tang Hon Tat[2]

Abstract: Only a few countries in the South Pacific are large enough for industrial forestry to be a key component of the national economy, but forests provide benefits to many people. The United Nations FAO South PacificForestry Development Programme was established in April 1988, at Port Vila, Vanuatu, with a $385,000 budget, and 14 nations participating. The Programme's aim is to "upgrade the status of forestry in the participating countries." The Programme, which extended to December 1991 with a budget totaling $1,046,121, has carried out a variety of development activities, including training, documentation, resource assessments, and species trials. Extension of the Programme beyond 1991 has not yet been decided. A number of projects that it could support have been proposed.

The countries in the South Pacific region vary considerably in land area, population, per capita income, and national and forestry development. Only a few countries, e.g., Papua New Guinea, Solomon Islands and Fiji, are large enough for industrial forestry to be an important component of their national economy. Most other countries are too small for industrial forestry to be practiced, and much of their timber requirements have to be imported.

Nevertheless, forests and trees play an important and even critical role in the socio-economic well-being of the societies in all countries in the region. Among other benefits, they provide people with shelter, food, fuel, medicinal and other traditional by-products. Forests serve to reduce soil erosion, including coastal erosion, and regulate water flow and quality. In many places, forestry has been integrated into traditional agricultural practices.

In most countries in the region, much of the natural vegetation has been or is being removed. In the larger countries, the motivation is usually to generate funds through the sale of logs or lumber, or to make way for commercial agriculture or food production. In the smaller countries, the motivation is usually simply to use the land for food production. In either case, the rate and methods of deforestation or devegetation have prompted concern over the long-term sustainability of forest resources and land for agriculture production, over the impacts on water resources, and ultimately, over, the quality of life of the people.

Forestry is usually accorded relatively low priority in most of the countries of the South Pacific region, particularly vis-a-vis the allocation of manpower and funds by governments. Forestry is also outside the effective ambit of the existing regional agencies, i.e., the South Pacific Commission (SPC), which is involved in agriculture development in the region, Forum Secretariet, or the South Pacific Regional Environmental Program (SPREP). Further, the provision of proper forestry support is often hampered by the land tenure system, under which land tends to belong largely to communities rather than the State or individuals. Although the priority rating for forestry may be improved as the negative impacts of reduced forest and tree cover are felt, it is unlikely that the countries will be able to afford the additional funds and manpower required to reduce, if not reverse, these impacts.

Despite these difficulties facing the "forests and trees sector," much can be done to improve the contribution of forests and trees to the general well-being of peoples in the region. One obvious way to do this is by harnessing the collective efforts, knowledge, and experience in the individual countries and sharing them among other countries in the region, and by regional collaboration in activities like training and research. This is particularly important because of the small size and wide geographical dispersion of the countries in the region, and of the many past, and on-going, bi-lateral aid programmes which would otherwise restrict their benefits to only a few countries.

Attempts to achieve greater regional cooperation have been mainly in the form of occasional ad hoc training courses, meetings, and seminars (Yabaki and others 1983), which invariably reiterated the need for further such cooperation. New Zealand has tried to fill this need by appointing its own regional forester, and Australia has also been urged to appoint a regional forester for the Pacific (Cameron 1986). However, no one country is able or willing to bear the cost of providing the level of regional services required.

In 1986, an Asia Pacific Forestry Research Directors' meeting in Honolulu recommended the formation of a Pacific Islands Forestry Council to "assist national forestry agencies and other forestry related organisations in the Pacific region obtain and share scientific and technical information needed for forest resource development, protection and management." But no further action on this recommendation was taken because of the proposal to establish a South Pacific Forestry Development Programme, which was designated as RAS/86/036.

This paper describes the development and outlines the history of the South Pacific Forestry Development Programme.

Formation of the Program

Because of the growing need for assistance to the forestry sector in the region, a proposal to establish a South Pacific Forestry Development Programme was tabled by United Nations Development Program at the forum of National Aid Coordinators of Pacific Islands Developing Countries in Suva, Fiji, in February 1986. It was then included in the list of priority

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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projects identified by the meeting. The project proposal was later discussed at a South Pacific Heads of Agriculture meeting in September 1986 in Apia, which suggested that this development project should, as far as possible, serve the needs of small island countries, assist countries organize forest resources databases, and assist in encouraging the utilization of coconut wood.

Other on-going or pipeline regional projects with related objects then were:

- RAS/86/032: for coconut wood utilization (pipeline)
- RAS/86/035: Development of Agricultural Statistics
- RAS/86/048: Asia Pacific Forest Industries Development Group based in Kuala Lumpur, Malaysia
- RAS/86/144, Improved Government Information Systems

In December 1987, establishment of the South Pacific Forestry Development Programme was approved by United Nations Development Program and Food and Agriculture Organization (FAO) with an allocation of $385,000 for a 2-year duration. The Programme was based in Port Vila, Vanuatu, with 14 participating countries: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa (Western), Solomon Islands, Tokelau, Tonga, Tuvalu, and Vanuatu. It was launched with the arrival of the project coordinator in April 1988. In April 1989, the Programme's budget was increased to over $500,000. The Programme's long-term objective is to "upgrade the status of forestry development in the participating countries, and thereby contribute to the socio-economic well-being of the peoples of the South Pacific."

1988 - 90 The First Two Years

Among the activities undertaken by the Programme during its first 2 years were:

- Preparation of formats for collection and assessment of forestry data by participating countries (Field Document No. 1), and use of the formats for four selected project countries (in preparation)
- Study of use of forests in Vanuatu and Tonga (in preparation)
- Training courses in coconut wood utilization (3-13 April 1989, Tonga, 15 participants from nine countries); and forest sector planning (3-21 July 1989, Vanuatu, 11 participants from eight countries. The latter was organized and funded jointly by the Programme and the Australian International Development Assistance Bureau (AIDAB)).
- Funding of participants from Programme countries to relevant training courses, study tours and meetings
- Publication and dissemination of Project News (two issues in 1990)

1990 to 1991 (21 months)

In view of the initial budget constraints and wide geographical dispersion of Programme countries, the implementation of Programme activities required considerable lead time. Subsequently, the Programme was extended for another 21 months to December 1991, i.e., the end of current UNDP 5-year budget cycle, with an additional budget of about $500,000, bringing the total budget to $1,046,121.

Among the activities implemented during this period (to date) were:

- Training course on remote sensing (23-27 July 1990, Noumea; five participants from two countries)
- Convening of South Pacific Heads of Forestry (HoF) meeting (26-28 November 1990, Suva, Fiji; attended by 8 HoF and 6 to 10 forestry or related agencies); and a Tripartite Review (TPR) of the Programme by Heads of Forestry (the previous TPR had been carried out by Heads of Agriculture, because of financial constraints)
- Preliminary study of manpower and training needs in Programme countries (report in preparation)
- Assessment of use of forest products by village communities in Vanuatu (report in preparation)
- Trial planting of commercially valuable rattans *(Calamus caesius, C. manan, C.* spp.) in six selected Programme countries (report in preparation); and
- Publication of a quarterly South Pacific forestry newsletter

Among other activities planned for the rest of 1991 are:

- A review mission on the forestry staffing and training needs and facilities in the region. This review was identified as a high priority activity by the 1990 HoF meeting and is aimed at proposing a realistic forestry training strategy and programme for the countries in the region. It is being jointly funded by the USDA Forest Service, the Australian International Development Assistance Bureau (AIDAB) and the Programme. The review will take 2 to 3 months, starting in June 1991.
- A study tour of forestry (particularly community, agro, and social forestry, high quality timber plantations, and non-wood forest products) activities in Indonesia and Malaysia for senior forestry personnel from the region. This would be in August 1991, and participants will be funded by the Programme and various aid agencies in the region.
- A Heads of Forestry and TPR meeting in early October 1991. The venue, actual dates, and agenda are being finalized.
- A training course on occupational health and safety in the logging and small/portable sawmill industries. This would be held over 2 weeks in September-October 1991 in Fiji in collaboration with the International Labour Organisation (ILO) /Fiji Ministry of Forests Forestry Training School.
- Publications on various aspects of agro-forestry and tree planting in the region through the use of authors' contracts.
- Compilation of forest plantation data and experience in the region in collaboration with the USDA Forest Service.
- Further development of the South Pacific forestry newsletter.

Several other activities, e.g., training courses in negotiation and communication skills, and in agro-forestry (in collaboration with the (German Technical Assistance Program) GTZ/Fiji Forestry Extension Project); compilation of land use experiences vis-a-vis forestry development in the region, etc., identified by the 1990 HoF meeting for implementation may have to be kept in abeyance in view of financial constraints.

Extension of the Programme

The further extension of the Programme beyond 1991 has not yet been decided. On the basis of experience gained to date, the following considerations should be borne in mind for any future support or assistance to the forestry sector in the region:

- Direct involvement of participating agencies in determining Programme activities and priorities.

One major drawback of the current Programme was the lack of funds to convene a Heads of Forestry meeting early in the Programme's life to discuss and determine the nature, scope, and priorities of activities. The usefulness and importance of such a meeting in fostering closer rapport, cooperation, collaboration and, perhaps even more important, a sense of involvement and participation among forestry agencies and foresters in the region, was clearly demonstrated by the 1990 HoF meeting in Suva.

The need for and importance of such a meeting is accentuated by the large number of countries in the region, each with its own national forestry priorities, and the invariably limited financial and manpower resources of the Programme. The meeting would be the best forum to discuss and decide on the optimal allocation of these resources.

As recommended by that meeting, another HoF meeting is scheduled for 1991, and every effort should be made to convene this meeting annually. These meetings should involve all interested countries in the region, and not only Programme countries.

- Provision of regular technical support services.

The small size of most countries in the region makes it unrealistic for them to develop capability in the various forestry or related fields, e.g., natural forest management, plantation forest development, forest products utilization, agro/community forestry, and research and development. However, there is an urgent need for such capability or expertise in all countries in order to develop and enhance the contribution of the forest and tree sectors to their respective economies.

This expertise can be effectively provided by a core of suitably qualified and experienced persons, through a regional forestry project. As continuity and personal rapport with local counterparts is a critical element of such technical support, this should be provided by full-time project staff instead of by visiting consultants, who should be brought in to provide more specialized support when the need arises.

Areas of Support

Five main areas proposed for support by the program would be:

1. *Natural forests management, development, conservation, and policy:* This includes providing advice or studies on the above subjects, especially vis-a-vis national development plans and priorities, and watershed and environmental considerations.
2. *Forest and tree resources development:* This includes the establishment of species and provenance trials of multiple-purpose and high quality timber species for either local or industrial uses; development of rattans, bamboos and other non-wood forest products (e.g., honey, medicinal plants, essential oils, dyes, etc.) and of appropriate agro- and community-forestry systems; etc. Pilot trial plantings should be encouraged in selected countries, and used for training purposes, probably on sub-regional bases.
3. *Forest and tree resources utilization:* This includes the adaptation of appropriate harvesting, processing, and marketing systems and technology for timber from natural forests, plantations, coconut stems, and other sources, as well as for non-wood forest or tree products, e.g., bamboo, rattan, etc. Particular emphasis is needed on proper logging and small sawmill practices, including basic training and technical support on selection, use, maintenance and repairs of equipment; processing (including treatment) of rattans, bamboo, and other similar materials into furniture, and handicrafts.
4. *Information processing, collection, and exchange*: This activity has been initiated, but requires the active support of all countries in order to be usefully sustained. The regional forestry newsletter recently published by the Programme can and should promote closer communication among foresters and forestry agencies in the region. Other means of achieving this object are through the Project Field Document series of publications, authors' contracts, and meetings of Heads of Forestry (already started), other operational staff and research personnel (to be started).
5. *Institutional development:* The provision of adequate numbers of suitably trained and experienced staff in all countries is critical to the sustained and proper management, utilization, and development of the forest and tree resources in the region. In view of the small size of most countries in the region, this can be best provided through a realistic, long-term, and regional staff training and development strategy and programme. The three-person review mission mentioned above should lay the foundation for this object.

No single agency can provide all the support needed in the Pacific Southwest region. Therefore, all aid-donor agencies must work closely, not only to ensure that their aid resources are not wasted on duplicative activities, but perhaps even more important, to try to achieve synergism through their coordinated collective efforts. The value of such coordination and collaboration has been demonstrated by the joint activities undertaken by the Programme and AIDAB, USDA Forest Service, International Labor Organization (ILO), and GTZ. But much much more can and must be achieved through further similar cooperation.

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Management of Tropical Forests for Products and Energy[1]

John I. Zerbe[2]

Abstract: Tropical forests have always been sources for prized timbers, rubber, tannin, and other forest products for use worldwide. However, with the recent concern regarding global change, the importance of effective forest products management and utilization has increased significantly. The USDA Forest Service's Forest Products Laboratory at Madison, Wisconsin, has embarked on a new program on the utilization and identification of and research on tropical tree species. This new work will be centered at the Laboratory and at the Forest Service's Institute of Tropical Forestry in Puerto Rico.

The USDA Forest Service's Forest Products Laboratory, at Madison, Wisconsin, has started a new program in tropical forestry. This utilization program emphasizes the identification of wood decay fungi in the tropics, improved drying processes for tropical species, and improved sawing of difficult to process tropical species. We are also investigating new panel and molded products capable of being manufactured with tropical species and recycled wood and plastics. We have strengthened our research effort in identification of extractives from tropical species. In an effort to permit construction of affordable houses with local materials, we are studying construction techniques for the tropics.

Other important work that can lead to improved economic opportunities in the tropics includes determination of properties and uses of native species and modification of production processes for mixtures of tropical species, utilization of plantation species such as eucalyptus for products and energy, and protection of wood under severe exposure conditions such as extreme moisture and the Formosan termite.

This paper describes the new work in tropical forestry planned for the Forest Products Laboratory, and in the Forest Service's Institute of Tropical Forestry in Puerto Rico.

Forest Products for Energy

That the tropical forests are being destroyed at an alarming rate is widely known and accepted. This prompted President Bush and the other world leaders at the recent Economic Summit in Houston, Texas, to call for a global forest convention or agreement to curb deforestation in their July 11, 1990, communique.

The motivation behind tropical forest deforestation is not widely understood. Most studies estimate that less than 20 percent of the deforestation is due to logging for timber. Most of the deforestation occurs because of land clearing operations for conversion to other uses such as grazing or agriculture, commonly slash and burn agriculture which leads to short-term use followed by desertification. Perhaps some trees are removed and utilized, but most are felled and burned to clear the site.

Although the importance of tropical deforestation is widely recognized, the basic reasons behind it are more subtle. The root causes of deforestation are primarily social ones: abject poverty, population pressure, overwhelmed institutions, and uncontrolled development. As a result of these factors, the tropical forests are under pressure by indigenous peoples who are forced to resort to slash and burn agriculture, by developers who want to convert the forests to other uses such as ranching, and by loggers who remove but a few commercial species per acre and leave the bulk of the trees that are unmarketable to be felled and burned. It is important to the world economy that industry, infrastructure, and domestic markets be established in developing countries so that the wood currently being wasted may be used, and so that the productivity of forest lands be sustained.

Tropical forests can contribute to economic development only if they are used. Furthermore, it is important that these forests be used in an efficient and sustainable way, thus providing an economic incentive for their continued management. This is where the need for utilization research enters in.

Tropical forests have always been sources for prized timbers, rubber, tannin, and other forest products for use worldwide. However, with the recent concern regarding global change, the importance of effective forest products management and utilization has increased significantly. Generally, commodity products are the highest value use of the sustainable resource worldwide, but industrial usage for energy is becoming more important. Traditionally, energy from wood in the form of solid wood or charcoal has been the principal source of cooking fuel in the tropics, but this use was, and still is, extremely inefficient.

The reasons why this material is unused are primarily because of the problems associated with utilization. For many species, the wood and its properties and suitable methods for processing are unknown; consequently it has no value. Improved utilization through research, therefore, can play a key role in enhancing the value of the forest and improve its prospects for sustainable management.

Forest health, productivity, and diminishing fuel wood supplies are becoming issues of international concern in light of the perceived impacts of tropical deforestation on global climate change. To reverse these deforestation trends, forest resources need to be improved, managed, and used. Atmospheric carbon dioxide increase may be as much as 3.0 gigatonnes per year as a result of deforestation. This compares with 6.6 to 7.0 gigatonnes per year from consumption of fossil fuels. Sustainability of forests and increases in forest production instead of wasteful incineration could reduce carbon dioxide emissions to the atmosphere through reducing both fossil fuel use and land conversion. Developed countries such as the United States should assist in sharing expertise and experience in managing forests

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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for sustainability and profitable use of production. As developing countries increase living standards and consume more raw materials and manufactured goods, the United States will face greater competition in supplying more goods on the world market. This condition requires more knowledge of demand, pricing, international markets and trade, and natural resource policies.

Needed Research

Most of the trees are left behind after commercial logging because of the many species found on the typical tropical site. The common practice is to harvest only the highest value material suitable for traditional products. The properties of wood from the remaining trees vary widely and in most cases are not known. Research is needed to determine the properties of these lesser-known species so that ones with similar properties and processing characteristics can be grouped to optimize their processing and use.

Most of the exported tropical timber is in log form or with very low levels of primary processing. This minimizes the favorable employment effect that would occur with additional domestic processing. Domestic processing and use within the originating country is limited because of the low recovery rates that are common in tropical areas; wastage is unacceptably high. Property and processing research are needed to improve recovery and lower degrade. Research can also lead to the processing of woods that are presently unused because of their high density and silica content.

Some tropical species such as rubberwood, coconut, eucalyptus, and teak are currently grown in plantations. These plantation-grown trees either do not have a long history of utilization for wood products, or have altered properties because of their plantation origins. Research is needed to determine the properties and optimize the processing and end use of these plantation species, thus helping to relieve some of the pressure on the natural tropical forests.

Adequate shelter is a critical need in the tropics, particularly after natural disasters. Tropical timbers could play a much more active role in providing this shelter if appropriate structural designs were available and if grades and standards were available to guide the appropriate use of these timbers. Also needed are ways of protecting these structures from biological deterioration, possibly by natural preservatives extracted from naturally durable tropical woods. The tropics furnish a fruitful field for insect and disease pests to operate. If some species of pests are destructive in the temperate zones, they are usually even more so in the tropics. And some species, such as the Formosan termite, are of concern only in the tropics and sub-tropics.

Finally, there is the question of domestic energy from wood and energy used in processing wood products. Fully a third of the world's population relies on wood for domestic fuel, and in some areas, such as Africa, this is a critical need. More efficient and appropriate cook stove designs and charcoaling techniques can help ease the demand if householders and colliers can be convinced of their effectiveness. As more lumber is processed at the points of origin, seasoning before shipment will also assume more importance. Seasoning of wood consumes considerable energy in lumber processing, and more efficient drying processes and alternative forms of energy are needed.

Planned Action

The Forest Products Laboratory is proceeding with plans to create a Tropical Woods Research Team at the Laboratory with some of the scientists located at the Forest Service's Institute of Tropical Forestry, in Puerto Rico. The unit is to be given a mission to conduct research on the utilization of tropical woods and the implementation of this research. The mission will extend beyond the utilization problems of the American tropics to include all tropical regions. However, initial emphasis will be given to the Caribbean and lowland landscapes of Latin America, particularly the Amazon basin.

The research team will focus on tropical wood utilization questions and provide vivid evidence of the Forest Service's commitment to the broader issues of tropical forest deforestation and economic development. It will be highly practical and applied and heavily slanted toward training and demonstration, possibly with support from the International Tropical Timber Organization Fellowships and Small Grants Program *(fig. 1)*. It will enable us to offer technical assistance, when needed, and will offer the advantage of a fast response, particularly in the case of responding to natural disasters. The team will also enhance opportunities for research monitoring within the Forest Health Monitoring Program/FIDR Initiative. Forest Health Monitoring is a focused Forest Service research effort with broad participation nationwide. The mycology work in the tropics could provide early indication of changing forest health that heretofore have been missed.

Areas of Emphasis

Research pertinent to tropical forest utilization includes the following areas which are anticipated to receive special attention.

Mycology

Initial efforts will survey the fungi present on the various sites. For the first time, we will have an organized study of the fungi found in the various tropical ecologies. This will provide background information for the selection and enhancement of fungi for site rehabilitation and for screening for biotechnological purposes. The expanded Center for Forest Mycology Research collection of wood rotting fungi, which will result, will serve as a resource for other scientists and industry who are attempting to employ fungi for biotechnological purposes.

Processing

Processing research would focus on methods of handling the large number of species that are difficult to process because of such characteristics as high density and the presence of silica *(fig. 2)*. Embodied in this work would be research on metallurgy and sawblade design. This would complement our ongoing efforts on sawtooth design and the effect of vibration on surface quality so it would be of interest to the domestic industry as well.

Figure 1—Training is critically needed in tropical institutes. At the USDA Forest Service's Forest Products Laboratory, a scientist from China learns how to use a universal testing machine from a Laboratory specialist.

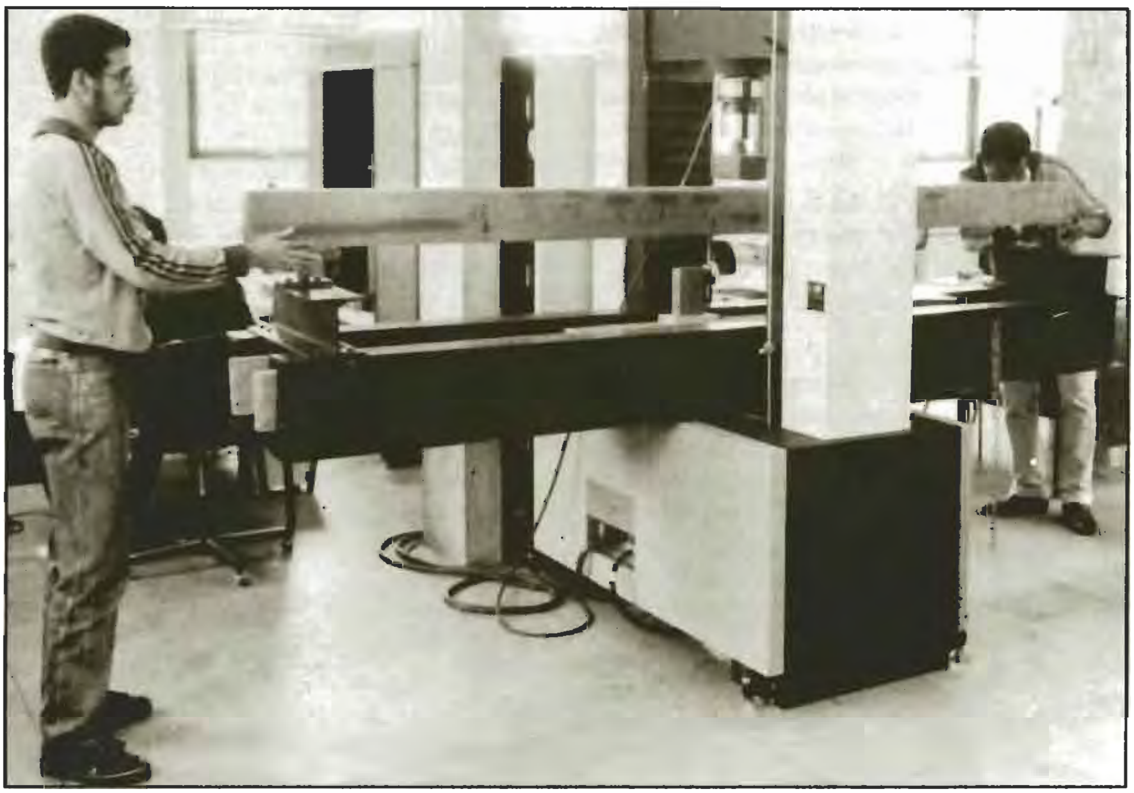

Figure 2—Timber is being readied for strength testing at an institute in Brazil. To optimize the processing and intended use of lesser-known tree species, research is needed on their properties.

Drying

Drying research will evaluate the utility of a variety of lumber dry kiln types and will develop proper kiln schedules and procedures. Species groupings will be evaluated as a presorting procedure to cope with the large number of species to be handled.

Composites

In the composites area, research will evaluate the feasibility of mixtures of tropical hardwoods as furnish for a variety of panel products and shaped sections for furniture and other local uses. Board investigations will include the feasibility of using mineral binders for producing a naturally durable panel for use in tropical applications. Also included here are evaluations of chemical modification of the fibers or particles so as to optimize the properties of the finished board or shaped product.

Wood Properties

Research will evaluate the anatomical and mechanical properties of the lesser known species to aid in their utilization. Additional research will evaluate other characteristics such as shrinkage, density, silica content, grain characteristics, appearance, and possible extractives from naturally durable trees that might be synthesized to produce protective compounds such as for sapstain control.

Grading

Alternative visual and automated grading systems will be developed to introduce species-independent grading. Such systems are necessary to handle the large numbers of species that will be handled at the typical small sawmill in the tropics. The development of alternative grading technology that is more suitable for a small sawmill would have domestic application as well.

Construction

Research here will focus on expanding the use of native species for much needed housing through the development of construction guidelines and design. Wood has natural advantages for such uses as in roof systems when we develop the appropriate truss designs. Also included here are designs and treatments to protect the structure.

Strength values are not critical for housing. But as strength values are determined for the various species or groups of species we can anticipate expanded use of these species in more engineered systems such as light industrial and commercial construction and timber bridges. Greater acceptance of wood in construction could expand the demand for domestic woods as well.

Economics

Overlaying all of this work is the need for economic feasibility analyses of new and emerging products and processes. Economic assistance is also needed to evaluate the domestic supply implications and international trade prospects as more of the lesser known species achieve commercial importance. We foresee a basis for effective trade and use of American wood products and processing equipment in tropical forest development and utilization.

Approach

We will start this new program through problem analysis or an integrated array of problem analyses on tropical wood utilization problems. As the work progresses it will probably involve outside researchers, especially those in the tropics. Tropical research institutions would undoubtedly have much to contribute.

The new unit for work on the problem at the Forest Products Laboratory will require the addition of three staff. Two of the positions will be located at the Institute of Tropical Forestry. They will probably consist of a Forest Mycologist and a Forest Products Technologist with a broad general background. The third position is that of the Tropical Forestry Manager, who will supervise the two positions located in Puerto Rico and provide day-to-day management of the entire team.

In all of this work, the need to respond to severe deforestation of lands throughout the tropics, and reverse serious adverse environmental impacts is the driving force. This is a long overdue step in the right direction.

Holistic Forest and Wildlife Management in Hawaii—Is It Possible?[1]

Michael G. Buck[2]

Abstract: Land management agencies face a highly introspective period. "New perspectives," "new forestry," and "holistic management" are all terms being used to "define" a different way of managing natural resources—a recognition that people are not satisfied with the status quo. As the population of Hawaii grows, the expectations of forest and wildlife resources are increasing. Along with this increase comes the management complexity generated by competing and often conflicting uses. What is holistic natural resource management? Is it possible in Hawaii? And how can we do it?

Holism is the principle that a part is understandable only in relationship to the whole. It is a very simple concept, but how can it be used to help better manage our forest and wildlife resources in Hawaii? Let us consider this opportunity in a series of four questions: (1) What is holistic management? (2) Is it possible to do in Hawaii? (3) Are we doing it now? and (4) What needs to happen? This paper seeks to answer these questions.

What Is It?

Land management agencies face a highly introspective period. "New perspectives," "new forestry," "holistic management" are all terms being used to "define" a different way of managing natural resources—a recognition that people are not satisfied with the status quo. The management of forest and wildlife resources has become a controversial subject, with much emotional and, at times, polarized debate. Special interest groups are numerous and vocal. Litigation has become a commonly used tool to influence government programs. Shifts in social values are calling for more responsive and aggressive natural resource management programs.

The forestry profession especially has been held up to public scrutiny. The Society of American Foresters, in its May 1991 issue, *Journal of Forestry*, introduced a "new" land ethic to deal with the changing times for its members to review. The new land ethic considered "entire forest *ecosystems*" rather than just forest land. It stressed "*maintenance* and *enhancement* of the *productivity* and *integrity* of forest land and associated resources *over time*." It also addressed "*sustainable* production of goods and other resource values." Well, all these warm, soft, and fuzzy buzzwords made me feel better about the concept of holistic management, but didn't exactly provide a road map for how to do it.

Looking for insight, I moved to the next article in the Journal on *sustainability*. "Ah ha," I said, "here will be the answer" — but lo and behold there were eight different types of sustainability. My heart dropped but I read on. The first four types were actually product mixes ranging from a dominant product to a global village concept with community and human benefit sustainability concepts sandwiched between. Following were four ecosystem sustainability concepts starting with self sufficient, then ecosystem type, and then ecosystem insurance. It ended at ecosystem-centered sustainability, which basically is a "live and let live but don't touch" concept. This all led to more confusion but brought clarity to the definition of what is holistic natural resource management?

I don't really know what holistic natural resource management is, but aren't we spending too much time trying to define it? I do know what it isn't and there are definitive symptoms that indicate when you are not on the right track. I also feel confident we'll know when we get there or at least moving in the right direction.

Is It Possible to Do It?

It is possible, and Hawaii has the potential to be a world leader. Hawaii, America's only tropical state, has the eighth largest State-owned forest and natural area reserve system in the United States. Within this system is a full range of tropical ecosystems, including lowland and montane rain forests, and some of the world's most unique examples of tropical biodiversity, much of it endangered. The State of Hawaii has historically recognized the importance of its tropical forest watersheds and is committed to managing them wisely. The Division of Forestry and Wildlife is one of the only integrated forest and wildlife agencies in the United States, bringing together managers of the species and the habitat. Cooperation and communication between Federal and State agencies has greatly improved, increasing effectiveness of limited resource management funds.

Private agencies such as the Nature Conservancy and the National Tropical Botanical Gardens are making significant contributions and commitment to Hawaii. Vehicles have been established for increased management of private lands with the passage of the Forest Stewardship and Natural Areas Partnership legislation, providing cost-sharing monies to private landowners who enter into long-term management agreements with the State. Finally, Hawaii's people are concerned with the future of the state's forest watersheds, which is reflected in increasing natural resource management budgets.

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[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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Are We Doing It Now?

We have made an excellent start and are improving, but still have a way to go. I won't list all our recent successes, which are many, but focus on some very disturbing symptoms that still exist:

- Communication is poor to non-existent between many special interests groups.
- Litigation is a way of life, wasting valuable resources that could be better used on the ground, not in the courts.
- Endangered species are still being lost. Some cannot be helped, based on historic loss of habitat and small gene pools, but new management paradigms could stem this trend.
- Natural resource productivity is still being degraded as the silt-flooded reefs of Molokai and the conversion of valuable koa forest land in Kona demonstrate.
- Private landowners are distrustful and becoming alienated by the process of public involvement in natural resource management issues.
- A renewable resource and sustained yield ethic is lacking. Many citizens and political leaders do not understand that natural resources, if managed wisely, can and need to be harvested to provide essential benefits.

What Needs to Happen?

Although the road map to holistic forestry and wildlife management in Hawaii is not completed, we will continue to move in the right direction if the following needs are addressed:

1. The battle for the budget dollar is the first major hurdle for any management agency. Holistic management would indicate that there should be a direct connection between the use of natural resources and the funds needed to manage and sustain those resources. Water has long been recognized as the most important resource of Hawaii's forest lands. Mountain watersheds are the source of water for the majority of the islands' developed urban, industrial, and agricultural areas. The monies available for watershed management dwarfs in relationship to the value of the product being used. Tourism is another example of where the use of and impact on forest and wildlife resources are not directly connected with the management of those resources. Beautiful landscapes, hiking, and other outdoor recreational opportunities attract many tourists who want to see the "real" Hawaii.

2. Holistic management should recognize the difference between public and private land and exploit it. Public and private land owners have different clienteles, time perspectives, and accountability concerns. At times, benefits for the public good will outweigh short-term economic concerns. Yet, availability of carrots (e.g., tax incentives, cost sharing programs) will have a longer lasting effect than the judicious use or threat of the stick (e.g., condemnation, law suits). Coercing people to comply with laws with penalties for non-compliance is a poor motivator of action. People do better when pulled by incentives rather than pushed by regulations or penalties. The amount and distribution of private land in Hawaii offers potential to create effective buffer zones and habitat corridors for public lands managed for native ecosystems.

3. More opportunities for Hawaii's people to participate in managing their own natural resources are needed. Meaningful volunteer programs need to be expanded. The University of Hawaii should develop a natural resource management curriculum so graduates can qualify for professional jobs in Hawaii. Holistic management recognizes that a sense of ownership is a powerful tool.

4. Applied research that is directly applicable to forestry and wildlife management must be accelerated. We need to work on the full spectrum of land uses ranging from agroforestry to koa silviculture to conservation biology. Holistic management recognizes that a little knowledge can be dangerous but better than none at all.

5. Holistic management recognizes that time and monies spent in court mean less time and money in the field. Better forums for communication, such as demonstration areas, town meetings, and newsletters, are needed to regain public trust and allow the professionals to get down to the business of managing land.

If America hopes to inspire the world to greater efforts to manage its tropical forest and wildlife resources, it must surely set a good example. Hawaii, America's only tropical state, could be a model for demonstrations of sustainable tropical land use systems, ranging from conservation biology to agroforestry, and provide a valuable training and extension resource for tropical land managers. The accomplishments over the last 10 years indicate we are on the right road and heading in the right direction. Let's continue and have the holistic accomplishments guide the holistic rhetoric.

The South Pacific Forestry Development Programme[1]

Tang Hon Tat[2]

Abstract: Only a few countries in the South Pacific are large enough for industrial forestry to be a key component of the national economy, but forests provide benefits to many people. The United Nations FAO South PacificForestry Development Programme was established in April 1988, at Port Vila, Vanuatu, with a $385,000 budget, and 14 nations participating. The Programme's aim is to "upgrade the status of forestry in the participating countries." The Programme, which extended to December 1991 with a budget totaling $1,046,121, has carried out a variety of development activities, including training, documentation, resource assessments, and species trials. Extension of the Programme beyond 1991 has not yet been decided. A number of projects that it could support have been proposed.

The countries in the South Pacific region vary considerably in land area, population, per capita income, and national and forestry development. Only a few countries, e.g., Papua New Guinea, Solomon Islands and Fiji, are large enough for industrial forestry to be an important component of their national economy. Most other countries are too small for industrial forestry to be practiced, and much of their timber requirements have to be imported.

Nevertheless, forests and trees play an important and even critical role in the socio-economic well-being of the societies in all countries in the region. Among other benefits, they provide people with shelter, food, fuel, medicinal and other traditional by-products. Forests serve to reduce soil erosion, including coastal erosion, and regulate water flow and quality. In many places, forestry has been integrated into traditional agricultural practices.

In most countries in the region, much of the natural vegetation has been or is being removed. In the larger countries, the motivation is usually to generate funds through the sale of logs or lumber, or to make way for commercial agriculture or food production. In the smaller countries, the motivation is usually simply to use the land for food production. In either case, the rate and methods of deforestation or devegetation have prompted concern over the long-term sustainability of forest resources and land for agriculture production, over the impacts on water resources, and ultimately, over, the quality of life of the people.

Forestry is usually accorded relatively low priority in most of the countries of the South Pacific region, particularly vis-a-vis the allocation of manpower and funds by governments. Forestry is also outside the effective ambit of the existing regional agencies, i.e., the South Pacific Commission (SPC), which is involved in agriculture development in the region, Forum Secretariet, or the South Pacific Regional Environmental Program (SPREP). Further, the provision of proper forestry support is often hampered by the land tenure system, under which land tends to belong largely to communities rather than the State or individuals. Although the priority rating for forestry may be improved as the negative impacts of reduced forest and tree cover are felt, it is unlikely that the countries will be able to afford the additional funds and manpower required to reduce, if not reverse, these impacts.

Despite these difficulties facing the "forests and trees sector," much can be done to improve the contribution of forests and trees to the general well-being of peoples in the region. One obvious way to do this is by harnessing the collective efforts, knowledge, and experience in the individual countries and sharing them among other countries in the region, and by regional collaboration in activities like training and research. This is particularly important because of the small size and wide geographical dispersion of the countries in the region, and of the many past, and on-going, bi-lateral aid programmes which would otherwise restrict their benefits to only a few countries.

Attempts to achieve greater regional cooperation have been mainly in the form of occasional ad hoc training courses, meetings, and seminars (Yabaki and others 1983), which invariably reiterated the need for further such cooperation. New Zealand has tried to fill this need by appointing its own regional forester, and Australia has also been urged to appoint a regional forester for the Pacific (Cameron 1986). However, no one country is able or willing to bear the cost of providing the level of regional services required.

In 1986, an Asia Pacific Forestry Research Directors' meeting in Honolulu recommended the formation of a Pacific Islands Forestry Council to "assist national forestry agencies and other forestry related organisations in the Pacific region obtain and share scientific and technical information needed for forest resource development, protection and management." But no further action on this recommendation was taken because of the proposal to establish a South Pacific Forestry Development Programme, which was designated as RAS/86/036.

This paper describes the development and outlines the history of the South Pacific Forestry Development Programme.

Formation of the Program

Because of the growing need for assistance to the forestry sector in the region, a proposal to establish a South Pacific Forestry Development Programme was tabled by United Nations Development Program at the forum of National Aid Coordinators of Pacific Islands Developing Countries in Suva, Fiji, in February 1986. It was then included in the list of priority

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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projects identified by the meeting. The project proposal was later discussed at a South Pacific Heads of Agriculture meeting in September 1986 in Apia, which suggested that this development project should, as far as possible, serve the needs of small island countries, assist countries organize forest resources databases, and assist in encouraging the utilization of coconut wood.

Other on-going or pipeline regional projects with related objects then were:

- RAS/86/032: for coconut wood utilization (pipeline)
- RAS/86/035: Development of Agricultural Statistics
- RAS/86/048: Asia Pacific Forest Industries Development Group based in Kuala Lumpur, Malaysia
- RAS/86/144, Improved Government Information Systems

In December 1987, establishment of the South Pacific Forestry Development Programme was approved by United Nations Development Program and Food and Agriculture Organization (FAO) with an allocation of $385,000 for a 2-year duration. The Programme was based in Port Vila, Vanuatu, with 14 participating countries: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa (Western), Solomon Islands, Tokelau, Tonga, Tuvalu, and Vanuatu. It was launched with the arrival of the project coordinator in April 1988. In April 1989, the Programme's budget was increased to over $500,000. The Programme's long-term objective is to "upgrade the status of forestry development in the participating countries, and thereby contribute to the socio-economic well-being of the peoples of the South Pacific."

1988 - 90 The First Two Years

Among the activities undertaken by the Programme during its first 2 years were:

- Preparation of formats for collection and assessment of forestry data by participating countries (Field Document No. 1), and use of the formats for four selected project countries (in preparation)
- Study of use of forests in Vanuatu and Tonga (in preparation)
- Training courses in coconut wood utilization (3-13 April 1989, Tonga, 15 participants from nine countries); and forest sector planning (3-21 July 1989, Vanuatu, 11 participants from eight countries. The latter was organized and funded jointly by the Programme and the Australian International Development Assistance Bureau (AIDAB)).
- Funding of participants from Programme countries to relevant training courses, study tours and meetings
- Publication and dissemination of Project News (two issues in 1990)

1990 to 1991 (21 months)

In view of the initial budget constraints and wide geographical dispersion of Programme countries, the implementation of Programme activities required considerable lead time. Subsequently, the Programme was extended for another 21 months to December 1991, i.e., the end of current UNDP 5-year budget cycle, with an additional budget of about $500,000, bringing the total budget to $1,046,121.

Among the activities implemented during this period (to date) were:

- Training course on remote sensing (23-27 July 1990, Noumea; five participants from two countries)
- Convening of South Pacific Heads of Forestry (HoF) meeting (26-28 November 1990, Suva, Fiji; attended by 8 HoF and 6 to 10 forestry or related agencies); and a Tripartite Review (TPR) of the Programme by Heads of Forestry (the previous TPR had been carried out by Heads of Agriculture, because of financial constraints)
- Preliminary study of manpower and training needs in Programme countries (report in preparation)
- Assessment of use of forest products by village communities in Vanuatu (report in preparation)
- Trial planting of commercially valuable rattans *(Calamus caesius, C. manan, C.* spp.) in six selected Programme countries (report in preparation); and
- Publication of a quarterly South Pacific forestry newsletter

Among other activities planned for the rest of 1991 are:

- A review mission on the forestry staffing and training needs and facilities in the region. This review was identified as a high priority activity by the 1990 HoF meeting and is aimed at proposing a realistic forestry training strategy and programme for the countries in the region. It is being jointly funded by the USDA Forest Service, the Australian International Development Assistance Bureau (AIDAB) and the Programme. The review will take 2 to 3 months, starting in June 1991.
- A study tour of forestry (particularly community, agro, and social forestry, high quality timber plantations, and non-wood forest products) activities in Indonesia and Malaysia for senior forestry personnel from the region. This would be in August 1991, and participants will be funded by the Programme and various aid agencies in the region.
- A Heads of Forestry and TPR meeting in early October 1991. The venue, actual dates, and agenda are being finalized.
- A training course on occupational health and safety in the logging and small/portable sawmill industries. This would be held over 2 weeks in September-October 1991 in Fiji in collaboration with the International Labour Organisation (ILO) /Fiji Ministry of Forests Forestry Training School.
- Publications on various aspects of agro-forestry and tree planting in the region through the use of authors' contracts.
- Compilation of forest plantation data and experience in the region in collaboration with the USDA Forest Service.
- Further development of the South Pacific forestry newsletter.

Several other activities, e.g., training courses in negotiation and communication skills, and in agro-forestry (in collaboration with the (German Technical Assistance Program) GTZ/Fiji Forestry Extension Project); compilation of land use experiences vis-a-vis forestry development in the region, etc., identified by the 1990 HoF meeting for implementation may have to be kept in abeyance in view of financial constraints.

Extension of the Programme

The further extension of the Programme beyond 1991 has not yet been decided. On the basis of experience gained to date, the following considerations should be borne in mind for any future support or assistance to the forestry sector in the region:

- Direct involvement of participating agencies in determining Programme activities and priorities.

One major drawback of the current Programme was the lack of funds to convene a Heads of Forestry meeting early in the Programme's life to discuss and determine the nature, scope, and priorities of activities. The usefulness and importance of such a meeting in fostering closer rapport, cooperation, collaboration and, perhaps even more important, a sense of involvement and participation among forestry agencies and foresters in the region, was clearly demonstrated by the 1990 HoF meeting in Suva.

The need for and importance of such a meeting is accentuated by the large number of countries in the region, each with its own national forestry priorities, and the invariably limited financial and manpower resources of the Programme. The meeting would be the best forum to discuss and decide on the optimal allocation of these resources.

As recommended by that meeting, another HoF meeting is scheduled for 1991, and every effort should be made to convene this meeting annually. These meetings should involve all interested countries in the region, and not only Programme countries.

- Provision of regular technical support services.

The small size of most countries in the region makes it unrealistic for them to develop capability in the various forestry or related fields, e.g., natural forest management, plantation forest development, forest products utilization, agro/community forestry, and research and development. However, there is an urgent need for such capability or expertise in all countries in order to develop and enhance the contribution of the forest and tree sectors to their respective economies.

This expertise can be effectively provided by a core of suitably qualified and experienced persons, through a regional forestry project. As continuity and personal rapport with local counterparts is a critical element of such technical support, this should be provided by full-time project staff instead of by visiting consultants, who should be brought in to provide more specialized support when the need arises.

Areas of Support

Five main areas proposed for support by the program would be:

1. *Natural forests management, development, conservation, and policy:* This includes providing advice or studies on the above subjects, especially vis-a-vis national development plans and priorities, and watershed and environmental considerations.
2. *Forest and tree resources development:* This includes the establishment of species and provenance trials of multiple-purpose and high quality timber species for either local or industrial uses; development of rattans, bamboos and other non-wood forest products (e.g., honey, medicinal plants, essential oils, dyes, etc.) and of appropriate agro- and community-forestry systems; etc. Pilot trial plantings should be encouraged in selected countries, and used for training purposes, probably on sub-regional bases.
3. *Forest and tree resources utilization:* This includes the adaptation of appropriate harvesting, processing, and marketing systems and technology for timber from natural forests, plantations, coconut stems, and other sources, as well as for non-wood forest or tree products, e.g., bamboo, rattan, etc. Particular emphasis is needed on proper logging and small sawmill practices, including basic training and technical support on selection, use, maintenance and repairs of equipment; processing (including treatment) of rattans, bamboo, and other similar materials into furniture, and handicrafts.
4. *Information processing, collection, and exchange*: This activity has been initiated, but requires the active support of all countries in order to be usefully sustained. The regional forestry newsletter recently published by the Programme can and should promote closer communication among foresters and forestry agencies in the region. Other means of achieving this object are through the Project Field Document series of publications, authors' contracts, and meetings of Heads of Forestry (already started), other operational staff and research personnel (to be started).
5. *Institutional development:* The provision of adequate numbers of suitably trained and experienced staff in all countries is critical to the sustained and proper management, utilization, and development of the forest and tree resources in the region. In view of the small size of most countries in the region, this can be best provided through a realistic, long-term, and regional staff training and development strategy and programme. The three-person review mission mentioned above should lay the foundation for this object.

No single agency can provide all the support needed in the Pacific Southwest region. Therefore, all aid-donor agencies must work closely, not only to ensure that their aid resources are not wasted on duplicative activities, but perhaps even more important, to try to achieve synergism through their coordinated collective efforts. The value of such coordination and collaboration has been demonstrated by the joint activities undertaken by the Programme and AIDAB, USDA Forest Service, International Labor Organization (ILO), and GTZ. But much much more can and must be achieved through further similar cooperation.

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Polycyclic Selection System for the Tropical Rainforests of Northern Australia[1]

Glen T. Dale Grahame B. Applegate[2]

Abstract: The polycyclic selection logging system developed and practiced for many years in the tropical rainforests of north Queensland has been successful in integrating timber production with the protection of conservation values. The system has been used by the Queensland Forest Service to manage north Queensland rainforests. The Queensland system has considerable potential as a model for developing appropriate management systems in other tropical countries in the Pacific region where maintenance of forest integrity is an important aspect in the integration of timber production with more traditional uses of the forest.

For many years, a system of polycyclic selection logging has been successfully employed within the tropical rainforests of north Queensland. This system is based on the philosophy of minimizing damage to the forest, and has the overriding objective of applying multiple use principles to achieve sustainable timber production within a balanced conservation program.

Many similarities exist between the management of tropical moist forests in north Queensland for timber production and conservation values, and the management of other tropical moist forests throughout the Pacific Islands region where timber production must be integrated with the harvesting of traditional forest products essential to the daily existence of the region's inhabitants. Both require that timber production does not affect the basic integrity of the forest such that its other values remain intact.

This paper describes the system and procedures developed by the Queensland Forest Service for managing north Queensland rainforests. It suggests many relevant aspects that could be incorporated in guidelines for managing other rainforests throughout the Pacific Islands countries.

The North Queensland System

Land Use Zoning

Land use zoning is the necessary first step to achieving a satisfactory balance between forest utilization, preservation and other land uses. It also ensures that land is allocated to its most appropriate use.

In north Queensland, a two-tiered zoning system has been applied. The first tier provides strategic zoning of all Crown Lands (State Forest, Timber Reserve, National Park, Leasehold). Undertaken at a scale of 1:500,000, this zoning level ensures coordinated management of Crown rainforest lands held under a variety of tenures.

Four zones are defined at the strategic zoning level: Principal Preservation Zone, Restricted Use Zone, Multiple Use Zone and Transition Zone.

Within the Crown tenures of State Forest and Timber Reserve, a tactical zoning tier known as Management Priority Area (MPA) zoning is employed. This is generally undertaken at a scale of between 1:25,000 and 1:50,000.

MPA zoning identifies a priority use for a given area and specifies compatible secondary land uses (Prineas 1987). It defines specific areas within which timber harvesting is permitted, and thus provides the basis from which gross productive area can be determined.

Area Estimation

Accurate estimates of loggable forest area are an essential component in yield prediction, since any errors in area estimates are directly proportional to errors in final yield estimates.

Loggable area is determined by deducting unloggable and unproductive fragments of forest from the area identified in zoning plans for logging. This process provides an estimate of the actual "on ground" area from which trees are harvested. The actual loggable area will vary between logging cycles as the volume of timber standing on any given area varies.

Yield Calculation

Within the area identified for sustained timber harvesting, it is necessary to obtain information on the forest stand, its species composition, size class distribution, rate of diameter increment, standing commercial timber volume, standing potential timber volume and rate of volume increment in order to be able to calculate the level of sustainable yield.

This calculation consists of six basic components:

1. Temporary inventory plots are established throughout the net productive rainforest area on a stratified random sampling basis to provide a detailed picture of the existing forest condition and the likely post-logging condition.
2. Permanent detailed yield plots maintained on a number of sites, some for up to 40 years, provide data forming the basis for development of the various increment functions used to simulate the future growth of different species and different forest types.
3. A computer-based growth model incorporating functions for diameter increment, mortality, and recruitment is applied to the temporary inventory plot data to predict the future condition of the forest. This model recognizes two site quality types and six soil parent material types. Because of the large number of species in the rainforest, the model "grows" trees not as individual species, but as

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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groups with similar growth habits. Species within a growth group also display similar ecological characteristics (Preston and Vanclay 1988).

4. At selected intervals, a timber harvesting model simulates future logging operations within the forest stands projected forward in time by the growth simulation model. The harvesting model simulates logging under standard tree-marking rules and allows for the proportion of defects in logged stems and mortality arising from felling and snigging damage to the residual stand.
5. One-way volume equations are used to convert projected stem diameters to log volumes. This step is undertaken since it is unnecessarily complex and inaccurate to project information other than stem diameter (Preston and Vanclay 1988). Volume equations used recognized site and species group differences.
6. Yield calculations undertaken to date have used a modified version of the Cutting Cycle Analysis procedure (McGrath and Carron 1966, Preston and Vanclay 1988). The analysis simulates the growth and harvesting of each inventory plot through three cutting cycles. This procedure ensures continuity of future harvests and provides an estimate of the yield that can be sustained under a given management regime and set of economic conditions.

A more sophisticated system, however, has been developed. This system, known as Yield Scheduling, simulates the growth of defined units of forest. When the total available yield from a given unit exceeds a specified minimum, that particular unit is highlighted as being available for logging (Vanclay and Preston 1989).

Scheduling of Logging Operations

Cutting Cycle Analysis provides an estimate of the overall quantity of timber that may be harvested each year. However, it does not provide an indication from where this timber may be obtained (yield scheduling does indicate a time sequence of areas available for logging).

A series of detailed logging history maps are maintained for scheduling logging operations. These maps illustrate the time (in 5-year periods) that each section of the area zoned for logging was last logged. They also indicate unlogged areas intended for future harvesting. Areas so identified from map records are then subjected to intensive field inventory to determine, first, if a viable yield could be obtained, and, second, what the likely long-term effect of logging under an assumed set of conditions will be. This procedure helps ensure that the logging practices employed on any specific area do not lead to a long-term downgrading of the stand structure and integrity.

Pre-operational Logging Planning

The preparation of detailed pre-operational logging plans are an integral and important component of timber harvesting practices in north Queensland.

Guidelines for the preparation of logging plans have been formalized in the Queensland Forest Service's "Environmental Guidelines for the Selective Logging of North Queensland Rainforests" (Queensland Forest Service 1982).

The primary task involves deliniating a suitable harvesting unit or "sale area." During this process, Special Management Areas are taken into consideration. These include areas of scientific, recreational or landscape significance, erosion prone sites, or particularly steep sites that are either required to be excluded from logging, or logged under special restrictions or conditions.

The actual preparation of a logging plan is undertaken as a joint task between the Forest Service and the proposed timber purchaser. The initial step involves both parties gaining a field knowledge of the terrain, including the location and relative concentration of available log resources.

The major infrastructure components required for harvesting of the sale unit are then physically marked out in the field by a combination of brushing undergrowth and paint marking trees. These components include haulage roads, ramp sites, and stream crossings.

The sale area boundary and the boundary of selected special management areas are also identified on the ground. These features are then transferred from the field onto a logging plan map which becomes an integral and binding part of the sale agreement between the purchaser and the Queensland Forest Service.

The basic philosophy inherent in the specifications and requirements of logging plans is to minimize damage to the rainforest canopy and the potential for soil erosion. The obvious benefits are more rapid recovery of the forest canopy, faster stabilization of the soil, and reduced harvesting costs through minimization of earthworks. Considerations in this regard include:

- Retention of buffer strips along streams within which logging or machine disturbance is not permitted *(fig. 1)*
- Identification of suitable stream crossing sites where necessary and construction of appropriate crossings to minimize soil erosion
- Restriction of lorry roads and snig tracks to within maximum permissible widths and grades
- Restriction of ramp sizes to less than a maximum area and ramp locations to sites below a maximum slope
- Location of lorry roads, snig tracks, and ramp sites on ridge tops or moderate side slopes for ease of drainage and minimization of earthworks
- Design of uphill logging systems feeding onto ridgetop ramps to disperse rather than concentrate runoff
- Provision of adequate drainage structures on roads and snig tracks, both during use and following completion of logging *(fig. 2)*

Treemarking

The Queensland Forest Service's "Treemarking Guidelines for North Queensland Rainforests" (Queensland Forest Service

Figure 1—After logging, cross drains are provided on snig tracks to control runoff and prevent erosion on exposed soil surfaces.

Figure 2—Before logging in a North Queensland rainforest, stream bank buffer zones are marked within which no logging is allowed.

1986) provide the silvicultural control on which the polycyclic selection system is based.

Consistent and accurate implementation of these guidelines is paramount to achieving sustainable timber production.

The treemarking guidelines provide for the removal of mature and defective trees, and the retention of advanced growth, vigorous mature trees and seed trees. These retained trees provide for regeneration, and are critical to ensure the availability and continuity of timber yields throughout future cutting cycles. Hence it is a necessary objective of treemarking for a polycyclic selection system to retain a scattering of trees after logging throughout the full range of commercial size classes to provide for future timber yields.

The treemarking guidelines used in north Queensland grouped the commercial species into five categories, each of which reflects both the relative timber desirability and the mature tree size attained. These groups are assigned an upper and lower cutting diameter. The lower diameter defines the minimum size a healthy tree may be cut under normal circumstances, and the upper limit defines the maximum size to which a tree carrying a commercial log may be retained. For example, group A species have a lower cutting limit of 80 cm d.b.h. and an upper limit of 100 cm d.b.h.

Defective trees below their normal minimum cutting diameter and above the absolute minimum cutting limit of 40 cm d.b.h. may be removed if they are defective or damaged in such manner that their likelihood of contributing to the yield of future cutting cycles is low, and if such trees may produce a log of at least minimum standard in the present cutting cycle.

Other considerations taken into account by the treemarker in addition to cutting limits include seed trees, outstanding trees, defective trees, canopy maintenance, and species preferences.

Notwithstanding guidelines for retention of seed and outstanding trees, the maximum canopy removal permitted by any harvesting operation is limited to a maximum of 50 percent. In practice, this level of removal is never reached. Typical logging operations remove around 8 to 12 stems per ha, generally comprising 20 percent of canopy, and approximately 9 percent of the ground area is cleared for snig tracks, lorry roads, and landing ramps. Therefore, the average overall mechanical ground disturbance in a normal harvesting operation is in the order of 24 percent, and the average removal of foliage cover is 20 percent.

In the treemarking operation, Forest Officers paint-mark trees for harvesting with a cross on the bole at eye height. They also mark direction of fall to ensure minimization of damage to retained growing stock. The falling direction is indicated by an axe bench in the tree butt, and may be highlighted with a vertical paint stripe. Each tree is assigned a number, which is written onto the axe bench or the base of the tree.

The axe bench is then embossed with the treemarker's own identifying brand. Species, estimated d.b.h. and treemarking number are recorded into a field notebook, as well as any specific reasons for removal of the tree (fungal rot, crown dieback, etc.).

This allows the Forest Officer to check trees marked against those cut, hence ensuring that all trees marked are cut and that unmarked trees are not cut. In addition to trees marked for removal, advanced growth of commercial species that is to be retained for its potential to contribute to timber yield in future cutting cycles is also paint marked by a ring around the circumference of the tree. The intention of marking such trees is to draw them to the attention of the logging contractors in order to avoid any damage to this valuable component of the retained stand.

Operational Control of Timber Harvesting Operations

Tracking Requirements

Prior to removing any logs from stump, it is necessary, in addition to roads and landings shown on the logging plan, for the minor extraction system to be planned. This system serves the purpose of "feeding" logs from stump, along winch lines, minor snig tracks, and major snig tracks, onto loading ramps.

The timber cutter can best identify the most efficient extraction route for logs from stump to ramp. The cutter is responsible for locating and marking the extraction route for each log to minimize disturbance to the forest. The cutter should also identify the end of snig tracks where machines are to stop and turn around, and from this point on, must also mark winch line paths to logs.

This practice eliminates the necessity for the extraction machine to drive right up to every log, thereby reducing overall clearing and damage to the stand. For this purpose, all snigging machines are required to carry a winch with not less than 30 m of wire rope.

Snigging machine operators are encouraged wherever possible not to blade off soil and vegetation from snig tracks, but to "walk" their machinery over the vegetation. This precaution retains the binding mat of surface roots and organic matter, and, therefore, considerably reduces the possibility of erosion, hastens the recovery of the forest, and reduces the visual impact of the operation. The logging operator is not required to carry out drainage works where an adequate mat of surface roots remains intact.

Harvesting Equipment

The type of equipment to be used in each logging operation is specified in the logging plan. General specifications applicable to all areas require the blade of any snigging equipment not to exceed 4 m (consistent with maximum snig track width), and all snigging machines to carry a winch with not less than 30 m of wire rope (consistent with extraction requirements).

Equipment capable of raising the front end of logs during snigging is favored. The benefits of such equipment, however, include reduced horse power requirement and reduced soil disturbance caused by the ploughing effect of the front of logs during snigging. This can often be achieved by winding the wire on to the winch such that the leading end comes from the top of the winch and not from the base.

Fork lift type loaders are the preferred equipment for the loading operation as they enable landing sizes to be minimized.

Drainage Requirements

After the felling operations and final extraction of logs are completed, the purchaser is required to "put the area to bed." This involves constructing diversion drains across all snig tracks and sections of haulage roads. Construction of diversion drains is carried out according to the specifications in the logging plan for the particular soil type and track grade involved.

Landing sites must also be drained to ensure surface runoff is dispersed into undisturbed vegetation or silt traps, and ponding does not occur.

Each year, the same drainage requirements as above must be carried out throughout each current sale area prior to the start of the wet season, and must remain in place throughout this period. All trees cut are also required to be removed from the sale area before the wet season.

Post Operational Control and Review

After the harvesting operations are completed and the satisfactory drainage within the area serviced by each landing ramp in the sale area is fulfilled, the Forest Officer must inspect and assess the purchaser's compliance with the logging plan.

All trees over 20 cm d.b.h. that have been unnecessarily damaged incur a fine which is charged to the purchaser. To avoid possible disputes, the damage is clearly defined as bark removal in excess of an area 10 cm × 20 cm, torn wood fibre on either the bole, roots, or complete removal of the tree.

Recording of Logging History

After the timber sale is completed, it is necessary to record the actual area that was logged over, the time period during which it was logged, and the reason particular areas may have been bypassed in logging (inaccessible, unproductive, etc.).

The compilation and maintenance of such information over the entire area zoned for logging is indispensable for effective management of the north Queensland rainforest for many reasons, including:

- Maintaining continuity of the current logging face
- Scheduling of logging operations, particularly in previously logged areas
- Accurately identifying the productive rainforest area for resource calculations
- Developing resource stratification for yield calculation purposes
- Referencing specific details for any particular area
- Readily identifying special management areas, and
- Passing on information concerning the specific details of forest management from one generation of managers to the next

The time period and extent of past logging is recorded on two sets of maps, known as Logging History and Logging Management maps. Logging History maps record information from the first cutting cycle, and Logging Management maps record information in the current cutting cycle. The Logging History maps are essentially an archive for information on logging, while the Logging Management maps provide a means for coordinating and scheduling logging operations throughout the current cutting cycle.

A completion report is prepared, and includes a map showing actual areas logged within the sale, the 5-year time period within which each section of the sale was logged is specified by a colour code. Inaccessible areas too steep to log, unproductive areas too poor to log, other areas not logged for special management reasons, and the location of lorry roads and loading ramps within the sale area are also included on the map. The data contained in the completion report is transferred onto the master Logging Management map.

Conclusions

The north Queensland polycyclic selection logging system is the result of a gradual evolution in techniques and practices over a period of around 40 years. Its success lies in the considerable amount of background data and research effort on which it is based, the rigorous application of the guidelines embodied in this system by dedicated Forest Service staff, and the acceptance and adherance to these guidelines by logging contractors.

The result of this system is the commercial harvesting of timber without damaging the basic integrity of the forest environment and thus the opportunity for harvesting of non tangible products. Under this system of forest utilization, the economic and social value of tropical forest is increased and the argument for retention of land under forest cover as opposed to conversion to alternative land use is strengthened.

While the specific data behind the north Queensland system may not be directly transferable to other tropical countries, the methodology behind the development of this system and its basic principles and philosophies provide a universally valuable model that may help solve at least the technical aspects of managing these forests. This is the first major obstacle which must be hurdled if the social problems inherent in tropical forest management are ever to be adequately addressed.

Acknowledgments

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Management and Utilization of Forest Resources in Papua New Guinea[1]

P.B.L. Srivastava[2]

Abstract: Papua New Guinea, with an area of about 46.7 million ha and a population of 3.7 million, is blessed with a large natural forest resource. Over 80 percent of the land is covered with forests of various types, ranging from swamp and lowland rain forests in coastal plains to alpine vegetation and moss forests in the highlands, most of which are owned by the people. About 15 million ha are considered commercial, with about 400-500 million cubic meters of high value timber. Current logging concessions are spread over 3.1 million ha. All the projects except one are based on selective cutting with a minimum cutting limit of 50 cm d.b.h. The current system of resources acquisition and allocation, extraction of timber, and its effect on the environment, including biodiversity is described. Possibilities of management options of these heterogenous forests on a sustainable basis are discussed.

During the last 5,000 years, people of Papau New Guinea have lived within numerous tribes and clans with diverse customs and languages that shared one invaluable friend—the natural forest. Despite centuries of subsistence gardening, today about 80 percent of 467,500 sq km is covered by forests, varying in types from the swamps and lowland forests of coastal plains to alpine vegetation and moss forests in the highlands. The forests have provided the basic needs of the people and are still an integral part of their social and cultural heritage. It is estimated that 15 million hectares can be developed into log exports and onshore processing. These forests contain about 400 wood species of varying properties, of which about 40 are commercially accepted. The forestry sector has contributed significantly to the development of the country in terms of employment (about 11,000) and foreign exchange earnings *(table 1)*.

However, management of forest resources in Papua New Guinea is at a crossroads today. If, on the one hand, politicians and planners view this renewable resource as a major means of export earnings and income to landowners, generations of employment opportunities, and infrastructure development in the hinterlands, then the vital question before foresters is whether the resource can be managed on sustainable basis. Conservationists and environmentalists, on the other hand, worry about irreversible ecological changes in these fragile ecosystems if the forest cannot be regenerated.

Resource Acquisition

The land and all the resources with it—whether forests, minerals or oil—are the most valuable possessions of a Papua New Guinea clan. Apart from town sites and a few other larger areas, the government owns only about 3 percent of total land. The rest of the land ownership and land rights are vested in 700 ethnic groups. Individuals have rights of usufruct, but guardianship is vested in patrilineage. When land is under such a closely interlocking system of rights and obligations, transfer of land to individuals or groups outside these relationships is difficult and rare. It also makes it difficult to obtain general agreement for a long-term land use, which may have no immediate benefits, e.g., reforestation.

The current Forestry Act. (Anon. 1976) provides for exploitation and development of forest resources mainly through Timber Right Purchase (TRP) Agreements. Under this Agreement, the government acquires rights of felling, removing and disposing of timber from customary landowners. Normally, a down payment is made on the basis of volume of timber which is recouped when royalty starts flowing.

The two other ways to develop timber projects, Local Forest Area (LFA) under Private Dealing Act and through Timber Authority (TA), are generally used for smaller operations. Currently, 3.1 million ha are covered by TRPs and LFAs (Anon. 1990b).

Table 1—*Exports of forest products ('000 cubic meters and millions of kina[1])*

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Logs	743	1063	1019	1284	1158	1314	1442	1361	1279	1084
Sawntimber	24	21	20	18	15	7	4	3	3	4.5
Plywood	8	6	6	5	1	.2	.02	0	0	0
Woodchips[2]	103	148	100	103	82	61	66	67	53	68
Value	**45**	**53**	**56**	**82**	**67**	**77**	**113**	**100**	**91**	**83**

[1]1 kina = 1.04 U.S.$
[2]Woodchips in '000 bone dry units.

[1]Submitted for publication in the Proceedings of the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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Resource Allocation

Following a TRP Agreement, a Timber Permit (TP) is issued to a registered timber company by tendering on agreed terms and conditions, including payment of royalties, (the major portion of which—75 percent—goes to the resource owners and the remainder—25 percent—goes to the respective Provincial Government), and other levies, such as reforestation levy, agriculture development levy, Forest Industries Council (FIC) levy, etc. The main conditions of a Timber Permit are:

- Log harvest and export at a pre-determined rate, processing and follow-up land use;
- Construction of roads and bridges and their maintenance during the life of the project;
- Infrastructure development, which may include construction of airstrips, school buildings, community hall, health posts, houses, new townships, churches, etc.;
- Environmental protection measures; an approved Environmental Plan is a prerequisite for starting the project;
- Submission of a Forest Working Plan which includes details of forest surveys, roads and bridges, production schedule, reforestation, environmental protection measures, fire control and preventive measures, control of insects and pests; and
- Listing of species which are not allowed to be cut, removed, or damaged. Normally this includes trees with edible fruit or of economic use other than timber.

Environmental Safeguards

Considerable efforts are made to minimize the deleterious effects of logging operations on forest ecosystems. Under the Environment Planning Act Chapter 370, each Permit Holder (Timber Company) is to submit an Environmental Plan for the project area. It is a comprehensive document which includes information on the purpose of development, socio-economic benefits to the resource owners, viability of the project, infrastructure development, resource harvesting and replacement practices, climate-edaphic environment, flora and fauna, and environmental impact safeguards, including existing and proposed conservation areas which include preservation of cultural and historic sites. The Environmental Plan is approved by the Minister in charge of the Department of Environment and Conservation after it has been evaluated by a number of experts and presented to the people of the project area.

The Timber Permit includes the following conditions to minimize adverse environmental impacts of logging operations:

1. No clearfelling is allowed on slopes up to 20 degrees.
2. Selective logging is allowed on slopes up to 30 degrees.
3. No logging is allowed on slopes greater than 30 degrees.
4. A 50 m buffer must be observed along rivers, streams, and creeks.
5. No logging is allowed (a) within 100 m of any garden (field), burial ground or area of cultural importance, or (b) within 500 m of any inhabited village.
6. Measures to minimize soil erosion must be taken.
7. Precautions must be taken to ensure that banks of any river or stream are not damaged, and that the course of any river or stream is not altered by logging operations.
8. No hauling or snigging of logs, timber or other forest produce through any flowing river or stream is allowed.
9. No obstruction of rivers or streams by logs, timber, other forest produce, debris, or other materials from its operations is allowed.
10. No pollution of rivers or streams by sawdust, oil, waste, debris, or other materials is allowed.
11. Should logging activities adversely affect community or domestic water quality or quantity or both, the permit holder shall provide an alternative water supply.

A number of the above conditions are flouted by timber companies due to poor control. The Department of Environment and Conservation does not have resources to monitor the situation. Generally it is the forest inspectors who report matters concerning adverse environmental impacts. In the majority of cases, loggers do not maintain 50 m buffers along rivers, often log above 30 degree slopes, damage river and creek banks, and block and pollute rivers and creeks with debris. Cases have been reported where companies have hauled logs through flowing rivers.

Resource Management

Logging Operations

Out of the three major phases in timber harvesting—felling and bucking, minor transportation, and major transportation—it is the second phases which causes the highest damage to the forest and site and determines the success or failure of selective logging. There is no clear cut provision in the Permit with regard to area control. Although submission of a 5-year Forest Working Plan (FWP) within 60 days of the issue of the Permit is a prerequisite for starting logging operations, very few timber companies follow it. Generally, the annual coupe is altered and no pre-planning is carried out for roading, snig tracks, and bush ramps. Very few companies conduct pre- and post-logging inventories. Even those who do so do not have any follow-up plan to use post-logging data to manage the residual stands. The standard of forest roads is generally poor, usually evidencing excessive clearing from 40 m to as much as 70 m wide. Crawler tractors and wheeled tracked skidders are the common types of equipment used in skidding. Some loggers occasionally use huge tractors for skidding, which not only have a high cost of operation but also cause much more damage to the forest cover. An articulated wheeled or tracked front-end loader is the common type of equipment used in loading. For hauling logs, two types of trucks are used in PNG: long chassis truck, and logging trucks with trailer or jinker, the latter being more common. *Table 2* shows an estimate of logging cost in PNG. Safety standards in logging in PNG are very low compared with those of other

Table 2—*An estimate of logging costs in Papua New Guinea*

	Managed by company or contractor cost/cu.m.		Managed by individual contractor cost/cu.m.	
	(Kina)	*Percent*	(Kina)	*Percent*
1. Forest planning and engineering	1.40	3.49	0.80	3.29
2. Road construction and maintenance	8.35	20.80	4.40	18.11
3. Felling and bucking	5.20	12.95	3.30	13.58
4. Bunching and skidding	11.65	29.01	7.60	31.27
5. Loading, hauling and unloading	9.05	22.54	3.70	15.23
6. Royalty	4.50	11.21	4.50	18.52
Total:	40.50	100.00	24.30	100.00

countries. It is evident that the present system of log harvesting in PNG is not compatible with sound forest management practices. Improvement of the system is imperative for sustained management of the resource (Buenaflor 1988a,b).

Yield

The minimum cutting limit, irrespective of stand composition and size class distribution, is 50 cm d.b.h. Adhering to this limit is known as selective cutting. Except in one project (Japan and New Guinea Timbers in Madang), which is based on clearfelling (using hardwood mixture for pulpwood chips), the rest of the projects in the country to-date are based on selective cutting. So far, however, it has not been obligatory for timber companies to mark trees, to conduct pre- and post-logging inventories and to follow directional felling to minimize damage to the residuals. There are no penalties in the Forestry Act for excessive damage to the residual crop or for cutting under size trees. In particular, yield regulations based on stand characteristics and sustained yield principles are not observed, and virtually no attention has been paid to manage the logged-over forests. As a result, there are no predictions for the next cut. Information on growth and yield is almost completely lacking. In certain situations, where the majority of the trees of a commercial species are above 50 cm d.b.h., almost a clearfelling situation may prevail though the company may have followed selective logging within the TP conditions.

Because of the very selective nature of logging, a so-called "creaming" of the forest, yield may vary from as low as 12 m^3/ha in a highly mixed forest to over 100 m^3/ha in areas where a single or a couple of commercially important species *(Calophyllum, Intsia, Nothofagus, Anisoptera)* become dominant. The average yield is estimated to be about 30 m^3/ha.

The important commercial species being harvested currently are: *Eucalyptus deglupta, Intsia bijuga, Araucaria* spp., *Terminalia* spp., *Calophyllum* spp., *Pometia* spp., *Syzygium* spp., *Endospermum* spp., *Celtis* spp., *Vitex cafessus, Pterocarpus indicus, Anthocephalus chinensis, Palaqui* spp., *Castanopsis* spp., *Lithocarpus* spp., *Nothofagus* spp., *Podocarpus* spp., *Homalium* spp., *Diospyrus* spp., *Anisoptera thruifera* , *Hopea* spp., etc. For export purposes, a MEP (Minimum Export Price) system is in operation. The MEP is revised periodically on the basis of international price. Certain species are banned from export in log form.

Biodiversity

Earlier studies on heterogeneity of flora in PNG were confined to commercial species. Paijmans (1970) recorded 122, 147, 145, and 116 species of trees above 10 cm d.b.h. in four 0.8-ha plots. However, in a recent study of total species count, as many as 363 species were recorded in a 0.64 ha plot in a lowland tropical rainforest. The species comprised of trees (49 percent), shrubs (18 percent), vines and climbers (15 percent), herbs (9 percent), vegetative clumps (8 percent), epiphytes (7 percent) and palms (3 percent). More studies are planned, especially to study the effect of logging operations on biodiversity in both lowland and hill forests (Kiapranis 1990).

Constraints for Sustained Yield Management of Natural Forests

There are a number of constraints, socio-political and economic on the one hand, and technical and logistical on the other, which have not allowed the management of forest resources on sustained yield principle so far in PNG. These include:

1. *Policies*: The 1979 Forest Policy (Anon. 1979) did not have strong emphasis on the management of natural forests for sustained yield in spite of the fact that it allowed increased log harvest and export to generate revenue.
2. *Landownership*: Since TRP Agreement allows removal of only the standing crop, it is not possible to manage the logged over forests unless the TRP and TP conditions are revised.
3. *Limited resources:* Inadequate financial resources and trained staff, both at the national and provincial levels, have resulted in poor control of harvesting operations resulting in excessive damage to the site and potential tree crops (PTC), overcutting, and wastage.
4. *Attitudes of Timber Companies*: There has been, in general, a lack of interest and commitment in proper management by timber companies, the majority of which are transnational either as Permit Holder or as logging and marketing contractor to the landowners companies, for proper management. This is partly due to the short period of the contract (normally a TP is issued for 10 years), weak conditions of the TP, landownership problems, and the absence of proper guidelines and suitable penalties in the Forestry Act for undersize cutting, excessive damage to residuals, and wastage.
5. Inadequate knowledge of silvics of even the prime timber species.

6. A belief that plantation forestry (reforestation) could meet the demands of timber more economically and efficiently. Hence every TP has a clause on reforestation which was not fulfilled by the majority of timber companies. Even companies that carried out reforestation planted areas that fell far short of the volume of the timber harvested or area logged. According to Gane (1985), there was an imbalance of 8:1 between harvesting and resource replacement. Besides, there are other problems such as availability of land, (landownership), sub-optional growth of planted species, high initial investment, insect pests and fire risks, quality of wood of planted species vis-a-vis high value timber species (choice of species), end-use, marketability and post-planting management practices which have to be considered in order to make reforestation an economically viable post-logging land-use in the country.
7. *Shifting Cultivation*: The majority of the rural population in PNG depends on subsistence agriculture. It has been frequently observed, especially in comparatively highly populated areas, that people immediately establish "gardens" in logged areas which are made accessible by logging roads. This results in the destruction of natural regeneration and advance growth by slash and burn.
8. A post-logging land-use pattern for concession area is not worked out before issuing the timber permits.

Factors Favoring Sustained Yield Management

The following factors would, however, favor sustained yield management of natural forests in PNG so as to perpetuate high-value timber species over large areas of TRPs:

Selective Logging

The majority of the timber products are (and will continue to be) based on selective logging. This would mean that if timber companies follow carefully planned harvesting techniques, leaving behind adequate number of undamaged residuals in the range of 20-50 cm d.b.h., it would be possible to have next economic cuts after a predetermined period following a polycyclic felling system. It would also ensure a heterogenous character of forest with comparatively less damage to the site and loss of gene pool.

Presence of Natural Regeneration

It has been observed that a number of commercial timber species such as *Anisoptera, Hopea, Pometia, Calophyllum, Anthocephalus* flower and fruit regularly and regenerate profusely on certain sites presumably because of regular climatic pattern and seasonal changes. Other species such as *Pterocarpus, Nothofagus, Intsia* regenerate by coppice and root suckers (Saulei 1985). Howcroft and Nir (1986) recorded an average of over 7,000 plants between 50 cm height and 45 cm d.b.h of *Anisoptera* in 4 one-hectare plots in a logged-over forest in Morobe Province. Anther study from the same area (Kingston and Nir 1988) showed 6 trees/ha of leading desirables over 50 cm d.b.h. with an estimated volume of 20 m^3/ha and 19 trees/ha over 30 cm d.b.h. In *Calophyllum* dominated forests in Manus, over 11,000 seedlings below 1 meter ht were recorded under the canopy of unlogged forests. However, there were very few trees between 20-50 cm d.b.h. Other observations of interest from the management viewpoint were that: (a) *Calophyllum* spp. flower and fruit regularly; (b) dispersal of seeds of both the species of *Calophyllum* was poor as indicated by a large number of seedlings under the mother trees; (c) seedlings remain suppressed under heavy canopy shade, most of which perish with time, and (d) with disturbance and opening, *Calophyllum* seedlings respond to light (Srivastava and others 1986).

Ecological Status of Forests

Observations indicate that in PNG, the forest over large tracts is "young" at a pre-climax stage. Due to frequent activities of volcanoes, earthquakes, fires, and the movement of riverbeds, the forest is "rolled-over" periodically. From an ecological view point, it is easier to regenerate a forest at a pre-climax stage dominated by light demanders than the one at climax stage, which is in equilibrium with site conditions.

Reforestation

Plantation forestry due to problems mentioned earlier has yet to develop its full potential in PNG.

Marketability

Native high value species such as Kwila, Rosewood, Taun, Mersawa, Pencil Cedar, and Planchonella will not lose their importance in the export oriented market in future. There will be no problem in selling these timbers either as primary products (logs) or as value-added secondary and tertiary products (sawn timber, furniture, etc.), even in a highly competitive and volatile international market.

Future Trends

During the last 3 to 4 years, especially after the Forest Inquiry Commission Report, a number of developments have taken place which, if successful, will ensure management of forest resources on a sustainable basis.

Forest Inquiry Commission

The Commission of Inquiry in forestry matters, which was set up in 1985, submitted its final report in 1988. It identified a number of weaknesses in the present system of management and utilization of forest resources in the country such as a weak

Forestry Act and other policies, inadequate knowledge of the resource base, poor monitoring of timber projects, prevalence of transfer pricing, and a lack of trained staff and other resources (financial, transportion, etc.) (Anon. 1988). All efforts are being made by the Government to implement the recommendations of the Commission.

Tropical Forestry Action Plan (TFAP)

In order to solve some of the problems highlighted by the Inquiry Commission, the government requested the UNDP/World Bank in 1989 to launch the Tropical Forestry Action Plan. The World Bank took the role of lead agency and fielded a team of experts, which submitted its final report in February 1990. The report came up with 14 priority projects covering wide areas such as resources appraisal, monitoring, agroforestry, human resource development, strengthening State Purchase Option, forest industry development, landowner awareness, rehabilitation of existing National Parks, and declaration of World Heritage Areas (Anon. 1990c). It sought cooperation of non-government organizations (NGOs) in forest resource management. In subsequent reviews, the project on rapid resource survey, revenue studies, and some aspects of research on forest management have been given priority.

New Forest Policy and Legislation

A new Forest Policy has been in place since April 1990. Some of the most important ingredients of this policy are (i) sustained yield management as the guiding principle for production forests, including non-timber products; (ii) management practices compatible with the environment, (iii) increase in onshore processing to add value to the product to generate more employment opportunities and increase in investment, (iv) resource acquisition in the form of Forest Management Agreement (FMA) instead of TRP, which would include post-logging management of the area (Anon. 1990a). Currently, the Forest Act is being revised to implement the new policy.

Institutional Changes

In line with the new policy, institutional changes are being made. A PNG Forest Authority will be established (replacing the present Department of Forests) as a statutory corporation for the management of forestry sub-sector. The Authority will be made of a National Forestry Board and a unified National Forest Service.

Research and Development

In 1989 the PNG Forest Research Institute was established in Lae with generous funds from the Japanese government. The institute is well equipped with laboratory facilities, including a scanning electron microscope, National Herbarium, a botanic garden, National Insect Collection, National Seed Centre, and two field stations at Bulolo and Madang. Four main areas of research are covered: forest botany, forest management, forest protection, and forest products. It has over 60 professional and supporting staff with an allocation of K1.2 million in 1991. Some of the priority areas in research are (i) productivity and silviculture of residual stands; (ii) genetics and tree improvement of reforestation species; (iii) biodiversity; (iv) flora exploration for completing flora of PNG; (v) agroforestry; (vi) environmental impact assessment; (vii) utilization of timber species, especially the lessor known with suitable techniques of processsing, seasoning, grading, and preservation; (viii) minor forest products (rattan, orchids); and (ix) insect and pest diseases of timber trees.

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Culture and Resource Management: Factors Affecting Forests[1]

Marjorie C. Falanruw[2]

Abstract: Efforts to manage Pacific Island forest resources are more likely to succeed if they are based on an understanding of the cultural framework of land use activities. This paper explores the relationship between agricultural systems, population density, culture, and use of forest resources on the islands of Yap. Agricultural intensification is related to population increases in the past. It appears that resources were, to some extent, managed via a highly organized stratified social system. Today, changes have resulted in a loss of insularity, and controls over resource exploitation are fading. Agricultural technology has become more extensive and forest resources are being expended rapidly. Participatory research is suggested as a means of focusing local attention on systems of food production which incorporate more sustainable use of forest resources.

This symposium deals with tropical forestry *for* people of the Pacific and we are concerned with the management of forest resources. We cannot assume that people with different cultural backgrounds perceive their environment the same way we do, or that we all share the same scientific values and attitudes (Chase and Sutton 1981, Smith 1987). This paper deals with some of the cultural factors affecting use of forests on the island of Yap in the Federated States of Micronesia. It is based on the author's observations over the last 15 years, a study of vegetation patterns, and data collected in an ongoing Forest Service study.

The Setting

Yap is a close cluster of four high islands lying within a broad fringing reef at lat. 9°33' N. and long. 138°09' E. in the Western Caroline Islands. The combined area of the four main islands is about 100 km^2 (39 mi^2), and the highest point is 174 m (571 ft). The climate is warm and humid. Mean annual temperature is 27 °C (81 °F). Mean annual rainfall is about 3000 mm (120 in). The driest months are February to April with an average of fewer than 180 mm (7 in) precipitation each month. Wettest months are July through October, with an average monthly rainfall of 330 mm (13 in).

Estimates of Yap's population prior to written history range from 25,000 (Hunter-Anderson 1983) to 40,000 (Underwood 1969). After contact, there was a drastic drop in population due to epidemics of introduced diseases. Population decline continued through 1946 when the population was estimated at 2,400 (Useem 1946). Since 1946, the island's population has been rising rapidly.

Results of the agricultural system employed to feed the large population of the past can be seen today in the island's anthropocentric vegetation pattern. Vegetation maps based on 1976 aerial photographs (Falanruw and others 1987) show that some 26 percent of the island had been developed into a system of tree gardens with taro patches. About 34 percent of the vegetation consisted of a mosaic of native forest, secondary forest, secondary vegetation and active garden plots. Another 22 percent of the interior was savanna grassland. Mangroves made up some 12 percent of the vegetation. Other types together made up less than 6 percent of the land area.

The Traditional Agricultural System

The agricultural system which produced this vegetation pattern has been described elsewhere (Falanruw 1985). Briefly, the system consists of tree gardens with taro patches associated with villages located mainly along the coast. Intermittent mixed gardens generally occur inland of villages. Here trees are burn-girdled to admit light and remove root competition. The clearing and burning practices observed today vary from the practices generally described for "slash and burn agriculture" (FAO 1957, National Research Council 1982) in that trees are not felled and burning is generally confined to the base of trees difficult to kill by girdling. Crops are planted before, along with, or after burning activities depending on the crop, site conditions, and weather. Gardens are cleared in the dry season and planted as rains begin. By the time the rainy season sets in, crops generally cover much of the ground. The most important crop is yams (*Dioscorea* spp.), but a variety of other crops may also be planted. Today's gardens often yield a succession of up to 15 crops as well as a number of useful materials and byproducts during and after the term of the garden per se. After one to three years, the garden is allowed to go fallow.

The intermittent gardens are the most dynamic component of the agricultural system. If the gardener settles in the area, it may progress toward a tree garden "agroforest" as useful trees are planted and taro patches are developed. Otherwise, succession may proceed towards forest, or savanna grassland, depending upon the subsequent history of the plot. The extent to which regenerated forest may differ from native forest is influenced by many factors such as the severity of the burn, the frequency of subsequent burns (Manner 1981, Gourou 1958), size of the clearing, selective weeding, and other activities of the gardener. Other factors are availability of seed sources, displacement by introduced species, and availability of seeding agents, which on Yap include fruit bats as well as birds. Land crabs and rodents may also modify regrowth. Mueller-Dombois (1981) suggests that species having wide spatial separation are likely to be lost. Studies of the species composition of plots on Yap before, during, and after gardens and of plots for which the fallow period is known are ongoing.

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The Impact of Population

Population pressure would necessitate the conversion of forest land to food production. It is postulated that lands under shifting cultivation have traditionally supported a population of fewer than 20 people per square mile (Nye and Greenland 1960). With a pre-Western contact population density estimated as high as 625 to 1000 people per square mile (Hunter-Anderson 1983, Underwood 1969), fallow periods could not have been long enough to allow for the regeneration of the forest canopy.

A census of garden plots and house platforms in one municipality on Yap gives some evidence of this process: Mahoney (1958) reports 2,127 garden plots and 485 stone dwelling platforms. This would give a ratio of 4.3 garden plots per household. If garden plots were developed each year and maintained for two years, the fallowing period could be only about two years. This would not allow enough time for the development of a mature forest canopy with primary forest species.

The inhibition of the formation of a forest canopy would result in decreased transpiration and the equivalent of an increase in precipitation (Sanchez 1976). The clearing and cropping practices are likely to result in a decrease in infiltration rate (Laland and others 1975, Sanchez 1976). Daubenmire (1972) compared filtration rates under forest and savanna and found a 45:1 relationship. If, with frequent burning and a nearby source of grassland species, forest areas are converted to grasslands, the evaporation rate rises and the overall effect is "too much water in the wet season and too little in the dry season" (Komkris 1978). The lack of a canopy would result in a decrease in biomass on the site and lowered rate of nutrient cycling. The reduction in soil fertility would support fewer trees (Budowski 1956). As a result, the area would be "stalled" as a savanna grassland sere.

There is a great deal of discussion in the literature on the relationship between swidden agriculture and the origin of grasslands (for example: Budowski 1956, De Schlippe 1956, Fosberg 1960, Manner 1981, Mueller-Dombois 1981, Nunn 1991, Ruddle 1974, Scott 1978, Spenser 1966, Whitmore 1975). The matter is complex and affected by a set of factors unique to each setting. There is general agreement, however, that frequent burning activities have contributed to the expansion of areas devoid of a tree canopy. Burning is not confined to swidden agriculture, but also occurs as accidental or intentionally started wildfires.

When asked about the origin of the savanna grassland, Yapese elders reply that it has always been thus. Indeed, the type is mentioned in the legendary history of Yap as early as the period when people interacted with spirits. Legends tell that it was in the savanna of old that a spirit taught people how to make and use fire for cooking.

Agricultural Intensification: Ditched-Bed Technology

Intensive methods for managing water, weeds, and soil fertility would be required if savanna grasslands were to be used agriculturally. These methods exist in the technology of ditched garden beds. Throughout Yap one can see garden beds surrounded by ditches, and the inverse, taro patches surrounded by raised areas. In open canopy gardens, the ditches provide drainage and the soil excavated from the ditches is mounded on top of the slashed vegetation on the beds to inhibit weeds and to provide fertile soil. The process is very labor intensive, especially prior to the general availability of metal tools, when a spade made from a split trunk of an *Areca* palm was used to loosen the soil and a flat basket woven from coconut leaves was used to transport the soil from the ditch to the garden bed. The ditches then served to demarcate the garden bed and secure the investment of energy of those who created it. Heavy rains would result in some erosion, especially if they came before plantings covered the site. Hurni (1982) suggests that drainage ditches can reduce erosion from swiddens by about half. Some of the topsoil which is washed into the ditches is returned to the garden plot the next time it is used. Silt which accumulates downstream of series of ditches collects in pits used for taro patches. In low-lying areas, ditches are made within taro patches to improve water circulation.

Given the intensive labor required, the ditches must have been made during periods of dense population when resources were at a premium. When today's gardeners are asked who made them, the answer has been that the original beds were made by the ancient people. The technology continues to be employed in the open canopy production of sweet potatoes and to a lesser extent in gardens made in less fertile sites covered with secondary vegetation.

Today ditched garden beds are clearly visible on aerial photographs on at least 33 percent of savanna grasslands. In the field they can also be seen below secondary vegetation and even forests. When gardens are made in well-developed forests it is not necessary to re-excavate the ditches around garden beds. To do so would, in fact, be quite difficult because of the presence of tree roots. Given these practices, it would appear that the existence of ditched beds indicates that much of Yap was once gardened so intensively that the forest canopy was, for a time, absent. The period of depopulation which continued through World War II resulted in the natural reforestation of many of these areas. Other areas appear to be stabilized disclimaxes of secondary vegetation and savanna grass and fernlands.

Clarke (1966) compared the agricultural systems of four New Guinea communities whose methods might be considered as "stages along a hypothetical chain of development from a simple extensive forest-fallow rotation to a more elaborate and intensive grass fallow cultivation" (Clarke 1966:347). With increased population density and a shortened fallow period, forest lands may be degraded to savanna grasslands and more intensive methods would be required to produce sufficient food. The systems on Yap show a similar intensification in the ditched-bed technology. When depopulation reduced the ratio of people to resources, however, forests regenerated. This has enabled people to return to the use of extensive methods which produce adequate returns for minimal efforts. Much of today's production is obtained via the expenditure of forest reserves. If this trend continues unabated, a loss in biodiversity and eventual environmental degradation can be expected.

Traditional Management of Land Resources

It has been suggested that island cultures are adaptive to the island ecosystem (Fosberg 1978, Rappaport 1963). If this is the case, we might expect to find some mechanisms within island cultures that would counteract the human tendency to overexploit resources to the point of environmental degradation. The practice of ecosystem conservation per se is not described in literature on Yap, nor has it been brought up by any elder interviewed in this project. Some conservation measures appear to have been inherent in the traditional religion, however, and the social system did have a number of features that limited opportunities for "the tragedy of the commons." Resources were managed via a highly organized stratified social system. This system might be illustrated by considering the controls on the activities of an individual gardener (*fig. 1*).

When a woman (A) marries into an estate, she and her children gain access to appropriate lands of that estate subject to the approval of estate elders (B). The resources of these lands are also subject to "trustees" from the sister's side of the family of the estate head, for although kinship inheritance is generally patrilineal, sisters and their children retain trustee rights. Trustees (C) may declare offensive behavior and take punitive action. They may also request resources for their needs and to fulfill obligations within their own respective groups.

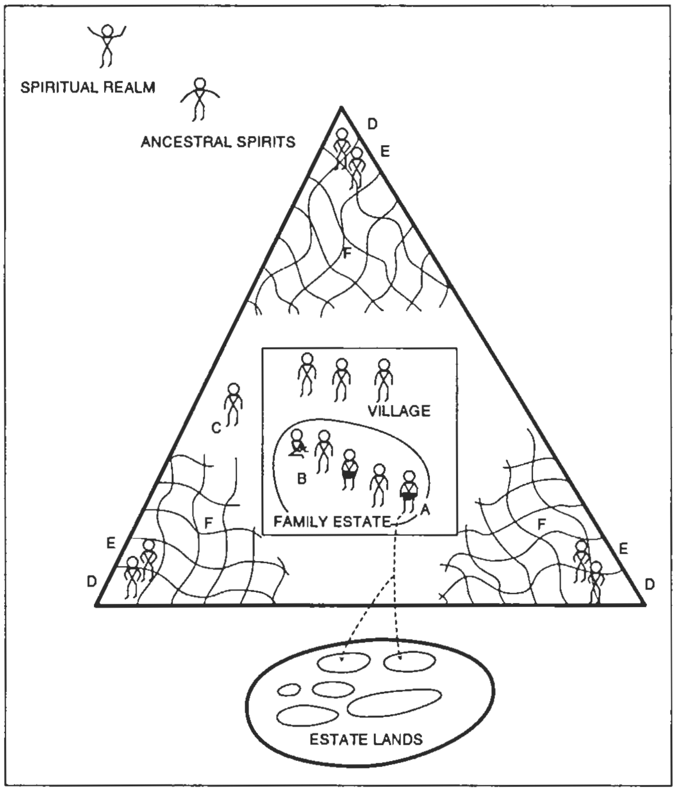

Figure 1—"Cultural constraints on use of land resources. When a woman (A) marries into an estate (oval unit), she and her children have access to appropriate lands of that estate subject to the approval of estate elders (B). The resources of these lands are also subject to "trustees" (C) from the sister's side of the family of the estate head. A number of estates exist within a village (square unit), which is directed by chiefs. Villages are organized in hierarchical relationships with three paramount villages (D), each linked with a village in another alliance (E). Each set of villages has a network of ranked villages in their respective alliance. The networks of ranked villages (F), combined with relationships of kinship, trustees and alliances, create a complex system of checks and balances on resource use.

A number of estates exist within a village, which is the basic community unit. Within villages there were three chiefs who directed the use of the village taro patch and garden lands and had some jurisdiction over other resources as well. Thus our gardener's activities are also governed partly by the chiefs of her village.

Villages are organized in hierarchical relationships with three paramount villages (D), each linked with a village in another alliance (E). Each set of villages in turn has a network of ranked villages in their respective alliance. About five social levels existed in an apparently dynamic ranking process. The networks of ranked villages (F), combined with relationships of kinship, trustees and alliances, create a complex system of checks and balances, and no one chief was capable of exerting total power or influence over his locale (Labby 1976, Lingenfelter 1975).

In addition to the social relationships governing land use, many areas were designated for specific uses. Some were sacred and should not be trespassed, others were prohibited to women. Thus even the physical area of the gardener's movement was prescribed. The social system had provisions for denying use of lands for a period of time. In addition, if one's land contained a limited resource, such as a big tree or bamboo patch needed for a community project, that resource should not be destroyed, and could be expropriated for community use. Effective physical, social, and spiritual sanctions existed in the past to support and enforce the system of controls (Falanruw 1982). The system was adapted to managing the resource-use activities of a dense population. Individual freedom was curtailed and funneled into group achievement. These achievements include major public works such as large men's houses, community houses, an extensive system of stone paths, and voyages for stone money.

The effectiveness of the control system in terms of sustainable resource management would depend on the wisdom of leadership as well as the degree of population pressure. It has been suggested that shifting agriculture in the Pacific was self-limiting (Alkire 1960, Labby 1976), and that the decreasing viability of shifting agriculture led to a predominance of taro cultivation in the South Pacific (Barrau 1961). In Southeast Asia, shifting agriculture has been supplanted by rice cultivation in many areas (Peters and Neuenschwander 1988). In the case of Yap, today's agricultural system consists of a mix of shifting agriculture, and site stable agriculture in the form of taro patches and mixed tree gardens. The combination has a greater potential for sustainability, and the systems in fact complement each other; the production of the intermittent gardens being counterpoint to that of breadfruit in the tree gardens with taro patches providing food throughout the year. Production from mixed gardens and tree crops is locally viewed as "giving the taro patches a rest," as well as providing a more varied diet.

The System at Work Today: an Example

In the past, the fruits and coconuts grown on the property of a deceased person were not harvested for about a year after the death in an observance called "lieu." The accumulated produce of the land was then gathered and presented to the appropriate relative of the deceased (Mueller 1917). Today lands of the deceased are no longer left fallow, and another type of "lieu" is practiced. The social purpose of the practice remains the same: the recognition of the relationship between the trustees of the land, and those living on the estate. The latter present generous amounts of yams to secure their residence on the land. The trustees in turn present valuables including stone and shell money, woven "begi," cases of soda and beer, hard liquor, and money. In a recent "lieu," some 710 baskets of yams totalling more than 11 tons were collected. This involved the contributions of at least 70 households, with many of the households in turn collecting contributions from within their own network.

Data on garden production now being collected will help estimate the amount of forested land converted to yam gardens for such an occasion. Today's technology for gardening includes metal tools, matches, and two new techniques for burn-girdling trees. The first is to burn old tires at the base of trees. The burning tires are moved about and enable a gardener to kill trees more efficiently. The second innovation, coming but two years after the establishment of a garment factory on Yap, is the use of the large volume of discarded cloth scraps for burning thickets of bamboo. The cloth is placed between the stalks of bamboo to use as tinder. These new techniques expedite the conversion of forest to gardens.

Influence of Change on Resource Use

Goodenough (1971) refers to culture as a reservoir of all the knowledge, skills, ideas, beliefs, values, recipes, and traditions that are known to one or more members of that society. He defines a society's "culture pool" as the sum of the contents of the propriospects of all the society's members (Goodenough 1971). A propriospect is each individual's private, subjective view of the world and its contents derived from personal experience. It embraces individuals' cognitive and affective ordering of their experience. The public culture is the modal point of the mix of the individual propriospects. The change with time of the modal point around which variance clusters shift has been described as "cultural drift" (Goodenough 1971, Smith 1987). This produces change without discontinuity.

Figure 2 shows the impact of new factors on the culture pool. The impact of these factors takes various forms. Depopu-

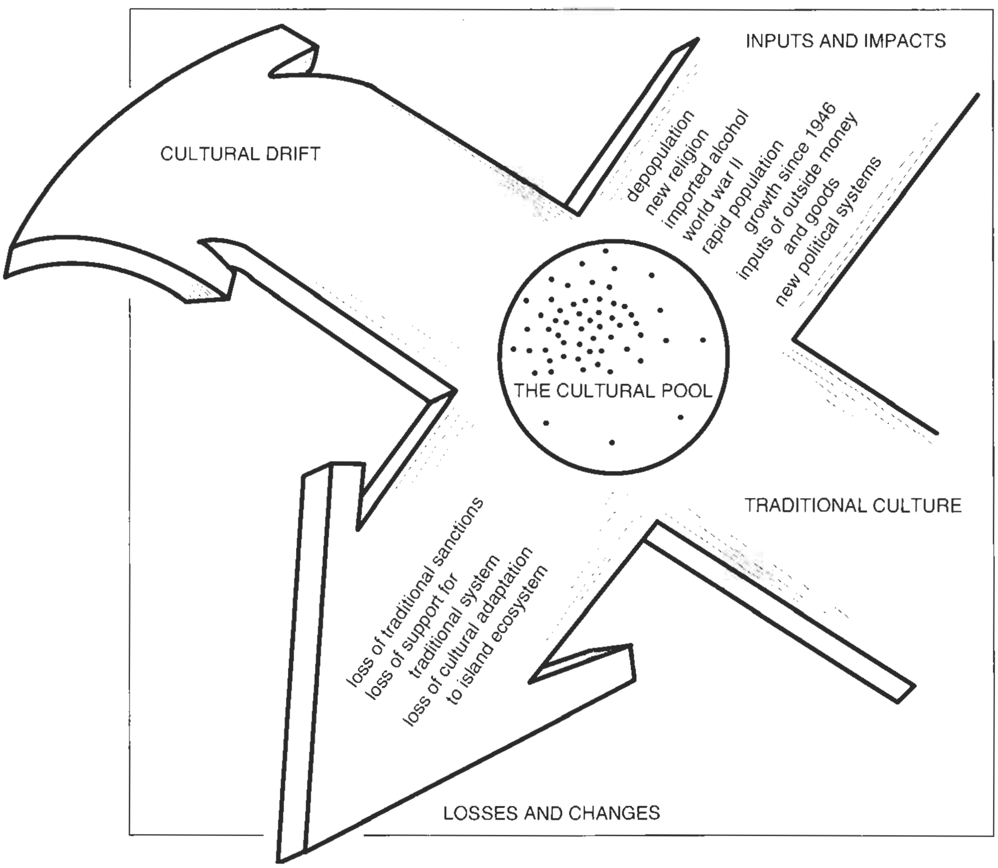

Figure 2—Influences of changes on resource use. The cultural pool consists of the propriospects of all of a society's members (Goodenough 1971). On Yap, inputs and impacts such as those listed have influenced propriospects resulting in a new modal point and cultural drift. The result has included a loss of traditional sanctions and a decrease in cultural adaptation to the island ecosystem.

lation left many "positions" in the highly organized and stratified society unfilled (Mahoney 1958), greatly weakening lines of support for the system itself. Christianity was introduced shortly thereafter, and traders began selling distilled alcohol. The Japanese occupation of the island and World War II followed. After the war, Americans introduced a democratic form of Government and directed aid through this system rather than through the system that supported the traditional hierarchy. In spite of all these changes, many aspects of the social system, such as kinship patterns and obligations, persist.

In the matter of controls over the use of natural resources, however, there seems to have been considerable change. Depopulation resulted in a lower ratio of people to resources, and the need for intensive methods decreased. Neither the new religion nor the new government placed controls on resource use. At the same time, Yapese culture was given a demonstration of the power of modern technology: nonbiodegradable materials, chemicals, fossil fueled machinery, electricity, and a dollar economy. These things are very impressive, and gradually the insular consciousness has changed to one which is not referenced to island resources alone. Sanctions have faded. When an old man tending an important shrine died, his successor on the land burned the area to make a garden and then built his house there. Within the context of the traditional religion, some misfortune should have befallen him as a result of his burning a sacred place. He suffered no such misfortune. Christianity taught people to share, and, as outside resources flowed in, there was much to share and use in traditional social exchanges. It is hard for a cognitive model in which resources are limited to persist under such conditions. The criterion of adequacy for a cognitive model is that it functions, not that it is accurate (Ellen 1982). Though Yap's natural resource base has not increased, outside inputs have made it possible for people to trespass the basic rules of caloric self-sufficiency without feeling the consequences. The culture has drifted away from one which was referenced and adaptive to the island environment to one which is much more reliant on outside support (Yap State Government 1980).

Implications for Forestry

It appears that although Yapese culture today retains its focus on social obligations, it has lost many of the controls over resource exploitation. This comes at an inopportune time. The combination of decreasing aid funds under the Compact of Free Association with the United States and a rapidly expanding population and more consumptive lifestyle will bring about greater exploitation of natural resources. There is definite need for sustainable resource management. If we are to assist people in managing their resources on a sustainable basis, we must help them to evaluate their use of resources and build appropriate experience in rational resource utilization. One way to do this is via participatory research projects. Sometimes "facts" are not as important as the context in which the "facts" are gathered (Ellen 1982). If a participatory approach is used in research and projects, the information and experience gathered will influence individual propiospects that make up the culture pool, and allow culture to readapt to ecological realities of the island ecosystem. Hopefully this change will occur before useful traditional technologies are forgotten.

Given traditional patterns of resource use, an important area of focus for participatory research projects lies in the area of food production systems involving a forest canopy. Although "slash and burn agriculture" as practiced by displaced peoples contributes to tropical deforestation (FAO 1957), its practice by generations of people confined to a small island may provide insight into the incorporation of natural processes of succession in agricultural systems. Site stable agriculture requires large inputs in order to suppress natural succession to "weeds," and to manage soil fertility and moisture. These inputs are expensive and often have undesirable impacts on the natural ecosystem. Traditional "nature intensive" systems utilize the ecological services of trees for these functions, and minimize human input. They allow for a succession of crops and secondary species and the maintenance of some wild species in the system. The impact on soil flora and fauna and important natural processes involved in nutrient recycling is less than that of chemical and mechanized agriculture. Land resources on islands are limited. If forestry does not address the matter of swidden agriculture, it will come into conflict with it at some point. It would be more effective to work with the practitioners of swidden agriculture, to enhance the system in a way which would make use of the services of trees while taking pressure off native forest resources.

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People and Forests in East Kalimantan[1]

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Abstract: Two major Indonesian-MAB (Man and the Biosphere) projects were carried out in the province of East Kalimantan, Indonesia, in the 1980s. Investigators found that farmers vary in their reason for practicing shifting cultivation of logging and agriculture, in their intensity of farming, and in the amount of damage they caused forests in their practices. Shifting cultivation includes a variety of practices that under some circumstances, however, can benefit people and protect their environment. In more recent times in East Kalimantan, commercial logging in lowlands has continued at a quicker pace, and the practice has shifted from the export of raw logs to plantation timber and local wood processing.

Research conducted under the UNESCOs' MAB (Man and the Biosphere) Programme began in East Kalimantan in 1979 with a joint Indonesian-U.S. project on "Interactions between People and Forests" (Kartawinata and Vayda 1984). The project brought together American and Indonesian scientists to investigate various forest-related activities throughout the province and some of their biological effects. East Kalimantan had been selected as the location for the Indonesian MAB Programme on "Project 1: Ecological effects of increasing human activities on tropical and subtropical forest ecosystems" (UNESCO 1974).

The initial project on "Interactions" was followed, from 1982 to 1984, by a second Indonesian-U.S. MAB project called "Shifting Cultivation and Patch Dynamics in an Upland Forest in East Kalimantan" (Mackie and others 1986). The "Patch Dynamics" project was more narrowly focused than its predecessor, but it continued the theme of studying people's forest-related activities and their effects on forest organisms, communities, and ecosystems. A number of smaller MAB projects also were conducted in East Kalimantan around the same time as these two, many focused on people-forest interactions but others on the basic ecology of intact or less heavily exploited forests (Kartawinata 1984, Kartawinata and others 1983).

The activities studied under the "Interactions" and "Patch Dynamics" projects were those known or believed to have clear and significant effects on forest organisms, communities, or ecosystems. These included large- and small-scale commercial logging, non-commercial timber-cutting, migrant pepper farming, the collection of non-timber forest products, and shifting cultivation. Among the biological effects of these activities, some that were studied were the removal of individual plants and animals, conversion of primary and secondary forests to other vegetation types and successional changes that followed, and changes in environmental conditions and nutrient flows following the removal of trees or forest conversion. These basic ecological studies helped to provide data on the "natural background" against which to interpret the biological effects of human activities.

In addition to identifying activities with a clear and significant impact on forests and studying some of the biological effects of those activities, the projects on "Interactions" and "Patch Dynamics" had another purpose. This was to develop a better understanding of who engaged in these activities, in what circumstances, and how and why the practice of those activities and their effects might vary. The methodology used in the research was called at first "situational analysis" (Vayda and others 1980) and later "progressive contextualization" (Vayda 1983). Human actions, the consequences of those actions (whether biological, environmental, or otherwise), and variations in both actions and consequences can be explained by placing them in a context of interconnected causes, constraints, and other influences affecting the actors. These include not only physical factors but also what a person knows and believes—at least those found to be relevant to the performance (or non- performance) of the actions under investigation. Some of these contextual factors are discovered in the particular cases studied in the field. Others can be deduced through comparison with other cases previously studied and perhaps already understood. A contextual explanation of any particular case or generalization from more than one case can be made progressively denser or more extensive by considering more factors in greater detail over a longer period of time, a greater number of actors, and so on.

In the "Interactions" project, in which a variety of forest-related activities were studied at several widely separated sites, the contexts built up by this method were in most cases not very dense. Our sample sizes were necessarily small and many potential factors that might possibly affect actions and or their consequences could not be investigated in detail or with great rigor. However, the contexts we developed were broad. They included, for example, linkages between people and places involving long distance migrations (from the remote interior of East Kalimantan to the lowlands and from other islands such as Sulawesi) and trade (for example, of forest products from upriver areas, through coastal ports, to cities such as Surabaya, Singapore, and Hong Kong).

The second MAB project ("Patch Dynamics") was focused on a smaller range of forest-related activities (shifting cultivation and non-commercial timber cutting) primarily within a single research location (the Apo Kayan, in the far interior). The contexts for these activities and their consequences (biological disturbance and successional recovery) could therefore be made denser than those developed in the first project. In particular, we gathered more detailed information on a whole range of factors affecting the spatial distribution and temporal frequency of gap-

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forming human activities, including histories of migration and forest use; we also conducted more thorough and rigorous biological studies of plant succession following anthropogenic (and some natural) disturbances.

This paper summarizes results of the two principal Indonesian-U.S. MAB projects in East Kalimantan and the various smaller projects carried out during the 1980s, and considers the future of the MAB Programme in East Kalimantan.

Results of the MAB Research

Logging and Agriculture

Kartawinata and Vayda (1984) reveal that integrated social and biological research at several tropical forest locations in the Indonesian province of East Kalimantan is indicating variation among farmers in their reasons for practicing shifting cultivation, the extensiveness of their farming, and the amount of forest damage they cause. It is among the most remotely located farmers that long-fallow, forest-maintaining practices are the norm. The subjects studied included migrant pepper farmers and unlicensed woodcutting teams in addition to shifting cultivators. All subjects were responsive to economic pressures and opportunities, but, with the possible exception of government-sponsored transmigrants, they engaged in activities causing environmental damage, not because no other means of gaining subsistence for themselves and their families were available, but rather because the activities seemed more profitable than any perceived alternatives. None of the subjects, however, cause as much forest damage as do timber companies. Studies in areas mechanically logged by the companies show genetic erosion, reduction in species diversity, and very slow recovery of the forest. The less damaging methods of our subjects may provide foundations for appropriate technologies of forest use and management.

During the explosion of general economic prosperity at the time of *banjir kap* (the name for practices which were common at the beginning of the timber boom in the late 1960s and early 1970s when trees were manually felled near rivers and then floated downstream), clever entrepreneurs built boats or shops which they retained after the general trade in logs was restricted to timber companies approved by the central government. Since that time, some of these relatively new entrepreneurs have limited their business activities to the sale of trade goods and foodstuffs; other have participated in the trade in minor forest products only when the prices for certain products have been particularly high; still others have taken on trade in minor forest products as a regular occupation. The competition at all stages of trade has thus increased sharply and is even more pronounced when the urban prices on forest products rise significantly. At such times, the number of part-time river middlemen looking for lucrative deals also increases. Collectors gain more bargaining power in that there are more potential buyers of their forest products, but they do not make the best of this situation by trying to improve the quality of their products. Rather, knowing that someone will buy, they offer large quantities instead of high quality. Formerly, regular traders could enforce greater quality control over contractors with whom they had credit ties. In addition, there seemed to be more mutual respect among the traders in certain locales in regard to territorial rights - the rights to forest products collected by particular contractors and other debtors. However, control is becoming increasingly difficult as part-time or new entrepreneurs offer, for example, to pay cash for wet or dry rattan of any quality in order to break into the market. Regular traders subsequently accept low-quality forest products to protect their relationships with, and their investments in, their contractors.

Here again, short-term economic considerations are apparently being put ahead of long-term ecological ones. Like the other investigators, Peluso (1983) found that her subjects typically acted in what they considered to be their best interests. The problem is not one of ignorance. Collectors, whose harvesting methods are destructive, know, for example, the regeneration cycles of the varieties of rattan growing in their locales and the reproductive cycles of the swiftlets whose nets are taken. The fact is that the people's resource-destroying behavior brings quick profit to them and, since traditional controls over these resources (such as the village chief's rights to certain valuable forest produce) have been eliminated, policies of harvesting as much as one can from a resource before somebody else gets to it inevitably gain ground. An important but often ignored implication of such findings is that education and propaganda will be insufficient to change people's behavior. Some way will have to be found to institute effective new controls in place of the lapsed traditional ones, or some concrete and profitable alternative sources of income will have to be offered to those who are now acting destructively.

Implications for Development: Comparison of Shifting Cultivation in Two Sites

The approach advocated and used in the East Kalimantan MAB projects has produced some findings which are important for development planning in the province and which may be relevant to other tropical forest areas. In the remote Apo Kayan, the inhabitants, the Dayak people, are not reckless destroyers of the forest—the prevalent image of shifting cultivators. Rather, they maintain and re- use sites, farming almost entirely in secondary forest with a long history of land use. Their migrations are not, in most instances, caused by a shortage of land but are mainly responses to economic problems brought about by their geographic isolation.

The more accessible Telen River lowland area, to which people have migrated from the Apo Kayan, is quite different. Despite the hopes of government planners that 'resettled' shifting cultivators could be induced to use more intensive agricultural methods, shifting cultivation there is more, not less, extensive than in the Apo Kayan, and it is being practiced mainly in primary rather than secondary forest. This is not due to any 'backwardness' on the part of Dayak farmers but is a result of inappropriate methods. These include irrigated rice cultivation, which has been promoted by extension workers and brought about by economic circumstances that, on the one hand, encourage extensive agricultural production (access to markets) and, on the other, make the clearing of large areas of primary forest relatively easy because of the ready availability of chain-saws, outboard motors, and fuel. A related factor is the low inherent fertility of soils in the area which precludes intensive sedentary agriculture.

In the homegardens, Soedjito (1988a) found 91 species in Sungei Barang and 129 species in Long Segar, indicating that the two Dayak settlements have sufficient additional food and medicinal plant supply. The function of homegardens tends to decline as a result of "modernization" influences as indicated by the settlement in Long Segar, although it has higher number of species cultivated which are mostly ornamental species not present in Sungei Barang.

Research to date suggests that development planners should pay close attention to circumstances which may vary from one locality to another and which can have important influences on people's actual behavior. Such circumstances are usually more important than generalities such as the "type" of agriculture practiced or a group's "level of development" or "culture." The generalization that "shifting cultivation is destructive and therefore should be eliminated" (or the reverse, that "shifting cultivation is not destructive") is bound to be wrong some of the time because "shifting cultivation" includes a great variety of actual practices in a diversity of environments. Under some circumstances, shifting cultivation can benefit people and protect their environment.

Shifting Cultivation and Patch Dynamics in the Apo Kayan

Shifting cultivation and tree-felling for timber in the remote Apo Kayan region of Indonesian Borneo are compared with natural disturbance events (tree-falls and landslides) generally known to affect tropical forests. The causes of spatial and temporal patters in human-caused disturbances are examined. Farmers in the Apo Kayan practice a traditional, forest-maintaining form of shifting cultivation, which over time has created a non-random mosaic of fields, old fields, secondary forests of varying age, and primary forest in "relic" patches.

Mackie (1987) found that tree species common in secondary forest appear early in old field succession. These species appear to be particularly well adapted to regenerate after shifting cultivation. Soedjito (1988b) found that roots of trees within secondary forests penetrate deeper into the soil, have longer lateral roots, and contain higher levels of nutrients and greater biomass than trees of primary forests. Field site selection is influenced by social interactions as well as by environmental factors and the local history of land use.

On a broader scale, migration has repeatedly redistributed villages and village-centered patterns of shifting cultivation within the Apo Kayan. Recent emigration from the region has greatly reduced the human population and has led to contraction of the areas affected by shifting cultivation. Most shifting cultivation has been in areas of secondary forest. Primary forest reserves are maintained near villages in order to supply local needs for timber and other forest products.

The gaps made by tree-felling for timber rather than for farming are similar to natural treefall gaps both in size and in the density of regenerating seedlings. Felling and extraction of timber cause little damage to the surrounding forest. Large landslides are similar in size to shifting cultivation fields. However, they disturb soil and vegetation more severely than any other natural or human-caused disturbance in the region.

The biological diversity of the Apo Kayan and the opportunities for basic and applied research there make it an excellent site for an international biosphere reserve. Recommendations are made for a program of research, forest conservation, and environmentally appropriate development within a biosphere reserve.

Studies on Primary and Secondary Lowland Forests

A study of a primary lowland dipterocarp forest in Lempake near Samarinda shows that it has a high degree of species diversity (205 tree species of d.b.h. > 10 cm in a 1.6-ha plot with a density of 445 trees/ha) (Riswan 1982, 1987), although slightly lower than that at Wanariset, near Balikpapan (239 tree species in a 1.6-ha plot with a density of 541 trees/ha) (Kartawinata and others 1981). The occurrence of secondary forest species at different proportions indicates regeneration within gaps caused by fallen trees. Naturally occurring gaps of different sizes were recorded also in the Wanariset forest (Partomihardjo and others 1987). Regeneration observations on an experimentally established gap of one hectare within the Lempake primary forest with partial burning treatment for a period of 1.5 years reveal that in the early stage of succession, seedlings play a more important role than coppices (Riswan 1982; Riswan and Kartawinata 1989), which is just the reverse of the regeneration in *kerangas* (heath) forest on podsolized soil over white sands in Samboja (Riswan 1982; Riswan and Kartawinata 1988b). The number of species, percentage of cover and frequency of seedlings and coppices, as well as the number of primary forest species, were greater in the unburnt plots than those in the burnt ones. Recovery in the unburnt plot was attributed primarily to an undisturbed seedbank in the soil, while that in the unburnt one mainly to seed rain.

In the Lempake Forest, a 35-year-old man-made gap of several hectares (i.e., a secondary forest developed from an abandoned pepper plantation) shows a relatively high species diversity (121 tree species of d.b.h.> 10 cm in a 0.8 ha plot with density of 578 trees/ha) (Riswan 1982; Riswan and Kartawinata 1988a). Although 70 percent of them were primary forest species, the biggest tree, the emergents and the most common species were secondary forest species, particularly *Macaranga* spp. Only one species of Dipterocarpaceae was recorded, although the plot was surrounded by primary dipterocarp forest. By using a floristic similarity index, stem biomass, and girth measurement, it was estimated that it would take around 150 to 500 years for the forest to reach the stage similar to the primary forest. Riswan and others (1985) compared the above data from primary, secondary, and experimentally cleared forest sites to estimate the minimum time required for various phases involved in the re-establishment of tropical rain forest after disturbance.

A model they developed predicts a minimum period for the stabilization of secondary species numbers of 60-70 years and the replacement of primary species in 150 years, at which point ~ap formation is initiated. After approximately 220-250, years ~nass stabilizes while individual trees exist for over 500 years.

.'uture of MAB Programme

Many changes have occurred in East Kalimantan since the MAB research of the early 1980s. Despite the devastating drought and fires of 1982-83, commercial logging in the lowlands has continued at a rapid pace, although there has been an important shift from the export of raw logs into local wood processing and, more recently, development of planted timber "estates." The trade in rattan has also expanded, with a ban on the export of raw cane, development of Indonesia's rattan manufacturing industry, and attempts to establish rattan plantations.

Transmigration and so-called "spontaneous" immigration into East Kalimantan from other provinces has continued, but there has been a decline in emigration from the Apo Kayan since the large migrations of the 1970s and early 1980s. Some resettlement communities in the lowlands (including those on the Telen River) were badly disrupted by the drought and fires of 1982-83, and people from those communities have since moved to other locations within the lowlands. Population growth has been especially rapid around the coastal town of Bontang, where industrial and mining projects have attracted immigrants. This has contributed to accelerated encroachment into nearby Kutai National Park. On the other hand, there has been more attention paid in recent years to the Kayan Mentarang Nature Reserve in the far interior of the province (including part of the Apo Kayan), where the human population is sparse and threats to natural forest are less than in the heavily exploited lowlands.

We who have been involved in the MAB Programme in east Kalimantan will continue to work closely, as in the past, with the Indonesian Institute of Sciences (LIPI) and the Mulawarman University. We are also developing closer ties with the Directorate General for Forest Protection and Nature Conservation (PHPA); the Office of Minister of State for Population and Environment (KLH); and such conservation organizations as the World Wide Fund for Nature (WWF), Indonesian Environmental Forum (WALHI), Conservation International, and others. We are in the process of planning conservation-oriented research and a training component in the Kayan Mentarang Reserve in collaboration with WWF, LIPI, and PHPA and with the possible participation of Wildlife Conservation International. We also continue to advocate the establishment of a biosphere reserve in the Apo Kayan, a goal supported by WALHI and Conservation International. This new generation of MAB research, training and guidance for policy-makers will build on the experience gained in the earlier Indonesian-US MAB projects focusing on forest biology, human ecology, and the involvement of local communities in conservation management.

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Forest Biological Diversity Interactions with Resource Utilization[1]

S.T. Mok[2]

Abstract: The most important forest resources of the Asia-Pacific region are the highly diverse rain forests. Utilization of the resource is a natural and inevitable consequence of the region's socio-economic development. The sustainable management and development of forest resources in the region can be achieved by implementing conservational forestry, which is based on blending Eastern wisdom and philosophy with Western expertise and technology. The most urgently needed technology in the region are cost-effective, integrated forest inventory and monitoring systems, information management and decision-support systems, and non-wood forest resources assessment and valuation systems. The conservational approach to forest management can have major beneficial effects in conserving resources and maintaining biological diversity.

Forests have served humankind beneficially since time immemorial. They are renewable natural resources. Natural forests are vital sources of food, fuel, medicine, and a host of other products essential for livelihood and welfare in all developing countries. They provide fertile land for agriculture and primary commodities for trade and industries which promote socio-economic progress. Besides producing tangible products, forests have heritage, socio-cultural, aesthetic, recreational, and other intrinsic values which enhance the quality of life. They play a critical role in the management of soil and water resources, maintenance of environmental quality, and conservation of biological diversity—all of which are essential for sustainable development.

In the Asia-Pacific region, forests constitute an integral part of the people's diverse cultures, religions, and socio-economic activities. Living in harmony with nature is a way of life in the region. Prudent use of forests contributed significantly to the rapid progress of civilization and socio-economic development. The region is home to more than half of the world's population, and is projected to increase to nearly 3,200 million by the year 2000 (Anon. 1987). It has a dynamic economy and is expected to become the economic growth center of the world in the 21st century. The growing population will inevitably increase pressure on the forests in the region, but socio-economic advancement will have a profound influence on the nature of these demands.

With increasing demands from a growing population, both regionally and globally, it is inevitable that the forests will continue to decline. According to the World Resources Institute (Anon. 1990a), the world's forests have declined by one-fifth, from 5 to 4 billion hectares, since pre-agricultural times. Temperate forests have lost the highest percentage of their area (32 to 35 percent), followed by subtropical woody savannas and deciduous forests (24 to 25 percent). Tropical evergreen forests have lost the least area (4 to 6 percent). However, the present highest rates of deforestation are in South America (1.3 percent) and Asia (0.9 percent). According to the Food and Agriculture Organization (FAO) of the United Nations, the rate of deforestation of 0.6 percent in 1980 has doubled to 1.2 percent, or almost 17 million hectares a year (Anon. 1990b). The rate of annual deforestation in the Asia-Pacific region during 1981-90 was close to 4.7 million hectares, compared with some 2 million hectares during 1976-80.

The impacts of rapidly growing world and regional populations, changing socio-economic circumstances, and declining forest resources, particularly on biological diversity, present major challenges to forest managers. The increasing awareness of the vital non-wood values, especially of tropical forests, makes the social and environmental aspects of forestry particularly important and the conservation of forests in general and forest biological diversity, in particular, imperative. Before these challenges can be met realistically and effectively, however, forest managers must have (a) timely, relevant, and reliable information on forest resources and biological diversity, (b) pragmatic policies and strategies for sustainable forestry development, (c) effective managerial expertise and operational skills, and (d) appropriate forest resources assessment, management and development technologies.

Forest Biological Diversity

The Asia-Pacific region has been well endowed with rich natural forests containing great biological diversity. However, the precise extent of forest areas is debatable due to a lack of consensus in definition and the rapid changes brought about by shifting cultivation, commercial timber harvesting, and conversion to other uses. The extent of closed forests has been estimated by the Asian Development Bank at 407.9 million hectares (Anon. 1987) and by the World Resources Institute at 495.7 million hectares (Anon. 1990a). According to the Asian Development Bank, broadleaved forests accounted for 376 million hectares or 92 percent of the natural closed forests in the region. More than half of the closed forests were found in insular Southeast Asia (144.4 million ha), continental Southeast Asia (95.9 million ha), and tropical Oceania (37.9 million ha). Closed forests covered more than 50 percent of the total land area of Indonesia, Malaysia, Papua New Guinea, and the Solomon Islands. Countries with the most extensive areas of closed forests are Indonesia (113.9 million ha), People's Republic of China (92 million ha), India (51.8 million ha), Papua New Guinea (34.2 million ha), Myanmar (31.9 million ha), and Malaysia (21 million ha). Substantial areas of non-forest land, especially in Southeast Asia, are actually under perennial tree crops such as rubber, oil palm, and cocoa.

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[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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The most important forest resources of the Asia-Pacific region are the tropical rain/moist forests of Southeast Asia and Oceania, which cover some 1,000,000 square kilometer (Anon. 1989). The region has a great diversity of plant and animal species of economic importance and is one of the cradles of agriculture where many of the world's major crop plants originated or have their center of diversity. Many plants and animals from these forests are important sources of fruits, drugs, oils, beverages, gums, vegetables, spices, medicine, ornaments, fibres, and rattan. Nevertheless, the precise extent, location, and value of these forests' biological diversity is generally very poorly known.

Indonesia, with forests spread over more than 13,000 islands encompassing three major vegetation regions from Asia to Oceania, probably has the highest biological diversity in the Asia-Pacific region. The country is estimated to have 25,000 to 30,000 species of flowering seed-bearing plants (4,000 trees), 750 species of mammals (100 endemic), 1,250 species of birds, and 12,000 species of arthropods/insects.

Malaysia's biologically rich tropical rain forests have some 14,500 species of flowering plants (890 reaching 45-cm d.b.h.), over 800 species of non-flowering plants, around 1,000 species of vertebrates, and 20 to 80 thousand invertebrate species. A high degree of endemism ranging from 30 percent of all tree species to 80 to 90 percent of some families has been observed.

The Philippines has a unique flora and fauna with high levels of endemism in both plants and animals. More than 950 terrestrial vertebrate species and some 8,000 species of flowering plants have been recorded. The forests support at least 12,000 species of plants, of which about 3,000 are endemic. The fauna is characterized by a high degree of endemism, with about 96 species of non-volant land mammals, of which at least 70 are found nowhere else in the world. The avifauna and herpetofauna, with some 860 species, also show a remarkable degree of endemism.

Thailand, which divides naturally into six geographical regions, has 10,000 to 15,000 species of plants, including 500 tree species and about 1,000 species of orchids; over 900 species of birds; 270 species of mammals; and 100 species of amphibians.

Papua New Guinea has an extraordinary diversity of ecosystems, ranging from mountain glaciers to humid rain forests, and some of the most remarkable wildlife on earth. The total number of vascular plants in the country is believed to be in the order of 11,000 species and about 2,000 species of ferns, with estimates of endemism ranging from 55 to 90 percent. The lowland forests are the richest with over 1,200 species of trees. The majority of the fauna is Indomalayan in origin, with a strong Australian influence in mammals, which have been estimated at almost 200 species. The avifauna is one of the richest and most varied in the world, as New Guinea is a major center of diversity for several species of birds. Approximately 740 species have been recognized (10 percent of them endemic), of which 445 dwell in the rain forests. There are some 90 species of snakes, 170 species of lizards, nearly 200 species of frogs, and 455 species of butterflies, over 80 percent of which are endemic.

Interactions with Resource Utilization

Resource utilization is a natural and inevitable consequence of the socio-economic development process. Forest utilization has been ongoing since the dawn of civilization and is a worldwide phenomenon which escalated with the advent of the agricultural and industrial revolutions. It has been sustained at a high level to satisfy the basic and socio-economic needs of growing populations in developing countries and to meet the insatiable demands for primary commodities in the developed world. As a consequence, extensive areas of land have been deforested or degraded throughout the world, causing widespread and serious losses of forest biological diversity.

In the Asia-Pacific region, which is environmentally, ecologically, and culturally very complex, forest biological diversity interactions with resource utilization are largely correlated with forest degradation and deforestation caused by a variety of traditional forestry and socio-economic development activities. The main activities which could degrade the forests, and, therefore, biological diversity, include hunting and gathering, shifting cultivation, fuelwood cutting, and commercial timber harvesting. Loss of forest biological diversity can result from burning and converting forests to continuous annual cropping, grazing, perennial food and primary commodity crops, and industrial forest plantations; and from construction of dams, settlements, highways, and infrastructures.

Forestry has been practiced traditionally but informally in the Asia-Pacific region from the time when people began to use natural forests to satisfy their basic needs. The forest people's pattern of land use, exemplified by nomadic hunting, gathering and traditional shifting cultivation, has evolved over thousands of years to take advantage of the regenerative capacity of natural forest ecosystems—a way of life both rational and sustainable so long as their populations remain low and their territories extensive (Anon. 1989). Some of the most technologically advanced cultures in the world in the period 13,000 B.C. to 4,000 B.C. flourished not in the Middle East or the adjacent Mediterranean, but in the northern reaches of mainland Southeast Asia, where cultures were based on traditional shifting cultivation (Anon. 1989). The system is considered to be well adapted to tropical rain forest management as it helps to maintain the biological diversity of forests and often provides significant benefits to wildlife populations.

However, shifting cultivation can become unsustainable, and thus impact adversely on forest biological diversity in at least three main ways: (a) by an increase in human population, which causes old plots to be recultivated too soon; (b) by inept agricultural practices such as prolonged cultivation of the land that allows persistent weeds to become established; and (c) by extension into an insufficiently humid environment such as deciduous forests, which have a much slower recovery rate (Anon. 1989).

The problem has been exacerbated in recent years by "shifted cultivators" from the lowland who lack the knowledge which generations of traditional shifting cultivators have accumulated.

The rapid growth of populations in the Asia-Pacific region in recent decades has compounded the problem as the increased pressure on the forests resulted in unsuitable areas being cultivated. Even in Southeast Asia, shifting cultivation is often no longer a viable option as the density of population is such that the practice will almost invariably lead to long-term degradation of the agricultural and forestry potential of the land (Anon. 1989). Non-traditional shifting cultivation or slash-and-burn farming by the landless and unemployed rural poor, who follow in the wake of logging, is a major cause of deforestation associated with commercial timber harvesting in most Asia-Pacific countries.

Fuelwood is a major source of energy in the Asia-Pacific region and accounts for the largest share of consumer products from forests and other wooded areas. It is usually collected locally for rural households and from areas surrounding the population centers for cooking, heating, and small-scale industries. Although the extent of fuelwood collection is virtually impossible to ascertain precisely, it is estimated that annual production generally accounts for about 80 percent of total wood removals in the Asia-Pacific region. Consequently, uncontrolled exploitation for fuelwood and charcoal often degrades open tree formations and sometimes closed forests, causing adverse interactions with forest biological diversity.

Commercial harvesting of permanent production forests in the Asia-Pacific region is not usually a direct cause of deforestation because it is mainly selective, and clear-cutting is rare (Anon. 1988). Selective logging usually removes 2 to 10 trees per hectare or 3 to 30 per cent of the total timber volume. The permanent forest estates in many countries of the Asia-Pacific region are legally constituted and protected by long-established forestry services. Most countries in the region have basically sound forestry policies and subscribe to the principles of sustained yield and sustainable development. However, few of them have adequate human, technical, and financial resources to ensure effective enforcement of forestry legislations and implementation of sustainable forest management and development, especially with respect to forest biological diversity. Consequently, commercial timber harvesting is often the precursor of serious degradation of forests in general and forest biological diversity in particular.

The increasing degradation of forest biological diversity is caused largely by the inflexible and inappropriate application of eurocentric conventional forestry ideals, concepts, principles and practices. As logging became more profitable than the extraction of non-wood forest products usually associated with traditional forestry, large-scale mechanization and the removal of maximum volumes were advocated on the grounds of full and efficient utilization, economy of scale, and maximum socio-economic benefits. Unlike temperate forests, however, intensive exploitation of tropical forests invariably brought about rapid resource depletion, excessive resource wastage, and, above all, adverse impacts on the forest resources, environment and biological diversity. The damage is often aggravated by the indiscriminate and systematic application of silviculture techniques, often without the necessary information on the residual stand or its ecological characteristics, to produce idealistic uniform and highly productive forests like those in Europe. Seemingly, there is a lack of realization that the highly complex forest ecosystems in the Asia-Pacific region, particularly those located in the tropical countries with intense population pressures, harsh climatic conditions, and fragile environments, are not amenable to such extreme treatments. Besides degrading the forests, conventional forestry has also been alleged to have contributed to inequitable distribution of the forest wealth and deprivation of indigenous people's rights to their forest resources.

Conserving Biological Diversity

The importance of forest biological diversity, especially the rich genetic resources in tropical moist/rain forests, has been gaining increased attention in recent years. Whatever the uncertainties of the economic value of tropical forests in terms of their included biodiversity, the certainty of irreversible loss of a significant quantity of existing genetic resources through current rates and patterns of deforestation and forest degradation is beyond question (Kemp1991). Consequently, action for the conservation of forest biological diversity has been initiated by various United Nations agencies, notably FAO, United Nations Environmental Program (UNEP), United Nations Education, Scientific, and Cultural Organization (UNESCO), and non-governmental organizations such as International Union for Conservation of Nature and Natural Resources (IUCN), and World Wildlife Fund (WWF). However, the action has tended to be conceptual, intellectual and conventional, although field activities have increased in recent years. Given the wide spectrum of scientific information that must be urgently gathered to guide the location and management of conservation programs, international research organizations such as International Union of Forestry Research Organizations (IUFRO) also have an important role, in concert with national research centers (Kemp 1991).

In the Asia-Pacific region, the people's awareness of forests' multiple functions and vital contributions to their welfare and quality of life prompted the countries to establish extensive reserves of protected areas for environmental protection and biological diversity conservation. According to IUCN (Anon. 1990c), the region has 2,303 protected areas covering about 139.2 million hectares of which 810 areas covering 66.2 million hectares are totally protected. Southeast Asia and Oceania account for about 74.5 million hectares or 53.5 percent of the protected areas. Protected tropical moist/rain forests cover about 28.1 million hectares in the Asia-Pacific region while approximately 23.3 million hectares have been proposed for protection. However, management of the protected areas ranges from nominal to non-existent, and knowledge of the extent, nature, and value of the forests' biological diversity is grossly inadequate. Given the complexity of the ecosystems and the lack of adequately trained taxonomists, ecologists, and other scientists in the countries concerned, the provision of technical cooperation as well as financial support is critically important (Kemp 1991).

Most of the countries in the Asia-Pacific region have less than 10 percent of their land under protection for biological diversity conservation. With ever increasing demands on the rapidly declining forests from geometrically growing populations, however, there seems to be very limited scope and extremely poor prospects for further expansion of the protected areas system in most of the countries in the Asia-Pacific region. Permanent production forests must be managed sustainably and conservationally to ensure that forest biological diversity interactions with resource utilization are minimized so that forest genetic resources can be protected objectively and effectively.

Conservational Forest Management

The principal measures required to achieve sustainable natural resources and biological diversity conservation in production forests must include pragmatic objectives and technically, socially, economically, ecologically, and environmentally sound forestry practices. Conservational forestry, based on integrated forest resources assessment, management with realistic forest resources and biological diversity conservation goals, and preventive or proactive rather than curative or reactive measures, offers the best practical prospects for both sustainable forest management and forest biological diversity conservation.

A conservational approach to sustainable forest resources and biological diversity conservation must be supported by the following policy directions:

(a) Manage and utilize the forest resources for maximum benefits based on the inherent capability of the forest and its optimal use
(b) Manage the utilization of the forest resources based on comprehensive forest land use and management plans
(c) Determine potential yield on the basis of systematic and in-depth appraisals of the forest resource base, its growth potential, and other relevant factors
(d) Harvest forest resources conservationally by selective felling and retention of adequate natural regeneration, consistent with economical harvesting, to ensure the sustainability of the forest resource base; and
(e) Apply optimal forest management regimes developed on the basis of information generated by systematic integrated forest management and operations research

The development strategy for conservational forest management should accord priority to the following:

(a) Conservational and sustainable use of natural forest resources and biological diversity
(b) Afforestation and reforestation of deforested and degraded lands
(c) Research to improve forest management and operations, optimal resource utilization, and conservation of forest biological diversity
(d) Education to create awareness of multiple values of forests and promote forest conservation

Conservational forestry, based on the proven concept of management by objectives, requires careful integrated pre-felling and post-felling assessments of the total forest resources and the application of technically, socially, economically, ecologically and environmentally sound forest management and development practices. The conceptual outline sequence of operations is as follows:

Year	Operations
F-2 to F-1	Pre-felling integrated forest inventory Determination of optimal forest management regime or option
F-1 to F	Tree marking for felling or retention, if necessary Climber cutting, if necessary
F	Directional felling of prescribed trees
F+1	Post-felling integrated residual forest inventory Determination of optimal silvicultural regime or option Silvicultural treatment, enrichment or plantation, as appropriate

The conservational approach to forest management recognizes social, political, economic, ecological, and environmental constraints and is based largely on technological, managerial, and operational considerations. It is expected to be practical and will have the following beneficial effects:

(a) conserve forest resources and biological diversity;
(b) ensure sustainable forest management and development;
(c) minimize investments required for reforestation;
(d) maintain environmental stability and quality; and
(e) reduce damage to the ecosystem and loss of biological diversity.

Conclusion

The sustainable management and development of forest resources in the Asia-Pacific region can be achieved by the implementation of conservational forestry based on a blending of Eastern wisdom and philosophy with Western expertise and technologies. The necessary expertise, particularly in policy and economic analysis, must be acquired and appropriate facilities established within the Asia-Pacific region as a matter of priority to enable the countries in the region to formulate realistic strategies and options for sustainable forest management and biological diversity conservation. There is also an urgent need to upgrade essential technological, managerial, and operational skills. This is not only to intensify integrated studies in forest management and operations to develop appropriate tools and needed management information, but more importantly, to apply appropriate technologies, expertise, and skills for sustainable management of forest resources and the conservation of the biological diversity. The most urgently required technologies and skills in the Asia-Pacific region seem to be efficient and cost-effective integrated forest inventory systems, change detection and monitoring systems; information management systems; operations management and decision support systems; and nonwood forest resources, especially biological diversity, assessment and valuation systems.

The formulation and implementation of realistic strategies and programs for sustainable forest management and development in general and for forest biological diversity conservation in particular can only be accomplished successfully after the evolution of a tropical forestry culture which is compatible with local social, cultural, political, economic, ecological and environmental conditions. The conservational and sustainable management and development of natural forests, especially tropical moist/rain forests, of the Asia-Pacific region require highly competent, innovative, and motivated forest managers and operators with the relevant expertise and skills; appropriate technologies and techniques; timely and reliable information; and adequate financial and human resources. Forestry specialists will need to acquire or upgrade their expertise and skills to conduct policy and economic analysis for optimizing sustainable management and biological diversity conservation; and to develop or adapt appropriate technologies and methodologies for environmentally-safe and ecologically-sound forest utilization and timber harvesting which ensure sustainable forest management and biological diversity conservation. In addition, they need to conduct cost effective integrated forest inventories to generate information for integrated forest management; to monitor changes in both natural and regenerating forests; to assess and evaluate non-wood forest and biological resources; and to conduct integrated studies in forest management and operations to evaluate the physical and economic impacts of alternative forest management, harvesting and silvicultural options on forest resources and biological diversity conservation.

The evolution of a tropical forestry culture, the formulation of realistic strategies and program for sustainable forest management and forest biological diversity conservation, and the effective implementation of conservational and sustainable forest management and development activities will require immense technical and financial resources to acquire or upgrade local capabilities. As most countries in the Asia-Pacific region are unlikely to be able to mobilize these resources nationally, they should be encouraged to collaborate and support the establishment of the following with external technical assistance:

(a) An Asia-Pacific Forestry Centre/Institute to conduct policy and economic studies necessary for the evolution of a tropical forestry culture; formulation and evaluation of strategic options for sustainable forest management and effective biological diversity conservation, and transfer of expertise and skills to national forestry personnel.

(b) Regional and National Centres of Excellence for Sustainable Forest Management and Development to develop or adapt, package, and transfer appropriate technologies, methodologies and techniques for integrated forest inventory, resource assessment, evaluation and monitoring; timber harvesting and reforestation; information management; and integrated studies in forest management and operations.

(c) Regional forestry programs to provide technical advice, guidance, and support necessary to upgrade national managerial, technical, technological and operational expertise and skills to ensure sustainable forest management and biological diversity conservation.

(d) An Asia-Pacific Forestry Information Centre to promote greater awareness and appreciation of the multiple values of forests and to provide technical advice, guidance, and support for upgrading national capacities and capabilities.

(e) A Global Forest Convention which encompasses biological diversity to ensure sustainable forest management and development and effective conservation of biological diversity as an integral component of the forest ecosystem.

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Evaluating Long-Term Cumulative Hydrologic Effects of Forest Management: A Conceptual Approach[1]

Robert R. Ziemer[2]

Abstract: It is impractical to address experimentally many aspects of cumulative hydrologic effects, since to do so would require studying large watersheds for a century or more. Monte Carlo simulations were conducted using three hypothetical 10,000-ha fifth-order forested watersheds. Most of the physical processes expressed by the model are transferable from temperate to tropical watersheds, but data to define the parameters are generally lacking.

Concerns that environmental quality is becoming increasingly degraded by the accumulation of multiple human activities have become worldwide. An example of such concerns is the degradation of air and water quality on a local as well as national scale. Perhaps the most far reaching of these concerns is the potential effect of human activities upon changes in the world's climate. Such concerns have become particularly thorny scientific, legal, and political issues.

Pollutant discharges at point sources can first be identified and then regulated directly. However, when point sources are many and widely dispersed, such as factory discharges into a river, even when the level of individual discharge is reduced, the total pollutant discharge from many sources can produce a "cumulative effect" that degrades water quality below acceptable levels.

To deal with non-point sources of pollution, such as stream sediment produced by erosion from agriculture or forest management operations, regulations are often developed that require land managers to reduce on-site erosion in order to keep the amount of sediment discharged from each project area within acceptable limits. The activities developed to meet these regulations are sometimes referred to as "Best Management Practices." As with the example of reduced factory discharges, Best Management Practices are designed to reduce pollutant discharge from a single project, but they may not solve the larger problem of the cumulative effect of multiple projects. Land managers and regulatory agencies are increasingly being required to address the cumulative effect of each proposed project within the context of all other projects within a specified area. At this time, however, managers and agencies have not yet clearly resolved what a cumulative effects analysis should contain, or even what constitutes a cumulative effect.

Cumulative Effects

The question of what a cumulative effect is has been argued at technical meetings and in the courts for many years. In 1971, the Council on Environmental Quality (CEQ) issued its guidelines for implementing the National Environmental Quality Act of 1969. The Council defined cumulative effects in a way that identified an approach to land management and impact mitigation that had not been employed in the past. This definition set the tone for subsequent legal decisions.

> 'Cumulative impact' is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.
>
> (Office of the Federal Register 1989)

Some key phrases in this definition continue to shape impact mitigation and stress the need for present and future research. First, in order for there to be a cumulative effect there must be an *impact on the environment*. Second, the action can be *individually minor but collectively significant*. Third, an evaluation of an action must account for *past, present, and reasonably foreseeable future actions*. And finally, the incremental effect of these minor actions can accumulate over *a period of time*.

Out of this important definition emerge two critical issues, the spatial scale and temporal scale of the analysis.

Spatial Scale

Traditionally, impact analyses have concentrated upon the on-site effects of land management proposals. On-site effects generally have a scale that ranges from several square meters to several hectares. More recently, regulators and land managers have become increasingly concerned about off-site effects. Historically, off-site effects have been considered to extend a relatively short distance from the immediate project—such as individual pools or individual stream reaches draining small upland watersheds, usually smaller than 100 ha. Managers are beginning to be required to evaluate the effect of a proposed project within the context of a drainage basin up to perhaps 20,000 ha. The size of the appropriate area of concern continues to expand. In some cases, land managers are now being asked to evaluate the effects of proposed projects within the context of entire drainage systems. An example is the emerging concerns related to the influence of forestry operations, hydroelectric dams, agriculture, and other human activities on salmon production in the Columbia River Basin. To provide an answer to a question of such an enormous scale requires understanding the influence of land management on survival of these anadromous salmonids from hatching in the River's headwaters in Idaho and British Columbia, migrating downstream through its estuary, to the ocean, and finally, after several years in the ocean, migrating up-

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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river to spawn. An analysis at this spatial scale is much more demanding and comprehensive than simply evaluating on-site effects.

Temporal Scale

Similarly, impact analyses traditionally consider only the short-term consequences of land management activities—usually several years at most. However, as with the issue of spatial scale, temporal effects have a wide range of appropriate scales that depend upon the question asked. For example, a domestic water user might be quite concerned about changes in turbidity during a single storm. Changes in insect production, that is in turn linked to fish growth, might be resolved at an annual scale. Changes that require a decade or more to become evident, are, for example, filling of pools with sediment or reduction in the supply of large woody debris, that, in turn, causes the stream bed to become unstable. Examples of changes requiring about a century are the failure of stream crossings designed to withstand a storm size that is expected to occur once in 50 years, the aggradation of alluvial downstream reaches, and increased frequency of streamside landslides. A specific example illustrates the long-term nature of some cumulative effects. Placer mining conducted in the Sierra Nevada of California in the 1840's placed a large quantity of coarse sediment in tributaries. Slugs of this material continue to enter the Sacramento River system, 150 years later.

Consequently, both environmental analyses and research programs must consider a larger area of concern and longer time period of concern related to land management. In addition, there must be an increased emphasis on dealing with complexity and interactions between issues. For example, it is important to integrate the physical and biological consequences of land management actions. It will no longer suffice to simply report the quantity of increased sediment output related to land management. The effect of that sediment on riparian ecosystems must be better understood.

A serious problem is that long-term cumulative effects cannot be measured. Increased measurement and monitoring at some point downstream from a proposed project is not an adequate strategy to evaluate long-term cumulative effects, because by the time a change is detected, the projects that caused the change have often been completed—in some instances, several decades or perhaps even a century before. In such a case, no amount of on-site project mitigation could be effective. Consequently, it is necessary to be able to predict what the consequences of the proposed project might be. That is, the cumulative effects of the proposed project must be modeled.

Cumulative Effects Model

To illustrate an approach, Ziemer and others (1991a,b) conducted Monte Carlo simulations of the long-term effect of three forest management strategies on erosion, sedimentation, and salmon egg survival within hypothetical 10,000-ha fifth-order forested watersheds *(fig. 1)*. One watershed was left undisturbed, one was completely clearcut and all roads constructed in 10 years, and another clearcut with roads constructed

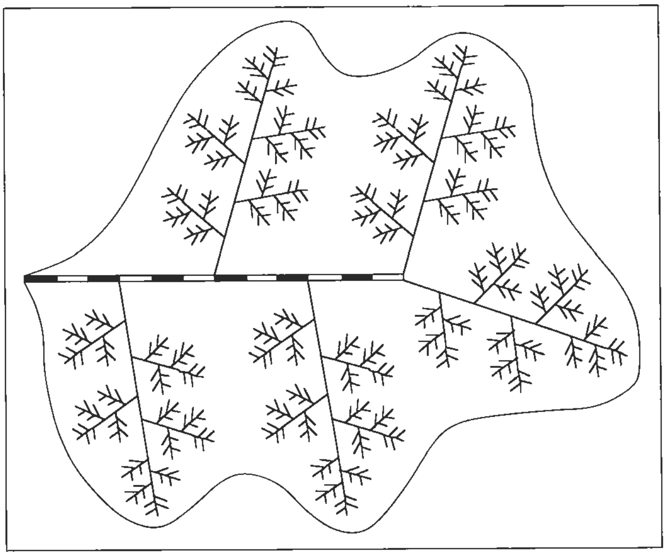

Figure 1—Modeled hypothetical 10,000-ha fifth-order watershed.

at a rate of 1 percent each year. These cutting patterns were repeated in succeeding centuries, rebuilding one-third of the road network every 100 years. Each fifth-order watershed was composed of five 200-ha fourth-order tributaries. The model predicted changes to twelve 1-km-long reaches of the fifth-order channel.

Rainfall is one of the primary causes of erosion in forested steeplands. Caine (1980) presented a relationship between rainfall intensity and duration that seemed to describe a "threshold" of worldwide occurrence of landslides. Rice and others (1982) reasoned that a good index of storm severity, and hence the probability of a landslide occurring, might be the distance in the intensity/duration space of a storm from Caine's landslide threshold function *(fig. 2)*. So, by knowing the amount and duration of rainfall expected for storms in particular watersheds, one could obtain the relative probability of landslides occurring during a specified time period.

One of the most important parameters contributing to differences in erosion rate between forested and harvested watersheds is the contribution of roots to soil strength. The roots of the trees provide pickets that tie the weak or unstable soil mass to the stronger stable bedrock underlying the soil. Also, roots provide tensile binders that strengthen the weak soil mass itself. When trees are cut, root biomass and consequently root strength decline quickly (Ziemer 1981). In studies conducted in coastal Oregon (Ziemer 1976, unpublished data), root biomass approached zero approximately 20 years after cutting *(fig. 3)*. Roots from the regenerating forest begin to grow soon after the area is cut, and root biomass recovers after some time to that found in the uncut forest. The net root strength of the watershed is related to the sum of the declining root biomass of the cut forest and increasing root biomass of the recovering forest. This U-shaped relationship reaches a minimum about 8 to 10 years after cutting. The inverse of this root biomass or root strength relationship can be expressed as the relative rate of landslide erosion from harvested areas *(fig. 4)*. This rate is influenced by storm severity.

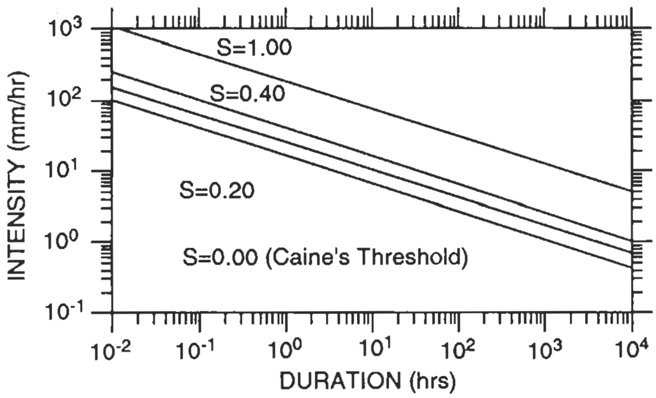

Figure 2—Storm severity (S) as a function of the duration and intensity of rainfall.

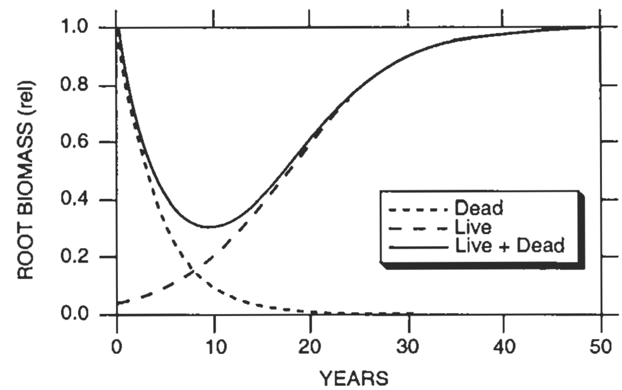

Figure 3—Change in live, dead, and total root biomass as a function of time following logging (from Ziemer, 1976, unpublished data).

The rate of erosion from roads decreases rapidly after construction (*fig. 5*), based on data reported by Lewis and Rice (1990). Once a road is constructed, the erosion rate remains higher than that on hillslopes without roads. As with erosion of harvested areas, the rate of road erosion at any time after construction increases with storms of progressively greater severity.

Once erosion occurs on the watershed, the sediment is routed in the model from the hillslope to and through progressively larger streams using a number of storage and routing equations. These equations were described in detail by Ziemer and others (1991a). Eventually, the sediment arrives at a modeled 1-km stream reach in the main stem where it is deposited or transported from the reach.

The model was run in an undisturbed watershed condition for 500 years to tune the algorithms for the tributary sediment delivery so that the parameters produced a watershed in an approximately steady state. Once a steady-state condition was attained, the logging strategies were applied. The effect of these logging strategies was calculated as the magnitude and frequency of changes in bed elevation in excess of those occurring in the undisturbed watershed (*fig. 6*). The values for each strategy are averages of all 12 reaches and 10 simulations during each 100-year period. The frequency of bed elevation changes, or events, declined with magnitude.

The importance of such changes in bed elevation depends upon the specific problem being addressed. For example, if one were concerned about survival of salmon eggs in redds, small changes in bed elevation might be of less concern than those greater than some magnitude, perhaps 0.10 m.

The amounts of erosion, of sediment transport, and of change in bed elevation are dependent on the timing and severity of storms (*fig. 7a*). During a single 300-year simulation, the largest storm occurred during year 280. This storm caused the bed to aggrade by about 0.3 m in the uncut watershed, but more than 1 m of bed aggradation occurred in the logged watershed (*fig. 7b*). Over the 300 years, the bed elevation in the uncut watershed fluctuated between 1.0 and 1.3 m. In the logged watersheds, the bed elevation increased from 1.0 to about 2.0 m during the first 100 years, and then established a new equilibrium bed elevation of about 2.2 m—about 1 m higher than that in the uncut watershed. In addition, the bed elevation in the logged watersheds became more responsive to severe storms than in the uncut watershed.

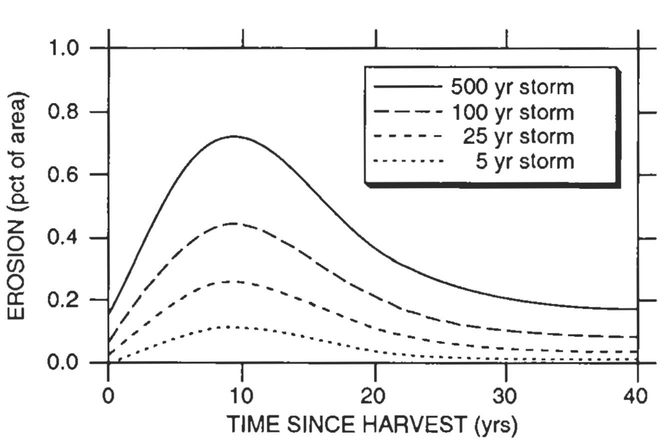

Figure 4—Relationship between erosion from harvested areas resulting from changes in soil reinforcement by roots following logging and time since harvest as affected by storm frequency (from Ziemer and others 1991a).

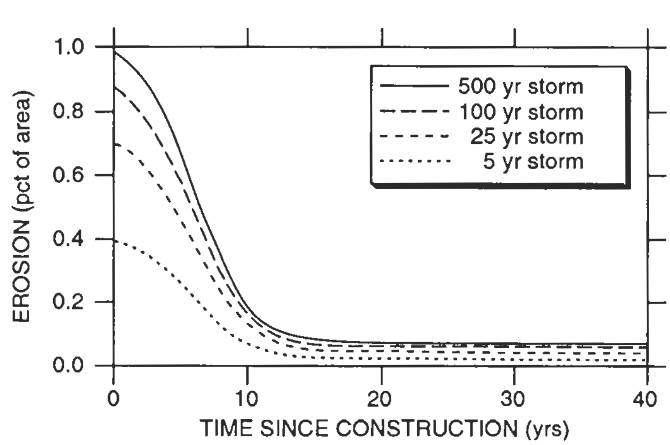

Figure 5—Relationship between erosion from roads and time since construction as affected by storm frequency (from Ziemer and others 1991a).

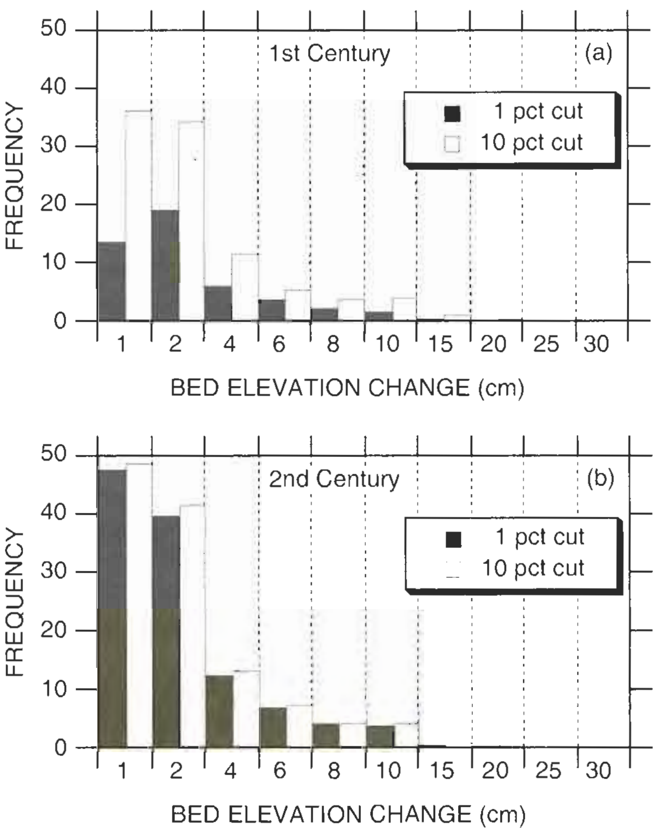

Figure 6—The distribution of the number of within-storm changes in bed elevation, in excess of that occurring in the uncut watershed, during (a) the first 100-year period and (b) the second 100-year period (Ziemer and others 1991a).

A cumulative effects analysis might require translating physical changes in the stream bed into biological consequences—for example, the loss of salmon eggs deposited in redds (Ziemer and others 1991b). During the first century, the 10 percent logging strategy produced a much greater egg loss for the first 50 years than did the 1 percent strategy *(fig. 8).* But during the last half of the first century, there was little difference between the 10 percent and 1 percent strategies. The 10 percent strategy required the watershed to be completely logged in the first 10 years of each century. The egg loss peaked about year 15, then declined as the watershed recovered from the logging. By year 50, only half of the watershed had been logged following the 1 percent strategy, while the watershed following the 10 percent strategy had been recovering from logging for 40 years. During the last 25 years of the first century, there was less egg loss using the 10 percent strategy than the 1 percent strategy *(fig. 9).* Both watersheds entered the second century having been completely logged and roaded. There was substantially less difference between the two strategies during the second century. During the first half of the second century, the 10 percent strategy produced more egg loss, whereas during the second half, the 1 percent strategy produced more egg loss.

Conclusion

Although logging began in the coniferous forests of northwestern North America in the mid-1800's, intensive logging in much of the Pacific Northwest did not begin until the 1950's. Consequently, the present condition of most watersheds in northwestern North America represents only that of the first century of the simulations. The simulations suggest that at least one century is required for the treated watersheds to attain a "steady-state" condition. With such long response times, it is difficult to collect contemporary field data to evaluate predictions by the model. However, without a long-term steady-state perspective, comparisons of the environmental costs among alternative land management strategies will be incorrect.

Another problem making any long-term evaluation nearly impossible is that water discharge is measured only in the larger and more important rivers. Very few small upland streams are gauged. The length of record for rivers and streams in the western United States is usually less than 100 years, and records less than 30 years long are most common. And, for those rivers having the good fortune to be gauged, the condition of none of the watersheds could be considered to be static over time—even those in National Parks where development is restricted. Even pristine forests change in density and compo-

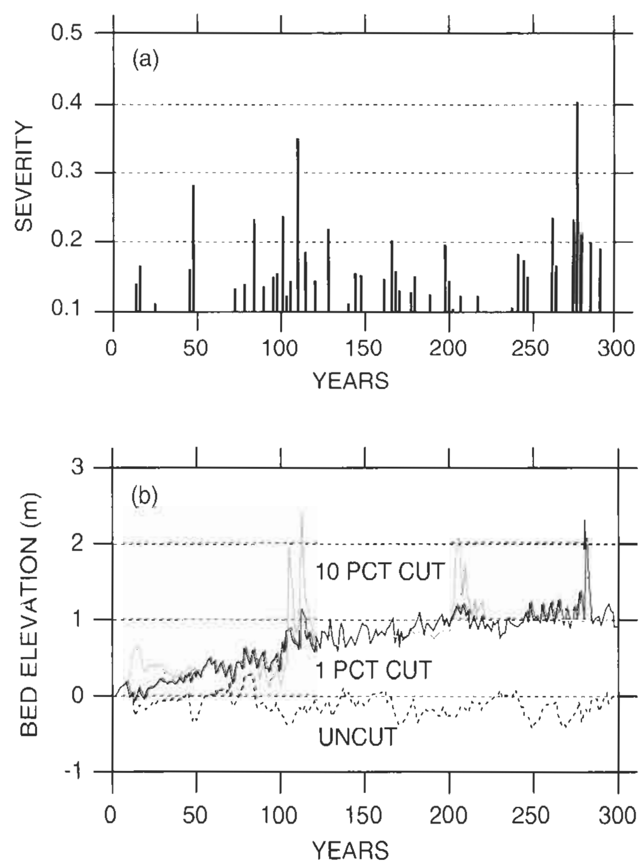

Figure 7—Distribution and magnitude of (a) severe storms and (b) bed elevation in the uncut, 1 percent cut, and 10 percent cut watersheds during a single 300-year simulation.

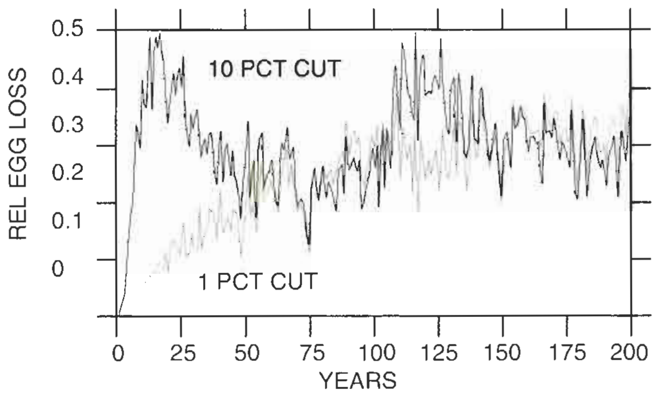

Figure 8—Comparison of relative salmon egg loss between logging strategies. Relative egg loss for a logging strategy is the difference in egg survival in the uncut watershed minus that in the treated watershed divided by the survival in the uncut watershed (Ziemer and others 1991b).

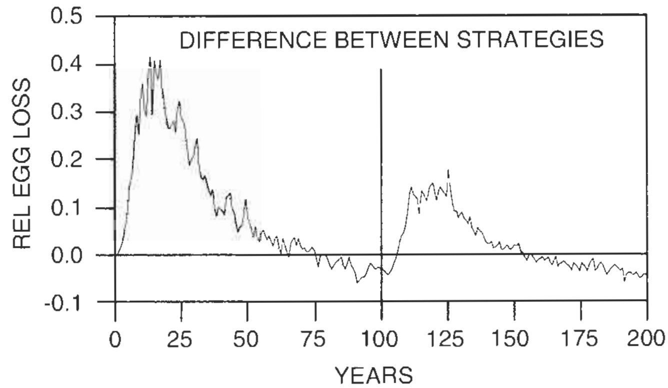

Figure 9—The difference in relative salmon egg loss between the 10 percent and 1 percent logging strategies (Ziemer and others 1991b).

sition as natural ecological processes, including insects, disease, wildfire, and old age, work their influence over time.

In the tropics, these problems are compounded many fold. It is difficult to find good streamflow records of virtually any length, and the number of gauged streams is decreasing in many areas. For example, in the portion of the Caroline Islands that now comprise the Federated States of Micronesia, streamflow was monitored on at least a daily basis at 34 stations in 1970. This number had been reduced to 16 stations by 1989. And, by 1991, nearly all of these stations had been discontinued.

Consequently, the basic data necessary to measure any long-term change in streamflow or sediment transport are missing—whether the suggested change is the result of a cumulative effect of land management or a shift in the world's climate.

Monte Carlo methods can be used effectively to identify critical gaps in knowledge that require additional research and data collection. For example, as a first approximation, data on rainfall threshold (Caine 1980) and storm severity (Rice and others 1982) can provide useful information when linked to other processes contributing to landslide occurrence, such as changes in root strength (Ziemer 1981). However, the nature of the interaction between rainfall, vegetation, and landslides needs to be tested under the local conditions for which the evaluation is intended.

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Fire Management in Central America[1]

Andrea L. Koonce Armando González-Cabán[2]

Abstract: Information on fire management operations in Central America is scant. To evaluate the known level of fire occurrence in seven countries in that area, fire management officers were asked to provide information on their fire control organizations and on any available fire statistics. The seven countries surveyed were Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama. Information from a survey of the literature was also collected. For each of the seven countries, results of these surveys of fire management and a description of the physical geography are reported.

Statistics on fire management operations for Central America are generally unavailable. The statistics which are available include only those fires which are prescribed by managers, and those reported wildfires which may or may not be suppressed. In order to evaluate the known level of fire occurrence, a survey was sent to fire management officers in each Central American country. Information on their fire control organizations and the available fire statistics were requested. The results of the survey are presented, augmented by information from the literature. A brief description of the physical geography is included to allow for comparison of the climate and terrain among the countries.

Guatemala

Physical Geography

Guatemala's climate varies with altitude and with the influence of coastal air masses. Coastal lowlands have high temperatures, averaging 25 °C (77 °F) on the Pacific coast and 27 °C (81 °F) on the Caribbean side. Relative humidity is also typically high, averaging 80 percent. Highland climates range from warm to cool, including an occasional frost between the elevations of 1500 to 1800 m during the November-April dry season. A rainy season prevails over most of the country from April to October, the highest rainfall occurring in August or September. Rainfall varies from less than 500 mm (20 inches) annually in the Oriente to nearly 5000 mm (200 inches) on the western slopes of Sierra Madre and in the Rio Dulce Basin. Topography is diverse; hills, plateaus, and steep mountain slopes, especially common in the central and western highlands, are dissected by a network of water-courses.

Fire Management

Guatemala's fire season extends through the dry summer months from February to May. From 1983 to 1988 the annual number of fires in forested habitats has increased from 137 to 224, some reaching high intensity. This increase may reflect improved accuracy of reporting or may signal an increase in the number of fires which are escaping into the forest. Untended agriculture and pasture fires are the principal causes of these fires resulting in forest degradation and increased susceptibility to insects and diseases.

Guatemala's fire protection program was started in 1988 under the direction of the forest protection section of the Department of Forest Management. Their 1989 budget was approximately 70,080 quetzales ($14,300). Five staff members are responsible for protecting 65,961.8 km^2 of *Pinus* and *Cupressus* species, as well as other mixed conifer and broadleaved species. There are some organized fire brigades and vehicles available to suppress fires, but funding is insufficient to adequately equip people in rural areas for forest protection.

Current fire program objectives are to organize, educate, and train local communities in fire suppression techniques. Major obstacles to these objectives are: 1. Guatemala's illiteracy problem. The high incidence of illiteracy among the population makes the use of written promotional materials ineffective. 2. The constant low budgets result in under-staffing and lack of adequate coverage in critical rural areas.

The fire program has attempted some prescribed burning to reduce hazards and clear land for pasture and agricultural use. Very little is known about fire effects in the tropical forests of Guatemala.

Belize

Physical Geography

Belize lies on the Caribbean coast of Central America, with Mexico to the northwest and Guatemala to the southwest. It has a subtropical climate tempered by trade winds. The average mean temperature varies little year-round, 24 °C to 27 °C (75 °F - 81 °F). Annual rainfall ranges from 1290 mm (51 inches) in the north to 4450 mm (175 inches) in the south. The rainy season lasts from May to February. The country encompasses varied landscapes ranging from the fertile northern limestone plateau to the southern Maya Mountains.

Fire Management

Forest fire protection was introduced in Central America in 1927 in the coastal plains of Belize and was extended to the Mountain Pine Ridge Forest Reserve by 1945 (Hudson and Salazar 1981). Belize was the first country in the region to establish a forest fire protection program because of the importance of its forest products exports to England.

Economic development of Belize initially depended on exporting logs *(Haematoxilium* spp.*)*. Exportation of forest products was the main source of economic development in Belize

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until the late 1940's (90 percent of total exports in 1945; 78 percent by 1946, and only 21 percent by 1961). The change was precipitated by the introduction of synthetic dyes enabling Honduran Mahogany *(Swietenia macrophilia)* to be substituted for logs from Belize. By 1977 forest exports were reduced to a trickle (only 2 percent of total exports).

Once the forestry sector no longer drove the economic development of the country, the forest fire protection program dwindled. The decrease in fire suppression efforts led to a dramatic increase in area burned. In the Mountain Pine Ridge Forest Reserve and adjacent private lands alone, 2,018, 12,119, 4,155, and 8,359 ha of pine forest were burned during 1964, 1968, 1972, and 1976, respectively (Hudson 1976).

Honduras

Physical Geography

Honduras is located well within the tropics, but temperatures are generally moderate rather than hot. A tropical climate prevails on the north coast below 600 m and near the Pacific coast below 450 m. Mean annual temperatures are approximately 25 °C (77 °F). A temperate climate, with mean annual temperatures changing from 16 to 24 °C (61 °F -75 °F), characterizes the highland areas (600-2100 m) and intermontane basins, which make up more than 80 percent of the land area (Evaluation Technologies 1981).

Rainfall averages 1500-2500 mm (60-100 inches) annually, most of it falling from mid April through October. The winter dry season lasts from November to April. Rainfall is higher on the north coast and northern mountain slopes than on the south coast and southern-facing slopes.

Fire Management

The most serious fires in Honduras occur between the months of February and June. The average annual number of fires fought over the past five years (1985 to 1990) is 2,500, but as many as 500 to 1,000 go unreported and without suppression (Salazar 1991). Over the same 5 years an average of 45,000 ha (111,150 acres) burned annually, of which more than 75,000 ha burned in 1990 alone. This area takes into account only the area burned by those fires actually reported and fought. Agricultural burning accounts for more than 50 percent of the total forest fires (Hudson and Salazar 1981). During the dry season fires and combustion columns can be seen everywhere in the fields and along the roadsides. The smoke problem is so severe during the fire season that the international airport in Tegucigalpa is closed, sometimes for up to two weeks at a time. When fire burns in young, unweeded plantations, damage to the trees can be severe because of crowning and widespread mortality.

A fire control program was started in Honduras in 1974 under the direction of COHDEFOR, the national forestry organization. Between 1980 and 1990 the budget doubled in nominal terms from 2 to 4 million lempiras ($1,011,561 to $755,000[3]), but the number of employees in COHDEFOR declined from 960 to about 600. Honduras has 45 funded fire brigades, a small cache of hand tools, and 45 vehicles which can be used to suppress fires (Salazar 1991). The area of fire control responsibility covers 22,260 km² of mostly young pine plantations.

A prescribed fire program was initiated in 1979 to reduce fire hazard and improve silvicultural management. Research was also initiated on fire effects, but little has been published to date. Most prescribed fires are conducted in August and between December and January, early in the dry season when conditions are more moderate. The prescribed fire program has had difficulties ranging from the lack of budget to poor cooperation between institutions and civilian personnel. Although appropriate legislation exists to support the fire program, it is not adequately implemented. The public has little interest in forest protection. For example, experiments and wood lots set aside for forest preservation and improvement are typically subject to trespass for firewood, construction materials, and game.

El Salvador

Physical Geography

El Salvador has a tropical climate throughout the entire country, although temperatures tend to be cooler in the highlands. Temperatures rarely fall below 18 °C (64 °F) except on the highest slopes of the volcanic ranges. Rainfall averages 1500-2500 mm (60-100 inches) annually, most of it falling from May through October. As in Honduras, the winter dry season lasts from November to April, with virtually no rain.

Most of the country consists of volcanic highlands of moderate elevations. Two parallel chains of volcanoes extend east-west through the country—the southern or Coastal Range and the northern or Sierra Madre Range.

Fire Management

During the 2 years that data were collected for this study, we were not able to obtain any information about the fire management program in this country. Due to the ongoing civil war it is likely that active natural resource management programs of any kind have been abandoned in favor of preservation of critical resources such as dams and roads.

Nicaragua

Physical Geography

Nicaragua's tropical climate changes to mild or cool weather in a few high altitude locations in the Central Highlands. Mean annual temperatures range from 20 °C (68 °F) in the highlands to 27 °C (81 °F) on the Pacific coast. Rainfall varies from 1500 to 6250 mm (60-250 inches) annually. Most falls from May through October in the Pacific and central highlands and year-round in the Caribbean plains of the Atlantic coast.

[3]The smaller budget level in dollar terms for 1990 is due to the devaluation of Honduran currency. Up to 1989 the exchange rate was two lempiras to a dollar; in 1990 the rate went up to 5.3 lempiras to a dollar. In addition, the country's economy is suffering from serious inflation cutting even deeper into the fire program budget.

Fire Management

The management of natural resources in Nicaragua is organized under the direction of IRENA, the Nicaraguan Institute of Natural Resources. There is no fire control organization independent of the forest and agriculture sections of IRENA, but fire control and management of slash and burn agriculture are being promoted in conjunction with other community development and education programs.

Northeastern Nicaragua is characterized by boggy lowlands and pine savannas along the Caribbean Sea. It is adjacent to a mountainous region that stretches north to the border with Honduras. The savannas are dominated by Caribbean pine *(Pinus caribaea)* in various configurations of native stands and plantations (Munro 1966). Eighty percent of these stands are burned every year from escaped fires lit by local villagers to clear their fields for planting food crops.

The understory has a grass component which forms a basal root mass which resembles a miniature elephant trunk and serves readily as a source of firebrands. It burns like gasoline under any weather condition, even when standing in 2 inches of water. This vegetation type suggests that Caribbean pine is a seral stage that, if not caused by fire, can be maintained by fire. The pines are highly resistant to fire and, unless completely consumed, will recover after being scorched. However, their form and vigor suffer from frequent burning.

Nicaragua's fire program, like that of other Central American countries, is understaffed and underequipped. Most of the current fire control programs are aimed at reducing the loss of established plantations and demonstration areas. Natural resource officials must rely on local citizens to patrol and suppress fires. Incentives such as supplying farmers with tools and training in appropriate agroforestry techniques, including forest protection, are being used.

Costa Rica

Physical Geography

Geographically, Costa Rica can be divided into three distinct regions: the central mountainous corridor running from northwest to southeast, the Pacific coast, and the Caribbean lowlands (Caufield Vasconez 1987). Costa Rica's regional climates vary depending on elevation and prevailing winds. Mean annual temperatures can be affected by the duration of the rainy season which varies among regions. Average temperature in the central Meseta region ranges from 15 °C (59 °F) to a maximum of 25 °C (77 °F). The rainy season varies from year-round in the Caribbean lowlands to six months, May to October, in regions of Guanacaste Province on the Pacific coast. The national average rainfall is 3,300 mm (132 inches) annually. The dry season lasts from November to April.

Fire Management

Costa Rica's fire control program was founded in 1987. It is directed by the Minister of Natural Resources, Mines and Energy. Like most fire programs in this region the fire control organization lacks financial and human resources: there is no allocated budget and only two full-time technicians. Secondary forest and plantations are the main vegetation types being actively protected. Fires in this type include surface and some crown fires which occur during the December-to-April dry period. Most fires are caused by humans, both accidentally or deliberately. Specific studies documenting the nature of the damage to these plantations are inadequately prepared or do not exist. Public information projects are being initiated to reduce ignitions by humans.

A prescribed fire program was started at the same time as the fire control organization. In 1987 and 1988, 840 and 830 ha were burned by prescription for the purposes of reducing hazard, agricultural clearing, silvicultural improvement, and forest pest reduction. Generally, burning is conducted in August and in December and January (the beginning of the dry season). The program is limited by the lack of trained personnel and equipment, and limited budgets.

Conservation Programs

More is known about the social and ecological aspects of fire in Costa Rica than in any other Central American country. The excellent research and extension work done by the CATIE staff (Center for Agricultural Research and Education) provides a source of information and academic leadership for the rest of Central America. Other environmental management and research organizations contribute to their effort, notably Dan Janzen, founder and director of the Guanacaste National Park, located near the Pacific coast in northeastern Costa Rica.

There are five parks (Parques Nacionales de Santa Rosa, Murciélago, Palo Verde, Barra Honda, and Guanacaste), two refuges (Refugios Nacionales de Fauna Silvestre Dr. Rafael Lucas Rodríguez Caballero, and de Fauna Silvestre de Ostional), and two reserves (Reserva Nacional Absoluta Cabo Blanco, and Lomas Barbudal Reserva Biológica) in Costa Rica set aside to preserve tropical dry forest habitat. Only the Santa Rosa and Guanacaste have been studied to any appreciable extent by biologists. Because of the publicity and outreach efforts of Dr. Janzen, the Guanacaste has received considerable attention in the popular and scientific press (Edgar 1989, Janzen 1986, Janzen 1988a, 1988b) and can be used as an excellent example of the type of conservation work being done to combat the unchecked effects of farming, grazing, harvest, and the persistent fires which accompany them.

The objectives of park land acquisition, protection, and management are to preserve dry forest habitat fragments and to restore the degraded pasture and agricultural lands to their indigenous fauna and flora. This forest type once occupied most of the Pacific side of the Central American landscape. Because of its accessibility and desirability for settlement, it now constitutes less than 2 percent of its original 550,000 km^2 area, and 0.08 percent in protected areas (Janzen 1988a).

Park management plans to develop and extend fire control and prescribed burning programs to protect the sensitive edges of the dry forest vegetation to prevent fires from spreading in burnable vegetation within the park boundaries. Much of the area has been planted with "jaragua" grass *(Hyparrhenia ruffa)* imported from Africa because of its tolerance for overgrazing by cattle. This grass is highly flammable and reaches heights of 2 meters when left ungrazed. It burns explosively in the dry season during the high winds characteristic of this region. Until the grass can be effectively shaded out by recovering vegetation, some grazing will be permitted to limit the height growth of the grass. Remaining patches of forest habitat will be used to provide seed for natural dispersal by wind and animals. When financially feasible, intensive reforestation projects will augment the natural process of recovery.

Physical parkland development will be augmented by an education and apprenticeship program designed to teach local residents, especially children, the value of natural habitat preservation and the techniques needed for its preservation. Ongoing research will contribute to the knowledge of the dry forest ecosystem and will continue to improve its management.

When fully developed, the Guanacaste park will serve as a gene and seed bank for dry forest flora and fauna, will provide a demonstration area for use and management of dry forest species and habitats, will help protect the regional watershed, and will enhance tourism.

Panama

Physical Geography

Panama has a tropical maritime climate (warm, humid and cool nights) year-round. There is little seasonal variation in temperatures, which average 23 °C to 27 °C (73 °F - 81 °F) in coastal areas. Most of Panama is coastal plains, with its larger rivers flowing into the Pacific. The backbone of the country is formed by two mountain ranges, the Cordillera Central from the Costa Rican border almost to Panama City and the lower Cordillera de San Blás from east of Colón to the Colombian border. The northern slopes of the two mountain ranges receive most of the rainfall, 3250 mm (128 inches) a year compared to 1720 mm (68 inches) a year on the southern slopes.

Fire Management

Panama's fire problem is no different from that of any of the other countries in Central America. By and large, most forest fires are caused by humans both accidentally and deliberately. Grasslands and forest habitats are regularly burned during the transition to agriculture and pastoral land uses. These fires go unchecked because of lack of funding for personnel and equipment. They are generally surface fires of moderate intensity, occasionally crowning during the driest periods between January and April. Fires cause mortality in the tree species they encounter and delay the growth of those plants which are able to regenerate. A general shift in species to those which are able to colonize the burned sites has been observed.

Panama currently has no fire control organization although discussions to initiate one are being held by the National Institute of Renewable Resources. Only five fire brigades and two vehicles, as well as a small assortment of hand tools, are available for fire suppression. There is no budget for protecting even small areas of Caribbean pine plantations frequently threatened by fire.

Although there is no organized prescribed burning program, two prescribed fires in 1980 and 1981 treated 50 ha (124 acres) and 60 ha (148 acres), respectively, to reduce fire hazard and improve silvicultural operations in plantations. One fire escaped and burned an additional 20 ha (49 acres). Nevertheless, the fires were successful in controlling unwanted understory vegetation in 70 percent of the areas treated and in obtaining 80 percent regeneration success. The principal objective of future burns is to treat 20-year-old plantations that contain hazardous levels of accumulated fuel.

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Soil Taxonomy and Land Evaluation for Forest Establishment[1]

Haruyoshi Ikawa[2]

Abstract: Soil Taxonomy, the United States system of soil classification, can be used for land evaluation for selected purposes. One use is forest establishment in the tropics, and the soil family category is especially functional for this purpose. The soil family is a bionomial name with descriptions usually of soil texture, mineralogy, and soil temperature classes. If the growth requirements of the tree species are known, they can be matched with the soil and land characteristics that are inherent in the taxonomic name.

In rating soils for specific uses or in land evaluation, land use requirements must be matched with the land characteristics. Examples of land use requirements are environmental conditions, soil moisture and nutrient status, soil depth, various management practices, and even socio-economic considerations. Land characteristics, on the other hand, include not only the various soil properties but also the slope of the land, the amount of rainfall, the amount and kinds of vegetation, and other factors which are normally a part of soil formation.

Because land characteristics actually show interactions, the Food and Agriculture Organization of the United Nations (FAO) (1976) has proposed the use of the term "land quality" in land evaluation. The concepts and principles of land evaluation as well as the various definitions associated with land evaluation are presented in the FAO publication "A Framework for Land Evaluation" (1976). Land quality is an interaction of different land characteristics. For example, the land quality of erosion resistance would include the interaction of characteristics such as slope angle and length, permeability, and soil structure, and rainfall intensity.

This paper describes the taxonomy and system for classifying soils and their requirements for forest establishment.

Soil Classification and Soil Taxonomy

There are many kinds of soils. Some are fertile while others are infertile; some are highly suited for a specified use while others are better suited for other uses. These soils are different because of some differences in properties and behavior. At the same time, similar soils have similar properties and behavior. With so many kinds of soils, it becomes a tremendous task to determine which of these soils behave similarly for a given use.

A classification scheme, however, can be used to group similar objects. Soil classification, furthermore, can be used not only to group similar soils but also to organize knowledge, so that the properties and behavior of these soils and their relationships to other properties and behavior can be easily remembered or understood for some specific purpose.

There are many systems of soil classification worldwide. Some are based on similar colors, while others are associated with similar parent materials, climate, or mode of formation. Still others, such as Soil Taxonomy, the United States system of classification, are based on properties (Soil Survey Staff 1975). Although developed by the U.S. Department of Agriculture Soil Survey Staff, Soil Taxonomy is a contribution of soil scientists from many different countries and agencies. Soil Taxonomy, therefore, is used almost worldwide, commonly together with the national classification system of a country.

Like the plant classification system, Soil Taxonomy is made up of several categories (Soil Survey Staff 1975). There are six categories in Soil Taxonomy: Order, suborder, great group, subgroup, family, and series. The soil order, the highest category, is based mainly on properties which are the result of soil-forming processes and is associated with general description of the soil. The lower categories, on the other hand, carry information not only of the higher categories but also of others which are more specific. For example, the soil family taxa is a bionomial name with descriptions usually of soil texture, mineralogy, and soil temperature classes with additional information on soil moisture status. If the land use requirements are known, they can be matched with the group of land characteristics or the land quality that is inherently contained in the taxonomic name.

Land characteristics can be determined without regard for soil classification, but such a practice would be site-specific without concern for information or technology transfer between similar soils.

Soil Taxonomy and Land Evaluation for Forest Establishment

Soil characterization and soil classification using Soil Taxonomy serve as efficient tools in land evaluation. The taxonomic names denote the various properties and behavior or land characteristics that are needed in the matching process with the land use requirements. Again, the soil family category with its capability of information transfer between similar soils is best suited for this matching process.

Forests require radiation, suitable temperatures, moisture, aeration, nutrients, suitable rooting conditions, and an absence of conditions that negatively affect tree growth or survival. For example, if *Acacia koa*, an endemic species in Hawaii, is selected for forest establishment, two growth requirements can be emphasized: the need for the plant nutrient phosphorus and moisture. These requirements are emphasized because of a preliminary nutrient study and the common habitat of the koa.

If the Wahiawa soil, an Oxisol, is considered as a site for koa forest establishment, the following land qualities may be used in the matching process: phosphorus availability and moisture availability. The interacting land (soil) characteristics associated with phosphorus availability are soil pH and mineralogy,

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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while those of moisture availability are soil moisture regime, mean annual rainfall and distribution, evapotranspiration, and vegetation indicators. An additional land quality could be seedling transplanting conditions, with the land (soil) characteristics of mineralogy, structure, and soil depth.

The Wahiawa soil is classified as Rhodic Eutrustox, clayey, kaolinitic, isohyperthermic family (Soil Survey Staff 1990). In relation to phosphorus availability, the taxonomic name suggests that the clayey texture and kaolinitic mineralogy, together with the iron content expressed in Rhodic Eutrustox, indicate that there will be at least moderate phosphorus fixation. Such behaviors are established relationships.

For moisture availability, the ustic soil moisture regime expressed in Eutrustox may be a limiting factor, especially during plant establishment and during the summer months when evapotranspiration is high and rainfall may be low.

For seedling transplanting conditions, the clayey texture and kaolinitic (and oxidic) mineralogy can also be related with the hard consistence (when dry) which would make seedling transplant time-consuming. For example, transplanting 1,000 koa seedlings may require as much as 54 person-hours in this soil, in contrast to only about 18 person-hours in a loamy soil. In the aggregated kaolinitic and oxidic (Rhodic) clayey soils, the cloddy structure also reduces plant survival after transplanting because of low moisture retention.

On the basis of matching of the koa establishment requirements with the land qualities mentioned above, the Wahiawa soil would be at best only moderately suited for koa forest establishment without further management input. Suitability is expected to improve with management inputs such as phosphorus fertilizer application and land preparation for transplanting the seedlings.

Land evaluation for a specified use can be accomplished by matching the land use requirements with the land characteristics. For koa tree establishment in a soil such as the Wahiawa soil, an Oxisol, tree growth requirements for phosphorus nutrient and soil moisture are matched with land qualities of phosphorus availability, moisture availability, and seedling transplant conditions that are influenced by characteristics such as soil pH, texture, mineralogy, soil moisture status, and so on. According to Soil Taxonomy, the Wahiawa soil is classified as Rhodic Eutrustox, clayey, kaolinitic, isohyperthermic family, and this soil is at best only moderately suited for koa establishment without additional management input. With management input such as fertilizer application and adequate land preparation, suitability is expected to improve. The use of Soil Taxonomy and its taxonomic names in land evaluation assures information transfer when dealing with similar soils.

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Cuticular Hydrocarbons for Species Determination of Tropical Termites[1]

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Abstract: Cuticular hydrocarbons can be used to discriminate species in *Coptotermes* and *Nasutitermes*, here discussed for selected species from locations in the Pacific Rim and several Caribbean islands. We recently reexamined the cuticular hydrocarbons of *Coptotermes formosanus* and identified several dimethylalkanes that may be unique to this species. Cuticular hydrocarbons of *C. curvignathus* are similar to those of *C. formosanus*; the primary difference is the absence of 9,13-DimeC_{27} and 13,15-DimeC_{29} in *C. curvignathus*. Hydrocarbons of *C. acinaciformis* include abundant quantities of $C_{27:1}$, which does not occur in any other species of *Coptotermes* examined thus far. *C. lacteus* makes two unusual dimethylalkanes: 15,17-DimeC_{37} and 15,17-DimeC_{39}. *C. testaceus* is notably different from the other *Coptotermes* species described here. Nearly all of the hydrocarbon components are monomethylalkanes. No *n*-alkanes or alkenes were identified. The predominant hydrocarbons in *Nasutitermes costalis* are mono- and dimethylalkanes: 13,17-DimeC_{31} accounts for nearly half of the total hydrocarbon. The most abundant hydrocarbons in *N. ephratae* are also mono-, di- and trimethylalkanes. Two dimethylalkanes (15,17-DimeC_{37} and 15,17-DimeC_{39}) separate *N. ephratae* from *N. costalis*. The hydrocarbon mixtures of *N. gaigei* and *N. guayanae* contain only late-eluting alkenes ($C_{37:1}$ through $C_{47:1}$). The major difference between these two species is the degree of unsaturation. The hydrocarbon profile of *N. acajutlae* appears to be bimodal: early-eluting hydrocarbons consist of *n*-alkanes, alkenes, and monomethylalkanes, while late-eluting compounds consist entirely of alkenes. *N. intermedius* predominantly makes long-chain alkenes with one or two double bonds ($C_{37:2}$ through $C_{41:1}$), including a homologous series of alkenes with an even number of carbons in the chain ($C_{36:2}$ through $C_{40:1}$).

The outer layer of the cuticle of all terrestrial insects consists of a thin layer of wax (Hadley 1985). This wax plays a key role in survival of the insect by providing protection from desiccation (Hadley 1980; Lockey 1988), as well as serving as a barrier to abrasion, microorganisms, and chemicals (Blomquist and Dillwith 1985). Hydrocarbons are ubiquitous components in insect cuticular lipids and can comprise up to 90 percent of the material (Blomquist and Dillwith 1985; Hadley 1985; Lockey 1988). They have been shown to be important semiochemicals, and have been postulated as species and caste recognition cues in termites (Howard and Blomquist 1982).

Alkanes occur in all insect surface lipids reported thus far in the literature (Blomquist and others 1987). *n*-Alkanes generally range from 21 to 31 carbon atoms; molecules with an odd number of carbons predominate. Terminally branched and internally branched monomethylalkanes are also prevalent in insect surface lipids and range from simple compositions, in which only one compound is present, to complex mixtures. In most monomethylalkanes, the methyl branch is located on an odd-numbered carbon atom between carbons 3 and 17. As careful analyses of mono-, di- and trimethylalkanes are made on more organisms, it appears that the methyl groups can be positioned almost anywhere on the chain.

n-Alkenes, with one, two, three, or four double bonds, have been characterized in about one-half of the insect species examined to date (Lockey 1988). The chain length of cuticular n-alkenes ranges from 23 to 47 carbon atoms, with odd-numbered chain lengths predominating. The position of the double bond can be almost anywhere in the chain, but is common at carbon 9 (Blomquist and Dillwith 1985).

Moore (1969) was the first to report the composition of cuticular hydrocarbons in a termite, *Nasutitermes exitiosus* (Hill). He found the majority of the hydrocarbons to be unsaturated with the degree of unsaturation ranging from four to eight double bonds; the major component was nonatriacontatetraene ($C_{39:4}$). Also present were paraffins from C_{24} to C_{47}; compounds with an odd number of carbons in the parent chain predominated. Blomquist and others (1979) and Howard and others (1978, 1980, 1982a,b) were next to completely characterize the cuticular hydrocarbons of three termite species. They found that *Reticulitermes flavipes* (Kollar), *R. virginicus* (Banks), and *Zootermopsis nevadensis* (Hagen) possess drastically different hydrocarbon profiles, and all three of these profiles differ markedly from those reported earlier for *N. exitiosus*. On the basis of these early results, Howard and Blomquist (1982) hypothesized that each insect species had a mixture of cuticular hydrocarbons that was peculiar to that species and potentially useful as taxonomic characters.

Insects synthesize most if not all of their complement of cuticular hydrocarbons *de novo* (Blomquist and Dillwith 1985). Insect species generally have from 10 to 40 major components in their hydrocarbon mixtures. The relatively large number of possible hydrocarbon components found in the cuticle of insects, ease of chemical analysis and identification of hydrocarbons, and apparent species-specific compositions for many insects make hydrocarbons attractive characters for use in chemotaxonomy.

We have been examining cuticular hydrocarbons as taxonomic characters with termites as well as other groups of economically important forest insects (Haverty and others 1988, 1989, 1990a,b, 1991; Page and others 1990a,b). We have found that characterization of cuticular hydrocarbons often leads to subsequent morphological, biological, or chemical studies which clarify taxonomic questions (Haverty and Thorne 1989; Thorne and Haverty 1989). However, by comparing our taxonomic separations on the basis of cuticular hydrocarbons with existing taxonomic divisions based on morphology, behavior, etc., we are broadening the data base of cuticular hydrocarbons as taxo-

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nomic characters of termites as suggested by Prestwich (1983). The groups of termites we have recently chosen to investigate are the economically and ecologically important, tropicopolitan genera: *Coptotermes* and *Nasutitermes.*

The Formosan subterranean termite, *Coptotermes formosanus* Shiraki, is considered one of the most voracious subterranean termites and a serious threat to wood in structures throughout its range. In addition to buildings, *C. formosanus* attacks live trees, creosoted transmission poles, structural pilings, and even underground utility cables. *C. formosanus* was introduced into Japan from mainland China before 1600 and subsequently into Hawaii before 1907. Since its introduction into Hawaii, *C. formosanus* has been imported to Guam, Midway, Sri Lanka, Taiwan, South Africa, and the mainland United States (Su and Tamashiro 1987). Although many of the infestations in the continental United States were first noticed after 1965, *C. formosanus* colonies were most likely established by movement of military goods after World War II (Beal 1987). Since 1980, established infestations in inland areas indicate that this species may now be transported in infested wood products via domestic surface commerce (Chambers and others 1988; La Fage 1987; Sponsler and others 1988).

Knowledge of how introductions of *C. formosanus* have been spread will help regulatory agencies formulate and reexamine quarantine policies and procedures. Has *C. formosanus* been introduced numerous times from Asia or Hawaii, or once introduced, has it spread from port to port via domestic, maritime, or surface commerce? Are all populations of *Coptotermes* in the mainland United States *C. formosanus,* or is it possible that introductions of other species of *Coptotermes*, such as *C. havilandi* (Holmgren) or *C. testaceus* (L.), have been introduced and simply misidentified? We hope that cuticular hydrocarbons will help to elucidate this problem.

Nasutitermes Dudley is the largest genus in the Isoptera, containing approximately 212 species worldwide (based on compiled lists in Snyder 1949; Roonwal 1962; Araujo 1977). Taxonomic discrimination is based on morphological characters. These characters are often subtle and variable, or most prominent in imagoes which are rarely collected. For example, soldiers of *N. corniger* and *N. costalis* are currently impossible to discriminate without locality information. Nest architecture is also indistinguishable. When collections are made outside of the confirmed *N. corniger* range (Central America, see Thorne 1980) or away from the recognized *N. costalis* distribution (Caribbean islands: Snyder 1949; Araujo 1977), species determination is equivocal. There is currently confusion over the extent of the distribution of each of these species in northern South America, with overlapping reports of each, and identifications of each from as far as Bolivia and Brazil (Roonwal and Rathore 1976, reviewed in Thorne 1980).

As part of a broad examination of the taxonomy of Neotropical *Nasutitermes,* other termites of the Caribbean Basin, and the pantropical *Coptotermes,* we decided to examine cuticular hydrocarbons as an adjunct to the study of morphology and behavior for taxonomic distinction of species. This paperbehavior for taxonomic distinction of species. This paper reports supplemental data on surface hydrocarbons of *Nasutitermes* (Howard and others 1988; Haverty and others 1990b) and *Coptotermes* (Brown and others 1990; Haverty and others 1990a; McDaniel 1990), and discusses whether this information helps us resolve diagnostic problems within the genus (Howard and Blomquist 1982).

Materials and Methods

Detailed descriptions of collection and extraction procedures for specific termite species have been published elsewhere (Blomquist and others 1979; Howard and others 1978, 1982b, 1988; Haverty and others 1988, 1990a,b). In this study, cuticular lipids were extracted by immersing 15 to 500 termites (depending on size and total quantity of cuticular hydrocarbon), as a group, in 2 to 10 ml of hexane for 10 min. After extraction, hydrocarbons were separated from other components by pipetting the extract and an additional 2 to 8 ml of hexane through 3 cm of activated BioSil-A in Pasteur pipette mini-columns. Hydrocarbon extracts were evaporated to dryness under a stream of nitrogen and redissolved in 30 to 100 µl of hexane for gas chromatography-mass spectrometry (GC-MS) analyses.

All termite specimens except *C. curvignathus* Holmgres were dried at the field location. Dried termites were then shipped to the laboratory in Berkeley, California, for hydrocarbon extraction and chromatographic analysis. Extracted termites, or additional termites from the same colony, were stored in 70 percent ethanol for later identification by morphological features and to serve as voucher specimens.

Gas chromatography-mass spectrometry (GC-MS) analyses were performed on a Hewlett Packard 5890 gas chromatograph equipped with a Hewlett Packard 5970B Mass Selective Detector interfaced with Hewlett Packard Chemstation computer. The GC-MS instrument was equipped with a fused silica capillary column (30 m x 0.2 mm ID, HP-1) and operated in split mode (with a split ratio of 20:1). Each mixture was analyzed by a temperature program from 200°C to 320°C at 3°C/min with a final hold of 10 to 20 minutes. Electron impact (EI) mass spectra were obtained at 70 eV. *n*-Alkanes were identified by comparing their retention times and mass spectra with external standards (n-C_{22}, n-C_{24}, n-C_{28} and n-C_{32}). Alkenes and methyl-branched alkanes were tentatively identified by calculating their equivalent chain lengths; mass spectra of methylalkanes were interpreted as described by Blomquist and others (1987).

Six colonies of *C. formosanus* were collected from the University of Hawaii campus; another came from Kaneoe on the island of Oahu. *C. formosanus* samples were separated from wood debris and carton material and subsequently dried in a desiccator. They were held dry at room temperature until hydrocarbons were extracted. Samples of *C. curvignathus* from Malaysia and Thailand were extracted live in hexane in the field. Samples of *C. acinaciformis* (Froggatt) from Darwin, Australia, *C. lacteus* from Erica Forest near Melbourne, Australia, and *C. testaceus* (L.) from Trinidad were dried in Australia or Trinidad and extracted in our Berkeley laboratory.

Samples from colonies of various *Nasutitermes* species were collected as follows: *N. costalis* (Holmgren) from Trinidad, Grenada, and Montserrat; *N. ephratae* (Holmgren) from Trinidad, Tobago, and Montserrat; *N. gaigei* Emerson from Trinidad and

Tobago; *N. guayanae* (Holmgren) from Trinidad and Tobago; *N. intermedius* Banks from Trinidad; and *N. acajutlae* (Holmgren) from Great Camino, Guana Island and Scrub Island in the British Virgin Islands, and Vieques Island (off Puerto Rico). Entire arboreal nests, or large sections of nests, were collected in the field and confined in plastic bags. Within 24 hours, live insects were removed from the carton matrix by briskly tapping a portion of nest material over sorting trays. Workers and soldiers were selected with forceps for extraction of hydrocarbons. Species were determined on the basis of nest architecture and soldier morphology (Emerson 1925; Snyder 1956; Thorne 1980; Thorne and Levings 1989).

Results and Discussion

Coptotermes

Recently we characterized the cuticular hydrocarbons from colonies of *C. formosanus* from four different geographic locations in the United States (Haverty and others 1990a). Concurrently, McDaniel (1990) characterized the hydrocarbons from nine colonies of *C. formosanus* collected from Lake Charles, Louisiana, and one from Honshu, Japan. McDaniel (1990, *table 1*) identified numerous mono- and dimethylalkanes, which occurred in trace amounts, that were not detected by Haverty and others (1990a). McDaniel (1990) also identified a unique trimethylalkane, 13,15,17-TrimeC_{29}, in trace amounts, which was not detected by Haverty and others (1990a). However, the major constituents reported by McDaniel (1990) and Haverty and others (1990a) agree with a few exceptions.

In this most recent re-examination of the cuticular hydrocarbons of *C. formosanus* from Hawaii, we identified fourteen hydrocarbons in small amounts that were not detected by McDaniel (1990) nor by Haverty and others (1990a) (9,13-DimeC_{27}; n-C_{28}; 3,17- and 3,15-DimeC_{27}; 2-MeC_{28}; 13,15-DimeC_{29}; 3-MeC_{29}; 3,15- and 3,17-DimeC_{29}; 3,7-DimeC_{29}; 13,15-DimeC_{30}; 13,15-DimeC_{31}; 15,17-DimeC_{39}; 16-MeC_{40}; 14,18-DimeC_{40}; and 15,17-DimeC_{41}—see *table 1*). We also detected 13,15,17-TrimeC_{29}, as well as some later-eluting monomethyl- and dimethylalkanes (see *table 1*) reported by McDaniel (1990), but not seen in our previous analysis (Haverty and others 1990a). Of the five species of *Coptotermes* we have investigated thus far, several unusual dimethylalkanes with one methylene group between the methyl groups (such as 13,15-DimeC_{29}) appear to be unique to *C. formosanus*, and could be considered diagnostic for this species. Analogous, but different, dimethylalkanes have also been identified in *Coptotermes* from Australia (Brown and others 1990).

A preliminary survey of the hydrocarbon composition of four additional species of *Coptotermes* demonstrates clear qualitative differences from *C. formosanus (table 1). C. curvignathus* Holmgren from Thailand is the most similar of these four species to *C. formosanus*. Nearly all of the major components in the hydrocarbon profiles of these two species are shared *(table 1)*. Two significant components, 3-MeC_{25} and 11,13,15,16-MeC_{39}, were not detected or occur in trivial amounts in *C. curvignathus*. The primary difference between *C. formosanus* and *C. curvignathus*, as mentioned above, is the absence of 9,13-DimeC_{27} and 13,15-DimeC_{29} in *C. curvignathus*.

In our characterization of the hydrocarbons of *C. acinaciformis* (Froggatt) from Darwin, Australia, we identified several abundant, unique hydrocarbons. Our hydrocarbon profile for *C. acinaciformis* from Darwin is nearly identical to the hydrocarbons of *C. acinaciformis* from Humpty Doo, Australia, as reported by Brown and others (1990), except that we did not identify any hydrocarbons that eluted after 13-MeC_{29}. The most dramatic difference that we, and Brown and others (1990), found in *C. acinaciformis* is the huge $C_{27:1}$ peak (ca. 52 percent of the total cuticular hydrocarbon composition). This hydrocarbon does not occur in any of the other *Coptotermes* species examined thus far.

We also characterized the hydrocarbons from workers of *C. lacteus* (Froggatt) from Erica Forest near Melbourne, Australia. Our results closely agree with hydrocarbon profiles of *C. lacteus* from Batemans Bay and Canberra, Australia (Brown and others 1990). Several minor components (2-MeC_{28}, *n*-C_{29}, 2-MeC_{29} and 3-MeC_{29}) were not detected from our workers nor were they found by Brown and others (1990) in soldiers or nymphs of the colonies they examined. One intriguing difference is our identification of two dimethylalkanes (15,17-DimeC_{37} and 15,17-DimeC_{39}) that coelute with their corresponding internally branched monomethylalkanes (X-MeC_{37} and X-MeC_{39}). Hydrocarbons with the methyl branches separated by a single methylene group are not common in insects (Blomquist and others 1987). However, this type of compound has now been identified in two species of *Coptotermes* (Haverty and others 1990a, McDaniel 1990).

Finally, we report the hydrocarbon profile from *C. testaceus* (L.) from Trinidad. *C. testaceus* is notably different from *C. formosanus* and the *Coptotermes* species from Southeast Asia and Australia. Nearly all of the hydrocarbon components are terminally branched monomethylalkanes (such as 2-MeC_{27} and 2-MeC_{29}) or internally branched monomethylalkanes. Small amounts of dimethylalkanes were found (11,15- and 13,17-DimeC_{29}; 13,17-DimeC_{30}; 13,17-DimeC_{31}). No *n*-alkanes, alkenes, 3-; 5-; or 7-methylalkanes were identified *(table 1)*. Therefore, we can conclude with reasonable certainty that none of the four *Coptotermes* populations we have studied in the United States was misidentified *C. testaceus*. Next we need to convince ourselves that *C. havilandi* Holmgren, now established in the Caribbean (Scheffrahn and others 1990), has not been introduced into the mainland United States.

Nasutitermes

We have begun to expand our data base on the cuticular hydrocarbons of *Nasutitermes* from the Caribbean islands. Previously Haverty and others (1990b) characterized the cuticular hydrocarbons of *N. costalis* and *N. ephratae* from Trinidad. They found that these species have hydrocarbon mixtures that are qualitatively and quantitatively distinct from one another, with sixteen major hydrocarbon components. No unsaturated components were found.

In this study we included samples of these two species from Trinidad, as well as samples from other Caribbean islands.

Table 1—*Composition of hydrocarbon mixtures from workers of five species of* Coptotermes[1]

Hydrocarbon[3]	form	curv	acin	lact	test
	Coptotermes species[2]				
n-C_{23}	o	o	o	tr	o
9-;11-MeC_{23}[4]	o	o	o	tr	o
2-MeC_{23}	o	o	o	+	o
n-C_{24}	o	o	o	+	o
9-;10-;11-; 12-;13-MeC_{24}[4]	o	o	o	+	o
2-MeC_{24}	o	o	+	++	o
$C_{25:1}$	o	o	tr	o	o
n-C_{25}	+	tr	++	++	o
9-;11-;13-MeC_{25}[4]	+	+++	++	+++	o
2-MeC_{25}	+++	+++	+++	+++	o
3-MeC_{25}	++	o	++	+++	o
n-C_{26}	+	+	++	+	o
9-;10-;11;12-;13-MeC_{26}[4]	++	++	tr	++	o
2-MeC_{26}	++	++	o[5]	+	o
3-MeC_{26}	tr	o	o	tr	o
$C_{27:1}$	o	o	+++[5]	o	o
n-C_{27}	++	++	++	tr	o
9-;11-;13-;15-MeC_{27}[4]	+++	+++	+++	+	+
7-MeC_{27}	o	o	++	o	o
2-MeC_{27} + 9,13-$DimeC_{27}$[6]	+++	+++[7]	++[7]	tr[7]	++[7]
3-MeC_{27}	+++	++	++	tr	+
$C_{28:1}$	o	o	+	o	o
n-C_{28}	+	++	o	o	o
3,17-;3,15-$DimeC_{27}$[4]	+	o	o	o	o
3,7-$DimeC_{27}$	o	o	tr	o	o
9-;11-;12-;12-; 13-;14-;15-MeC_{28}[4]	++	++	tr	o	+
2-MeC_{28}	+	o	+	o	+
3-MeC_{28}	tr	o	o	o	o
$C_{29:1}$	o	o	++	o	o
n-C_{29}	o	+	tr	o	o
9-;11-;13-;15-MeC_{29}[4] + 13,15-$DimeC_{29}$[6]	+++	++[7]	+[7]	o	+++[7]
9,13-$DimeC_{29}$	+	o	o	o	o
11,15-;13,17-$DimeC_{29}$[4] + 2-MeC_{29}[5]	tr[7]	o	o	o	+++
3-MeC_{29}	+	o	o	o	+
13,15,17-$TrimeC_{29}$	+	o	o	o	tr
3,15-;3,17-$DimeC_{29}$[4]	+	o	o	o	o
3,7-$DimeC_{29}$	+	o	o	o	tr
10-;11-;12-;13-MeC_{30}[4]	o	o	o	o	++
13,15-$DimeC_{30}$	+	o	o	o	o
13,17-$DimeC_{30}$ + 2-MeC_{30}[6]	o	o	o	o	tr
11-;13-;15-MeC_{31}[4]	o	o	o	o	+++

Table 1—*Composition of hydrocarbon mixtures from workers of five species of* Coptotermes,[1] continued

Hydrocarbon[3]	form	curv	acin	lact	test
	Coptotermes species[2]				
13,15-$DimeC_{31}$	+	o	o	o	o
13,17-$DimeC_{31}$	o	o	o	tr	+
3,7-$DimeC_{31}$	tr	o	o	o	tr
10-;12-;16-MeC_{32}[4]	o	o	o	o	+
11-;13-;15-;17-MeC_{33}[4]	+	o	o	+	++
13,17-;15,19-$DimeC_{33}$[4]	o	o	o	+	o
10-;11-;12-;14-MeC_{34}[4]	o	o	o	tr	tr
12,16-$DimeC_{34}$	o	o	o	tr	o
11-;13-;15-;17-MeC_{35}[4]	+	o	o	++	++
11,15-;13,21-$DimeC_{35}$[4]	o	o	o	++	o
10-;11-;12-;13-;14-; 15-;16-;17-MeC_{36}[4]	o	o	o	+	tr
12,16-$DimeC_{36}$	o	o	o	+	o
11-;13-;15-;17-;19-	+	o	o	o	+
MeC37[4] + 15,17-$DimeC_{37}$	o	o	o	+[8]	o
11,15-;13,17-; 15,19-$DimeC_{37}$[4]	+	o	o	+++	o
12-;14-;15-;16-; 17-;18-MeC_{38}[4]	tr	o	o	+	o
12,16-$DimeC_{38}$	o	o	o	+	o
11-;13-;15-;16-MeC_{39}[4]	++	o	o	o	tr[7]
+ 15,17-$DimeC_{39}$[6]	+	o	o	++[8]	o
11,15-;13,17-; 15,19-$DimeC_{39}$[4]	++	o	o	++	o
16-;15-;14-;13-MeC_{40}[4]	+	o	o	o	o
14,18-$DimeC_{40}$	+	o	o	o	o
13-;15-MeC_{41}[4] +15,17-$DimeC_{41}$[6]	++	o	o	o	o
13,17-;15,19-$DimeC_{41}$[4]	++	o	o	o	o
13-;15-MeC_{43}[4]	+	o	o	o	o
13,17-;15,19-$DimeC_{43}$[4]	+	o	o	o	o

[1] Hydrocarbons are quantified as follows: +++ indicates ≥ 5.0 percent of the total, ++ from 1.0 to 5.0 percent of the total, and + from 0.5 to 1.0 percent of the total hydrocarbon component. Some trace (tr) components appear infrequently or consistently in very small quantities (< 0.5 percent of the total). A zero indicates the hydrocarbon has not been identified for the species.

[2] form = *Coptotermes formosanus* from Honolulu, Hawaii, curv = *C. curvignathus* from near Bangkok, Thailand, acin = *C. acinaciformis* from Darwin, Australia, lact = *C. lacteus* from Erica Forest near Melbourne, Australia, and test = *C. testaceus* from Trinidad.

[3] Carbon number is the total number of carbons in the parent chain, excluding methyl groups, e.g. 3-MeC_{25} = 3-methylpentacosane.

[4] An isomeric mixture. These components co-elute in this peak.

[5] 2-MeC_{26} co-elutes with $C_{27:1}$.

[6] Because of incomplete separation of these hydrocarbons both peaks are included as one value.

[7] Only the monomethylalkane occurs in this species.

[8] Only the dimethylalkane occurs in this species.

Since the earlier study by Haverty and others (1990b) and the report by Howard and others (1988) on *N. ephratae* and *N. corniger* (Motschulsky), we have discontinued the use of a flame ionization detector (FID) on our capillary gas chromatograph and now use a mass selective detector (MSD). We have also changed our methods for collecting, shipping, and extracting specimens. We now dry specimens at the field location and extract dry specimens in the laboratory in Berkeley, rather than extracting fresh specimens in the field and shipping liquid or dried extracts to the laboratory. These changes have resulted in much superior separation, identification and quantification of the hydrocarbon components, especially the later-eluting components.

The predominant classes of cuticular hydrocarbons in *N. costalis* are internally branched, mono- and dimethylalkanes *(table 2)*. Normal alkanes and an alkene ($C_{27:1}$) occur, but only in relatively small quantities ($\leq$ 1.0 percent). No terminally branched, monomethylalkanes were found. The preponderance of one component (13,17-DimeC_{31}) accounts for nearly half of the total hydrocarbon of *N. costalis.*

The hydrocarbon profile of *N. ephratae* is much more complex than previously described (Haverty and others 1990b; Howard and others 1988). These earlier reports failed to identify the compounds that elute after 13,17-DimeC_{33}. In our samples from Trinidad and Tobago we consistently identified 24 hydrocarbons in significant ($\geq$ 1.0 percent of the total hydrocarbon) quantities *(table 2)*. As with *N. costalis*, the predominant classes of hydrocarbons are the internally branched, mono-, di- and trimethylalkanes. Most of these compounds have isoprenoid spacing between the methyl branches. We also found trimethylalkanes (13,15,17-TrimeC_{31}; 13,15,17-TrimeC_{37}; and 13,15,17-TrimeC_{39}) with only a methylene group between the methyl branches. These rare trimethylalkanes elute very soon after the analogous dimethylalkanes (15,17-DimeC_{31}; 15,17-DimeC_{37}; and 15,17-DimeC_{39}). *N. ephratae* does make significant quantities of *n*-alkanes (*n*-C_{23} and *n*-C_{27}) and alkenes ($C_{23:1}$, $C_{25:1}$, $C_{27:1}$, and $C_{29:1}$). We found no terminally branched, monomethylalkanes.

Although we found no qualitative differences in hydrocarbon mixtures between workers and soldiers of the same colony, we think it is important to point out significant differences between the hydrocarbon profiles of *N. ephratae* from Trinidad versus those from Tobago *(table 2)*. Our samples from Trinidad contain two isomers of $C_{29:1}$, whereas those from Tobago apparently do not make these compounds. Instead, the Tobago specimens produce a 12,16-DimeC_{28} which elutes at about the same time as $C_{29:1}$. In addition, our samples from Tobago include 11,15- and 13,17-DimeC_{39}; 13,17-DimeC_{41}; 11,15,19-TrimeC_{39}; and 13,17,21-TrimeC_{41}. These hydrocarbons were not found in our sample from Trinidad. These differences will require further elucidation.

N. gaigei and *N. guayanae* make a very simple, yet unique, hydrocarbon mixture. The only hydrocarbons we recovered from these species are late-eluting alkenes ($C_{37:1}$ through $C_{47:1}$) *(table 2)*. We found only trivial amounts of an occasional *n*-alkane or methylalkane. The major difference between these two species is the degree of unsaturation. Hydrocarbons of *N. gaigei* have either three or four double bonds; those of *N. guayanae*

Table 2—*Mean percent composition of hydrocarbons from workers of six species of* Nasutitermes[1]

Hydrocarbon[3]	*Nasutitermes* species[2] cost	ephr	gaig	guay	acaj	inte
$C_{23:1}$	o	+	o	o	tr	o
n-C_{23}	tr	++	o	o	+	o
n-C_{24}	tr	o	o	o	tr	o
2- or 4-MeC_{24}	o	o	o	o	+	o
$C_{25:1}$	tr	++	o	o	+++	o
n-C_{25}	+	+	o	o	+++	o
11-;13-MeC_{25}[4]	tr	+	o	o	+	o
9,13-DimeC_{25}	o	+	o	o	o	o
2- or 4-MeC_{25}	o	o	o	o	++[5]	o
3-MeC_{25}	o	o	o	o	++[5]	o
$C_{26:1}$	o	o	o	o	tr	o
n-C_{26}	o	o	o	o	+	o
11-;12-;13-MeC_{26}[4]	o	+	o	o	o	o
2- or 4-MeC_{26}	tr	o	o	o	+	o
$C_{27:1}$	+	+++	o	o	+	o
n-C_{27}	+	++	o	o	+++	+
9-;11-;13-MeC_{27}[4]	tr	+++	o	o	tr	tr
11,13-DimeC_{27}	o	++	o	o	o	o
11,15-DimeC_{27}	+[6]	++[6]	o	o	o	+[6]
9,13-DimeC_{27}	o	++[6]	o	o	o	o
2- or 4-MeC_{27}	+[6]	o	o	o	tr	+[6]
3-MeC_{27}	tr	o	o	o	tr	o
9,13,17-TrimeC_{27}	o	+	o	o	o	o
n-C_{28}	tr	tr	o	o	tr	o
12-;13-;14-MeC_{28}[4]	tr	+	o	o	o	o
11,15-;12,16-DimeC_{28}	tr	++[7]	o	o	o	o
2- or 4-MeC_{28}	+	o	o	o	tr	o
$C_{29:1}$	tr	++[7]	o	o	o	o
9,13,17-TrimeC_{28}	o	+	o	o	o	o
n-C_{29}	+	+	o	o	+	+
9-;11-;13-;15-MeC_{29}[4] + 13,15-DimeC_{29}	++[6]	+++[6]	o	o	tr	+
11,15-;13,17-DimeC_{29}	++	+++	o	o	o	o
9,19-DimeC_{29}	o	o	o	o	tr	o
9,17-DimeC_{29}	o	+++[6]	o	o	o	o
9,13-DimeC_{29}	o	+++[6]	o	o	o	o
11,15,19-; 9,13,17-TrimeC_{29}[4]	tr	++[8]	o	o	o	o
3-MeC_{29}	tr	o	o	o	o	o
12-;13-;14-; 15-;16-MeC_{30}[4]	tr	+	o	o	o	o
12,16-DimeC_{30}	++	++	o	o	o	o
$C_{31:1}$	tr	tr	o	o	tr	+
11,15,19-TrimeC_{30}	o	tr	o	o	o	o
n-C_{31}	tr	o	o	o	o	++

Table 2—*Mean percent composition of hydrocarbons from workers of six species of* Nasutitermes,[1] continued

Hydrocarbon[3]	cost	ephr	gaig	guay	acaj	inte
	Nasutitermes species[2]					
11-;13-;15-MeC$_{31}$[4]	++[6]	++[6]	o	o	o	+[6]
11,13-DimeC$_{31}$	++[6]	o	o	o	o	o
13,15-DimeC$_{31}$	++[6]	o	o	o	o	+
15,17-DimeC$_{31}$	o	++[6]	o	o	o	o
13,15,17-TrimeC$_{31}$	o	+	o	o	o	o
13,17-DimeC$_{31}$	+++	+++	o	o	o	o
11,15-DimeC$_{31}$	o	+	o	o	o	o
11,15,19-TrimeC$_{31}$	o	++	o	o	o	o
12-;14-MeC$_{32}$	+	o	o	o	o	o
14,18-DimeC$_{32}$	+	o	o	o	o	o
C$_{33:1}$	o	o	tr	o	o	+
n-C$_{33}$	o	o	tr	o	o	+
13-;15-;17-MeC$_{33}$	+[6]	+	o	o	o	o
+ 13,15-DimeC$_{33}$[4]	+[6]	o	o	o	o	o
15,19-DimeC$_{33}$	+	+[6]	o	o	o	o
13,17-DimeC$_{33}$	o	+[c]	o	o	o	o
11,15-DimeC$_{33}$	+	o	o	o	o	o
16-MeC$_{34}$	tr	o	o	o	o	o
C$_{35:2}$	o	o	o	o	o	+
C$_{35:1}$	o	o	o	o	o	+
17-MeC$_{35}$	tr	o	o	o	o	o
15,17-DimeC$_{35}$	o	tr	o	o	o	o
11,21-DimeC$_{35}$	tr	o	o	o	o	o
11,15-DimeC$_{35}$	tr	o	o	o	o	o
C$_{36:2}$	o	o	o	o	o	++
C$_{36:1}$	o	o	o	o	o	+
C$_{37:4}$	o	o	+++	o	o	o
C$_{37:3}$	o	o	+++	o	o	o
C$_{37:2}$	o	o	o	o	o	+++
C$_{37:1}$	o	o	o	++	tr	+++
15,17-DimeC$_{37}$	o	+	o	o	o	o
13,15,17-TrimeC$_{37}$	o	++	o	o	o	o
C$_{38:4}$	o	o	+	o	o	o
C$_{38:3}$	o	o	tr	o	o	o
C$_{38:2}$	o	o	o	o	o	++
C$_{38:1}$	o	o	o	+	tr	++
Unknown	o	o	o	o	+	o
C$_{39:4}$	o	o	+++	o	o	o
C$_{39:3}$	o	o	++	o	o	+
C$_{39:2}$	o	o	o	tr	tr	+++
C$_{39:1}$	o	o	o	+++	+++	+++
n-C$_{39}$	o	o	o	tr	o	o
11-;13-;15-MeC$_{39}$[4]	o	o	o	+	o	o
15,17-DimeC$_{39}$	o	++	o	o	o	o

Table 2—*Mean percent composition of hydrocarbons from workers of six species of* Nasutitermes,[1] continued

Hydrocarbon[3]	cost	ephr	gaig	guay	acaj	inte
	Nasutitermes species[2]					
13,15,17-TrimeC$_{39}$	o	++	o	o	o	o
13,17-;11,15-DimeC$_{39}$	o	++[9]	o	o	o	o
11,15,19-TrimeC$_{39}$	o	+[9]	o	o	o	o
C$_{40:4}$	o	o	tr	o	o	o
C$_{40:2}$	o	o	o	o	o	+
C$_{40:1}$	o	o	o	+	+	+
Unknown	o	o	o	o	++	o
n-C$_{40}$	o	o	o	tr	o	o
C$_{41:4}$	o	o	++	o	o	o
C$_{41:3}$	o	o	+	o	tr	o
C$_{41:2}$	o	o	o	+	+	+
C$_{41:1}$	o	o	o	+++	+++	++
13-MeC$_{41}$	o	o	o	+	o	o
15,17-DimeC$_{41}$	o	+	o	o	o	o
13,17-DimeC$_{41}$	o	+[9]	o	o	o	o
13,15,17-TrimeC$_{41}$	o	tr	o	o	o	o
13,17,21-TrimeC$_{41}$	o	+[9]	o	o	o	o
C$_{42:1}$	o	o	o	+	tr	o
Unknown	o	o	o	o	+	o
C$_{43:2}$	o	o	o	+	++	tr
C$_{43:1}$	o	o	o	++	++	+
13-MeC$_{43}$	o	o	o	tr	o	o
C$_{44:1}$	o	o	o	tr	tr	o
C$_{45:2}$	o	o	o	tr	+	o
C$_{45:1}$	o	o	o	++	++	o
C$_{47:1}$	o	o	o	+	++	o

[1] Hydrocarbons are quantified as follows: +++ indicates ≥ 5.0 percent of the total, ++ from 1.0 to 5.0 percent of the total, and + from 0.5 to 1.0 percent of the total hydrocarbon component. Some trace (tr) components appear infrequently or consistently in very small quantities (< 0.5 percent of the total). A zero indicates the hydrocarbon has not been identified for the species.

[2] cost = *Nasutitermes costalis* from Trinidad and Grenada, ephr = *N. ephratae* from Trinidad and Tobago, gaig = *N. gaigei* from Trinidad and Tobago, guay = *N. guayanae* from Trinidad and Tobago, acaj = *N. acajutlae* from Great Camino, Guana Island, Scrub Island (British Virgin Islands) and Vieques, and inte = *N. intermedius* from Trinidad.

[3] Carbon number is the total number of carbons in the parent chain, excluding methyl groups, e.g. 3-MeC$_{25}$ = 3-methylpentacosane.

[4] An isomeric mixture. These components co-elute in this peak.

[5] These isomers occur inconsistently; when present they are fairly abundant.

[6] Because of incomplete separation of these hydrocarbons both peaks are included as one value for *N. costalis, N. ephratae*, and *N. intermedius*.

[7] Two isomers of C$_{29:1}$ occur in *N. ephratae* from Trinidad and not in the sample from Tobago; 12,16-DimeC$_{28}$ occurs in the *N. ephratae* from Tobago but not in the sample from Trinidad.

[8] Only the 9,13,17-TrimeC$_{29}$ isomer was found.

[9] 13,17-DimeC$_{39}$; 13,17-DimeC$_{41}$; 11,15,19-TrimeC$_{39}$; and 13,17,21-TrimeC$_{41}$ have been found only in samples of *N. ephratae* from Tobago.

have one or two double bonds. The predominant hydrocarbon in *N. gaigei* has 37 carbons, whereas the major component of *N. guayanae* has 39 carbons.

The hydrocarbons of *N. acajutlae* differ from the four previously described species in that the chromatograms appear to be bimodal. The early-eluting hydrocarbons consist of *n*-alkanes (n-C_{23} through n-C_{29}), alkenes ($C_{25:1}$ and $C_{27:1}$), and terminally branched monomethylalkanes *(table 2)*. The late-eluting compounds consist entirely of alkenes with one, two or three double bonds *(table 2)*. Only trivial amounts of internally branched, monomethylalkanes were found. No di- or trimethylalkanes were found.

We hesitate to report upon the single colony of *N. intermedius* collected from Trinidad. However, given the consistency of hydrocarbon profiles among samples of other species of *Nasutitermes*, the uniqueness of this observation is worthy of mention. This species makes predominantly long-chain alkenes with one or two double bonds ($C_{37:2}$ or 1 through $C_{41:2}$ or 1) *(table 2)*. This species even produces a homologous series of alkenes with an even number of carbons in the chain ($C_{36:2}$ or 1 through $C_{40:2\ or 1}$). We have not seen this with the other species of *Nasutitermes*. In addition, this sample yielded no hydrocarbons before n-C_{27}, no terminally branched monomethylalkanes, and only trivial amounts of internally branched, mono- and dimethylalkanes.

The taxonomy of the Caribbean *Nasutitermes* is in need of revision and is a topic of our work in progress. Keys that distinguish these species on the basis of morphological characters (Banks 1919; Emerson 1925; Snyder 1956, 1959) often lead to equivocal determinations. Diagnostic keys and synonomies are being re-evaluated on the basis of comparisons with type specimens and studies of additional collections.[3] We are certain enough about morphological groupings, however, to be confident of species determinations made on material used in this study.

A brief discussion of diagnostic morphological characters among *Nasutitermes* involved in this project follows, with comments on inferred phylogenetic relationships among the species. *N. costalis* and *N. ephratae* overlap geographically on Trinidad and Tobago, and in northern South America based on known ranges (Araujo 1977; Emerson 1925). Morphologically, these two species are close, but imagoes are distinguished by position of ocelli (Emerson 1925; Snyder 1956) and soldiers may be separated on the basis of the pattern of setae on the tergal sclerites (Emerson 1925; Snyder 1956; Thorne 1980). Nests of these species are easily identified on the basis of both exterior and interior architectures (Darlington In press; Haverty and others 1990b; Thorne 1980). *N. costalis, N. ephratae*, and the Central/South American species *N. corniger* (Motschulsky) are all considered to be close relatives based on morphological similarities, but a comprehensive phylogenetic analysis involving these groups has not yet been undertaken.

In this paper we designate the specimens from the British Virgin Islands and Vieques Island as *N. acajutlae*, resurrecting a name previously synonomized as *N. nigriceps* by Snyder (1949). The "*N. nigriceps* complex" is a broadly dispersed and morphologically variable group, ranging throughout Central America and the Caribbean, with isolated reports from a number of locations in South America (Araujo 1977, American Museum of Natural History collection). In work still in progress, Thorne has examined material throughout the *N. "nigriceps"* range and isolated three morphological characters which consistently differentiate soldiers of *N. nigriceps sensu strictu* from soldiers found in the American and British Virgin Islands and Puerto Rico. The latter groups compare favorably to soldiers of the COTYPE specimens of *"Eutermes acajutlae"* (collected from St. Thomas, Virgin Islands, determined by N. Holmgren, American Museum of Natural History collection). The three distinguishing characters are: (1) density of hairs on the head capsule of *N. acajutlae* soldiers greatly exceeds that of *N. nigriceps* soldiers; (2) small hairs are found on the ventral surface of the soldier head on either side of the postmentum in *N. acajutlae* (absent on specimens of *N. nigriceps)*; and (3) the anterior margin of the soldier pronotum is distinctly emarginate in *N. acajutlae*, flatter in *N. nigriceps*. On the basis of these characters, specimens from Jamaica sort as *N. nigriceps*; samples from localities in the Lesser Antilles examined to date separate as *N. acajutlae*. A formal treatment of the taxonomy of the *N. nigriceps* complex is in progress, comparing morphological data with hydrocarbon analyses.[4]

Nasutitermes gaigei, N. guyanae and *N. intermedius* are each distinct morphospecies, identified in these samples on the basis of characters of the soldier caste and comparison to determined specimens. Diagnostic suites of characters and geographical distributions of each species are being revised.[5]
As we continue to survey *Nasutitermes* hydrocarbon profiles throughout the Caribbean, we anticipate that correlations between hydrocarbon profiles and morphology will assist us in further resolution of the taxonomy of this genus.

Our study represents only the fourth report of the cuticular hydrocarbons of species of *Nasutitermes*, one of the most ubiquitous and abundant pantropical groups of termites. Moore (1969) provided the first description of the cuticular lipids of the Australian termite, *N. exitiosus*. His report that the long-chain, unsaturated component $C_{39:4}$ was the predominant hydrocarbon is consistent with our characterization of four of the six species we have investigated.

The consistent similarities among the hydrocarbon mixtures of the species of *Nasutitermes* examined thus far (Moore 1969; Howard and others 1988; and Haverty and others 1990b) indicate that cuticular hydrocarbons can be valuable chemotaxonomic characters for all *Nasutitermes* species. As has been found with other taxonomic character systems (Gush and others 1985), hydrocarbon profiles may not show exact qualitative or quantitative species-specificity, especially across a broad geographic range. Further sampling within *Nasutitermes* and in other groups should be encouraged to determine the prevalence of such variability, and to ascertain its biological and taxonomic relevance.

[3] Thorne, Collins and Darlington, unpublished data.

[4] Thorne, Haverty and Collins, unpublished data.

[5] Darlington, unpublished data.

Conclusions

There are still some unresolved questions to be addressed to optimize the use of cuticular hydrocarbons for taxonomic studies of termites. They are: (1) What is the influence of genetics and the environment (e.g., temperature, relative humidity, and diet) on hydrocarbon composition? Does drying the samples before extraction quantitatively or qualitatively change the hydrocarbon mixture? (2) Are cuticular hydrocarbons, or the other chemicals present in the wax layer, responsible for species or caste recognition? (3) Are hydrocarbon profiles within "good species" qualitatively identical or are there some exceptions to the rules? Can different biological species have identical hydrocarbon profiles? (4) What is the rate of change in hydrocarbon profiles as species evolve? Do slight differences in profiles mean that the species are closely related? and (5) Can hydrocarbons be used to determine phyletic relationships among groups within a genus? Resolution of these questions will greatly advance the precision of cuticular hydrocarbons as chemotaxonomic characters in all insects.

Even though there are numerous unresolved questions concerning the utility of hydrocarbons as taxonomic characters, an increasingly convincing body of knowledge is accumulating which indicates that hydrocarbon profiles are species-specific in termites (Brown and others 1990, Clément and others 1985, 1986, Haverty and others 1988, 1990b, Howard and others 1978, 1980, 1982a,b, 1988; Watson and others 1989). Our experience in applying knowledge of cuticular hydrocarbon composition to the identification of termite species has been encouraging. We have used hydrocarbons to initially sort specimens (Haverty and others 1988) to identify a new diagnostic morphological character for *Zootermopsis* species (Thorne and Haverty 1989). Geographical races of *Coptotermes formosanus* can be distinguished on the basis of the concentrations of individual hydrocarbon components (Haverty and others 1990a). And most importantly, we now realize that cuticular hydrocarbons are extremely useful taxonomic characters for separating species of termites where morphology has proven inadequate in the past (Brown and others 1990, Watson and others 1989).

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Role of Decaying Logs and Other Organic Seedbeds in Natural Regeneration of Hawaiian Forest Species on Abandoned Montane Pasture[1]

Paul G. Scowcroft[2]

Abstract: Natural regeneration is one mechanism by which native mixed-species forests become reestablished on abandoned pasture. This study was done to determine patterns of and requirement for natural regeneration of native species in an open woodland after removal of cattle. Ten 50- by 50-m quadrats were randomly selected within a 16-ha exclosure located at 1,700-m elevation inside the Hakalau Forest National Wildlife Refuge on the island of Hawaii. In 1989 and 1991, data were collected for all regeneration in the quadrats, including species, height, and seedbed type. More than 2,000 individuals were found in 1989, two years after the cattle were excluded. By 1991, the number had doubled to more than 4,000 individuals. Ohia was the most abundant species both years. Mineral soil accounted for about 97 percent of the potential seedbed area inside the exclosure, but less than 25 percent of all regeneration was rooted there in 1989 and less than 33 percent in 1991. In contrast, decaying logs made up less than 2 percent of the potential seedbed area, but they supported about 70 percent of all regeneration in 1989 and 53 percent in 1991. The data indicated that organic seedbeds are preferred sites for recruitment, establishment, and early growth of olapa, kawau, and ohelo. Ohia's preference for organic seedbed was less pronounced. Tree fern showed a strong preference for mineral soil. Koa was nondiscriminatory.

During the past 10 years, interest has grown in developing technology for restoring native mixed-species forests to deforested and degraded forest lands of Hawaii. Concern for the recovery of endangered species has been a key motivating factor for this interest. Federal and State forest landowners are mandated by law to protect and restore endangered species. Much of the effort to accomplish those goals is focused on habitat protection and restoration.

The Forest Service has no National Forest land in Hawaii, and hence it has no management responsibilities in the State. However, the Forest Service maintains an active forest research program in Hawaii to help other Federal, State, and private forest owners develop technology for better management. Part of that research program is focused on reforestation.

A 16-ha exclosure, hereafter called the woodland exclosure, was built by the Hakalau Forest National Wildlife Refuge in 1987 to provide a cattle-free area for conducting reforestation experiments (Conrad and others 1988). Two years after the fence was erected, I observed that native woody species were regenerating naturally, but almost always in association with fallen, decaying logs or other organic seedbeds. This study was done to determine if organic seedbeds were as important to natural regeneration of native species as cursory observations suggested. Specifically I wanted to (1) determine the abundance of native regeneration, by species and seedbed type, and (2) determine the areal extent of each seedbed type. The findings, if confirmed by similar studies elsewhere, could have application in evaluating the potential for natural regeneration of open pasture where organic seedbeds no longer exist.

Methods

The tropical montane study site was on the east flank of Mauna Kea, island of Hawaii, at about 1,700 m elevation inside the Hakalau Forest National Wildlife Refuge. The climate is cool and moist year around. Mean daily air temperatures average less than 15°C, with an annual variation of only 5°C. Diurnal variation in temperature averages less than 10°C throughout the year. During winters frost is common. Rainfall averages about 2,500 mm per year, with greater amounts falling during winter months. Tradewind-generated clouds often shroud the refuge in mist in the afternoon.

The study area supported an open woodland dominated by Hawaii's two principal native overstory tree species, koa *(Acacia koa)* and ohia *(Metrosideros polymorpha)*. Grazed by cattle for 50 to 100 years, the native forest understory was destroyed and replaced by introduced grasses and forbs. Kikuyu grass *(Pennisetum clandestinum)*, sweet vernal grass *(Anthoxanthum odoratum)*, and velvet grass *(Holcus lanatus)* dominated the ground vegetation.

We divided the woodland exclosure into 50- by 50-m quadrats. I selected ten of these at random using a random number generator. In 1989 and again in 1991 a crew of 3 to 4 persons carefully and thoroughly searched each quadrat for natural regeneration. The grass cover was dense, and I know we must have missed some hidden regeneration that was rooted in mineral soil. However, we found that mineral soil seedbeds with natural regeneration had a certain characteristic that helped us in our search. The banks of cattle tracks and erosion scars often supported regeneration, so we examined especially these areas. Organic seedbeds were generally easy to see or find. I do not think we missed any regeneration rooted in organic material.

For each plant found in 1989, we recorded species, height, and seedbed type. I expanded the data set in 1991 to also include crown diameter, elevation of root collar above the soil surface, seedbed characteristics (such as degree of decomposition, grass covered, etc.), and projected area of each seedbed. Space considerations prevent discussion of all of these data in this paper.

Differences in mean plant height among the various seedbed types were examined using one-way ANOVA and Tukey's method of multiple comparisons. Sample size was 10 in all cases. Because sampling was from a finite population (i.e., 54, 50- by 50-m quadrats), all standard errors of the means shown in this paper were adjusted using the finite population correction factor (0.911 in the present study). Plant density refers to number of individuals per hectare of exclosure, not per hectare of seedbed type.

[1]An abbreviated version of this paper was presented at the Session on Tropical Forestry for People of the Pacific, XVII Pacific Science Congress, May 27-28, 1991, Honolulu, Hawaii.

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Results

Abundance of Natural Regeneration

We found 2,024 individual plants in 1989 within our sample quadrats *(table 1)*. Most of these plants (1756) were ohia seedlings. Ohelo *(Vaccinium reticulatum)*, olapa *(Cheirodendron trigynum)*, kawau *(Ilex anomala)*, and pukiawe *(Styphelia tameiameiae)* were the other native species tallied. No natural koa regeneration occurred within our sample, but we saw what we assumed were root sprouts growing elsewhere in the woodland exclosure.

Two years later, in 1991, we found 4,140 individuals, more than double the number tallied in 1989 *(table 1)*. Every species except pukiawe increased in abundance during the 2-year interval. Once again, the most abundant species was ohia, with 3,557 individuals. In addition to the species encountered in 1989, we tallied three new species—koa, kolea *(Myrsine lessertiana)*, and tree fern *(Cibotium glaucum)*. Much to our surprise, there were 150 young tree fern in the sample quadrats. We did not expect tree fern to invade the grass-dominated site so soon, especially considering the total absence of adult tree fern. There were 31 koa and one kolea.

Table 1—*Total count of natural regeneration of native species in sampled areas of the woodland exclosure, Hakalau Forest National Wildlife Refuge, by seedbed class and year.*

	1989		1991	
Species	Mineral soil	Organic beds	Mineral soil	Organic beds
Ohia	443	1,313	1,214	2,343
Ohelo	18	199	22	312
Olapa	1	43	2	55
Kawau	1	1	0	6
Pukiawe	1	4	1	3
Koa	0	0	14	17
Tree fern	0	0	126	24
Kolea	0	0	1	0
All species	**464**	**1560**	**1380**	**2760**

Seedbed Area

We counted 110 live and standing dead trees in our sample quadrats, or an average of 44 trees per hectare (std. err. = 12). These stems occupied 58 sq. m of basal area, or about 0.2 percent of the sample area. Because these areas were already occupied, they were usually unavailable for seedling recruitment.

Mineral soil accounted for an average of 97 percent of the potential seedbed area in the woodland exclosure *(fig. 1)*. Fallen trees in various stages of decay accounted for about 2 percent of the seedbed area. Moss-covered root mats, pockets of organic matter perched in fissures and hollows of live trees, and exposed, decaying wood of live trees each made up less than 0.5 percent of the potential seedbed area.

Seedbed Preferences

Analysis of the data confirmed our initial hypothesis that organic seedbeds are important sites for recruitment of native species. In 1989, more than 75 percent of the natural regeneration was found growing on organic material of one type or another *(table 1)*. In 1991, 67 percent was found on organic seedbeds.

Organic seedbeds contained a disproportionate number of plants relative to their surface area. Although mineral soil accounted for 97 percent of the available seedbed area, only one-

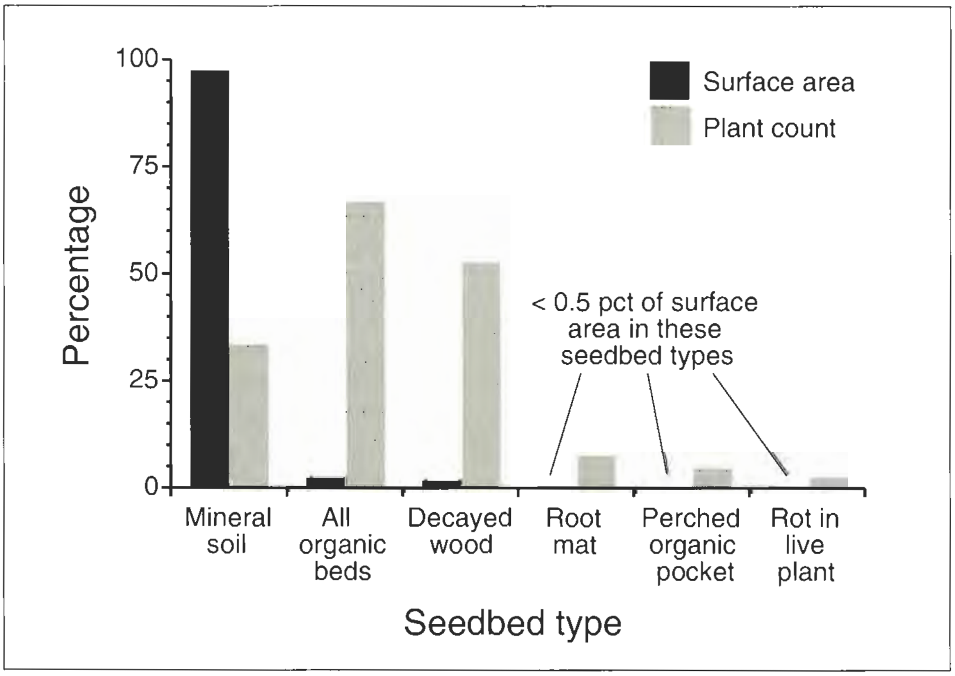

Figure 1—Average proportion of each type of seedbed in the woodland exclosure (surface area) and the average percentage of natural regeneration found growing on each type of seedbed (plant count) in 1991. Sample size (n) was 10.

third of the regeneration was found growing there in 1991 (*fig. 1*). In comparison, decaying logs and limbs made up less than 2 percent of the seedbed area, but they supported more than one-half of the regeneration. Moss-covered root mats, which appear to be important microsites for growth of some native species, supported 7 percent of the regeneration, but represented only 0.3 percent of the available seedbed area.

Seedbed preferences were already evident in 1989 (*table 2*). Ohia showed a moderately-strong preference for organic seedbeds—an average of 524 ohia were rooted in organic material compared to 177 rooted in mineral soil. Ohelo and olapa showed a strong preference for organic seedbeds; more than 90 percent of the regeneration of each of these species was rooted in organic material. The greatest densities of ohia, ohelo, and olapa were found on decaying wood. Too few kawau and pukiawe seedlings were sampled to determine their seedbed preferences.

The seedbed preferences expressed in the 1989 data were confirmed by the 1991 data (*fig. 2*). Natural regeneration of ohia continued to show a moderately-strong preference for organic seedbeds—about 65 percent occurrence in 1991. Decaying logs and other large woody debris were the favored organic site for recruitment of ohia seedlings. An average of 800 ohia per hectare (std. err. = 233) were found on decaying wood.

Natural regeneration of ohelo and olapa also continued to show a strong preference for organic seedbeds (*fig. 2*). Ninety-three percent of the ohelo and 96 percent of the olapa were growing on organic beds in 1991. Decaying logs and large organic debris were less important as safe sites for recruitment of ohelo and olapa than for recruitment of ohia. The largest percentage of olapa occurred on pockets of organic matter perched in crevices and hollows along the surface of living trees. An average of 10 olapa per hectare (std. err. = 5) were growing in such organic pockets.

In contrast to the woody species described above, tree fern regeneration showed a strong preference for mineral soil in 1991 (*fig. 2*). Out of 150 plants, 84 percent were rooted in mineral

Table 2—*Mean density[1] of natural regeneration of native woody species 1989, by species and seedbed type*

Species	Mineral soil	Decaying wood	Root mat	Organic pocket	Rot in tree
	plants per hectare				
Ohia	177 (23)[2]	478 (183)	42 (28)	3 (2)	1 (1)
Ohelo	7 (4)	72 (36)	8 (4)	0 (0)	0 (0)
Olapa	<1 (<1)	10 (5)	5 (4)	2 (1)	0 (0)
Kawau	<1 (<1)	0 (0)	<1 (<1)	0 (0)	0 (0)
Pukiawe	<1 (<1)	0 (1)	<1 (<1)	0 (0)	0 (0)

[1]Mean density = plants per hectare of exclosure; sample size = 10.
[2]Standard error of the mean shown in parentheses.

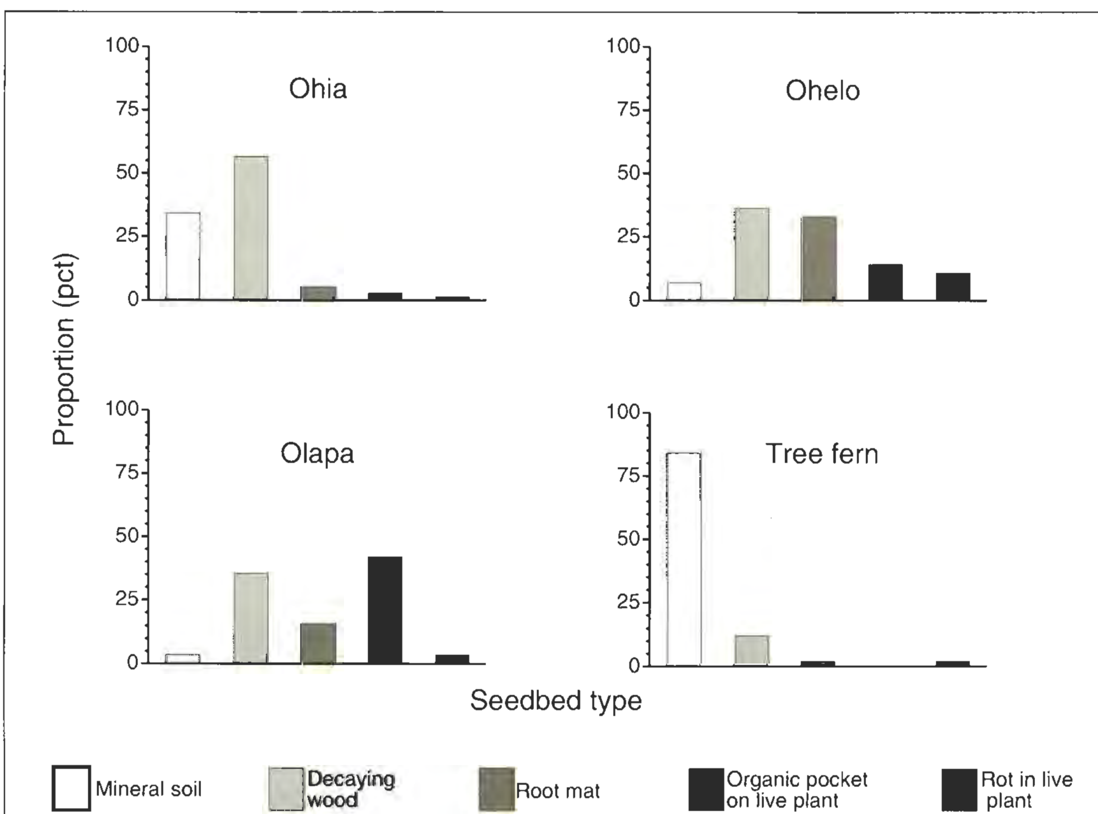

Figure 2—Average proportion of natural regeneration growing in the five different types of seedbeds in 1991, by species. Sample size (n) was 10.

soil. This amounted to an average of 50 ferns per hectare (std. err. = 16). Of the organic seedbeds, decaying logs were the most common sites for establishment of tree fern. But there were only 7 individuals per hectare (std. err. = 3) on decaying logs. No tree fern were observed growing in perched pockets of organic matter.

Height-Seedbed Type Relationships

Mean height of natural regeneration in 1991 was a function of species and seedbed *(fig. 3)*. Ohia seedlings growing in mineral soil averaged 7.8 cm in height (std. err. = 1.2). Those growing in organic seedbeds were more than twice as tall, averaging 20.6 cm (std. err. = 1.0). The difference was statistically significant ($p \leq 0.05$). There was little difference in mean height among the four different types of organic seedbeds.

Olapa seedlings rooted in mineral soil averaged 8.7 cm in height (std. err. = 0.2); those rooted in organic seedbeds averaged 117.3 cm in height (std. err. = 55.8). The difference in height was significant. Moss-covered root mats appeared to be the best seedbed for rapid height growth of olapa seedlings. On that type of seedbed olapa averaged 2.8 m in height. No other species of natural regeneration had attained such tall stature. Variation in height of olapa on root mats was also large (std. err. = 1.7 m).

Height of tree fern was not significantly greater on mineral soil than on organic seedbeds—17.2 cm (std. err. = 1.7) versus 19.6 cm (std. err. = 7.7), respectively *(fig. 3)*. Tree fern, like olapa, was tallest on moss-covered root mats [76.5 cm (std. err. = 42.4)].

The height class distributions for populations rooted in mineral soil were quite different from those rooted in organic seedbeds *(fig. 4)*. I selected ohia, ohelo, and olapa to illustrate this point. For ohia, about an equal number of soil-rooted and organic-rooted seedlings occurred in the smallest height class (0.1 to 9.9 cm). But in all the other classes there were significantly more organic-rooted ohia than soil-rooted ohia. I suspect that recruitment is a continuous process on both types of seedbed, but survival is poor on the mineral soil seedbed because of intense grass competition.

The height class distributions for soil-rooted ohelo were flat *(fig. 4)*. The inverse-J shape common to an actively recruiting, all-age population was absent. There were significantly fewer soil-rooted ohelo than organic-rooted ohelo in all height classes. The distribution for ohelo rooted in organic matter showed active seedling recruitment, and good survival and growth of established plants.

Soil-rooted olapa occurred only in the smallest height class (<9.9 cm). I suspect that recruitment on mineral soil seedbeds occurred slowly, and the seedlings either failed to survive or grew slowly. The distribution for organic seedbeds showed active seedling recruitment, and good survival and growth. I arbitrarily truncated the height class distributions, so those individuals taller than 1.6 m are not shown in *fig. 4*.

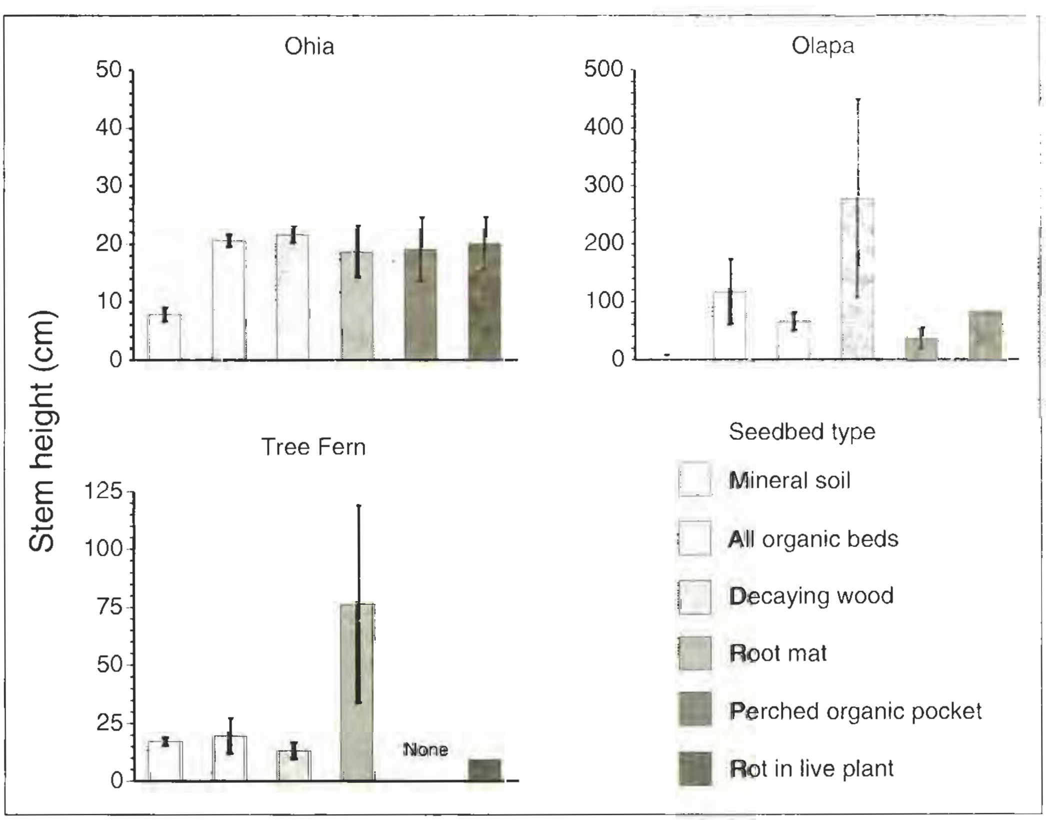

Figure 3—Average height of natural regeneration of ohia, olapa, and tree fern in 1991, by seedbed type. Vertical bars denote standard errors of the mean. Sample size (n) was 10.

Competition and Seedbed Type

A universal feature of mineral soil seedbeds in the woodland exclosure is dense grass cover. Seedlings germinating in the soil would therefore face competition for light, moisture, and nutrients. The grass cover would also affect the soil temperature. Many of the organic seedbeds are free of grass, and hence free of interspecific competition. Whether such competition or the lack of it affects growth and survival of native species in my study site cannot be directly assessed from my data.

Recall the height class distributions for ohia, ohelo, and olapa (*fig. 4*). Little of the regeneration on mineral soil was growing into larger height classes. In contrast, lots of the regeneration on organic beds was apparently growing into larger classes. *Table 3* shows the percentage of plants, by species, that was growing under a grass overstory. A large proportion of the ohia, ohelo, and olapa rooted in mineral soil were grass covered. A smaller proportion rooted in organic matter were grass covered. Could grass competition account for the differences in height class distributions? Additional research will be needed to satisfactorily answer that question.

Table 3—*Percent of plants that were growing under an overstory of grass in 1991, by species and seedbed class*

Species	Mineral soil	Organic beds
	percent	
Ohia	95.4	45.4
Ohelo	63.6	22.8
Olapa	50.0	20.0
Kawau	–	0.0
Pukiawe	100.0	0.0
Koa	92.9	81.9
Tree fern	92.9	66.7
Kolea	100.0	

Discussion

On the basis of my analyses, I concluded that organic seedbeds were important sites for natural regeneration of several but not all native species in the woodland exclosure. It is possible that site factors are primarily responsible for the preference. The natural vegetation of the study area has been drastically modified by humans and cattle—only a scattering of the overstory remains, along with a few remnant individuals of shrub and fern species on elevated logs. Throughout the area, introduced grasses covered the ground to a depth of more than 0.5 m. Light, temperature, and moisture regimes of mineral soil at ground level were no doubt much different from those found in a natural forest. Relative to healthy forests at slightly lower elevation, there were few decaying logs and other organic seedbeds.

Still, some of the seedbed preferences I observed have been noted by others, albeit in habitats quite different from the one in which I worked. Burton and Mueller-Dombois (1984) reported that ohia seedling preferentially established on moss-covered logs and other bryophyte-covered organic seedbeds in an intact

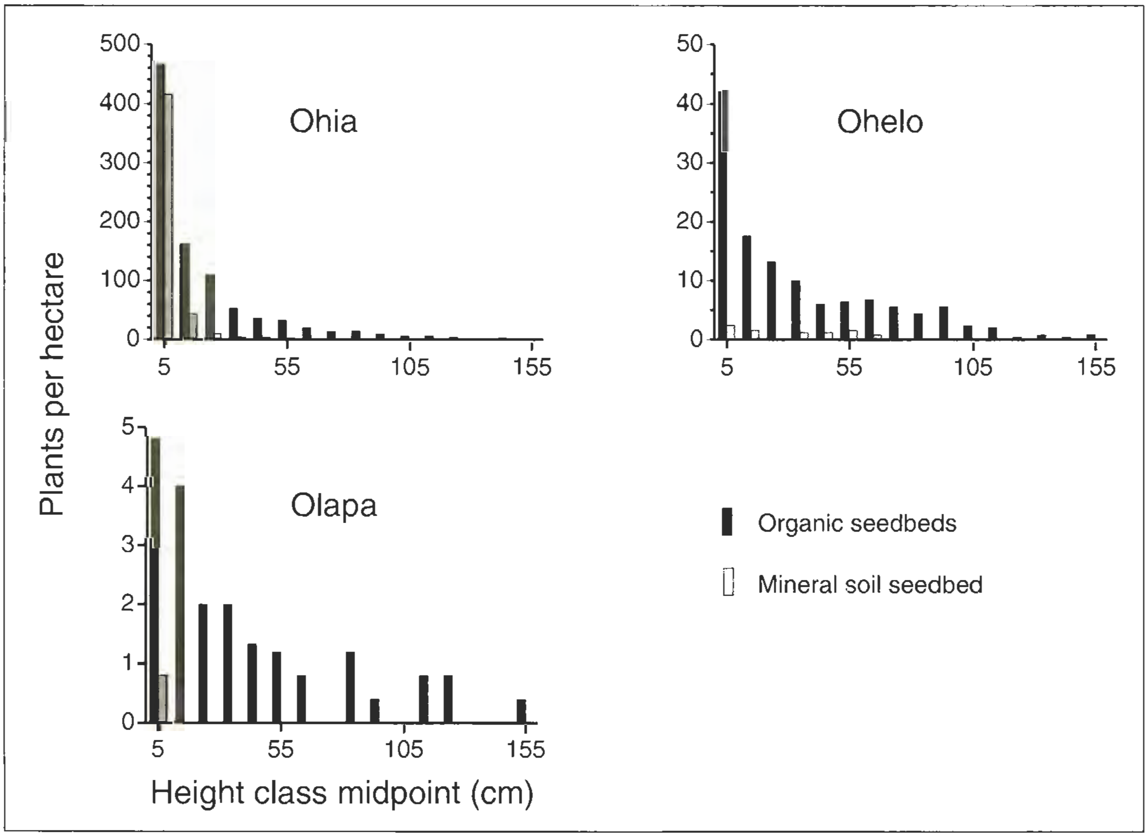

Figure 4—Average number of plants per hectare of exclosure growing in mineral soil and organic seedbeds in 1991, by height class and species. Each height class was 10 cm wide.

wet ohia-tree fern forest. A similar preference was found for other species as well as ohia in an intact mesic ohia-koa forest on Mauna Loa, island of Hawaii (Cooray 1974). There the ratio of log-established trees to soil-established trees was significantly greater ($p \leq 0.01$) than expected on the basis of the ratio of log seedbed area to soil seedbed area, a finding similar to that shown in *fig. 1*.

Two explanations have been offered to account for the preference of some species for organic seedbeds. The explanation heard most often is that logs and other organic seedbeds are elevated out of reach of rooting feral pigs. Such elevated beds thus serve as safe sites for seedling recruitment. There is little doubt that disturbance by pigs is extensive in montane rain forests (Mueller-Dombois and others 1981), and that pig rooting interferes with natural regeneration in general (Diong 1983; Higashino and Stone 1982; Katahira 1980). But studies to date have used unreplicated exclosures, and they have not been designed to test the hypothesis that the preference for organic seedbeds is an artifact of pig rooting in mineral soil seedbeds.

The second explanation is that the temperature and water holding capacity of decaying logs (especially moss-covered ones) and other organic seedbeds are higher than those on mineral soil. These factors are thought to favor seedling establishment on the organic seedbeds (Burton and Mueller-Dombois 1984). Burton (1982) found that as temperature decreased below 20°C, germination of ohia seeds declined sharply. Under low light levels, which are common in closed canopy rain forests, germination ceased at about 12°C.

In the present study, pigs were not a factor. So the first explanation does not apply. The second explanation, however, bears closer examination. Air temperatures in the vicinity of the exclosure are generally below 15°C. At 10 cm depth beneath dense grass, soil temperatures average 17°C. I do not have data for the temperature of the soil surface under a dense stand of grasses, but I suspect it is close to the air temperature. At these temperatures germination could well be inhibited. The surfaces of logs are generally elevated above the grass, and exposed to higher solar radiation than the soil surface. Their surface temperature could be higher than at ground level.

I have no data comparing moisture holding capacity and moisture depletion curves of soil and organic seedbeds. I assume, however, that while the dense stands of grass inhibit evaporation from soil surfaces, they promote soil drying by transpiration. On the other hand, although decaying logs may not undergo large losses of water through transpiration, they are exposed to evaporative losses. The question of water relations of organic versus grass-covered mineral soil needs to be explored.

Light levels at the soil surface under grass are probably very low, perhaps even lower than under a closed canopy native forest. Such low light levels may not inhibit germination, but they could reduce growth and survival. My data showed that ohia less than 10 cm in height were just as abundant in mineral soil as in organic material. But relatively few seedlings on mineral soil grew into the larger height classes. Low light could be a factor, especially if coupled with low temperature and low moisture availability.

Management Implications

Before considering the management implications of these findings, I need to sound a note of caution. This study is unreplicated. No data exist that will allow me to assess variability of natural regeneration over the range of woodland sites present in the Hakalau Forest National Wildlife Refuge, much less extrapolate to other abandoned pasture lands located elsewhere on the island of Hawaii or in the State. This study did not address the issue of regeneration dynamics as a function of proximity of seed sources, means of seed dispersal, or any other factor associated with seed rain and seed storage. Thus, the following comments are subjective and speculative.

What are the implications of these findings for managers faced with the difficult task of restoring native forest to abandoned pasture lands? First, managers should realize that recolonization of sites devoid of organic seedbeds probably will be slow for some species, even assuming that seed rain is not limiting. Extensive areas of open pasture land on Mauna Kea lack organic seedbeds because of natural decay, fire, harvesting, etc. If a manager wants or needs to rely on natural regeneration in such areas, then organic seedbeds will have to be created. Fast-decaying or partially decayed organic matter (logs, hapuu trunks, bagasse, etc.) could be brought on site but would be costly. Furthermore, the probability of success is unknown. No studies have been done to determine if artificially created organic seedbeds would stimulate natural regeneration of the desired species.

Second, given the anticipated high cost of creating organic seedbeds and the uncertainty of success, managers may decide to rely on artificial regeneration to restock sites with species such as olapa. Such a decision has its own set of unknowns. Will the species establish at all in mineral soil, or does it still require organic matter in which to root? How well does it compete with pasture grasses? Does it require shade? What are the costs of getting plants established in the field? These and other questions need to be answered before artificial regeneration can be adopted for widespread use.

Third, these findings should remind managers that logs and other coarse woody debris are not undesirable waste or trash to be disposed of quickly and efficiently. Not only are they important as sites for natural plant regeneration, but they also perform other ecosystem level roles—nutrient reservoirs, energy sources for microorganisms, water reservoirs, homes for forest invertebrates, and soil-stabilizing structures. Thus, whether managers are trying to rehabilitate degraded forest land or to manage intact forests, coarse organic material needs to be recognized as an important component of ecosystem structure and function.

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Use Classification of Mangrove Areas, Pohnpei, Federated States of Micronesia[1]

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Abstract: An integrated biotic inventory of mangrove areas of Pohnpei, Federated States of Micronesia, was undertaken to determine priority areas for preservation and sustained-yield management. Criteria for the designation of reserve areas included: the presence of threatened or endangered species; rare species or particularly rich biota; undisturbed old-growth communities; the need to maintain intact mangrove to protect biotic resources from excessive wave action or sedimentation; or similarly, to protect cultural and economic resources; areas of high fisheries or forestry productivity; timber stocking, and proximity to wood-consuming businesses or other infrastructure. Standard forest inventory plots consisting of five sample points distributed over 1.4 ha were placed at random throughout the mangrove to describe stand composition and stocking and to estimate the area of mangrove forest exploited and the amounts and types of products removed. Results of studies to date and recommendations for reserves are reported.

At the request of the state government of Pohnpei, one of the four states of the Federated States of Micronesia, an assessment of the mangrove resource on the main island of Pohnpei was undertaken to determine priority areas for preservation and for sustained-yield management. Components of the study included: estimation of the standing volume of mangrove timber by species and size class, assessment of the exploitation of mangrove wood and wildlife products, and estimation of pressure on mangrove areas for uses other than forest. Data on these components and on additional ground and aerial photo surveys have been combined to assign use categories to all mangrove areas. This paper provides an overview of the on-going study and reports preliminary results and recommendations.

Pohnpei is a high volcanic island in the Eastern Caroline Islands (6°54' N, 158°14' E), approximately 4,983 km southwest of Hawaii (*fig. 1*). It is roughly circular with a diameter of about 23 km and a total area of about 35,488 ha, 16 percent of which is mangrove forest. The mean annual temperature on the coast in Kolonia, the capital, is 27°C, and mean annual rainfall is 4,820 mm. Temperatures vary little, but rainfall shows slight seasonality; January and February are drier than the average month (MacLean and others 1986). The main island of Pohnpei, where this study was done, consists of five municipalities (Nett, Uh, Madolenihmw, Kitti, and Sokehs) plus the capital city.

The vegetation of Pohnpei was described and mapped by MacLean and others (1986). The area of Pohnpei mangrove was estimated to be 5,525 ha, with 5,290 ha capable of commercial timber production. A forest inventory based upon the vegetation mapping estimated that Pohnpei had 403,000 m^3 of standing mangrove timber (MacLean and others 1988). Only four plots in this region-wide inventory were in the Pohnpei mangrove. In order to provide more reliable and detailed estimates of mangrove timber volumes on Pohnpei, an additional study with 77 plots was undertaken. This study (Petteys and others 1986) estimated total mangrove volume at 698,380 m^3; it differed from the first study in that measurements were not reduced for poor form or rot, no fixed plot data were included, each plot contained only one rather than five sample points, and the plots were not permanently installed. The second study reduced the estimated area of mangrove timberland to 4,855 ha.

Pohnpei has a significant mangrove timbershed; however, several factors suggest that if conservation measures are not taken now, the best of the resource may be lost. Mangroves are under constant development pressure because they occur in coastal and estuarine areas, also centers of human settlement (Lal 1990). This is true worldwide, but especially so on islands such as Pohnpei where flat land is extremely scarce. Pohnpei's population has grown rapidly since 1950 (*fig. 2*) and currently has an annual growth rate of around three percent. Because 46 percent of the population was less than 15 years of age in 1985 (Federated States of Micronesia 1988), this growth rate is expected to increase through 2000, even though the fertility rate is declining.

The population grows, and so do individual material expectations. Per capita consumption of manufactured goods such as televisions, video cassette recorders (VCRs), and motor vehicles (*fig. 3*) continues to increase (Pohnpei State 1990). In the absence of data on Gross National Product, the growth of the general fund of Pohnpei State, which increased from $12,742,800 in 1984 to $17,653,800 in 1989, perhaps indicates the accelerating pace of economic activity. More people, consuming and producing more than previous generations, are placing ever-increasing demands on the resource base. Mangrove forests are particularly subject to increased use pressures in the areas of fisheries; timber for construction, furniture, fuel, posts, poles, and other small-dimension lumber and craftwood; and for alternative uses of the land itself. These forests have been and are disturbed by road-building, dredging, waste-dumping and the construction of homes, marinas, and other structures. These uses are expected to intensify with the expanding population and economic activity, especially tourism.

Planning and allocation may enable Pohnpei to conserve representative areas of the mangrove ecosystem, and provide for the sustained production of all commodities traditionally obtained from mangroves. The first objective of this study was to place all mangrove areas into one of three broad use categories: (a) preservation, (b) sustainable use and, (c) general-use areas not specifically reserved for (a) or (b). Criteria in the assignment of use categories were (1) presence of endangered or threatened species, rare species or particularly rich biota, and undisturbed,

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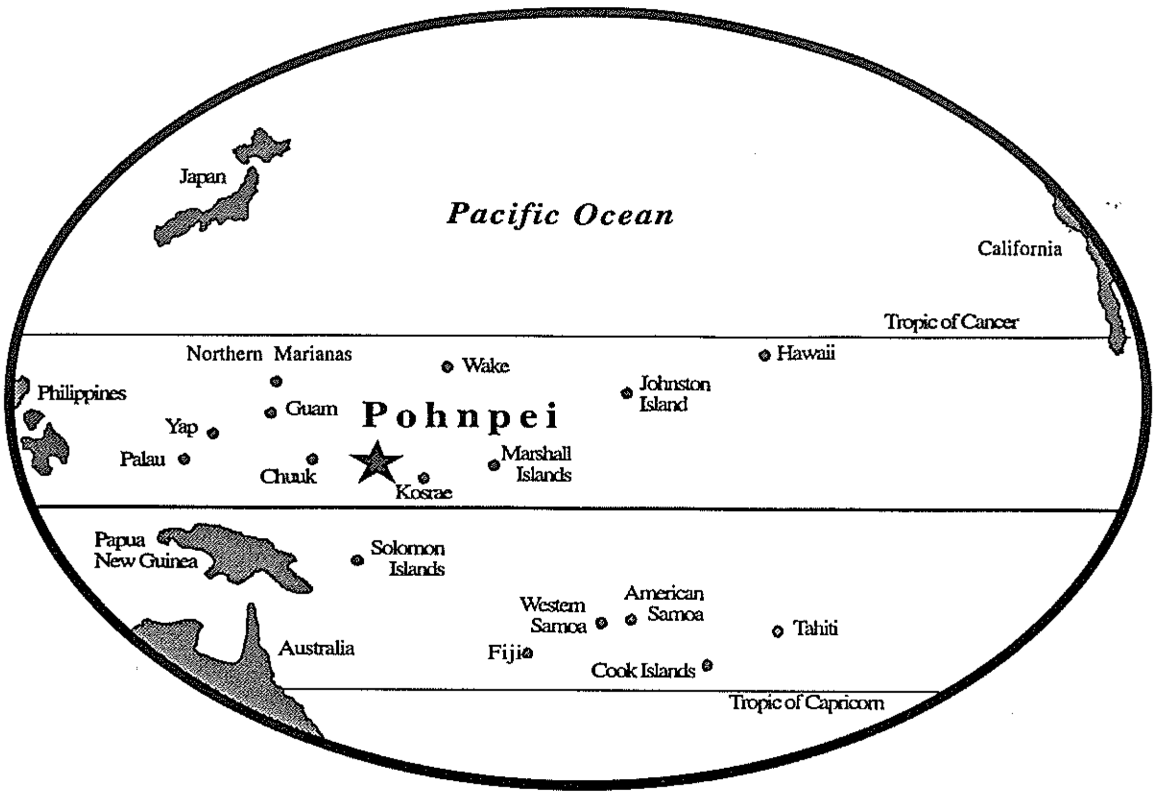

Figure 1—Location of Pohnpei, Federated States of Micronesia. Pohnpei lies at 6°54' north latitude, 158°14' east longitude.

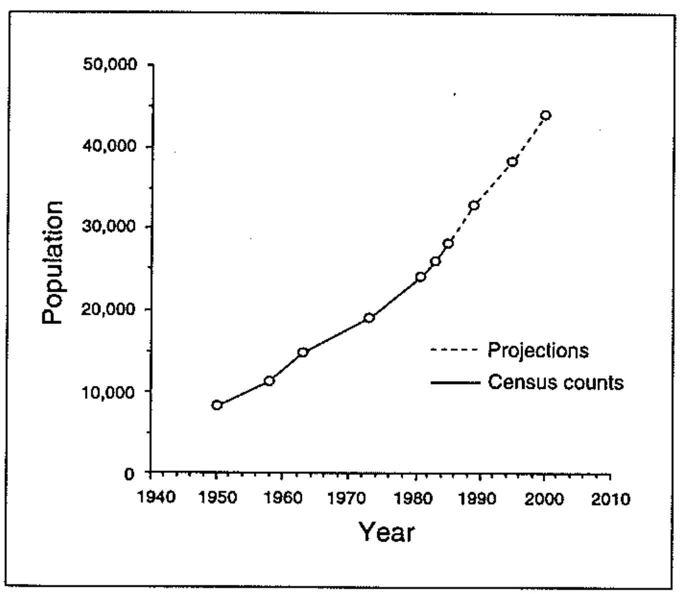

Figure 2—Population of Pohnpei since 1950 (Pohnpei State Government 1986, 1990; Federated States of Micronesia 1988). The projections shown are the lowest from the range given in the Pohnpei State 1985 Census Report (Federated States of Micronesia 1988).

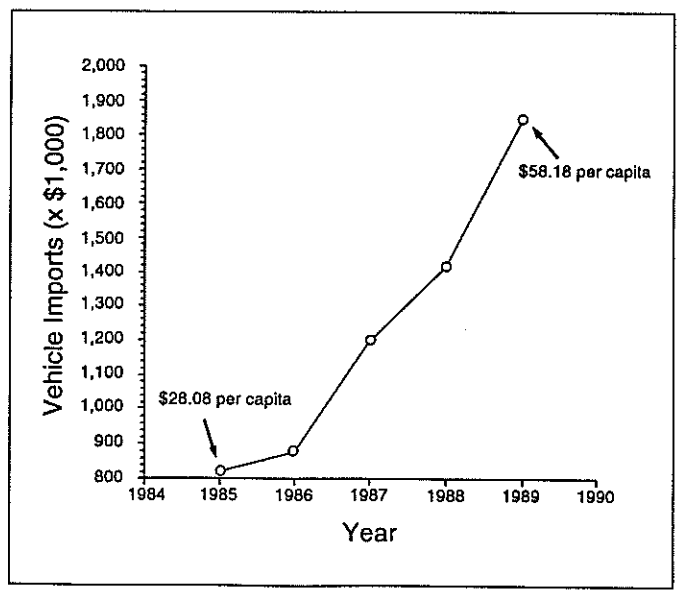

Figure 3—Cost of automobile imports to Pohnpei from Japan and the United States (Pohnpei State Government 1990).

old-growth communities; (2) the need to maintain intact mangrove to protect biotic resources from excessive wave action or sediments, or similarly, to protect cultural and economic resources; (3) presence of fisheries or forests of high productivity, (4) amount of timber stocking and (5) proximity to processing installations and other infrastructure.

Methods

Forest Inventory

The present inventory differs from previous ones in that exploitation is estimated by tallying stumps in addition to standing timber stock; cull is reduced from the volume estimate, and all mangrove areas, even dwarf stands, are included.

Plots were selected on a square grid using a random start. Grid intersections falling within areas mapped as mangrove were selected as field plots. Selected grid points were pinpricked on aerial photographs and located on the ground. Plots were permanently referenced for future remeasurement. For each plot, a cluster of five sample points was established, with the points distributed over approximately 1.4 ha in a standard USDA Forest Service inventory plot (*fig. 4*). Two samples were taken at each point. The first sample included all trees greater than 2.4 cm and less than 12.5 cm diameter at breast height (d.b.h.) within 2.36 m of point center. The fixed plot sample picked up stocking, growth and regeneration data on smaller trees not measured in the second sample. The second sample was a variable radius plot of all trees within the limiting distance of a metric basal area factor-seven prism (USDA Forest Service 1983).

Species, d.b.h., total height, bark thickness, crown ratio, crown class, azimuth, and distance from point center were recorded for all trees. Each tree greater than 12.4 cm d.b.h. was visually divided into logical segments, and end diameters of these segments were measured or estimated. The segments were then classified as either sawtimber, poletimber, craftwood bolts, crotches, branches, or upper stems. Defective segments were identified as cull.

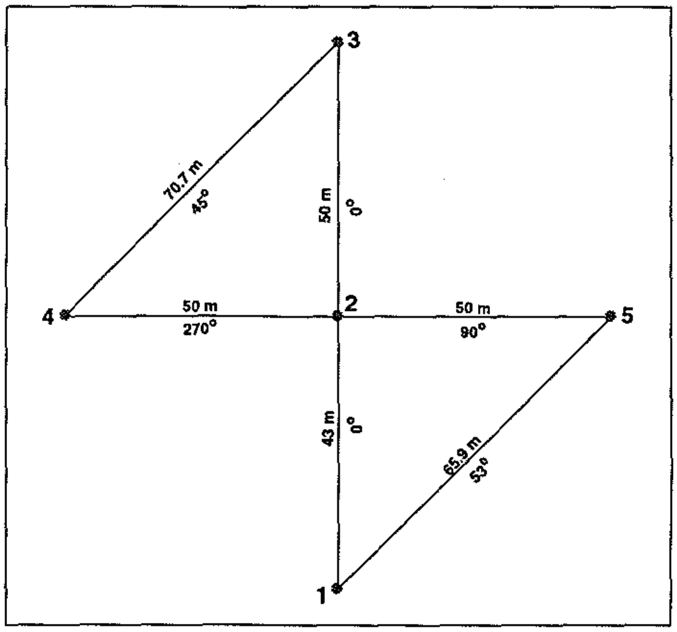

Figure 4—Standard USDA Forest Service plot layout. The sample points are numbered 1, 2, 3, 4, and 5. The distances between the points and the bearings by which they are reached are shown.

MacLean and others (1986) categorized mangrove stands as either:

MN0–trees of small stature with average d.b.h. less than 12.0 cm,
MN1–trees generally between 12.1 and 30.0 cm d.b.h., or
MN2–trees with average d.b.h. greater than 30.0 cm.

Estimated areas of each of these strata were taken from MacLean and others (1986), thus providing a means of expanding plot data from the per hectare level to the stratum and island level. Data from the field tallies were analyzed with an inventory program developed at the USDA Forest Service Pacific Northwest Research Station. Ground reconnaissance of randomly chosen transects in areas not inventoried was used to assess presence of rare or unusual plant species. Areas identified as old growth from aerial photographs were field-checked.

Timber Cutting Permits and Sawmill Survey

Both the State of Pohnpei and the individual municipalities claim legal authority to regulate mangrove exploitation (relevant legislation outlined in *Appendix*). This jurisdictional dispute aside, municipalities established permit requirements for exploitation, which vary by municipality. Permits were examined to see whether their numbers, types, and costs would provide information on the volume of timber removed, the number of persons involved in exploiting mangrove wood, or the revenues returned to the municipalities from these permits. Another attempt to estimate harvesting independently of the forest inventory was made by canvassing sawmills on Pohnpei.

Demand for Non-forest Use of Mangrove Areas

Land sought for conversion was estimated by reviewing applications for filling and building permits for mangrove areas filed with the Pohnpei State Department of Lands between 1985 and 1991.

Results

Forest Inventory: Standing Timber and Exploited Volume

The inventory was designed to estimate the average stocking (m^3/ha) by stratum within 20 percent of its true value at the 82 percent probability level for the MN1 stratum and at the 95 percent probability level for the MN2 stratum. Based on coefficients of variation derived from the first four plots taken in each stratum (61 percent for the MN1 stratum and 42 percent for the MN2 stratum), 21 plots were required in the MN1 stratum and 17 plots in the MN2 (Dilworth 1970). The results presented here are based only on 7 MN1 and 8 MN2 plots.

Projections of total volume based on these preliminary data (*table 1*) are about 40 percent higher than values found in the

Table 1—*Mangrove net volume by segment and stratum*

Stratum[1]	Roughwood	Sawlog	Bolt	Branch	Pole	Inside bark total	Outside bark total
MN0	3,328	0	0	7,179	32,187	42,713	58,939
MN1	80,434	62,235	26,636	30,010	125,292	324,716	418,429
MN2	104,830	326,843	25,298	35,858	95,527	588,269	703,539
Total	188,592	389,078	51,934	73,047	253,006	955,698	1,180,905

[1] MN0 Trees of small stature with average diameter at breast height (dbh) less than 12.0 cm
MN1 Trees generally between 12.1 and 30.0 cm dbh
MN2 Trees with average dbh greater than 30.0 cm

previous inventory (Petteys and others 1986). This is probably due to a bias created by the order in which the plots in this study were installed. Because the first objective was to evaluate areas already identified from other reconnaissance as having the highest values for preservation and management, the plots that fell in these areas were installed first. No conclusions can be drawn from these data until the entire sample is taken.

However, these data do suggest some noteworthy trends. The range of volumes per hectare is larger than previously thought, with more variation in site quality and stand response than has been noted before or elsewhere in mangroves. Although stem dimensions are generally quite small, the MN0 stratum is densely stocked and standing basal area is nearly the same as that in the MN1 stratum. Useful products do come from the dwarf mangrove (*table 2*), and among other things, it represents a significant carbon store.

Species tallied were (nomenclature after Fosberg and others 1979):

Bruguiera gymnorhiza (L.) Lam.	Rhizophoraceae
Lumnitzera littorea (Jack) Voigt	Combretaceae
Rhizophora apiculata Bl.	Rhizophoraceae
Rhizophora mucronata Lam.	Rhizophoraceae
Sonneratia alba J.E. Smith	Sonneratiaceae
Xylocarpus granatum Koen	Meliaceae
Heritiera littoralis Dryand	Sterculiaceae

Table 2—*Average net volume in m³ and international board feet (IBF), quadratic mean diameter (QMD), and basal area per hectare (BAPH) by stratum and species*

Species[1]	Inside bark Roughwood	Sawlog	Bolt	Branch	Pole	Total	Outside bark Total	IBF	QMD	BAPH	Stump BAPH
	m^3								*cm*	m^2/ha	m^2/ha
Stratum MN0											
BR GY	.0	.0	.0	.0	.0	.0	.0	.0	.00	.11	.00
LU LI	6.1	.0	.0	11.4	53.9	71.4	101.5	.0	16.70	22.92	4.48
RH AP	.6	.0	.0	3.0	10.7	14.4	16.8	.0	14.49	4.14	.00
RH MU	.0	.0	.0	.0	.0	.0	.0	.0	.00	1.78	.00
SO AL	.0	.0	.0	.0	.0	.0	.0	.0	.00	2.15	.00
Total	**6.7**	**.0**	**.0**	**14.4**	**64.6**	**85.8**	**118.4**	**.0**	**16.41**	**31.10**	**4.48**
Stratum MN1											
BR GY	8.0	6.3	1.5	5.2	21.6	42.8	61.0	872.3	21.62	12.98	.73
RH AP	1.8	4.0	.0	.8	19.9	26.5	35.2	559.7	20.47	6.36	.00
RH MU	1.2	.0	.3	.4	7.6	9.4	13.2	.0	16.71	3.25	.00
SO AL	8.8	11.9	.5	.9	5.2	27.2	33.6	1,715.8	32.92	4.90	.00
XY GR	13.6	1.6	6.7	3.3	7.9	33.1	6.7	193.2	21.13	5.22	.23
Total	**33.3**	**23.7**	**9.0**	**10.6**	**62.3**	**138.9**	**179.7**	**3,341.0**	**21.72**	**32.71**	**.96**
Stratum MN2											
BR GY	14.8	23.9	.8	4.2	12.5	56.2	73.1	3,380.8	28.14	10.69	.35
HE LI	.0	.0	.0	.1	1.3	1.4	1.5	.0	.00	.31	.00
RH AP	6.3	22.2	1.0	2.9	11.8	44.3	52.8	3,527.0	27.98	5.41	.17
RH MU	2.3	.8	.0	.8	5.6	9.3	12.1	33.7	20.32	2.09	.00
SO AL	14.5	52.4	4.8	3.1	1.3	76.1	88.9	7,540.6	59.65	10.32	.00
XY GR	8.5	33.5	3.4	3.0	3.7	52.1	57.1	4,715.5	44.44	6.87	1.95
Total	**46.4**	**132.8**	**10.1**	**14.0**	**36.2**	**239.5**	**285.6**	**19,197.5**	**33.99**	**35.69**	**2.47**

[1] BR GY = *Bruguiera gymnorhiza*; LU LI = *Lumnitzera littorea*; RH AP = *Rhizophora apiculata*; RH MU = *Rhizophora mucronata*; SO AL = *Sonneratia alba*; HE LI = *Heritiera littoralis*; XY GR = *Xylocarpus granatum*.

Heritiera littoralis is found in the transition zone between the agroforest or lowland forest and the mangrove; the others are true mangrove species occurring only in the mangrove.

The species with the majority of volume varies by stratum (*table 2*). The volume summations are only for growing stock trees, which have d.b.h. greater than 12.4 cm. The results for the MN0 stratum are thereby distorted, because the very small but numerous stems of *Rhizophora mucronata* and *R. apiculata* do not enter the calculation. *Lumnitzera littorea* dominated because only the largest trees were considered; *R. apiculata* followed. *Lumnitzera littorea* was found in this sample only in stratum MN0. The species occurs outside the dwarf mangrove, but most of the large dimension *Lumnitzera*, Pohnpei's most valuable mangrove species, has been logged. None of the inventory plots fell in the cut-over areas. Replacing this population and stewarding what is left are high priorities for the Pohnpei forest management program. In the MN1 stratum, *Bruguiera gymnorhiza* had the highest volume. In the MN2 stratum, *Sonneratia alba* predominated.

As can be seen in *table 2*, *Lumnitzera littorea* is harvested even as small stems. Commercial harvesting accounted for most of the exploited volume, with stump basal area nearly 20 percent of the standing basal area/ha. Stump basal area/ha was 28 percent of standing basal area/ha for *Xylocarpus granatum* in the largest size classes. *Xylocarpus granatum* is a high-value wood; branchwood is carved into handicrafts while larger stems are sawn for cabinetry, flooring, and other interior construction. Harvesting in the pole timber sizes was mostly *Bruguiera gymnorhiza* (stump basal area/ha about six percent of standing basal area/ha) and *Rhizophora apiculata* (stump basal area/ha approximately three percent of standing basal area/ha). Cutting of these species as pole-sized stems is almost certainly subsistence extraction for house timbers. Smaller stems of these species are also taken on a subsistence basis for uses such as fence posts.

Timber Cutting Permits and Sawmill Survey

Kolonia does not regulate mangrove exploitation. Uh kept no records. Madolenihmw had eight records on file for the period February 1987 through January 1991 for which a total of $634 was collected, $500 of which was a permit for a commercial sawmill. By contrast, Nett had 10 records on file for the period October 1990 through February 1991 for which a total of $10 was collected. Kitti had 48 records on file for the period August 1990 through May 1991. Five of these 48 records were from persons who had already held at least one permit. Kitti records included the location of the requested harvest; the number of days for which the permit was valid; and for 10 of the records, the number of trees taken. These 10 records summed to 1,240 trees. Two hundred dollars was collected; most of the permittees were not charged. Only two of the permit requests filed in Kitti could be for commercial purposes (the data are not explicit), and these are for 100 trees or less. It is often said but not documented that virtually all the mangrove timber now being sawn on Pohnpei is coming from Kitti; the implication is that the municipality is not capturing all the revenue to which it is entitled.

Sokehs had 384 permit applications on file for the period October 1985 through March 1991; these generated $1419 for the municipality. There were two gaps in the holdings, the last months of 1989 and February-May 1990. The records indicate that most of the exploitation in Sokehs is by woodcarvers from Kolonia who sell their handicrafts to tourists. Firewood cutting was a close second, most of the requestors also residing in Kolonia. Approximately 50 percent of the permit applications filed during this period were from persons who had already held at least one permit. Because of proximity to Kolonia, activity in Sokehs cannot be taken as representative of the whole of Pohnpei. The Sokehs permits allow unlimited cutting for three days, so it is unknown what wood volume they represent.

Records from defunct sawmills were unavailable. Among operating mills, only one acknowledged that records of sawn volume were kept. This mill was involved in building a controversial tourist facility and so refused to disclose any records. In the course of the canvassing, it was learned that the first sawmill began operation on Pohnpei in 1942. In 1952, a second mill started up and both operated through 1972. One closed and two new ones were established in 1973; three mills were sawing through 1975. In 1976, one of the mills started in 1973 closed. By 1985, four mills were operating, one intermittently. Two closed the following year. A new mill opened in 1988, and three mills have continued to function, two intermittently, since then. It is noteworthy that so few permits for commercial milling are on file while three mills are operating on this small island. Other wood-consumers include furniture makers and a soap factory; I have no estimates of their consumption.

Demand for Non-forest Use of Mangrove Areas

From 1985 through 1990, at least 62 applications for development of mangrove areas were filed with Pohnpei State Department of Lands (*table 3*). Because of the disorder of the records and gaps in the holdings, these data appeared incomplete. Of the 62 permit requests on file, 57 were granted. Most of the requests were for the filling of the swamp and building or expansion of residential facilities on what is legally public land. Only three public works projects were officially sited in the mangrove. Of the 57 approved applications, 13 were for unspecified amounts of land. The total area explicitly approved for conversion was approximately 10 ha; the actual amount may have been much higher. Most of the requests on file were from municipalities with the least land; Uh with 24 percent of the permit applications, 6 percent of the total land area, and 9 percent of the population; and Sokehs with 47 percent of the permit applications, 12 percent of the land area and 18 percent of the population (Pohnpei State 1986). Much of the land in Sokehs is too steep for any form of development.

Data from building and filling permits are too sketchy to reflect actual land use pressure. Viewed from the circumferential road, recent encroachment appears to be considerably greater than 10 ha. Mangroves are a popular location for piggeries and outhouses, presumably because tides flush the areas. In addition to the existing, unpermitted conversion, there are plans afoot for developments that would destroy extensive mangrove tracts. One of these is a 500-bedroom hotel proposed for Nett.

Table 3—*Applications for filling and building in mangrove forest filed with the Pohnpei State Department of Lands 1985-1990*

Municipality	Applications denied	Area in each (total) m^2	Applications approved	Area in each (total) m^2	Total area approved for conversion *ha*
Uh	None	0	11 Resi[1]	50,454	
			1 Resi	unspec	
			2 Comm	4,500	5.53
			1 Public	334	plus unspec
Sokehs	2 Resi	745	20 Resi	20,967	
			4 Resi	unspec	
			2 Comm	711	2.60
			1 Public	4,500	plus unspec
Nett	1 Comm	7,607	1 Resi	2,500	
			1 Public	2,322	0.48
Madolenihmw	None	0	3 Resi	1,620	0.16
			3 Resi	unspec	plus unspec
Kitti	None	0	None	0	0
Kolonia	2 Resi	1,640	1 Resi	520	
			5 Resi	unspec	0.78
			1 Public	7,333	plus unspec

[1]Resi = Residential, Comm = Commercial, unspec = unspecified

I continue to measure (through sampling) current and past exploitation in the mangrove as one estimate of the demands on the resource. Since some desired uses will have been frustrated (i.e., cutting and building permit requests that were discouraged before an application was filed), demand must be underestimated. I anticipate that increasing demand will at least parallel expanding population; probably, demand will accelerate faster than population due to increased economic activity.

Discussion

Holthus (1987) listed the prohibition of clear cutting on the lagoon side of mangrove forests and in areas where the mangrove strip is less than 250 m wide as the highest priority management intervention for the protection of coastal resources. Ecological services of mangroves include: protection of coastline and infrastructure from the action of wind and waves; filtration of upland sediment, thereby protecting lagoon and reef systems; critical habitat for larval and juvenile fish; habitat for other wildlife, especially birds, and conservation of germplasm.

Preservation and conservation measures are necessary now. While the filling and building permit applications suggest that little mangrove is legally converted to other uses, field reconnaissance indicates that the active degradation of mangrove is extensive. Known clearcuts apart from those for development total only about 150 ha, but of all the mangrove covered on foot during 1990 and 1991, not a single site was without evident harvesting.

According to the US Fish and Wildlife Service (Herbst and Engbring 1991), no plant species are listed as threatened or endangered from the Pohnpei mangrove, nor are the mangroves critical habitat for any threatened or endangered species. However, old-growth stands are prime habitat for a number of seabirds and for the fruit bat *(Pteropus mariannus)*. The USDA Forest Service recently sponsored a study of epiphytes in the mangrove that found a number of taxa not previously described; it is not yet known how widespread these are. For the tree component, there are no rare species or unusual assemblages in the Pohnpei mangrove. The remaining criteria for assigning use categories (see Introduction) remained operational at the close of this assessment.

Recommended Sites for Preservation and Management

The following categories are proposed to designate reserve areas:

A. Preserve: access severely restricted. Uses limited to protective functions, wildlife habitat, and non-manipulative research.

B. Sustainable Use: Class 1 Parks. Access unlimited, activities restricted: No timber harvesting; hunting and fishing by permit only.

B. Sustainable Use: Class 2 Demonstration and Production Forest. Access unlimited, activities restricted. Forest management to be conducted by Pohnpei State Division of Forestry; harvesting of marked timber by permit (subsistence) or concession (commercial) granted by the Division of Forestry; hunting and fishing by permit only.

A well-designed reserve system generally includes core areas that are strict nature preserves where no anthropocentric influence is allowed. Surrounding core areas are zones designated for uses of varying intensities, with the least intensive uses contiguous with the core area.

The following 11 sites, totalling 1915 ha or 35 percent of the total mangrove area, are suggested as those most important to include (*fig. 5*). Category A accounts for 434 ha, category B1 for 176 ha, and category B2 for 1305 ha. The area within either preserves or reserves is limited to what can optimistically be protected and in some cases, managed, to maximize benefits to society. The features referred to below can be seen clearly on the U.S. Geological Survey 1:25,000 topographic maps of Pohnpei (U.S. Geological Survey 1983).

1. *Dausokele, Nett.* Category A. 30 ha MN2, 18.5 ha MN1. This reserve should include all land along the Dausokele, especially the area south of the circumferential road and north of Pilen Sepeipei. This area is sought primarily for maintenance of aquatic habitat and water quality. The mangrove also protects an important taro cultivation area.

2. *Parempei Island, Nett.* Category A. 20 ha MN2, 26 ha MN1/0; Category B2. 41 ha MN1/0. The core area contains some of the oldest and least disturbed dwarf and MN1 mangrove on Pohnpei; the production forest borders it on the south.The reserve is desired to preserve this valuable community and to

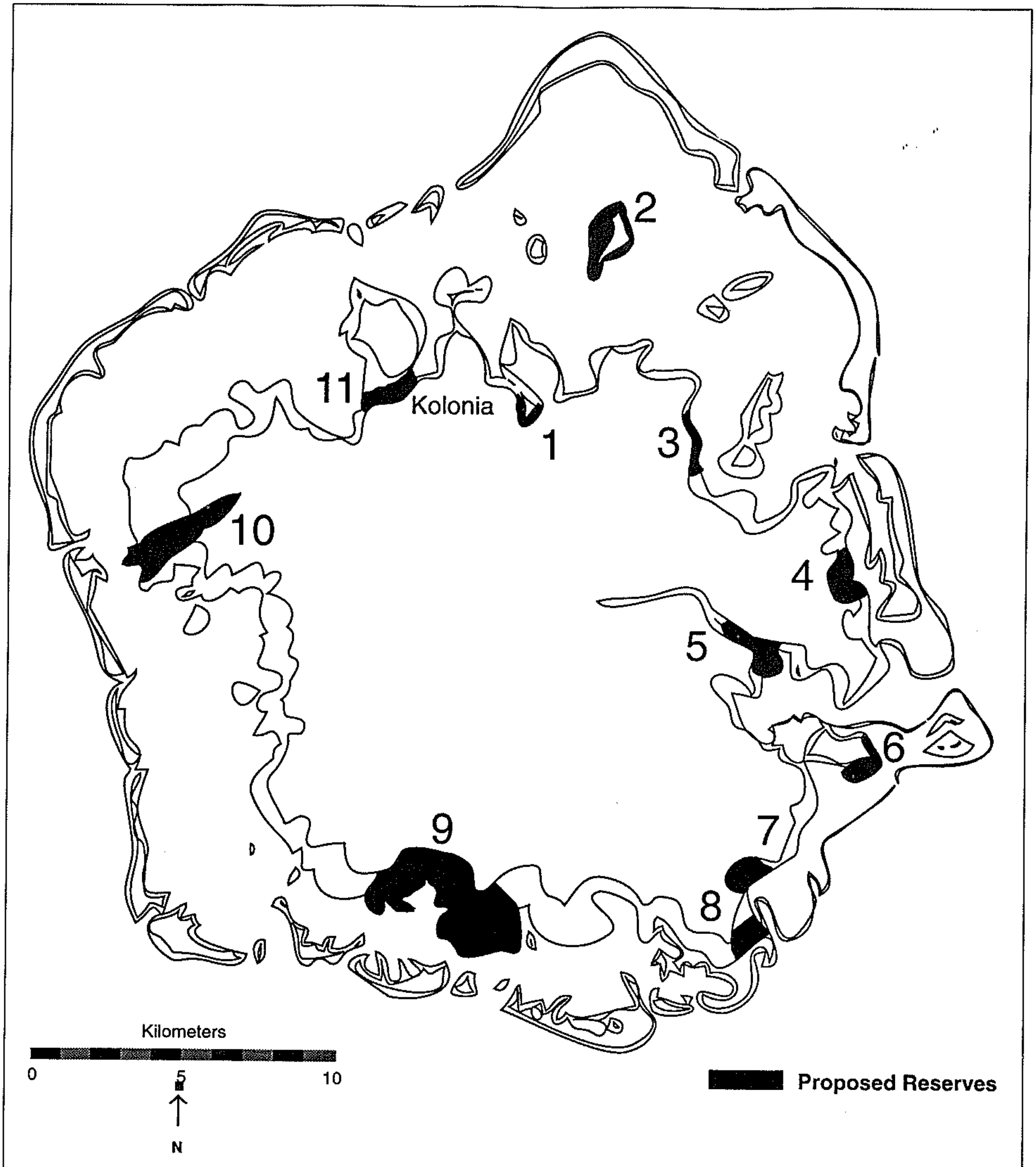

Figure 5—Darkened areas represent proposed mangrove reserves, Pohnpei, Federated States of Micronesia: (1) Dausokele, Nett; (2) Parempei Island, Nett; (3) from Nansalohi to channel north of Maramosok, Uh; (4) from the Lamahi to the Dien Outcrop, Madolenihmw; (5) Dauen Sapwalap, Madolenihmw; (6) Nan Madol, Madolenihmw; (7) land between Pilen Kihlid/Dauen Wapar and Dauen Lohd, Madolenihmw; (8) land between Kepindau Pohnahtik and Nan Diadi, Madolenihmw; (9) land between Dauen Semwei and Dauen Rakis, Enpein, Kitti; (10) Dauen Soundau, Sokehs; and (11) Dau Mwoakote, Sokehs. The island is surrounded by a barrier reef.

safeguard the health of Parempei Island's fringing reef and the barrier reef surrounding Pohnpei. The interior of Parempei is high and extremely steep, especially on the north side; without complete mangrove cover, water-borne sediments would quickly silt the near-shore corals. Parempei and surrounding waters were proposed as a marine park (Holthus 1987) and described as especially rich in octopus (U.S. Army Corps of Engineers 1985).

The production forest is necessary to provide for the material needs of the small Parempei Island population. If the reserve is well-managed, all the house timbers, posts, and poles required can be supplied from a relatively small area. Parempei would be an excellent site to begin intensive forest management because of the small user population, absence of commercial use pressure, and relative ease of controlling access.

3. *From Nansalohi to channel north of Maramosok, Uh.* Category A. 42 ha MN2. A considerable volume of fresh water of upland origin drains through this mangrove through two rivers and a host of smaller streams. Water moves from the extreme slopes of the crest at the Nett-Uh boundary at high velocities during storm events. Because vegetation has been greatly reduced on the east-facing slopes, the sediment load is probably high. This mangrove should be preserved to protect water quality. The forest has been "picked over" for various products but is a well-developed old-growth area interesting in its own right. U.S. Army Corps of Engineers (1985) identified this area as important habitat for the mangrove crab. Much of the mangrove on the lagoon side of the circumferential road through Uh has been severely degraded; it is recommended that action be taken immediately to protect this section.

4. *From the Lamahi to the Dien Outcrop, Madolenihmw.* Category A. 44.5 ha MN2; Category B2. 57 ha MN1, 17 ha MN0. This preserve area is sought for some of least-disturbed old-growth MN2 on the eastern side of Pohnpei, with a management area to surround and buffer the core area. Forest manipulation should be confined to the landward side of the reserve in order to protect a highly productive reef fishery; this area was also identified as important habitat for the mangrove crab (U.S. Army Corps of Engineers 1985). Low use pressure in the locale suggests that this reserve should be relatively easy to protect. Some timber of suitable dimensions might be available from this reserve to feed the two sawmills in Nett.

5. *Dauen Sapwalap, Madolenihmw.* Category A. 30 ha MN2, Category B2. 43 ha MN1. Much of this area was logged during the Japanese era; the best and least-accessible stands should be preserved in a core area. The tallest and largest mangrove on the island is here. High forest productivity is inferred from the existing stand, topography, and substrate. The reserve should be between the mouth of the Sekereriau and Wetiak channels, easy features to find on the ground. This reserve could contribute feedstock to the mills in Nett and to the Ponape Coconut Products soap factory (thinnings).

6. *Nan Madol, Madolenihmw.* Category B1. 13 ha. Nan Madol is perhaps the premier archeological site in the western Pacific. Much of the mangrove near the ruins on Temwen has been cleared for gardening and house lots; the vegetation on the small islands of the ruins themselves has been extensively modified. The site should receive special legal status, probably as a State Park, to maintain the character of the area and to protect the ruins. Restoration and conservation of the mangrove would protect the reef fishery and lobster habitat (U.S. Army Corps of Engineers 1985) at the nearby reef passage. Holthus (1987) recommended that this area be a species preserve for top shell *(Trochus)*, giant clams *(Tridacna)*, and lobster *(Panulirus)*. My recent examination disclosed that the reef nearest Nan Madol has been highly disturbed.

7. *Land between Pilen Kihlid/Dauen Wapar and Dauen Lohd, Madolenihmw.* Category B2. 29.5 ha MN2, 8.1 ha MN1. One of the few areas known where large *Lumnitzera littorea* occurs. One section was logged in 1988 with an appalling waste of wood; another part was logged earlier and regeneration is lacking in both areas. The clearcuts should be regenerated with slash reduction and tests of seed bed and light level effects on germination and establishment of lumnitzera. Large-dimension thinnings and products of limited selection harvesting could feed the Kitti and Nett mills from this reserve. The channel has a deep silt bed, and silt deposits are found out toward the reef (U.S. Army Corps of Engineers 1985). Tree cover should be restored and manipulated on the landward side only, with selection and shelterwood cuttings to minimize soil exposure. Highly productive reef fisheries, sea grass beds, fish aggregation areas, and fish migration routes are found at the mouth of the channel (U.S. Army Corps of Engineers 1985).

8. *Land between Kepindau Pohnahtik and Nan Diadi, Madolenihmw.* Category B2. 22.5 ha MN2, 50 ha MN1, 4.9 ha MN0. This area carries the highest timber volume in the Pohnpei mangrove. Logging of *Lumnitzera littorea* took place in the central portion of the parcel. This reserve is sought for management, research, and demonstration primarily because of its productive capacity and the occurrence of stands in many developmental stages within a small area. Timber for the Kitti mill could come from here. Forest manipulation should be confined to low-intensity operations on the landward side to prevent siltation of the sea grass beds, which are known sea turtle feeding areas. Mangrove crab is abundant; a rich reef fishery, fish migration route, lobster and lipwei *(Anandara antiquata)* clam beds are also found (U.S. Army Corps of Engineers 1985). Holthus (1987) proposed this area as a species preserve for trochus, giant clams, and lobster.

9. *Land between the Dauen Semwei and Dauen Rakis, Enpein, Kitti.* Category A. 76 ha MN2; Category B1. 83 ha MN2, 80 ha MN1 (plus lagoon areas); Category B2. 151 ha MN2, 230 ha MN1, 135 ha MN0. (Total area 755 ha). The primary factor indicating desirability of a reserve in this area is the need to trap sediments carried by the major drainages in the locale. Deep sediments line the channel (U.S. Army Corps of Engineers 1985). A concentration of known sea turtle feeding and nesting sites are found in this area, the reef complex is especially rich in lobster and trochus, and the forest contains abundant mangrove crab (U.S. Army Corps of Engineers 1985). In addition, some of the forest is particularly well-developed and contains the now scarce *Lumnitzera littorea*. The truly majestic and little modified mangrove has mostly been placed in Category A.

The Category B1 area includes the canoe landing and waterways presently used by the Enpein Marine Park (EMP) Corporation for their ecotourism enterprise. Considerable backing has been amassed for legally constituting this area a State or National Park; this would have social as well as conservation benefits. The condition of the forest visible along the canoe route is surprisingly good, considering that there is effectively no control on exploitation. The area is exploited by locals for a range of materials and foodstuffs. Except for the cutting done by the Enpein Marine Park Corporation itself, the exploitation has been low impact. The best mangrove is to the west of the canoe landing, not at present part of the park tour. However, within the western section of the park tract there is also a clearcut of perhaps 8 ha. The clearcut should be treated as a B2 inclusion, rehabilitated, and used to study regeneration of *Lumnitzera littorea*. The park should extend to and include the reef.

The land immediately west of the Dauen Semwei is proposed as a research and management location. While the landward end of the peninsula between the Semwei and Enpein Pah is mostly old-growth forest, it has been heavily exploited by commercial timber interests, and because of accessibility via an extensive channel network, is now heavily exploited by locals for smaller timbers (poles, posts, canoe wood, fuel, etc.). The west central area of this peninsula is dwarf mangrove. Land to the west of Dauen Pakein and east of Dauen Rakis is also a proposed management area. Some of this is important wildlife habitat; some is well-stocked pole timber that would be excellent for study of response to thinning and other silvicultural intervention, and some is dwarf and MN1 that is included to protect the marine environment, shoreline, and the interior forest. Subsistence and mill timbers can be produced. Holthus (1987) proposed a marine park for the area west of the Dauen Rakis.

10. *Dauen Soundau, Sokehs.* Category A. 50 ha freshwater swamp, 21 ha MN2, 19 ha MN1; Category B1/2. 387 ha MN1, 83 ha MN0 (Total 560 ha). Much of the land interior to and elevated above this large drainage has been under agriculture since the Japanese era. The mangrove should be given special status to safeguard water quality; the river bed is deeply silted. A reserve here is also desired to protect the unique freshwater swamp community within. The larger reserve may have some potential as a park; the market for this park would be the community associated with Federated States of Micronesia government functions at Palikir. The B2 lands could also be managed in time to feed the small-dimension lumber market centered on Kolonia, which is now consuming Sokehs mangrove further east. Mangrove crab populations were reported to be high immediately north and south of the Soundau (U.S. Army Corps of Engineers 1985). Holthus (1987) proposed a marine park for the reef complex off the Soundau, which includes small mangrove islets reported to be important sea bird nesting sites.

11. *Dau Mwoakote, Sokehs.* Category A. 56 ha MN2; Category B1/2. 45 ha MN1. A reserve is needed here to protect the banks of this fast-moving channel and to reduce the movement of pollutants from Kolonia into Sokehs Harbor. South of the channel there is some excellent old-growth mangrove which has been little disturbed. At the west end of the channel are sea grass and lipwei clam beds and an important reef fishery (U.S. Army Corps of Engineers 1985). Because the channel and surrounding forest are beautiful and close to both Kolonia and Palikir, this reserve may have some potential as a park.

I foresee serious problems with the acceptance of designated reserves of any description on the part of elected officials and the general public unless well-structured public education is undertaken now. People need to understand what the costs and benefits of reserves will be and how these will be equitably distributed. In order to successfully implement a reserve system, appropriate legislation conferring special legal status upon these areas is necessary. The authority to enforce this legislation, a budget sufficient to execute demarcation, management and protection of the reserves, and additional skilled professionals to carry through the program with dedication and vision are all requisite to success.

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This work was done in close cooperation with Pohnpei State Division of Forestry. I relied upon the Pohnpeian foresters, especially Salis Peter and Herson Anson, for their superior knowledge of the resource and for their sense of how things can best be done in their culture. I also had considerable backing from the USDA Forest Service team in Honolulu, notably Forester Tom Cole. On Pohnpei, Bill Raynor at the College of Micronesia Land Grant contributed to some parts of this study. Special thanks go to the Director and staff of the Ponape Agriculture and Trade School, whose generous hospitality so facilitated this work.

Appendix: Legislation Relating to Mangrove Use

Under the Trust Territory government, Public Law 104-67 gave municipalities the right to tax and regulate the use of mangrove and upland forest. Each of the municipalities except Kolonia passed laws to this effect, beginning with Uh and Kitti in 1961. In 1979, the State of Pohnpei passed the Forest Management Act (D.L. No. 4L-203-79), transferring jurisdiction over lands below the high tide mark to State government agencies. Another state law, the Pohnpei Watershed Forest Reserve and Mangrove Protection Act (L.B. 381-85), was passed in 1987. This act was intended to restrict cutting, dredging, building, and polluting in mangrove areas upon the filing of regulations to accompany the law. The regulations have yet to be signed into law. The municipalities in some cases revised their earlier legislation but without recognizing the state authority. The present situation is that State agencies maintain that only they have the authority to permit or restrict exploitation in the mangrove, while the municipalities also claim this authority.

Uh passed a law in 1961 (Uh Municipal Ordinance 5-61) that levied a charge of $1.00 for the cutting of any tree larger than 30.5 cm (12 inches) d.b.h.. This legislation has not been revised. It appears that the law is not enforced; no records indicating revenues collected were located.

Kitti also passed a law in 1961 (Kitti Municipal Ordinance 5-61) that taxed residents $1.00 per year for the exploitation of mangrove and upland forest trees. Sawmills were required to pay a $10-per-year license fee.

Kitti Ordinance 5-61 was superseded by Kitti Law 2I-96-90 in 1990. No permit or tax is now required of Kitti residents cutting for their own consumption, and religious and municipal government agencies are exempted from permit requirements provided that harvested timber be used "for the benefit of Kitti Municipality or the religious organization." Harvesting for commercial purposes requires a $50.00 permit fee, plus cutting fees of $150.00 for every 50 trees greater than 10 cm (4 inches) diameter at the base, and $50 for every 100 trees with basal diameter smaller than 10 cm that are taken.

Madolenihmw's 1969 law charged a $1.00 cutting fee for up to 300 trees up to 28 cm (11 inches) basal diameter taken for personal use. Additional trees required additional permits. The fee charged for each tree taken for canoe or boat-making was $3.00; for each tree greater than 28 cm basal diameter processed in a sawmill or for personal use, $3.00; and for each tree up to 28 cm basal diameter taken for commercial use, $1.00. The law stipulated that mangrove trees not be cut from the ocean side of the swamp.

The Madolenihmw law was revised in 1990 (MB 10-90). A $5.00 permit fee is charged to harvest an unlimited number of trees for personal use during one day at one location; $100.00 is charged for commercial permits under the same conditions.

Nett passed its first ordinance governing mangrove exploitation in 1978 (Nett Municipal Ordinance 11-78). This law required anyone seeking a cutting permit to pay a $1.00 application fee. In 1991, a commercial cutting license fee of $500.00 was added (Nett District Law 73-91).

Sokehs passed a law in 1971 (Sokehs Municipal Ordinance 1-71) levying the following charges for cutting trees for personal use:

$0.25 per tree, up to 50 trees, up to 7.5 cm (3 inches) basal diameter
$0.50 per tree, up to 50 trees, 7.5-15 cm basal diameter
$1.00 per tree, 15-28 cm basal diameter, or smaller if processed in a sawmill,
$1.50 per tree for trees 28 cm and larger basal diameter
$2.50 per tree for any tree 28 cm or larger in basal diameter used for carving a canoe

Trees cut and removed for commercial uses or for the construction of any business facility were charged:

$0.30 per tree for any tree 10 cm or less in basal diameter
$0.50 per tree for any tree 10 cm or less in basal diameter processed in a sawmill
$1.00 per tree for any tree 10-28 cm basal diameter
$3.00 per tree for any tree greater than 28 cm basal diameter.

Only twisted, gnarled or dead trees could be taken for firewood. Sokehs passed a new law in 1986 (Sokehs Municipal Law SC1-40-86) that revised these fees:

$2.50 for cutting house timbers
$2.00 for firewood for personal use, $5.00 if firewood is to be sold
$10.00 for harvest of wood for handicraft production or "other related businesses"
$50.00 for harvesting for a commercial sawmill
$5.00 for harvesting for any purpose not included above.

These permits place no restrictions on volume, and are valid for up to three days after being signed.

Kolonia has no laws relating to mangrove exploitation. According to the mayor, "There are not enough mangroves to worry about." In fact, there are about 50 ha of good mangrove within Kolonia that have not been eradicated due to limited accessibility.

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Biological Control of Introduced Weeds of Native Hawaiian Forests[1]

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Abstract: Among the many threats to the continued existence of the remaining native forests and other native ecosystems of the Hawaiian Islands, the most severe and the most difficult to control are the invasion and replacement by introduced species of plants. Because conventional methods of plant management have failed to control this invasion, a multiagency, state and federal program was initiated in 1980 to attempt control through the use of classical biological control: the introduction, release, and establishment of the natural enemies of the weeds, including both insects and pathogens. Currently, active programs are under way against six different introduced weeds: banana poka *(Passiflora mollissima)*, firetree *(Myrica faya)*, gorse *(Ulex europaeus)*, introduced blackberry *(Rubus argutus)*, Koster's curse *(Clidemia hirta)*, and strawberry guava *(Psidium cattleianum)*. Under the present program, five insects and one pathogen have been tested and released in Hawaii. Three more insects are waiting final approval, and one pathogen has been approved but not released. Ten other insects and pathogens are being tested in Hawaii, and we are supporting scientists in five foreign countries who are studying the plants in their native ecosystems to identify further agents for us. On the basis of the high rate of success of previous programs for biological control of agricultural weeds in Hawaii, we hope that this program will be a successful tool for managing forest weeds. It will also offer a relatively cheap, safe, but effective method of vegetative management in forest ecosystems on other Pacific islands.

The native forests of Hawaii are unique. Evolving over millions of years on the most isolated pieces of land in the world, most of the trees, shrubs, and ferns that compose the forest and the associated birds, arthropods, and other invertebrates are native only to the Hawaiian Islands (Carlquist 1980). This complex represents a unique ecosystem, but unfortunately one that is rapidly disappearing. The destruction of the Hawaiian forest began when the first Polynesian settlers began clearing land for farming, but accelerated greatly after contact with the rest of the world (Smith 1990).

Fortunately, some of the most pristine of our remaining forest ecosystems are now protected in state forest reserves, natural areas, parks, and wildlife refuges. Even in these protected areas, these ecosystems are not safe, because they are subjected to continual degradation, mostly from introduced species of animals, particularly cattle, goats, and pigs, as well as from replacement by introduced species of plants.

Most of our problem weeds were introduced to Hawaii as desirable plants, i.e., for their flowers and fruits or for agricultural use. But soon they escaped into the wild where, without their complex of natural enemies, they spread and multiplied unrestricted. The problems the weeds cause in these native ecosystems, and particularly in forests, are only now being recognized (Vitousek, in press) and include physical displacement of other species, competition for sunlight and moisture, competition for nutrients, interference with nutrient cycling and shading out or smothering of regenerating native species. The full impact of introduced weeds on Hawaii's native forests has not been fully studied, but it is estimated that if their invasion remains unchecked, our native forests and their complex of associated animals could be extinct within 50 to 100 years.

Invading plants can be controlled by conventional methods including grazing, herbicides, and mechanical weeding (Smith 1990). All these methods have been tried, but all were found to be expensive, often as destructive to the native forest as the weeds to be controlled, and at best, suitable for only limited areas. It was obvious that a new approach to forest weed management was necessary and in 1980 an interagency cooperative program between the State of Hawaii's Department of Land and Natural Resources, the Hawaii Department of Agriculture, the University of Hawaii, the USDA Forest Service, and the USDI National Park Service was established to attempt the use of biological control as a means to control forest weeds in Hawaii.

Biological control is based on the observation that plants, when introduced by humans to a new area, have often escaped from the constraining influence of the complex of natural enemies with which they evolved in their natural homeland (DeBach 1964). Biological control, therefore, is simply an effort to locate the original homeland of a weed, identify its natural enemies (usually insects or plant pathogens) and import and introduce these enemies into the new area, where they can once again attack their original host.

In Hawaii biological control has been tried against more than 20 species of agricultural weeds (Funasaki and others 1988), mostly found in pasture lands, and has been successful in more than half the attempts (Markin and others, in press). On a worldwide basis, this approach has been tried on more than 75 different weeds with about the same ratio of success (Julien 1987).

Exploratory work to study the weeds in their original homeland to identify their natural enemies began in 1982. An insect quarantine facility, which is the key to our insect biological control program, was constructed at Hawaii Volcanoes National Park in 1984, and the first shipment of insects from a foreign country was received in December of that year. More than 20 weeds have been identified as problems in our National Forests (Gardner and Davis 1982), and 12 cause problems serious enough to justify immediate control efforts (Smith 1990). Biological control programs are active against six of these.

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Progress to Date

Clidemia hirta (Melastomatacae) (Clidemia)

Clidemia, or Koster's curse, is a native of low-elevation lands of the northern parts of South America. It was introduced into Hawaii probably as an ornamental plant for its veined and attractive leaves (Wester and Wood 1977). Near sea level in Hawaii, it has invaded moist areas on all major islands except Lanai. Once established, it forms dense stands 1 to 2 m high that exclude all native and most other introduced plants. Clidemia also at one time was a major problem in grazing lands in Hawaii, but programs in the 1950's introduced two insects that eliminated it in open areas (Nakahara and others, in press). Unfortunately, the insects were not effective in shade, particularly where clidemia grows as an understory in the forests. A new program has resulted in the release of a disease agent, the fungus *Colletotrichum gloeosporioides* (Trujillo and others 1988), in 1987, and the leaf mining beetle *Lius poseide*, in 1988, both of which are now well established. Many other insects have been discovered and tested in Trinidad (Nakahara and others, in press), but the expense and work necessary for releasing them is being postponed until the impact of the two new agents, in combination with the two earlier established agents, can be studied to determine whether they are capable of exerting sufficient control.

Passiflora mollissima (Passifloraceae) (Banana Poka)

Locally known as banana poka or banana passion fruit because of its elongated yellow fruit, this weed is a domestic plant grown throughout the Andes of South America. Introduced to Hawaii around 1900, it soon escaped from cultivation and found the higher-elevation (1,000 m and above) native forests of Hawaii a perfect habitat (La Rosa 1983). It is now established on three of the Hawaiian islands, where it infests 40,000 ha and is still spreading (Warshauer and others 1983). In areas where it is well established, banana poka forms mats of vegetation that can cover native trees and breaks them with their weight, or increases their chance of blowdown during storms. On the ground these mats of vegetation smother shrubs, seedlings, and even small trees. Where banana poka is well established, regeneration of Hawaii's native forests has ceased to occur (Markin and Nagata 1989).

Exploration in South America to find natural enemies of banana poka began in 1982 and although many potential biological control agents are now known (Pemberton 1989), the inaccessibility and political instability of most of the countries of the Andes make it difficult to conduct the necessary studies of this plant in its native homeland. To date, only two insects have been released. An attractive blue moth *Cyanotricha necyria* (Lepidoptera: Dioptidae), the larvae of which feed on the leaves, was released in 1988 (Markin and others 1989). A second moth, *Pyrausta perelegans* (Lepidoptera: Pyralidae), the larvae of which attack the flower buds, was released in February 1991. We hope that once *P. perelegans* is established, destruction of flower buds will reduce fruit set and slow the further spread of this weed. Four other insects are presently in quarantine undergoing evaluation, and under a new cooperative program, entomologists in Venezuela are searching for additional species. Two plant pathogens, a vascular wilt fungus *(Fusarium oxysporum)* and a powdery mildew *(Acrosporium* sp.), are also being studied. The powdery mildew has been approved for use in Hawaii, but has not actually been released in the field.

Ulex europaeus (Leguminosae) (Gorse)

Gorse is a spiny, dense-growing shrub native to western Europe that was extensively used for hedges to contain livestock before the development of barbed wire. As a beneficial plant, it was exported to many parts of the world by European settlers, but it soon escaped from cultivation (Markin and Yoshioka 1989). Around the Pacific, gorse is a problem in Australia, New Zealand, Chile, northwestern United States, as well as in Hawaii. In Hawaii, gorse is established on only two islands, usually at elevations between 1,000 and 2,000 m. It currently infests only 14,000 ha, but despite extensive efforts to contain, or eradicate it, it continues to spread (Markin and others 1988).

In recognition of gorse's role as a rangeland pest, Hawaii has had a long-standing program to find and introduce biological control agents for the weed, although the earlier programs succeeded in establishing only the seed weevil *Apion ulicis* (Coleoptera: Curculionidae) (Markin and Yoshioka 1989).

Gorse, also a forest weed, is capable of invading open forest lands, where it competes with native species, interferes with forest access and management, and competes with seedlings planted for reforestation. Because gorse is primarily a rangeland weed, the present program is still headed by the Hawaii Department of Agriculture, but receives assistance from our forest weed biological control program, as well as from cooperators in Chile, New Zealand, and Oregon. The present program has evaluated more than 10 species of insects, mainly from England and Portugal, and in 1989 released the foliage feeding moth *Agonopterix ulicetella* (Lepidoptera: Oecophoridae). This insect is now well established with an expanding population. In 1990 we also released a gall-forming weevil *(Apion scutellare* (Coleoptera: Apionidae)), and this summer we will begin releasing a small foliage feeding thrips *(Sericothrips staphylinus* (Thysanoptera: Thripoidae)). Our cooperators in New Zealand have also successfully established a gregarious web-forming mite, *Tetranychus lintearius* (Acaria: Tetranychidae), that is already killing gorse plants at some locations. We hope to introduce this mite along with several other insects still in quarantine within the next few years.

Because of the support of the agricultural community in Hawaii, cooperation from several foreign countries, and the ease of working with a plant from Europe, the gorse program is our most advanced, and we tentatively plan to discontinue the search for and testing of new insects by 1993. At that time we hope to have established a complex of at least five species of arthropods, each attacking a different part of the plant. We will then enter a phase of redistribution and monitoring for a 5- to 10-year period to allow the populations to expand and determine their impact before we decide whether further releases are necessary.

Myrica faya (Myricaceae) (Firetree)

Firetree is native to the Azores, Madeira, and Canary Islands of the eastern Atlantic and was probably introduced by Portuguese settlers from the Azores Islands who were brought to Hawaii in the 1880's as sugar cane workers. The plant readily found a new home in Hawaii and has now spread over 35,000 ha on five islands (Whiteaker and Gardner 1985). In stands of native vegetation, particularly those on new soils, lava flows or cinder fields, firetree's association with nitrogen-fixing actinomycetes in root nodules and the distribution of its seeds by birds allow this tree to rapidly outgrow and outcompete most native species (Vitousek and others 1987).

A new program was initiated against firetree in 1984. Several visits to its original islands have shown an abundance of native enemies (Hodges and Gardner 1985, Gardner and others 1988) and resulted in a cooperative program with entomologists at the University of the Azores to study them. To date, three plant pathogens have been found, two of which are undergoing testing at the USDA-ARS Plant Disease Research Laboratory, Ft. Detrick, Frederick, Maryland. The fungi are species of *Nectria* and *Cryphonectria,* which cause bark cankers in stems and branches and have the potential to kill cambial tissue and girdle the tree.

The work on insects has progressed further than that on pathogens, and the first agent was just approved for release in Hawaii. The small moth, *Phyllonorycter myricae* (Lepidoptera: Graciliaraceae), has larvae which feed in a shelter formed by rolling the tip of the leaf. Several other insects are presently being tested in quarantine in Hawaii or are being studied by cooperators in the Azores.

Rubus argutus (Rosaceae) (Blackberry)

This blackberry was introduced into Hawaii for its edible fruit, but was quickly spread by birds into the forests where, like gorse, it forms spiny, impenetrable canebrakes that replace native vegetation and interfere with forest access and management. Blackberry was originally also a pest of pasture lands, but the establishment of three insects in the 1960's resulted in its effective control in open areas. The three insects also attack it in the forest (Nagata and Markin 1986), but their impact is generally insufficient to reduce the plant to acceptable levels. Rather than introducing additional insect species that might compete with the existing complex, the present program is focusing on plant pathogens. A European rust fungus *(Phragmidium violaceum)* was introduced to Chile (Oehrens and Gonzales 1974) and later to Australia (Bruzzese and Field 1984), where it successfully attacked and suppressed related introduced species of blackberries. This pathogen was recently tested against *Rubus argutus* in a cooperative program in Chile; unfortunately, it was found incapable of attacking this blackberry species. Present efforts are continuing on finding pathogens in North America, and tests are under way on the rust *Gymnoconia nitens* in North Carolina, one of the areas that may be the original home of this particular blackberry.

Psidium cattleianum (Myrtaceae) (Strawberry Guava)

Strawberry guava is another South American plant introduced to Hawaii probably for its small, flavorful fruit (Neal 1965). It has been spread widely by birds on all of the Hawaiian islands, particularly at an elevation between 500 and 1,000 m. It is capable of becoming established in the densest forests but does best in disturbed areas where it often forms dense stands containing 50 stems per square meter.

Strawberry guava is the newest weed to be considered for biological control as part of our forest weed program. We have conducted surveys for it in South America to locate its origin, which apparently is in southern Brazil, and have a cooperative agreement with a university in Curitiba, Brazil, to survey its associated insects and diseases. It will be several years before the most promising agents have been identified, studied, and are ready for shipment to quarantine in Hawaii for further testing. Strawberry guava *(P. cattleianum)* is very closely related to the commercial guava *(P. guajava)* which is an important crop in Hawaii and is grown on approximately 400 ha, primarily for juice (Anonymous 1985). Finding an insect or pathogen that will attack only the strawberry guava and not the commercial guava will probably be difficult.

Additional Weeds Targeted for Biological Control

Rubus ellipticus (Rosaceae) (Himalayan Raspberry)

Himalayan raspberry is a native of Asia and is believed to have been introduced to Hawaii sometime in the 1950's in the area of Volcano Village on the island of Hawaii (Neal 1965). Birds feeding on its small yellow fruit have now spread it to up to 30 miles from its original site of introduction. This weed is particularly dangerous because of its ability to become established in undisturbed native forests, whereas many of our weeds at least need disturbances such as pig rooting, roads, blowdowns, or fires to get their initial foothold.

Tibouchina spp. (Melastomatacae) (Glory Bush)

Glory bush is another South American plant introduced probably as an ornamental for its attractive dark blue flowers. For many years it was thought to be only an incidental introduced plant that had become feral because it was confined to only a few small and limited areas. Recent surveys, however, indicate that for some unknown reason it has begun to expand its range and now threatens a major watershed and one of our national parks.

Pennisetum setaceum (Gramineae) (Fountain Grass)

Fountain grass is a native of North Africa, and its bushy and attractive seed heads indicate it was brought to Hawaii probably as another ornamental. The plant is unpalatable to cattle and is a pest of grazing land, so a program for its control is high on the wish list of Hawaii's ranching industry. Fountain grass also creates an extreme fire danger; wildfires carried by this grass have recently destroyed hundreds of hectares of dryland native ecosystems and forests (Tunison, in press). Biological control has never been tried against any species of grass because of the potential danger that an introduced agent might also attack some related agriculturally important species (Pemberton 1980). The experience and techniques developed in biological control over the past 90 years have now reached the level that crossover by an introduced agent from its target weed to another plant is no longer a danger. Fountain grass would be an ideal species on which to attempt the first effort at biological control of a grass species.

Conclusions

Our program in Hawaii, we believe, is the first to attempt specifically to control introduced weeds of forests and other native ecosystems using biological control, although a similar program is currently under development for the Everglades of Florida. Although our program is only 10 years old, we already have released six agents and are ready to release four more. Several of the released agents are well established, increasing in numbers, and spreading through the range of their target weeds. It is still too early to tell which of these agents will be successful, since establishment and population buildup to sufficient levels to damage the plant usually require 5 to 10 years or more. On the basis of the success of earlier programs against agricultural weeds in Hawaii, we are confident that most of our programs will eventually be successful.

Our experience in Hawaii has shown us that biological control has several disadvantages. It is neither fast, nor cheap, and occasionally conflicts of interest arise with groups opposed to such a program, because to them the target weed may be beneficial (Markin 1989, Markin and Yoshioka, in press). However, we have also learned that in many instances biological control is the only tool available to us for managing weeds in forest ecosystems and when successful will give a permanent solution.

As we have watched our program progress and now see insects and pathogens that we introduced attack the weeds, we believe the program is showing the first sign of success and that biological control will eventually become a key method for weed management in forest areas and other natural ecosystems here in Hawaii and probably on other Pacific islands.

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