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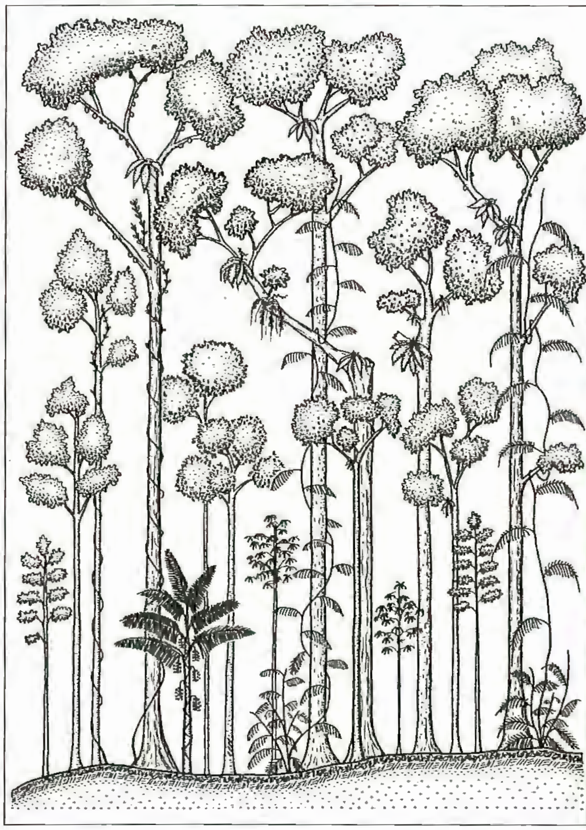

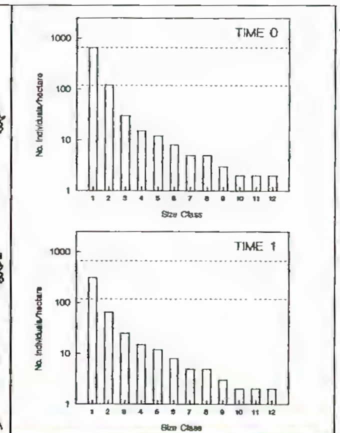

Sustainable Harvest of Non-timber Plant Resources in Tropical Moist Forest: An Ecological Primer

By Charles M. Peters

The Biodiversity Support Program is a USAID-funded consortium of World Wildlife Fund, The Nature Conservancy and World Resources Institute.

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Charles M. Peters
Institute of Economic Botany
The New York Botanical Garden
Bronx, New York 10458

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WWF

The Nature Conservancy

The Biodiversity Support Program (BSP) was established in 1988 with funding from the Research and Development Bureau of the U.S. Agency for International Development (USAID), under cooperative agreement number DHR-5554-A-00-8044-00. BSP is implemented by a consortium of World Wildlife Fund, The Nature Conservancy, and the World Resources Institute. The central purpose of the program is to support efforts to conserve biological diversity in developing countries through information, networking, pilot implementation projects, and research and analysis of conservation and development techniques.

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Includes bibliographic references
1. Forest products industry—Tropics
2. Forest products industry—Environmental aspects—Tropics
I. Peters, Charles M.

Cover design by Mimi Hutchins, World Wildlife Fund, Washington, D.C. Text design and layout conceived by Charles M. Peters, The New York Botanical Garden, and executed by Margaret Bjerklie, Biodiversity Support Program.

The cover uses three formats—photo, graphs, and profile—to illustrate the process of monitoring non-timber forest product harvests. The size-class histograms are derived from measurements like those being taken by the man in the photo. The histogram at time 0 depicts a plant population with a large number of seedlings, fewer saplings and very few adult trees; a similar pattern is illustrated in the profile diagram to the left. The histogram at time 1 shows population structure five years later in a situation where overexploitation has caused a notable decrease in the number of seedlings and saplings.

Printed by Corporate Press Inc., Landover, MD

Printed on recycled paper.

ERRATUM

Omitted from the back of the title page:

Cover illustration by Elysa J. Hammond. Profile diagram is based on transect data collected from a managed forest in Sambas District of West Kalimantan, Indonesia. Photograph, by Judith Mayer, shows Sebastianus Sudin, a Jangkang Dayak, taking diameter measurements in a mixed forest orchard near the village of Ensibau in Sanggau District, West Kalimantan.

Sustainable Harvest of Non-timber Plant Resources in Tropical Moist Forest: An Ecological Primer, by Charles M. Peters

This little book is dedicated to EJH, CHP, LHP and to all the tropical ecologists and foresters who have laid the foundation for the ideas expressed herein.

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FOREWORD: A USER'S GUIDE TO THE MANUAL

The promise of achieving conservation and development objectives through "green" forest-based enterprises has excited great enthusiasm. Mechanisms are being devised for ensuring sustainable use of forest products: The Forest Stewardship Council's new certification guidelines for sustainable harvest of timber from tropical forests is one example. Most of the world's forests, however, are harvested for both timber and non-timber forest products (NTFPs).

In many areas occupied by traditional societies, management for NTFPs is part of traditional forest management, but new demands on forests are leading communities to seek more formal monitoring processes to guide the allocation and management of their shrinking biological resources. At the same time, managers of protected areas are seeking ways to accommodate the needs of traditional forest users while maintaining the integrity of the ecosystems that the protected areas were created to safeguard. To meet the widespread demand for formal guidance to determine ecological sustainable harvest levels for non-timber forest products, the Biodiversity Support Program (BSP) commissioned the production of *Sustainable Harvest of Non-timber Plant Resources in Tropical Moist Forest: An Ecological Primer*. As is true for other guidance for ecological sustainability, this manual provides a subset of the necessary tools. The following discussion will provide the user of this manual with information about what the manual does and does not aim to accomplish.

The reader might think of this manual as a "toolbox" that provides simple and effective tools for the *what* and *how* of determining sustainable harvest levels of NTFPs in tropical moist forests. Biology is the ultimate determinant of sustainability—species and ecosystems die, survive, or flourish depending on whether their ecological requirements are met. Nature provides the grist to meet those requirements, but it is the mill of social organizations, individual decision makers, and markets—not nature—that determines whether the ecological requirements of species and ecosystems will be met. Thus, sustainability greatly depends on political, socioeconomic, and institutional factors.

To a large extent, the achievement of sustainability through the use of the biological monitoring tools in this manual will depend on *who* uses the tools. If the *who* includes local people and other forest users in the roles of decision-making planners and results analysts, then biological information developed from the toolbox will provide critical material for constructing a sustainable system for harvesting NTFPs. The tools can be applied in widely different situations. In some cases, government agencies will seek to use them to set harvest limits in state forest reserves; in other cases, community groups will use them to assess which of their forest's products offers the best option for sustainable, commercial harvests. In either case, the local forest users must cooperate in the application of the tools if sustainability is to be achieved.

It is, therefore, essential that the reader of this manual think about the *who* as well as about the *what* and *how*. Who will do this work, who will analyze the results, and who will benefit from sustainable harvests? Who is using the forest and for what purposes? What are their priorities? Other manuals are available to help answer these questions and to address other aspects of sustainable harvesting—for example, identifying or creating forest management committees, describing what kinds of information are essential for making decisions, or developing an appropriate process for making decisions on the basis of the information gathered.

This manual is meant to be used in an effort to plan and implement ecologically sustainable extraction of NTFPs. That effort must invoke the levels of user participation essential for (1) choosing products for increased extraction, and (2) monitoring the impact—two important steps for achieving sustainable harvests. The first decision will require an assessment of labor investment, economic and social feasibility, and other demands on the forest and its users. Users have important "indigenous knowledge" about the species, but more importantly, they are critical actors in both extraction and monitoring. They must be actively involved in the six steps outlined in the manual, not just used as a source of limited information.

For example, if this manual is being used by a project manager, the terms of reference he/she develops for analysis of ecological sustainability of a proposed project should include a Participatory Rural Appraisal (PRA) by the community to ascertain all the uses—present and planned—of the forest. The PRA should determine who makes decisions about forest management and who enforces those decisions. It should consider labor requirements and how they might conflict with existing or planned labor investment in other activities. User communities should rank the importance of NTFPs, both cash and non-cash benefits, as well as rank the importance of game, wood products, and the ecological services that they currently enjoy from the targeted forest. This information should be considered when choosing to increase levels of exploitation of one or more products and to evaluate the impacts of choosing one option over another. In addition, the decision-making body should consider the potential negative effects should the enterprise fail to be sustainable and decide whether the community wants to take that risk.

There is no recipe for achieving people's participation in any activity, just as there is no recipe for achieving ecological sustainability. Adding PRA to a project, for example, is not synonymous with achieving participation. Like the methods outlined in this manual, PRA is a tool. Following Borrini (1993), *participation* is a process by which people assess their needs and resources, recognize opportunities offered by projects, participate in planning and decision making, act and provide resources to implement projects, acquire benefits from projects, and develop partnerships with other project stakeholders. The steps that are necessary to achieve participation vary from project to project. Planning for participation is a serious part of project planning and requires investment of significant time and resources. If participation processes are fully established, the ecological monitoring processes described in this manual will provide participants with a powerful means to gain valuable information for sustainable forest-based enterprises.

BSP is also developing a *Guide to Social Sustainability* that will help project managers, aid agencies, and communities to identify the relevant social processes and organizations that should be engaged in and monitored for longterm ecological sustainability of conservation projects. Since this social primer is not yet complete, a short list of suggested readings is provided below. The two excellent manuals produced by the Joint Forest Management National Support Group in India (Poffenberger, et al., 1992) have combined participatory planning, monitoring, and assessment with tools for measuring biological factors at the local level. The manual from FAO/Bangkok (Borrini, 1993) provides practical guidance for incorporating participation into national level programs. The other books in the list offer specific advice for working with both local and national institutions and provide useful bibliographies.

Finally, the monitoring process described in this manual not only monitors the health of NTFP species, it also provides indicators that may function as an alarm system for telling the resource users that ecological changes are occurring. If the alarm is triggered, the changes may be caused by the NTFP harvest or some other factor. If regeneration is not occurring at the desired levels, users should examine the possibilities of excessive harvests as well as consider alternative explanations. This alarm system can be used to identify ecosystem-level problems only if those problems are causing a negative impact on the species in question. Whether negative changes at the ecosystem level will be mirrored by negative changes in the NTFP species will depend on the ecological role played by the species.

In order to maintain forests for their full range of benefits beyond NTFP production, the tools in this manual should be applied in conjunction with other tools to monitor ecosystem health, including methods developed by traditional societies and those developed by biologists. For example, monitoring the health of wildlife populations can provide an indicator of ecosystem health. The reading list below contains two methods source books for monitoring wildlife populations (Schemnitz, 1980; Caughley and Sinclair, 1994). These methods can be integrated with hunters' traditional methods for monitoring the health of game populations.

A healthy forest can provide many benefits for people. BSP hopes that this manual will help people to gain and apply new information about their forests. As always, BSP seeks feedback on this manual so that an improved second edition will include lessons learned by the manual's users. Spanish and French language editions will be available in 1995.

— Janis B. Alcorn
Biodiversity Support Program
September 1994, Washington, D.C.

Suggested readings to complement this manual:

Borrini, G. 1993. Enhancing People's Participation in the Tropical Forests Action Programme. Food and Agriculture Organization, Bangkok, Thailand.

Brown, M. and B. Wyckoff-Baird. 1992. Designing Integrated Conservation and Development Projects. Biodiversity Support Program, World Wildlife Fund, Washington, D.C., USA (Available in English, French, and Spanish)

Caughley, G. and A.R.E. Sinclair. 1994. Wildlife Ecology and Management. Blackwell, Boston, Massachusetts, USA.

Cernea, M.M. 1985. Putting People First: Sociological Variables in Rural Development. Oxford University Press, New York, New York, USA.

Hope, A. and S. Timmel. 1984. Training for Transformation: A Handbook for Community Workers. Mambo Press, Gweru, Zimbabwe.

International Alliance of Indigenous-Tribal Peoples of the Tropical Forests. 1992. Charter of the Indigenous-Tribal Peoples of the Tropical Forest. (Available from Cultural Survival, 215 First Street, Cambridge, MA 02142, USA, or World Rainforest Movement, 8 Chapel Row, Chadlington OX7 3NA, UK)

Korton, D.C. and R. Klauss, eds. 1984. People-Centered Development: Contributions Toward Theory and Planning Frameworks. Kumarian Press, West Hartford, Connecticut, USA.

Poffenberger, M., B. McGean, A. Khare, and J.Campbell. 1992. Field Methods Manual II. Community Forest Economy and Use Patterns. Society for Promotion of Wastelands Development, Joint Forest Management National Support Group, New Delhi, India. (Available at no cost from Ford Foundation, 55 Lodi Estate, New Delhi - 110 003, India)

Poffenberger, M., B. McGean, N.H. Ravindranath, and M. Gadgil. 1992. Field Methods Manual I. Diagnostic Tools for Supporting Joint Forest Management Systems. Society for Promotion of Wastelands Development, Joint Forest Management National Support Group, New Delhi, India. (Available at no cost from Ford Foundation, 55 Lodi Estate, New Delhi - 110 003, India)

Schemnitz, S.D. 1980. Wildlife Management Techniques Manual. The Wildlife Society, Washington, D.C., USA

Uphoff, N. 1986. Local Institutional Development: An Analytical Sourcebook with Cases. Kumarian Press, West Hartford, Connecticut, USA.

For useful newsletters and publication series, write to:

Biological Diversity Handbook Series, Smithsonian Institution Press, Department 900, Blue Ridge Summit, PA 17294-0900, USA. (Currently the only volume available is *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*)

Forest, Trees and People Program, Community Forestry Unit, Forestry and Planning Division, Forestry Department, FAO, Via delle Terme di Caracalla, I-00100 Rome, Italy. (FTP Newsletters available in French, Spanish or English; several publication series)

The Forest Stewardship Council—contact Michael Kiernan, WWF, 1250 24th Street, NW, Washington, DC 20037, USA or Timothy Synnott, Executive Director of The Forest Stewardship Council, Avenida Hidalgo 502, 68000 Oaxaca, Oaxaca, Mexico. (For information on "Principles and Criteria for Natural Forest Management")

International Institute for Environment and Development (IIED), 3 Endsleigh St., London, WCIH ODD, UK (Participatory Rural Appraisal newsletters and publications)

Species Survival Commission Specialist Group on Sustainable Use of Wild Species, IUCN, Rue Mauverney 28, CH-1196 Gland, Switzerland. (Developing guidelines for sustainable use of wildlife)

EXECUTIVE SUMMARY

The controlled exploitation of non-timber forest products holds great potential as a method for integrating the use and conservation of tropical forests. This report attempts to narrow the gap between the potential and the reality of this land-use practice. The main objective is to give a concise overview of the ecology, exploitation, and management of non-timber tropical forest plant resources in terms that can be easily understood by non-specialists.

The report is divided into three main sections. Section I summarizes the principal ecological characteristics of tropical plants that limit the nature and intensity of resource exploitation. Section II discusses the potential long-term ecological impacts resulting from the harvest of different plant parts. Section III presents a general strategy for managing non-timber plant resources on a sustained-yield basis. Within the context of the report, a sustainable system for exploiting non-timber resources is defined as one in which fruits, nuts, latexes, and other products can be harvested indefinitely from a limited area of forest with negligible impact on the species being exploited.

The report focuses exclusively on the ecological context of non-timber tropical forest products, with particular emphasis on the structure and dynamics of tree populations. It does not address the innumerable economic and social factors which are also important in determining the overall sustainability of forest resource exploitation.

THE ECOLOGY OF TROPICAL TREES AND FORESTS

1. Tropical forests are characterized by a large number of tree species per unit area. Most of these species occur at densities of only one or two trees per hectare. Low density resources are difficult for collectors to locate, require long travel times, produce a low yield per unit area, and are extremely prone to over-harvesting.

2. Tropical trees vary greatly in terms of the timing, duration and intensity of flowering and fruiting. Very few tropical forest species produce reliable fruit crops during a well-defined, predictable season each year.

3. The great majority of tropical trees rely on animals to pollinate their flowers and disperse their seeds. Any serious program of commercial resource exploitation must include measures to conserve viable populations of these animals.

4. There is a high probability that a seed will come in contact with an animal during the time between seed dispersal and seed germination. In most cases, this encounter proves fatal for the seed. In terms of total numbers, seed predation is one of the most severe sources of mortality during the life of a plant. Mortality is still extremely high following germination, and over 90% of the new seedlings may die before becoming established in the understory. Only a very small fraction of

these seedlings (less than 1 in 1,000,000 for some species) will ever make it to the canopy and produce fruit.

5. The regeneration of many forest species is linked to the occurrence of canopy gaps. Based on the gap requirement and general shade tolerance of different species, three regeneration types or "guilds" can be recognized: (1) early pioneer species, (2) late secondary species, and (3) primary species. The establishment, growth, reproduction, longevity, and management potential of the species in each group are markedly different.

6. The population structure or size-class distribution of tropical trees can be described by three basic types. A Type I structure is displayed by populations that maintain a more or less constant rate of seedling establishment. A Type II structure is characteristic of populations that experience sporadic or irregular seedling establishment. The final type of population structure, Type III, reflects a species whose regeneration is severely limited for some reason. Although these three types correlate well with the regeneration guild of a species, a single species may exhibit any of these types depending on the environment and its current rate of seedling establishment.

IMPACT OF HARVESTING

7. Almost any type of resource exploitation conducted in tropical forests will have an ecological impact. The exact magnitude of this impact depends on the floristic composition of the forest, the nature and intensity of harvesting, and the particular species or type of resource under exploitation.

8. Given that the initial impact of resource extraction is determined largely by the specific type of resource or plant tissue harvested, the enormous variety of non-timber plant resources produced by tropical forests can be grouped into three major categories: (1) fruits and seeds, (2) plant exudates (e.g. latexes, gums and resins), and (3) vegetative structures (e.g. stems, leaves, roots, barks, and buds).

9. Although unnecessary, many fruits and seeds are currently harvested by felling the tree. This practice has led to the serious depletion of several important fruit and oil seed-producing species. Even in the absence of destructive harvesting, the collection of commercial quantities of fruits and seeds can cause notable changes in the structure and dynamics of a tree population. These changes are typically precipitated by a reduction in seedling establishment due to over-harvesting. If uncontrolled, this process can result in the gradual extinction of the population under exploitation.

10. When properly conducted, the extraction of plant exudates does not disturb the forest canopy, kill the exploited tree, or remove its seeds from the site. There are, however, several examples of exudate-producing trees that are harvested destructively, and even the non-

destructive tapping of rubber can cause a reduction in the growth and reproduction of wild *Hevea* trees.

11. The harvest of vegetative structures produces one of two different impacts. The plant species will either be killed in the process, or, in a limited number of cases, it will survive and later regenerate the vegetative structure removed. Rattan is a well-known example of the former scenario, and uncontrolled harvesting is rapidly depleting this non-timber resource in Southeast Asia. Leaves and buds are examples of vegetative structures that regenerate after harvesting.

STEPS TOWARD SUSTAINABILITY

12. An overall strategy for managing non-timber tropical plant resources on a sustained-yield basis is presented. The procedures described are sufficiently general that they can be applied to any class of non-timber resource, or to a mixture of different resources, on a scale from 100 to 100,000 hectares. They can be applied in forests that have already been heavily exploited for non-timber resources, as well as in more pristine, undisturbed habitats. These guidelines, however, do not comprise a single management technology or "package" that can be blindly applied without modification. Instead, the basic concept is to provide a constant flow of information about the ecological response of a species to varying degrees of exploitation. Sustainability is achieved through a continual process of adjustment in which any change in seedling establishment or population structure results in a corresponding change in harvest level.

13. The complete process of sustainable exploitation is composed of six basic operations or steps: (1) species selection, (2) forest inventory, (3) yield studies, (4) regeneration surveys, (5) harvest assessments and (6) harvest adjustments. The actual sequence of operations is not fixed and can be adapted to a variety of different situations.

14. **Species selection** will be based largely on economic and social criteria. A third criterion that should also be considered is the overall potential of the resource to be managed on a sustained-yield basis. Although the fact is frequently overlooked, some forest species are inherently better able to withstand the continual perturbations caused by resource extraction than others. Important ecological factors to consider include the life cycle characteristics of the species (e.g. phenology of flowering and fruiting, pollination, and seed dispersal), the type of resource produced, its abundance in the forest, and the size-class distribution of natural populations.

15. Density and size-class structure data are the most fundamental pieces of information required for management. The collection of these data requires a quantitative **forest inventory**. The inventory should provide an estimate of the total number of harvestable trees per hectare in different forest types and should document the existing size-class distribution of adult trees. These data will be used to construct a size-class histogram for the species being harvested. It is strongly

recommended that a professional forester or inventory specialist be involved in the planning and execution of this fieldwork.

16. **Yield studies** are conducted to estimate the total quantity of resource produced by trees of varying size. Just as foresters use growth data to avoid cutting timber faster than it is produced in the forest, the sustained-yield management of non-timber resources also requires information about the productive capacity of the species being exploited. Probably the easiest way to obtain production data is to train local collectors to weigh, count, or measure the quantity of resource produced by different sample trees during harvest season. These studies should be repeated every few years using the same group of sample plants to monitor the variation in yield over time.

17. Periodic **regeneration surveys** are used to quantify the initial density of seedlings and saplings in the populations being exploited, and to monitor the way in which these densities fluctuate in response to differing harvest levels. The results from these surveys are divided into height classes and then added to the size-class histograms constructed from the inventory results to provide a complete picture of population structure from seedlings to large adult trees. Repeating these surveys every five years is probably sufficient for most species.

18. **Harvest assessments** are visual appraisals of the behavior and condition of adult trees that are conducted concurrently with harvest activities. In many cases, these quick assessments can detect a problem with reproduction or growth before it becomes serious enough to actually reduce the rate of seedling establishment.

19. The seedling and sapling densities recorded in the original regeneration survey are used as the threshold values by which sustainability is measured. As long as densities remain above these values, and no major problems are detected in the harvest assessments, there is a high probability that the current level of exploitation can be sustained. If seedling or sapling densities are found to drop below this value, however, immediate steps should be taken to reduce the intensity of harvest. Two different procedures are described to make these **harvest adjustments**. The first method regulates the number or size of the plants being exploited. The second method limits the total area from which the resource can be harvested. For populations that have never been exploited before, a good first approximation is to extract no more than 80% of the total harvestable yield during the first collection cycle.

20. The six-step management strategy provides a simple and effective method for achieving a sustainable harvest of most non-timber forest products. In some cases, however, a more intensive form of management may be required. If, for example, seedling densities continue to drop in spite of drastic harvest reductions, or productivity declines, or trees start to die, some form of remedial treatment should be initiated as soon as possible.

Potential courses of action include enrichment planting, selective weeding, and the cutting and removal of woody vines.

CONCLUSIONS

21. There are convincing ecological reasons to implement the management strategies outlined in this report. If practiced on a sustainable basis, the exploitation of non-timber forest products provides a unique way to use species-rich tropical forest for profit and still conserve most of the biological diversity and ecosystem functions of the forest. No other form of land-use practiced in the tropics has the potential to do this.

INTRODUCTION

One of the most basic and rarely questioned assumptions underlying much of the current interest in **non-timber tropical forest resources** is that the commercial harvesting of these commodities has little or no ecological impact on a tropical forest. This ubiquitous idea has appeared in books, magazines and newspapers, on television and radio shows...and even on the back of cereal boxes and ice cream cartons. Unfortunately, this assumption is both untenable and potentially dangerous.

Non-timber forest products are biological resources other than timber which are harvested from either natural or managed forests. Examples include fruits, nuts, oil seeds, latexes, resins, gums, medicinal plants, spices, wildlife and wildlife products, dyes, ornamental plants, and raw materials such as bamboo and rattan.

If intensive resource extraction is the only activity planned within a tropical forest, there is a very high probability that these resources will be gradually depleted over time. The basic tenets of forest ecology tell us this. So does the long history of forest exploitation in the tropics. Regardless of the species, land tenure or marketing system involved, collectors simply cannot harvest commercial quantities of fruits, nuts, latexes and oil seeds year after year and then expect the forest to magically replenish these stocks. As elsewhere, there is no free lunch in a tropical forest.

In reality, the **sustainable** harvest of non-timber tropical forest resources requires quite a bit more than "blind faith" in the productive capacity of tropical plants. It requires careful selection of species, resources and sites. It requires controlled harvesting and periodic monitoring of the regeneration and growth of the species being exploited. More than anything, however, it requires a greater appreciation of the fact that ecology and forest management are the cornerstones of sustainable resource exploitation. There are ways to harvest non-timber products without damaging a tropical forest. This report will hopefully provide a framework for taking the first steps to achieve such an objective.

Sustainability is a tricky word. Although there appears to be a general consensus that the exploitation of tropical forests should embody this concept, there is a considerable degree of confusion about what the word actually means. Within the present context, sustainability will be defined in a restricted ecological sense. From an operational or management perspective, **a sustainable system for exploiting non-timber forest resources is one in which fruits, nuts, latexes, and other products can be harvested indefinitely from a limited area of forest with negligible impact on the structure and dynamics of the plant populations being exploited.**

OBJECTIVES

The main objective of this report is to give a concise overview of the ecology and exploitation of non-timber tropical forest resources in terms that can be easily understood by non-specialists. The material has been written with two potential audiences in mind. In the first group are the innumerable NGOs, individual entrepreneurs, "green" businesses, and other commercial concerns who are currently promoting the increased exploitation of non-timber tropical forest products. The second group includes local community organizations, extension agents and forest managers who are already actively involved in the harvest of these resources. Although the setting, frame of reference, and scale of operations may be different in each case, both groups have a vested interest in the long-term sustainability of tropical forest exploitation.

The controlled exploitation of non-timber forest products holds great potential as a method for integrating the use and conservation of tropical forests. This report attempts to narrow the gap between the potential and the reality of this land-use practice. The following pages provide a general background on the ecology of non-timber resources and present a series of management operations designed to minimize the impact of harvesting these resources. The procedures described are <u>not</u> a blueprint for eliminating the potential impacts on all components of a forest ecosystem (e.g. soils, hydrology, or associated plant and animal species), or for maintaining forests in a pristine condition. The immediate objective being addressed here is simply that of defining a level of resource harvest that can be sustained over time by the **plant populations** being exploited.

The term **plant population** refers to a group of plants of the same species growing together within a limited area of forest. In the ecological hierarchy, this level of resolution falls between the individual and the community. Much will be said about plant populations in this report because it is at this level that the effects of harvesting are most readily visible.

METHOD OF PRESENTATION

The report is divided into three main sections, each section treating a different aspect of the ecology and exploitation of non-timber tropical forest resources:

- **Section I** summarizes the principal ecological characteristics of tropical plants that limit the nature and intensity of resource exploitation.

- **Section II** builds on this information by discussing the potential long-term ecological impacts resulting from the harvest of different plant parts.

- **Section III** takes a more applied, field perspective. A general strategy for managing non-timber forest resources on a sustained-yield basis is outlined, and specific procedures for selecting resources, collecting baseline data, and monitoring the impact of harvesting are described.

Every attempt has been made to make the text as readable and as easily understood as possible. Definitions and supplementary material have been provided in the margin for easy reference; key words and concepts are highlighted in **bold** typeface. A list of pertinent references is included at the end of each section for those readers desiring additional information on a particular topic.

SCOPE

The report is focused exclusively on non-timber *plant* resources, with particular emphasis on trees. Crocodiles, butterflies, iguanas, turtles, bird's nests, and the innumerable other animal resources and products collected from tropical forests are not discussed here. The sustainability of harvesting forest fauna is undeniably an issue of great importance. The basic ecology of plants and animals is just too different to lump together in a work of this size.

The reader is strongly advised to look beyond the **examples** and to focus on the underlying concepts being illustrated. Tropical moist forests contain different species and exhibit different ecological characteristics than tropical dry forests, but the basic procedures required to achieve a sustainable harvest are essentially the same in each environment. Similarly, an understanding of population density and yield is as important for managing herbaceous plants, shrubs, and lianas as it is for trees.

Whenever possible, specific botanical **examples** are given to illustrate basic concepts. In view of the author's previous field experience, the majority of these examples have been taken from the tropical moist forests of South America and Southeast Asia. This geographical bias should not be taken to imply that there are no interesting or useful plants in the African tropics, that the problems of over-exploitation and resource depletion are absent from this region, or that the extensive dry forests found in more seasonal tropical environments are somehow unsuited for sustainable management.

The text is largely concerned with primary forests, either undisturbed or already subjected to some degree of exploitation, and the ways in which non-timber resources can be harvested from them with a minimum of ecological damage. The selective management of pioneer species, tree felling, or the deliberate creation of secondary vegetation within these forest areas are neither advocated nor discussed. The extensive areas of secondary forest that have been created throughout the tropics indeed represent an important source of non-timber products. A discussion of the use and management potential of these habitats, however, falls outside the scope of the present work.

A final comment. There is no question that economic, social, and political factors play an extremely important role in determining the success or failure of forest exploitation. This report, however, attempts to tell the story strictly from the plant's point of view. The reason *why* too many fruits are removed from the forest is not really the issue here. What we want to know is *what happens* as a result to the plant populations being exploited...and *what can be done about it*. The mechanics of over-exploitation are the same regardless of whether the fruits are collected by a village cooperative or a multi-national corporation, or whether the trees are growing in an extractive reserve, a state forest, or a logging concession.

SECTION I. THE ECOLOGY OF TROPICAL TREES AND FORESTS: A CRASH COURSE

In a very basic sense, tropical forest trees are really no different than any other type of plant. Their seeds germinate, they grow, they flower, they produce fruit, and eventually they die. What makes tropical trees unique—and the object of so much scientific inquiry and public concern—is the amazingly complex and diverse ways in which they accomplish these routine life functions. Put a large number of these trees together, each species germinating, growing, flowering, and fruiting in a different way, at different times and with varying degrees of success, and you have some idea about why we understand so little about the ecology of tropical forests. What we do know at this point, however, is that most tropical forests exhibit several ecological characteristics that make sustainable harvesting more elusive than it might first appear.

TREE DENSITY AND ABUNDANCE

One of the most fundamental and well-known characteristics of tropical forests is the large number of species that grows in them. To illustrate this point specifically for trees, floristic data collected from small tracts of tropical forest in Amazonia and Southeast Asia are presented in Table 1. Although there is quite a bit of variability in the estimates from different sites, it is clear that the tropical forests in both regions are extremely diverse and may contain from 100 to almost 300 different tree species in a single **hectare**. To put this in perspective, a mixed hardwood forest in the northeastern United States contains about 17 tree species per hectare.

Table 1. Total number of tree species larger than 10.0 cm in **diameter (DBH)** within small plots of tropical forest in Amazonia and Southeast Asia.

Site	Soils/Habitat	Area	No. Species
Amazonia			
Yanamono, Peru	Alluvial sediment	1.0 ha.	283
Mishana, Peru	White sand	1.0 ha.	275
Rio Xingu, Brazil	Upland forest	1.0 ha.	162
Breves, Brazil	Upland forest	1.0 ha.	157
Para, Brazil	Flooded forest	1.0 ha.	103
Southeast Asia			
Gunung Mulu, Sarawak	Alluvial sediment	1.0 ha.	225
Gunung Mulu, Sarawak	Red-yellow clay	1.0 ha.	215
Wanariset, Kalimantan	Upland forest	1.0 ha.	180
Andalau, Brunei	Upland forest	1.0 ha.	140
Raya-Pasi, Kalimantan	Upland forest	1.0 ha.	135

The most common and easily measured expression of tree size is **diameter**. Following general convention, diameter measurements are usually taken at approximately 1.4 meters above the ground or at "diameter breast height" (i.e. **DBH**).

One **hectare** = 10,000 m^2 or 2.47 acres.

From a management standpoint, the high species diversity exhibited by tropical forests is a two-edged sword. On the positive side, the large number of different plant species present frequently implies that there is an equally large assortment of useful plant resources available. It has been estimated, for example, that one out of every six species found in the lowland forests of Southeast Asia produces an edible fruit, nut, oil seed, medicine, latex, gum or other non-timber forest resource. In most of the tropical areas where this has been studied, "resource richness" is a direct consequence of high species diversity.

Unfortunately, an additional consequence of high species diversity is that the individuals of a given species usually occur at extremely low densities. There is a limit to the total number of trees per hectare that can be packed into a tropical forest. If you have a large number of species, each species can only be represented by a few individuals.

This trend of high species diversity coupled with low species density has been repeatedly documented in tropical forest inventories. The results from two such inventories, one conducted in Brazilian Amazonia and the other from Pasoh Reserve on the Malay Peninsula, are shown graphically in Figure 1. As the histogram clearly documents, the great majority of the tree species at both sites are represented by only one or two individuals. Less than ten percent of the species had populations with more than four trees per hectare.

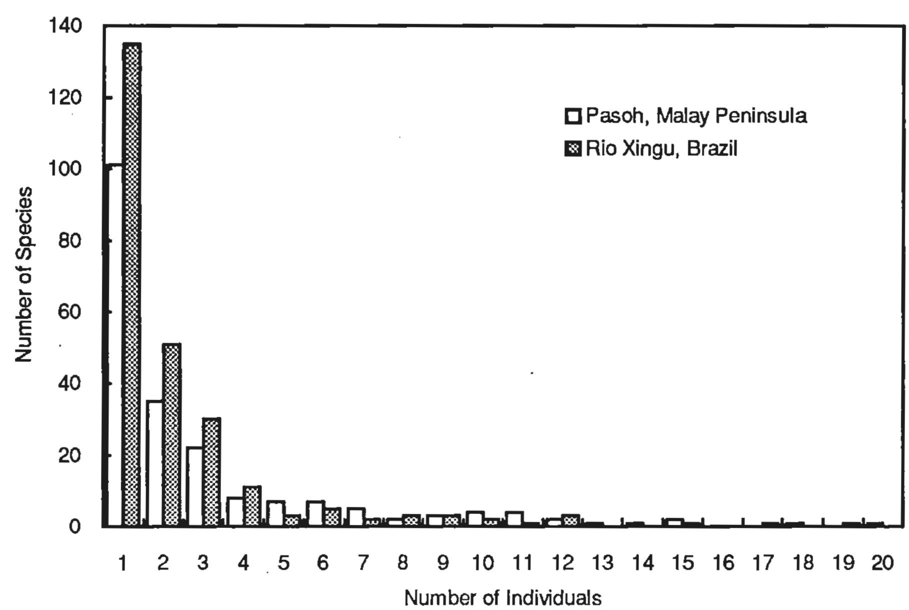

Figure 1. Densities of different tree species within 3.0 hectare tracts of tropical forest in Amazonia and Southeast Asia.

The basic problem here is straightforward. Tropical forests contain a lot of different species. Although many of these species produce valuable non-timber products, most of the trees of interest are scattered throughout the forest at very low densities. **Low density resources are difficult for collectors to locate, require long travel times, produce a low yield per unit area, and are extremely susceptible to over-harvesting.**

It is important to note that there are numerous exceptions to the rule of high species diversity in tropical forests. Although the fact is seldom mentioned in much of the current literature, dense aggregations of a single tree species are known to occur in habitats where severe flooding, shallow soils, or frequent disturbance preclude the formation of species-rich forest. These oligarchic forests (Gr. *oligo*=few, *archic*=dominated or ruled by) have been reported from almost every region of the wet tropics. The extensive stands of **aguaje** palm found in the lowlands of Amazonia are notable examples of this type of forest.

The **aguaje** palm (*Mauritia flexuosa*) is a massive tree common throughout lowland Amazonia; pure stands of this palm extend over a million hectares in Peru alone. Its fruits are eaten raw or processed into a sweet paste for beverages and ice creams. The fruits and seeds also yield an edible oil of good quality.

In terms of tree density and yield, oligarchic forests rival many of the commercial plantations that have been established in the tropics. Given their wide distribution, productivity, and relative ease of harvest, these unique plant communities would seem to have great potential for supporting a program of sustainable resource exploitation.

FLOWERING, FRUITING AND REPRODUCTIVE DYNAMICS

The different ways in which tropical trees produce their flowers and fruits can be a major stumbling block to resource exploitation. This unavoidable fact of life is perhaps most obvious in those cases where the actual resource of interest is a fruit or a seed, and where the seasonality and magnitude of fruit production have a direct impact on harvesting. It should be remembered, however, that fruits contain the seeds necessary for a species to regenerate and maintain itself in the forest. Irrespective of the species or type of resource being exploited, plant reproduction is a key issue in sustainability.

PHENOLOGY OF FLOWERING AND FRUITING

Detailed studies of flowering and fruiting **phenology** have been conducted in almost every area of the tropics. The results from these studies have shown that tropical trees vary greatly in terms of the timing, duration and intensity of flowering and fruiting. Different species may produce flowers annually, supra-annually, i.e. with an interval of several years between flowering events, or even several times a year. The periodicity of fruit production exhibits similarly complex patterns. **Very few tropical forest species produce reliable fruit crops during a well-defined, predictable season each year**.

Phenology refers to the timing or seasonality of specific biological events (e.g. leaf fall, growth or, as in this case, the production of flowers and fruits.)

One of the most interesting examples of supra-annual flowering and fruiting is exhibited by the Dipterocarpaceae, a large family of dominant canopy trees in Southeast Asia. At irregular intervals of from two to ten years, numerous dipterocarp species will more or less simultaneously start to flower within the forest. This *mass flowering* phenomena is usually followed by an extremely abundant level of fruit production known as *mast fruiting*. In an especially intense mast year, almost every dipterocarp and up to 80% of all canopy trees may burst into flower.

The exploitation and management of tropical forests would be considerably easier if the production of flowers and fruits occurred on a more predictable basis. In fact, it is hard to imagine a more difficult management situation than one in which the key species produce fruit at irregular intervals of from two to ten years. This, however, is exactly the framework within which the **illipe nut** trade in northwestern Borneo is forced to operate.

Illipe nut is the commercial name for the winged fruits produced by about 20 different species of *Shorea* trees. The seeds from these fruits contain an oil whose chemical and physical properties are remarkably similar to cocoa butter. The oil content of some seeds may be as high as 50%. Large quantities of illipe nuts are collected and sold to be used in the manufacture of chocolate, soap and cosmetics. In 1987, a recent mast year, over 13,000 tons of illipe nuts valued at over 5 million dollars (US) were exported from West Kalimantan, Indonesia alone. Less than 50 tons were collected the following year.

POLLINATION

The low density and scattered distribution of individuals in most tropical tree populations represents a dilemma for pollination. How do you move pollen effectively from the flowers of one tree to another when the distance between these individuals may be in excess of 100 meters? A brief look at Table 2, which lists the principal pollinators of twelve commercially important tropical trees, suggests the answer to this question.

Table 2. Pollinators of a selected number of tropical plant resources. Animals listed represent principal pollinators; the flowers of each species may also be visited by other animals.

Species	Common Name	Use	Pollinator
Shorea spp.	Illipe nut	oil seed	thrips
Hevea brasiliensis	Rubber	latex	thrips/midges
Theobroma cacao	Cacao	oil seed	midges
Mangifera indica	Mango	edible fruit	flies
Artocarpus heterophyllus	Jackfruit	edible fruit	flies/beetles
Orbignya martiana	Babassu	oil seed	beetles
Bactris gasipaes	Peach palm	edible fruit	beetles
Bertholletia excelsa	Brazil nut	edible seed	bees
Euterpe oleracea	Açai	edible fruit	bees
Ceiba pentandra	Kapok	fiber	bats
Durio zibethinus	Durian	edible fruit	bats
Parkia speciosa	Petai	edible seed	bats

Tropical trees have evolved relationships with a variety of animals, ranging from tiny thrips and midges to bees and large bats, to shuttle pollen between trees. These relationships can be quite specific, with one type of insect being solely responsible for pollinating the flowers of a particular forest species. It is important to emphasize that these plant-animal interactions are not simply isolated anecdotes from tropical forest folklore. **The large majority of tropical trees rely exclusively on animals to transfer their pollen**. One study conducted within a small tract of lowland forest in Costa Rica found that 139 (96.4%) of the 143 tree species surveyed were pollinated by animals.

There is an important lesson to be gained from these findings: no pollinators, no fruits; no fruits, no seedlings; no fruits or seedlings, no products or profit. Any serious program of commercial resource exploitation conducted in tropical forests must necessarily include measures to insure adequate pollination. In some cases, this requires a greater appreciation of the fact that land-use practices far away from the immediate harvest site can be extremely disruptive to populations of wide-ranging animals such as bats or even bees. The current situation with the nectivorous bat, *Eonycteris spelaea*, provides a dramatic, yet unfortunate, example of this.

Eonycteris bats are apparently the exclusive pollinators of **durian** trees in Peninsular Malaysia. These bats, however, feed preferentially on the flowers of *Sonneratia alba*, a coastal mangrove which occurs in dense groves and produces a few large flowers continually throughout the year. In order to forage on this reliable food source, the bats fly 20 to 40 kilometers from their roost each night. During this journey to the coast, any durian trees that they may encounter are pollinated almost as a dietary afterthought. Any attempt to maintain a viable population of these important pollinators in Malaysia must inevitably address the fact that the principal food source of *Eonycteris spelaea* is currently being decimated by coastal development.

Durian (*Durio zibethinus*) is unquestionably the premier market fruit in Southeast Asia. Some describe it as the most delicious fruit in the world; others have suggested that the flavor is a little bit like eating french custard in a public latrine. This undeniably smelly fruit resembles a football covered with sharp, woody spines.

SEED DISPERSAL

The importance of animals in the reproductive biology of tropical trees does not end after pollination. Once fruits and seeds have been successfully nurtured to maturity, the next problem faced by flowering plants is what to do with these offspring. Given the incredible variety of different fruit types produced by tropical trees, many of them extremely rich in protein, starch, or sugar and quite "costly" for the plant to produce, it is clear that these fruits have not evolved to simply drop to the ground beneath the parent tree. It seems more likely that these fruits have been specifically designed to be eaten—to be eaten, and the intact seeds within the fruit effectively dispersed to a new location.

The seeds of several commercial tree species are dispersed by wind (e.g. many dipterocarps in Southeast Asia). Wind dispersal is especially common in tropical dry forests.

Seed dispersal offers at least three ecological benefits to a plant. A dispersed seed has a greater probability of escaping the excessive crowding and mortality that invariably occurs under the crown of the parent tree. Dispersal may also allow a seed to spread its species into new habitats. Finally, some types of dispersal may position a seed in the precise site required for successful germination and growth.

These benefits are not mutually exclusive, and all three may occur depending on the plant species, the dispersal agent and the immediate environment. There is, however, an ecological cost associated with seed dispersal, especially when animals are involved. During the process of handling, transporting, or feeding on fruits, **frugivores** may destroy a large proportion of the seeds inside.

A **frugivore** is an animal which feeds on fruits.

The large number of tropical trees with animal-dispersed fruits suggests that the actual costs of using these dispersal agents are greatly outweighed by the potential benefits. Research conducted in the tropical forests of Central and South America indicate that over 90% of the canopy trees produce fruit adapted for consumption, and subsequent dispersal, by animals; related studies in Southeast Asia have produced similar results. Clearly, bats, birds, primates, peccaries, **fish** and a wide assortment of other vertebrates are responsible for moving an enormous quantity of seeds around in a tropical forest. These animals may either remove fruits directly from the tree, or they may forage on fruits which have already fallen to the ground.

A somewhat curious example of seed dispersal by animals has been observed in tropical riverine forests. A large proportion of the trees in these seasonally flooded habitats drop their fruits directly into the water. These fruits are eaten by **fish** which eventually defecate the seeds, usually after swimming a considerable distance.

The presence of fruit-eating animals in a tropical forest can be a problem for commercial collectors. These animals damage or consume large quantities of fruit, and their activities quickly become a nuisance when the species being eaten is an economically important one. In those cases where collectors and frugivores are actively competing for the harvest of the same species, the animals invariably get there first. It is not surprising that a common solution to this problem has been simply to eliminate the animals from the forest.

It is worth remembering, however, that forest frugivores play an important role in dispersing the seeds of many commercial tree species. The seeds of some species, in fact, will not even germinate without first being cleaned by animals. **The distribution and abundance of the seedlings produced by a forest species are frequently controlled by the action of dispersal agents, and, like it or not, the great majority of these dispersers are animals.** Failing to conserve viable populations of these animals would be a serious management error.

REGENERATION AND GROWTH

Safe arrival from the parent tree to the forest floor does not, by any means, guarantee that a seed will germinate and become established in the understory. The seed must avoid being eaten, it must encounter the appropriate light, moisture, and nutrient conditions for germination, and it must be able to germinate and grow faster than the seeds of all the other species that are trying to establish themselves on the same spot.

There is a high probability that a seed will come in contact with an animal during the lapse between dispersal and germination. In most cases, this encounter proves fatal for the seed. In terms of total numbers, **seed predation** is unquestionably one of the most severe sources of mortality during the life of a plant. Over 98% of the seeds of some forest species are lost to predation; rodents, beetles, ants, and weevils are the most frequently cited seed destroyers.

Seed predation refers to the destruction of seeds by animals that attack, eat, lay eggs on, or otherwise damage them.

Even assuming that a seed has successfully germinated and a new seedling has put down roots and unfurled its first new leaves, there is still very little chance that the plant will become established on that site. The first year of life for a seedling is plagued with problems. To begin with, light levels in the forest understory are usually so low (1 to 2% that of full sun) that it is difficult for the seedling to grow. Added to this is a very high probability that it will be browsed on by an animal, outcompeted by its neighbors, smashed by a falling branch, attacked by fungal pathogens, ripped out of the soil by a rolling rock, or wilted by wildly fluctuating moisture levels.

A graphic example of the severe mortality experienced by tropical tree seedlings during their first year is provided by the three survivorship curves shown in Figure 2. *Brosimum alicastrum* is a widely distributed canopy tree in Central and South America; *Shorea curtisii* and *Shorea multiflora* are both common components of mixed **dipterocarp forest** in Southeast Asia.

As the name implies, **dipterocarp forests** are dominated by trees from the Dipterocarpaceae family.

As is illustrated in this figure, seedling survivorship by these three species after 12 months ranges from a high of 22% for *S. curtisii* to a low of only 3% for *B. alicastrum*. Five months after germination over 50% of the seedlings

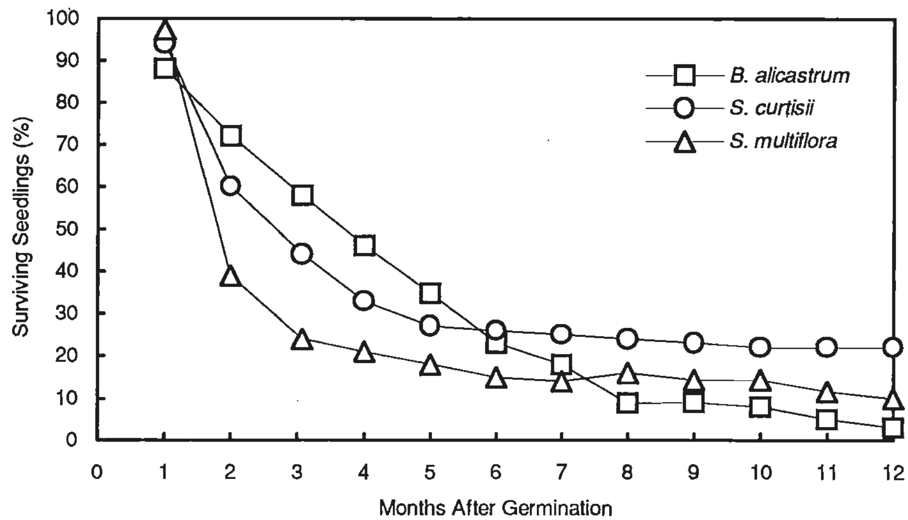

Figure 2. Seedling survivorship curves for *Shorea curtisii*, *S. multiflora* and *Brosimum alicastrum*. All three species are primary forest trees.

of each species have already died. Taking into account seed predation and lack of germination, less than 0.1% of the seeds produced by *B. alicastrum* become established seedlings. **Only a very small fraction of these seedlings (approximately 1 in 1.5 million) will ever make it to the canopy and produce fruit**. Data such as these, which are by no means atypical of tropical trees growing in primary forest, provide a convincing demonstration of how difficult it is for a tree population to maintain itself in the forest—even in the absence of any type of resource harvesting.

CANOPY GAPS

The excessive seedling mortality that characterizes the regeneration of many forest species raises an important management question. Where are the few seedlings located that actually survive? What type of site provides the necessary conditions for seed germination, and also allows the new seedling to express an optimal rate of growth relative to its neighbors? The specific combination of environmental conditions which describe such a site may be thought of as the *regeneration niche* of a species. To a large extent, the area and distribution of these niches are what regulate the number of seedlings that become established in the forest.

Extensive research on seedling establishment has shown that the regeneration niches of a large percentage of tropical trees have one feature in common —they are all in some way related to the sporadic occurrence of treefalls. Tropical trees may blow down, get struck by lightning, or simply die from old age and fall down. Each of these events produces an opening or "gap" in the forest canopy that allows direct sunlight to enter the understory. In addition to the increased sunlight, canopy gaps also exhibit lower humidity, higher temperatures, and higher soil moisture levels than those found under a closed canopy.

Shade-tolerant species possess certain physiological adaptations (e.g. enhanced photosynthetic system) that better enable them to survive in the shade.

These abrupt changes in the understory environment have a notable effect on most of the seedlings in the vicinity of a canopy gap. In smaller gaps, many of the more **shade-tolerant** seedlings which have managed to survive under a closed canopy will display a significant increase in growth in response to the higher light levels. Numerous canopy species exhibit this behavior. Their seeds germinate in the shade and the young seedlings grow until they have produced about two or three leaves. The seedlings then appear to enter a state of suppression in which they exhibit little or no height growth. There are only two possible outcomes to this physiological condition. The seedlings slowly die over time, or they are "released" by the occurrence of a canopy gap overhead.

Light-demanding species are specifically adapted for growth and reproduction under high light levels.

In larger gaps, the drastic increase in light level and soil temperature may trigger the germination and growth of **light-demanding** species. The seedlings of these species grow extremely fast under sunny conditions, and large gaps are soon swamped with these aggressive, "weedy" plants. Any shade-tolerant species which may occupy the site are soon outcompeted. Classic examples of light-demanding species include *Ochroma lagopus* (balsa wood) and *Cecropia* in the American tropics, and many of the over 250 species of *Macaranga* found in Southeast Asia.

Canopy gaps play a critical role in the establishment and growth of tropical trees; up to 75% of the canopy trees in some areas require the occurrence of a treefall for seedling establishment. The problem is that there is absolutely no way to predict exactly when and where a canopy gap will be created. There is also no guarantee that the desired species will actually colonize a gap should it occur.

REGENERATION GUILDS

The **life strategy** of a plant refers to all of the physiological, morphological and behavioral adaptations that have evolved to increase the survival of that species.

Tropical trees have evolved an incredible variety of different **life strategies** to pollinate their flowers, to disperse their seeds, and to enhance the establishment of new seedlings into their populations. It has long been noted, however, that there are certain similarities and patterns in these strategies which allow tropical species to be grouped into distinct ecological categories. Light tolerance (i.e. shade-tolerant or light-demanding), for example, is one of the most frequent ecological characteristics used to group species. The reason for grouping species is not to obscure the inherent diversity of different strategies found within a tropical forest. Rather, these categories provide a useful tool for more rapidly understanding the basic ecological requirements of a forest species.

For the purpose of this report, it is useful to define three groups or "guilds" of forest species based on their regeneration characteristics, growth rate and life span. These three regeneration guilds are: (1) **primary**, "climax", or mature forest species, (2) **early pioneer** or "secondary" species, and (3) **late secondary** species. In spite of the names applied to these different groups, all three types can occur in mature tropical forest. A schematic listing of the basic ecological characteristics of each guild is presented in Table 3.

Table 3. Basic ecological characteristics of early pioneer, late secondary, and primary tropical forest species.

Character	Early Pioneer	Late Secondary	Primary
Distribution	very wide	very wide	usually restricted; many endemics
Seed dormancy	well-developed	slight to moderate	none
Seed or fruit size	small	small to intermediate	large
Seed dispersal	birds,bats,wind	mainly wind, but also mammals	mammals, birds
Shade tolerance	very intolerant	intolerant	seedlings very tolerant, later intolerant
Gap size required	large	intermediate	small
Seedling abundance	very scarce	usually scarce	abundant
Growth rate	very fast	fast	slow to very slow
Wood density	light	light to medium	very hard
Life span	10 to 25 years	40 to 100 years, sometimes more	100+ years

Primary tree species germinate in the shade and can survive in the understory for a considerable length of time until a canopy gap opens overhead. Their seeds are usually large and few, with abundant seed reserves and little or no dormancy. These species, as a group, are highly shade-tolerant and possess a photosynthetic system adapted for growth under very shady conditions. Growth is relatively slow and wood density, as a result, can be extremely high. Primary trees may live for several hundred years and attain heights of over 60 meters. Many valuable tropical hardwoods fall into this guild, together with several important fruit and oil-seed trees. Many understory palms and herbs are also primary species.

Early pioneers frequently persist for long periods in the soil as dormant seeds. Their seeds, which are small and produced in abundance, require the stimulus of a large gap opening (i.e. increased soil temperature or light intensity) to germinate. After germination, these species exhibit high maximum rates of photosynthesis and growth. Wood density is correspondingly light. Early pioneer tree species mature rapidly, reproduce early, and die young (*circa* 10 to 25 years).

Late secondary plants represent an intermediate guild between primary and early pioneer species. These species are typically light-demanding, but their seeds do not exhibit the stringent dormancy of early pioneers and smaller gap sizes are required for germination. Seed dispersal into gaps is facilitated by wind, birds, bats, or ground mammals. Late secondary species exhibit the fast growth and maximal photosynthesis of many pioneer species, but they grow to a much larger size and persist for longer periods in the canopy. Wood density is variable, but usually lower than that of primary species.

Every plant does not fall neatly into one of these groups. There are varying degrees of shade tolerance and a complete spectrum of responses to varying degrees of light, soil moisture, and competition from other species. Even within a single species, the genetic make-up of different individuals can cause great variability in growth rate, wood density, fruit production, seed germination and seedling establishment. A true understanding of the ecological behavior of a species can only be gained through careful observation and detailed study. Such an effort, however, is highly warranted. **Sustainable resource use hinges on a species' ability to continually establish new seedlings while being subjected to repeated and intensive harvesting. A basic knowledge of its regeneration and growth requirements can greatly facilitate this process.**

POPULATION STRUCTURE

Population structure refers to the numerical distribution of individuals of differing size or age within a population at a given moment of time.

The ultimate criteria by which the life strategy of a species must be measured is its effectiveness in "recruiting" new individuals into its population. The more effective this strategy, the longer the population will be able to maintain itself in the forest. One method of measuring this success is to monitor the frequency and abundance of seedling establishment over a period of several decades, and to record the resultant increase or decrease in population size over time. Fortunately, it is not always necessary to conduct this laborious and time-consuming procedure. In many cases, the recruitment history of a particular species is reflected by the size distribution of individuals within its population. A rapid appraisal of population structure can frequently provide information about whether or not a species is regenerating itself in the forest.

Population structure data have long been used by foresters and ecologists to study the regeneration dynamics of forest species. The results from these studies have shown that the structure of most tree populations can be described by a limited number of size-class or diameter distributions. Three of the most common types of population structure are shown in Figure 3.

The Type I size-class structure displays a greater number of small trees than large trees and an almost constant reduction in the number of trees from one size class to the next. This type of population structure is characteristic of shade-tolerant, primary species which maintain a more or less constant rate of seedling establishment. In these populations, it is pretty safe to assume that the death of an adult tree will, at some point, be replaced by individuals growing up from the smaller size classes. **A Type I structure is thought by many authors to represent the ideal of a stable, self-maintaining population.** This is the type of structure that you strive to preserve in natural populations of non-timber forest resources.

A Type II size-class structure is characteristic of populations which experience sporadic or irregular seedling establishment. The actual level of regeneration may be sufficient to maintain the population, but its infrequency of occurrence causes notable "peaks" and "valleys" in the size-class distribution as the new

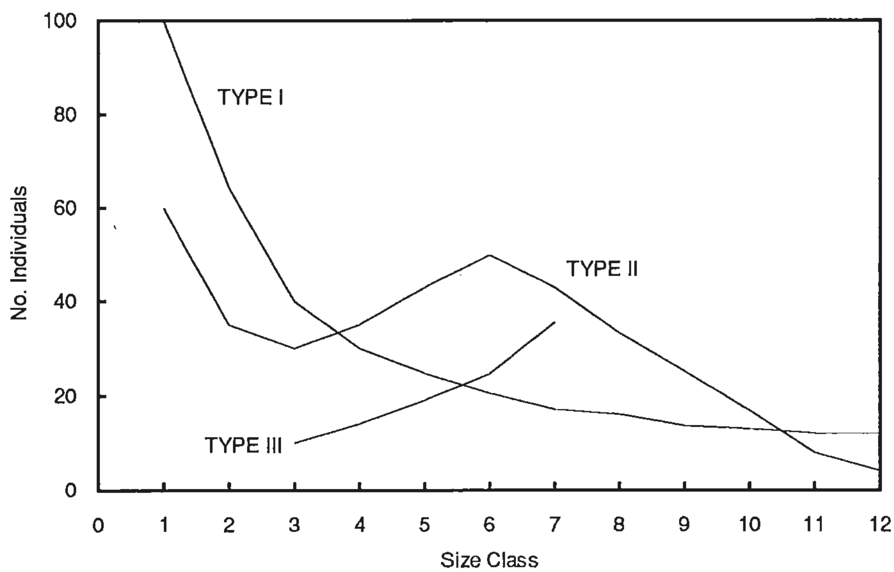

Figure 3. Three idealized size-class distributions exhibited by tropical tree populations. Size-class intervals are 10 cm DBH.

seedlings grow into larger size classes. This type of distribution is common among late secondary species that depend on canopy gaps for regeneration. It may also reflect a population whose regeneration has been temporarily interrupted through excessive harvesting of fruits or seeds, direct physical damage to seedlings (e.g. trampling by collectors), or lack of pollinators or dispersal agents.

The final size-class distribution, Type III, reflects a species whose regeneration is severely limited for some reason. Most of the individuals in these populations are more or less the same size, and although many of them may be producing flowers and fruits, no seedlings have been successfully established. Type III population structures are frequently encountered among light-demanding, early pioneer species which require large canopy gaps for regeneration. In the absence of such a disturbance, these species may *temporarily* disappear from the forest—the former population represented only by the seeds lying dormant in the soil. A Type III distribution is not restricted to early pioneer species. Populations of late secondary or primary species can also exhibit this pattern if seedling establishment is interrupted for a long enough period of time. Unless conditions change, these populations will *permanently* disappear from the forest.

Although the three size-class distributions correlate well with the three different regeneration guilds, it is important to remember that the population structure of a species is extremely dynamic and sensitive to changes in the level of regeneration. A Type I distribution can easily change into a Type II if existing rates of seedling recruitment are reduced. Further constraints on regeneration may drive the population to a Type III distribution. Given this behavior, it is most useful to view the three structural types as a single sequence through which a population passes on its way to extinction. The occurrence of a Type III structure in a population of shade-tolerant, primary trees, for example, is a sure sign that something is wrong.

Although necessarily brief, the preceding discussion has attempted to show that tropical forest species display a variety of different ecological characteristics that can make sustainable harvesting a very difficult objective to achieve. The major problem areas are:

- the high diversity and low population density of plant species
- the irregularity of flowering and fruiting
- the importance of animals for pollination and seed dispersal
- the high mortality and low success rate during seedling establishment
- the sensitivity of population structure to changes in the level of natural regeneration

These five characteristics are immutable facts of plant life in the tropics. As will be shown in Section II, ignoring them can cause serious, in some cases irreparable, damage to the plant populations being exploited.

LITERATURE

Several excellent textbooks are available to readers desiring further information about the ecology of tropical trees and forests. A few examples are cited below:

1. Gentry, A. (ed.) 1990. *Four Neotropical Rainforests*. Yale University Press, New Haven.

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4. Richards, P.W. 1952. *The Tropical Rain Forest*. Cambridge University Press, Cambridge.

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6. Whitmore, T.C. 1990. *An Introduction to Tropical Rain Forests*. Clarendon Press, Oxford.

SECTION II. IMPACT OF HARVESTING

The complex inter-relationships and ecological processes described in Section I exist in a very delicate balance. This balance is easily disrupted by human intervention, and land-use practices that at first seem benign can later have a severe effect on the structure and dynamics of forest tree populations. Almost any type of resource exploitation conducted in tropical forests will have an impact. It may not be immediately visible to the untrained eye—but it is definitely occurring.

In general, the overall ecological impact of forest utilization depends on the floristic composition of the forest, the nature and intensity of harvesting, and the particular species or type of resource under exploitation. Sporadic collection of a few fruits may have little effect on the long-term stability of the tree populations being exploited. Intensive annual harvesting of a valuable oil seed, on the other hand, can gradually eliminate the species from the forest. The felling of adult trees can produce a similar result in a much shorter period of time.

In spite of all the discussion surrounding the sustainable use of tropical forests, surprisingly little has been written about the ecological impacts of non-timber resource extraction. The purpose of this section, therefore, is to summarize what is currently know about the topic, and to assess the potential long-term impacts of harvesting different types of plant resources.

Given that the initial impact of resource harvesting is largely determined by the specific type of plant tissue or compound extracted, the following analysis employs an ecological, rather than a commodity, approach. From a marketing or use perspective, fruits, nuts and oil seeds are completely different products. The act of harvesting these products, however, produces a similar ecological impact—it removes seeds from the forest, and hence reduces the total number of seedlings that can potentially be recruited into the plant populations being exploited.

Using this approach, the enormous variety of non-timber plant resources produced by tropical forests can be grouped into three basic categories: (1) fruits and seeds, (2) plant exudates, and (3) vegetative structures. This classification scheme is illustrated in Table 4. Specific examples of each resource group and type of plant product from Amazonia and Southeast Asia are also included. All species listed are primarily natural forest species, but some of the plants may also be cultivated. The listing in Table 4 is far from exhaustive.

Table 4. Selected examples of non-timber tropical forest products grouped by resource category and plant part. Local nomenclature and use information taken from personal observations.

Resource Category	Plant Part	Example: South America	Example: Southeast Asia
Fruits and Seeds	Fruit	Aguaje (*Mauritia flexuosa*)	Durian (*Durio zibethinus*)
		Caimito (*Pouteria spp.*)	Rambai (*Baccaurea motleyana*)
		Uvos (*Spondias mombin*)	Rambutan (*Nephelium lappaceum*)
	Nut/Seed	Almendro (*Caryocar spp.*)	Petai (*Parkia speciosa*)
		Castaña (*Bertholletia excelsa*)	Melinjau (*Gnetum gnemom*)
	Oil seed	Ungurahui (*Jessenia bataua*)	Tengkawang (*Shorea spp.*)
		Babassu (*Orbignya phalerata*)	Kemiri (*Aleurites moluccana*)
Plant Exudates	Latex	Shiringa (*Hevea brasiliensis*)	Gutta percha (*Palaquium spp.*)
		Balata (*Manilkara bidentata*)	Jelutong (*Dyera costulata*)
	Resin	Copal (*Protium, Dacryodes*)	Damar (*Dipterocarpus spp.*)
			Gharu (*Aquilaria spp.*)
	Floral nectar		Aren (*Arenga pinnata*)
Vegetative Structures	Stem	Pona (*Socratea, Iriartea*)	Rattan (*Calamus, Korthalsia*)
	Leaf	Chambira (*Astrocaryum spp.*)	Pandan (*Pandanus spp.*)
	Root	Barbasco (*Lonchocarpus spp.*)	Tuba (*Derris spp.*)
	Bark	Chuchuhuasa (*Maytenus spp.*)	Medang (*Litsea spp.*)
	Apical bud	Açai (*Euterpe oleracea*)	Aren (*Arenga pinnata*)

FRUITS AND SEEDS

To isolate the specific ecological consequences of collecting fruits, nuts, and oil seeds from a tropical forest, it is important to first separate out the negative effects of destructive harvesting. In many tropical regions, an increasingly common practice is to simply cut down a tree to harvest its fruit. This damaging, short-sighted, and wasteful practice can have a drastic impact on the distribution and abundance of fruit resources within a forest.

The **ungurahui** palm (*Jessenia bataua)* forms dense populations in seasonal swamp forest; it is common throughout Amazonia. Its fruits are used to make a nutritious beverage and are also the source of a high-quality edible oil.

Babassu palms (*Orbignya phalerata)* grow along the southern and eastern fringe of Brazilian Amazonia; oligarchic forests of this species occupy almost 29 million hectares. The fruits of babassu provide a variety of subsistence and commercial products. The seeds contain an oil useful for cooking, soap-making and burning. Flour, animal feed, medicines and beverages are produced from the fruit.

In Peruvian Amazonia, for example, the female trees of the aguaje palm are frequently felled by commercial collectors. After very few of these "harvest" cuts, the forest is left with a preponderance of barren male trees. Over time, the species disappears completely from the forest. Destructive harvesting has also seriously reduced the abundance of the **ungurahui** palm, the **babassu** palm, and a wide variety of other important Amazonian fruit trees. **No program of commercial fruit extraction will ever be sustainable as long as harvesting involves an ax.**

Even in the absence of destructive harvesting, the collection of commercial quantities of fruits and seeds can still have a significant ecological impact. The manifold difficulties experienced by tropical trees during the germination and seedling establishment stages were described in Section I. Periodic fruit harvests can make the process of seedling recruitment even more problematic.

In terms of simple demographics, if a tree population produces 1,000 seeds and 95% of the new seedlings produced from these seeds die during the first year, the population has still recruited 50 new individuals. If, on the other hand, intensive fruit harvesting removes all but 100 of these seeds from the site prior to germination, the maximum number of seedlings that can be recruited into the population is reduced to only 5. This ten-fold shortfall in recruitment can cause a notable change in the structure of the population.

In reality, this example is probably overly optimistic. First, it is assumed that all of the seeds produced are deposited precisely in the appropriate site for germination and early growth (i.e. the regeneration niche of the species). Second, there is always the possibility that the fruits and seeds left in the forest after harvesting will experience a mortality rate higher than 95%. Commercial collectors are, in effect, competitors with forest frugivores, and their activities reduce the total supply of food resources available to ground-foraging animals. In response to decreased fruit densities, frugivores might be forced to increase their foraging to obtain sufficient food. The net result would be an increase in the total percentage of fruits and seeds destroyed.

Rather than increasing their search for a constantly diminishing food source, it is also possible that some frugivores will simply migrate to more isolated tracts of forest in response to commercial fruit collection. This response could have a serious impact on seedling establishment for those species whose seeds require cleaning by animals to germinate. Additionally, some of the frugivores that migrate off-site may have played an important role in seed dispersal. Without a dispersal agent, a higher proportion of the fruits and seeds produced by these species will fall directly under the crown of the parent tree where they are more easily harvested by collectors, more easily encountered by seed predators, and more susceptible to the effects of competition from other seedlings.

All of these factors interact in a synergistic fashion to inhibit the recruitment of new individuals into a plant population. Over time, this lack of recruitment will modify the size-class distribution of the population being harvested. If commercial fruit collection continues uncontrolled, the target species can be eliminated from the forest. This process of gradual population disintegration is illustrated in Figure 4. The size-class intervals depicted are 10.0 cm DBH; note the change of scale in the latter three time periods to compensate for the decrease in total population size.

As is shown at TIME 0, the hypothetical population initially displays the Type I size-class distribution of a shade-tolerant canopy tree with abundant regeneration. After several decades of fruit collection, however, the structure of the population has been notably changed (TIME 1). The infrequency of seedling establishment has caused a reduction in the smaller size classes; the greater number of stems in the intermediate size classes reflects the growth of saplings that were established prior to exploitation. The structure of the population at this point conforms to a Type II distribution. By TIME 2, the population has been even further degraded by the chronic lack of regeneration. There are intermediate size classes that contain no individuals at all, and it appears that the existing level of saplings and poles is insufficient to re-stock these classes. Finally, the size-class histogram shown for TIME 3 represents the culmination of a long process of over-exploitation. The population

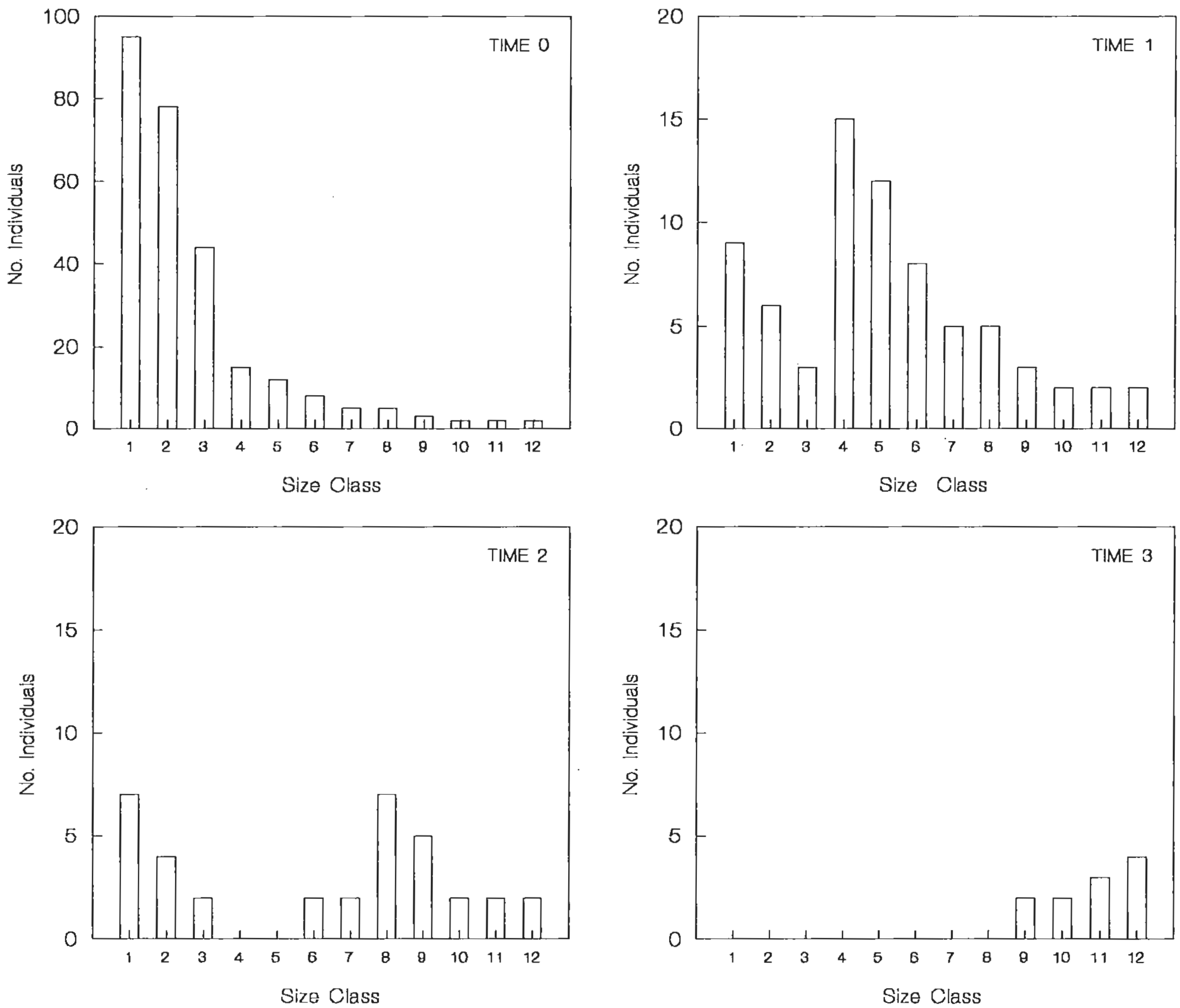

Figure 4. Hypothetical example of change in population structure experienced by a forest tree species in response to intensive collection of fruits, nuts, or oil seeds. Size-class intervals are 10 cm DBH; each time period represents approximately 30 years. Note change of scale in the size-class histograms for latter three time periods.

consists of only large, old adult trees, none of which are regenerating (Type III population structure). In the absence of remedial action, it is only a matter of time before this tree species becomes locally extinct. At no point during this process is there any dramatic visual evidence (e.g. dead or dying trees) that anything is wrong. The forest still contains adult trees of the desired species which continue to produce fruit—and harvesting will probably continue unabated.

The example shown in Figure 4 represents an extreme case of uncontrolled over-exploitation, and does not necessarily imply that every level of harvesting involving fruits and seeds leads directly to species extinction. Some species and populations will be more susceptible to over-exploitation than others. The key ecological parameters to be considered here have to do with (1) the initial density or size of the population, (2) the actual intensity of fruit or seed collections, (3) the degree to which the plant depends on animals for pollination and dispersal, and (4) the specific regeneration and growth requirements of the species being exploited.

As a general rule, forest species that occur in high densities, exhibit abundant regeneration, and are pollinated by either "generalist" animals (e.g. small insects) or wind are able to tolerate more intensive harvesting. Conversely, low density populations that display a Type II or Type III size distribution and possess an obligate relationship with a specific pollinator or seed disperser will have a much lower sustainable yield of fruit and will be much more prone to over-exploitation. It is worth noting that most of the forest populations of **Brazil nut** that are currently being so intensively exploited in Amazonia exhibit all of these latter characteristics.

Brazil nuts (*Bertholletia excelsa*) are produced by an enormous forest tree (up to 50 meters tall and over a meter in diameter) which is widely distributed throughout the upland forests of Colombia, Venezuela, Peru, Bolivia and Brazil. The commercial exploitation of this species was initiated over 150 years ago. During the past thirty years, the annual harvest of Brazil nuts has fluctuated between 40,000 and 100,000 metric tons.

Finally, in addition to its impact on seedling establishment, population structure, and the foraging behavior of local animal populations, **harvesting commercial quantities of fruits, nuts, and oil seeds can also affect the genetic composition of the tree population being exploited**. In this case, the important question is not so much how many fruits or seeds are harvested, but rather which ones.

Tropical tree populations usually exhibit a high degree of genetic variability. A single population of forest trees, for example, will usually contain several individuals that produce large succulent fruits, a great number of individuals that produce fruits of intermediate size or quality, and a few individuals that produce fruits that, from a commercial standpoint, are inferior because of their small size, bitter taste, or poor appearance. If this population is subjected to intensive fruit collection, the "inferior" trees will undoubtedly be the ones whose fruits and seeds are left in the forest to regenerate. Over time, the selective removal of only the best fruit types will result in a population dominated by trees of marginal economic value. This process, although more subtle and occurring over a longer period of time, is identical to the "high-grading" or "creaming" of the best tropical timbers that occurs in many logging operations.

PLANT EXUDATES

When properly conducted, the tapping of latexes, resins, and gums does not disturb the forest canopy, kill the exploited tree, or remove its seeds from the site. In theory, this activity probably comes the closest to conforming to the ideal of sustainable non-timber forest product extraction. In actual practice, the exploitation of plant exudates can be very destructive.

In West Malaysia, oleo-resin is collected from ***Dipterocarpus*** trees by chopping large holes into the trunk and then building a fire inside to maintain the flow of resin. This sequence of "boxing and firing" is usually repeated several times, and a large tree may be "boxed" at two or three places along the trunk. This process severely weakens the vigor of the tree. Internal resources which might have been allocated to basic ecological functions such as fruit production and growth are spent on resin production and the formation of callous tissue to heal the wounds. The damaged trees are almost certainly not replacing themselves in the forest.

Several species of ***Dipterocarpus*** trees produce an oleo-resin or "damar" which has long been valued as a source of varnish, caulking, and, more recently, as a base for perfumes.

Gharu is the local name for the resinous, fungal-infested heartwood produced by several species of *Aquilaria* trees. This plant exudate, which is extensively exploited in West Malaysia, Borneo and Indochina, is used in traditional medicine as well as for incense and ritual purposes. The blackened, diseased wood does not occur in every *Aquilaria* tree, and even when present the quantity is extremely variable.

The collection of **gharu** (*Aquilaria spp.*) in most parts of Southeast Asia is accomplished by felling the tree. As there are no external signs to indicate whether a tree contains this valuable resin, collectors frequently fell every *Aquilaria* tree they find. Once a tree containing gharu has been felled, collectors use axes and knives to hack out the blackened heartwood. The uncontrolled exploitation of this exudate, together with the wasteful trial and error method of searching for it, has virtually eliminated *Aquilaria* trees from all but the most remote and inaccessible forest areas.

The destructive harvest of plant exudates is not limited to either resinous trees or Southeast Asia. *Couma macrocarpa* is a valuable latex and fruit-producing tree in many parts of Amazonia. The species produces copious amounts of creamy latex which is used in the manufacture of chewing gum; the latex is also occasionally used as an adulterant in Para rubber (*Hevea brasiliensis*). Although the species can be tapped repeatedly as easily as rubber and exploited every year for its fruits, opportunistic collectors have felled an incalculable number of *Couma* trees to quickly drain them of their latex.

Rubber, chicle (*Manilkara zapota*), and jelutong (*Dyera costulata*) are common examples of plant exudates that are tapped in a non-destructive fashion. It is tempting to assume, therefore, that the exploitation of these resources will be automatically sustainable in the long term. It should be remember, however, that **maintaining a continual supply of latex is contingent on these species being able to replace themselves in the forest**. There is currently a large number of tappable rubber trees growing in Amazonian forests. These trees will eventually die. Are any provisions being made to insure the recruitment of a second or third generation of *Hevea* trees?

It is useful in this context to briefly examine the physiology of rubber production by *Hevea* trees. Rubber latex is manufactured in special cells using stored carbohydrates. In addition to rubber, the latex contains proteins, sugars, tannins, alkaloids, and mineral salts. Although the exact biological function of this rich concoction is unknown, biochemically it is very expensive for the tree to produce. The abundant production of rubber latex by *Hevea* trees is an abnormal response to injury—a tapped tree produces hundreds of times more latex than it would have formed had it not been tapped. The net result is that commercial tapping regimes cause the tree to divert a considerable proportion of the resources normally used for growth and reproduction to the production of rubber. This diversion of resources can cause a measurable reduction in the growth of rubber trees subjected to commercial tapping regimes.

As is shown in Figure 5, tapping reduced the diameter increment of plantation-grown rubber trees in Southeast Asia by as much as fifty percent over a five year period. In this experiment, the sample trees were growing in an open environment with abundant light, water, and nutrients, and free of competition from other plants. The growth of wild *Hevea* trees in a forest environment would undoubtedly be even more severely affected.

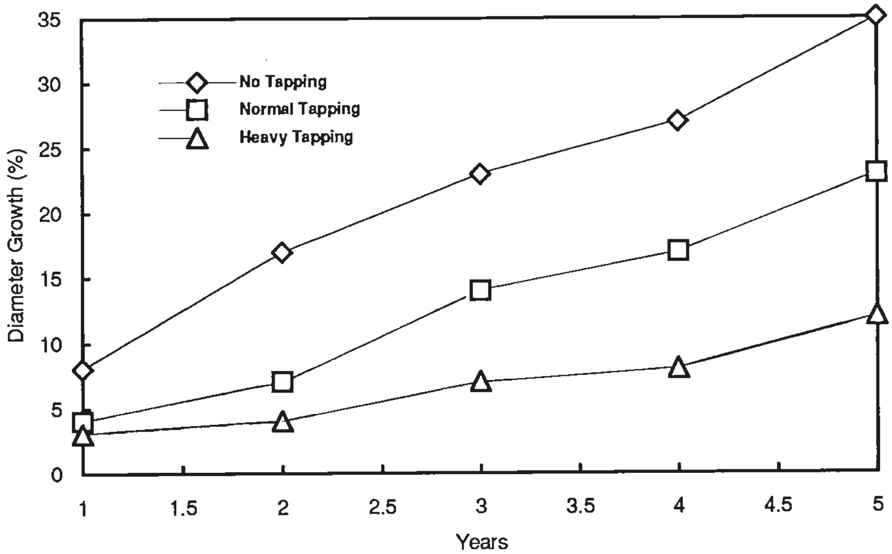

Figure 5. Diameter growth exhibited by plantation-grown *Hevea* trees when left untapped or subjected to two tapping intensities.

It is highly possible that this reduction in vegetative growth would also be accompanied by a reduction in seed output. Several studies have shown that loss of vigor caused by disease, seed predation, or herbivory can reduce total fruit production by increasing the rate of fruit abortion. There is no reason to assume that repeated tapping will not produce a similar response. The physiological demands of producing a continuing supply of latex are in conflict with the ecological imperative of producing seeds.

VEGETATIVE STRUCTURES

The final category of non-timber forest resources contains a diverse assemblage of different plant tissues used for fiber, building materials, medicines, fish poisons, and foods (see Table 4). The actual plant part exploited may be either the root, stem, leaf, bark, or **apical bud**. Although the origin and use of these products are very different, their harvest produces a similar ecological impact. The plant species will either be killed during the collection process, or, in a limited number of cases, it will survive harvesting and later regenerate the vegetative structure(s) removed.

The **apical bud** of a plant is the primary growing point or meristem located at the apex of the stem.

There are numerous examples of plant resources that are killed or fatally wounded by the harvest of vegetative structures. The current situation with **rattan** in Southeast Asia provides a particularly useful illustration of the deleterious effects of harvesting commercial quantities of stem fiber.

Rattans are climbing, spiny palms that occur in the mixed dipterocarp forests of Southeast Asia. The largest concentration of species occurs in Peninsular Malaysia and Borneo where at least 104 and 151 species, respectively, have been identified to date. The stem fibers of about 20 of these palm species are widely sought after as a source of cane for manufacturing furniture, woven mats, baskets and other types of wickerwork.

After locating a suitable specimen in the forest, rattan is harvested by cutting the plant at the base and then pulling the entire spiny stem and leaves out of the forest canopy by repeated strong tugs. Given that a large cane may be over 100 meters long, this is a particularly arduous task. Once on the ground, the spiny leaves and sheath around the stem are removed with a knife and the stem is bundled for transport out of the forest.

The actual impact of harvesting depends on the specific growth form or type of rattan that was cut. Large cane rattans usually possess a single stem that does not re-sprout after cutting. Harvesting kills these individuals. Smaller cane rattans, however, are typically multi-stemmed and can re-sprout after cutting if sufficient time is allowed between harvests. As might be expected given this trait, intensive and uncontrolled harvesting has drastically reduced the abundance of solitary rattans in many localities (e.g. the Philippines, Indonesia and Malaysia). Unfortunately, the rising demand for small-diameter canes has also caused the over-exploitation of many multi-stemmed species, collectors cutting them too young or too close to the ground to permit re-sprouting.

The commercial collection of other types of vegetative structures can also cause an ecological impact, although this impact is frequently less notable than that produced by the extraction of stem tissue. Harvesting leaf fibers may have a negligible effect on the plant population being exploited if:
(1) individual plants are not killed in the process, (2) a sufficient number of healthy leaves are left on each plant to photosynthesize, (3) the reproductive structures and apical bud are not damaged, and (4) sufficient time is allowed between successive harvests for the plant to produce new leaves. The periodic collection of leaves from the **chambira** palm in Peruvian Amazonia, for example, has little effect on the vigor of exploited trees, and the species appears to be maintaining itself well in local forests under current levels of exploitation.

Chambira (*Astrocaryum spp.*) is a large, spiny palm found in many regions of Amazonia. Its leaf fibers are widely used for cordage and weaving material. The ubiquitous Amazonian "jikra" (woven sling bag) is made from chambira fibers.

The collection of roots and bark tissue usually kills or fatally weakens the exploited tree species. The impact of this selective mortality can become quite severe under high levels of exploitation. In the early 1930s, for example, a significant export trade in **barbasco** was developed in many parts of Amazonia. Commercial collectors began digging up, and not replacing, every barbasco plant they could find. The species was quickly depleted in the wild and is now produced almost exclusively in plantations.

The roots of the **barbasco** plant (*Lonchocarpus spp.*) contain rotenone, an extremely potent natural insecticide.

Apical buds represent the final category of non-timber forest products harvested from vegetative structures, with palm hearts being the most important and well-known example. In Amazonia, two forest palms are the preferred source of this delicacy, *Euterpe oleracea* and *Euterpe precatoria*. *Euterpe oleracea* is a slender, multi-stemmed palm that is widely distributed in the seasonally flooded forests of eastern Amazonia; the species forms extensive oligarchic forests along the floodplain of the Amazon estuary. *Euterpe precatoria* grows in a similar habitat in western Amazonia, but is a solitary or single-stemmed palm. These differing growth forms play a major role in determining the overall ecological impact of harvesting.

In a single-stemmed palm species, harvesting the "heart" or apical meristem necessarily kills the tree. This is exactly what happens when palm hearts are extracted from *E. precatoria*. The establishment of a palm heart canning factory in Iquitos, Peru during the mid-1980s was sufficient impetus to destroy almost every population of this species in a wide radius around

Iquitos. The factory was eventually forced to close due to the scarcity of palms.

The vast stands of *E. oleracea* found in eastern Amazonia are also exploited quite heavily for palm hearts. Fortunately, the multi-stemmed growth form possessed by *E. oleracea* enables the species to sprout back after cutting, and this ecological factor has greatly facilitated its survival in the region. In an exemplary demonstration of forest management capabilities, local collectors on Onças Island near Belem, Brazil have developed an innovative system for harvesting palm hearts on a sustained-yield basis using weeding and pruning techniques to take advantage of *E. oleracea*'s unique ability to sprout from the stump after cutting.

The initiative of the forest farmers on Onças Island in the Amazon represents an appropriate point of closure for this section. **The exploitation of almost any type of non-timber forest resource produces a measurable impact on the structure and dynamics of tropical tree populations.** There are typically two responses to this impact. One is to completely ignore that it is occurring, the other is to implement appropriate management activities that will minimize the intensity of this impact. The former course of action, or lack thereof, inevitably leads to forest degradation and resource depletion; the latter may ultimately produce a sustainable form of land-use.

The first two sections in this primer have been concerned with the ecology of tropical plant populations—how these populations are structured, how they function, and what happens to them when they are subjected to commercial resource exploitation. The unfortunate conclusion to be drawn from this material is that much of the current exploitation of non-timber tropical forest products is not being conducted on a sustainable basis. There are, however, ways to change this. With this objective in mind, the overall focus of the primer now shifts to issues of a more applied or practical nature. How can a knowledge of plant population dynamics be incorporated into a program of sustainable resource exploitation? What can be done to monitor the ecological impact of harvesting? What types of information are needed to minimize these impacts while maximizing the long-term economic returns from forest exploitation? These types of questions are addressed in Section III.

LITERATURE

A comprehensive treatment of the ecological impacts of harvesting non-timber tropical forest products has yet to be written. The following articles, however, will provide the interested reader with a good start on this important topic:

1. Conelly, W.T. 1985. Copal and rattan collecting in the Philippines. *Economic Botany* 39:39-46.

2. Kahn, F. 1988. Ecology of economically important palms in Peruvian Amazonia. *Advances in Economic Botany* 6:42-49.

3. Peluso, N.L. 1983. Networking in the commons: a tragedy for rattan? *Indonesia* 35:95-100.

4. Peters, C.M. 1990. Plenty of fruit but no free lunch. *Garden* 14:8-13.

5. Siebert, S.F. and J.M. Belsky. 1985. Forest product trade in a lowland Filipino village. *Economic Botany* 39:522-533.

6. Vazquez, R. and A.H. Gentry. 1989. Use and mis-use of forest harvested fruits in the Iquitos area. *Conservation Biology* 3:350-361.

SECTION III. SIX STEPS TOWARD SUSTAINABILITY

The commercial exploitation of non-timber resources is currently plagued by destructive harvesting, over-exploitation, and a basic disregard for the functional ecology of tropical plant populations. There are better ways to exploit a tropical forest. From an ecological standpoint, one of the most essential ingredients required to achieve a sustainable level of resource use is information: information about the density and distribution of resources within the forest, information about the population structure and productivity of these resources, and information about the ecological impact of differing harvest levels. An overall strategy for collecting this information, and for applying it in such a manner as to guarantee that the plant populations being exploited will maintain themselves in the forest over time, is presented and discussed in this section.

The different procedures described are sufficiently general that they can be applied to any class of non-timber resource (e.g. fruit and seeds, plant exudates, or vegetative tissue). Furthermore, their application allows flexibility so that management operations can be tailored to suit the specific ecological requirements of a particular site, species, or population. The procedures can be applied in forests that have already being heavily exploited for non-timber resources, as well as in more pristine, undisturbed habitats.

These guidelines do not comprise a single management technology or "package" that can be blindly applied without modification. The basic concept is to provide a constant flow of diagnostic information about the ecological response of the species or resource to varying degrees of exploitation. Sustainability is achieved through a continual process of adjustment in which any change in seedling establishment or population structure results in a corresponding change in harvest levels. The exact nature of this "fine tuning" process will depend on the site, the experience and judgment of local resource managers, the effectiveness of harvest controls, the precision of the diagnostic data collected, and, most importantly, the ecological behavior of the plant populations selected for exploitation.

As is shown in Figure 6, the complete process is composed of six basic operations or steps: (1) Species Selection, (2) Forest Inventory, (3) Yield Studies, (4) Regeneration Surveys, (5) Harvest Assessments, and (6) Harvest Adjustments. Taken together, these operations accomplish three fundamental management tasks. The species or resources to be exploited are first **selected**. **Baseline data** about the current density and productivity of these resource are then collected. Finally, the impact of harvesting the resources is **monitored** and harvest levels are adjusted as necessary to minimize this impact.

The actual sequence of operations is not fixed and can be adapted to a variety of different situations. Existing programs of resource exploitation, for example, have already selected the species to harvest. In such cases, management should start with forest inventory operations. There may also be

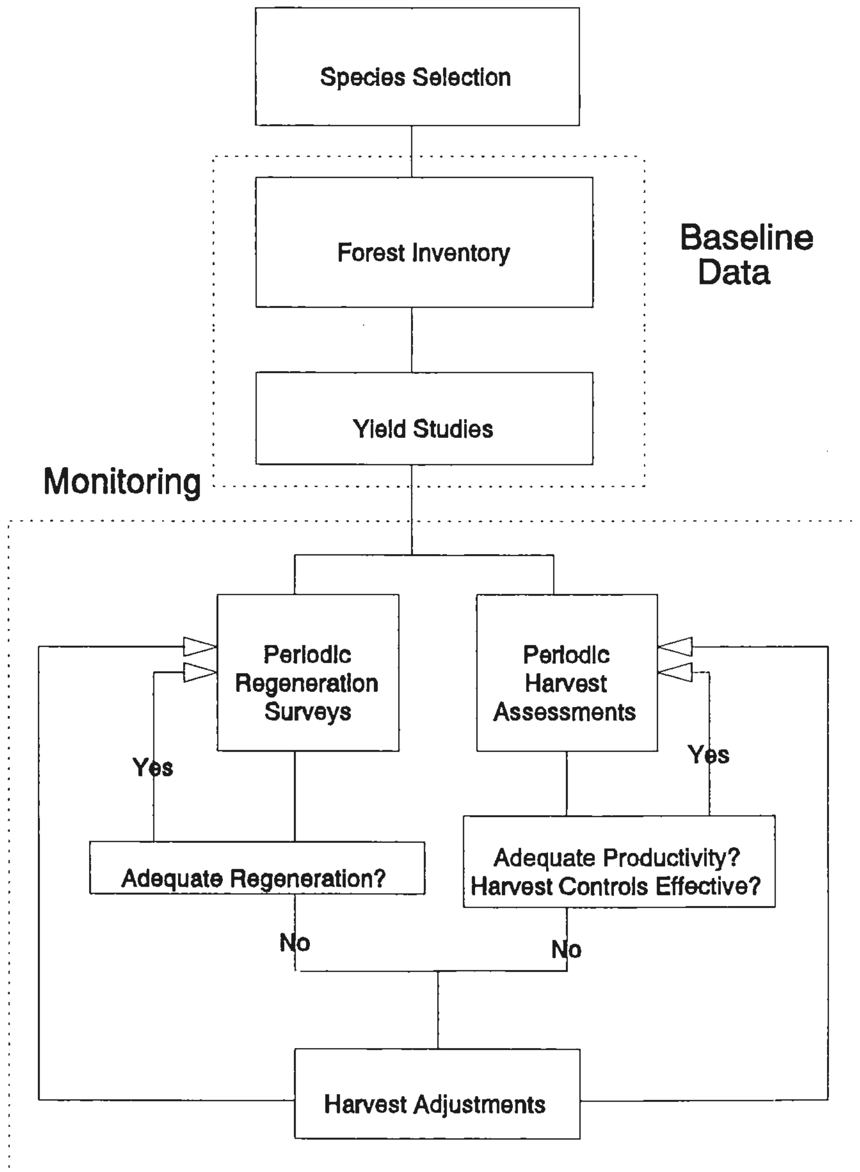

Figure 6. Flow chart of basic strategy for exploiting non-timber tropical forest plant resources on a sustained-yield basis. Complete process is composed of six steps: (1) Species Selection, (2) Forest Inventory, (3) Yield Studies, (4) Regeneration Surveys, (5) Harvest Assessments, and (6) Serial Harvest Adjustments. See text for explanation of each management operation.

situations in which a particular tract of land has only recently been made available for resource exploitation (e.g. an extractive reserve or community forest). In these situations, species selection should follow inventory operations so that the results from this fieldwork can be directly input into the selection process. There is no need to interrupt the harvesting and sale of resources during management operations. Data collection and monitoring can be conducted as background activities and a supplement to routine harvesting.

For ease of presentation, the following discussion focuses on the selection, inventory, and monitoring of a single species or resource. In most field situations, however, management operations will be concerned with the simultaneous exploitation of several different resources. The basic procedures employed are the same regardless of the number of species involved.

SPECIES SELECTION

The decision of which plant resources to harvest will be based largely on economic concerns. Those resources possessing the highest current market price or the greatest potential for future market expansion will usually be chosen first. Social factors can also come into play here. Some forest resources may have a long history of extraction and traditional use in the region, and local people may have a strong cultural preference towards continuing to exploit these resources. Other resources (e.g. medicinals or plants of ceremonial importance) may be subject to certain taboos that prohibit commercial exploitation.

In addition to economic and social factors, a third set of criteria should also be considered—the overall potential of the resource to be managed on a sustained-yield basis. **Some species, because of their reproductive biology, regeneration and growth strategies, or population structure, are inherently more able to withstand the continual perturbations of resource extraction than others.** This fact is frequently overlooked.

The basic concept here is quite simple. Given a group of resources with similar economic profiles, why not select those that are the easiest to manage and have the highest potential for sustainable exploitation? Ideally, four basic pieces of information about a species' ecology should be input into the selection process:

- life cycle characteristics
- type of resource produced
- density and abundance in different **forest types**
- size-class distribution of populations

Tropical forests are not one homogeneous mass of vegetation. Subtle differences in climate and soil produce a remarkable amount of variation in forest structure and composition from one place to the next. In response to this variability, tropical forests are usually described with reference to a particular **forest type**, e.g. swamp forest, mixed dipterocarp hill forest, peat forest, etc. in Southeast Asia.

It would be convenient if all of this information could be easily looked up in a book somewhere. For the great majority of species, it can't. Compile as much information on these topics as possible from published sources, and spend time with local collectors to record their experiences and observations. Estimates of density and population structure will probably require a preliminary field reconnaissance of potential production areas. Try to coordinate these trips with the flowering or fruiting season of the species of interest so that specimens can be collected to document the exact taxonomic identity of the plant.

To give credit where credit is due, tropical ecologists and botanists have amassed an enormous quantity of information on the ecology of certain forest species. Detailed information about the botany, phenology, and reproductive biology of many non-timber forest resources can, in fact, be gleaned from published sources.

The **life cycle characteristics** of a species can either facilitate or severely complicate commercial harvesting. Species that fruit at unpredictable intervals and require specific animals for pollination and seed dispersal probably represent the worst case scenario. An annually fruiting species serviced by more common, generalist pollinators such as small insects or bees is much easier to work with. In terms of regeneration guilds, primary forest species adapted for growth and regeneration under a closed canopy will, in most cases, be preferable over fast-growing **pioneer species** that require the occurrence of large canopy gaps for seedling establishment.

Maintaining the density of a **pioneer species** within a closed forest environment is more difficult and entails a larger ecological impact than that of a primary forest species. The management of these species also carries with it a subtle motivation to fell trees and increase the areal extent of canopy gaps within the forest. Given the present objective, i.e. selecting species that can be exploited in primary forest with minimal ecological impact, the selection of pioneer species is usually not recommended.

The **type of resource** produced by a particular species can also have a major influence on its potential for sustainable exploitation. The harvest of bark, stem tissue, and roots almost always kill the tree. Managing these populations on a sustained-yield basis can be a difficult and expensive proposition. The harvest of latex, fruits, oil seeds and leaves, on the other hand, does not necessarily kill adult trees or drastically alter the size-class distribution of the population. Although the extraction of these resources is certainly not exempt from having an ecological impact (see Section II), these impacts are somewhat easier to avoid or correct.

A third key criteria for resource selection is the current **density and distribution of the species**. Abundant species which are obviously regenerating in the forest are considerably easier to manage than low-density scattered populations. The forest types within which a species occurs must also be taken into consideration. A resource may be extremely abundant in one forest type and completely absent in others. If this particular type of forest occupies only a very small area, or is inaccessible during certain times of the year (e.g. seasonally flooded forests), resource supply can become a problem.

Even more important than the overall abundance of plant resource is the **size-class distribution** of the individuals within its populations. A species may be the most abundant in the forest in terms of number of stems, but if all of these stems are of a similar size or if the population is characterized by a preponderance of large adult trees and exhibits no regeneration, the species is having trouble with seedling recruitment. If the establishment of new seedlings is a problem in the absence of harvesting, commercial levels of exploitation will undoubtedly be extremely difficult to maintain on a sustained-yield basis. **If at all compatible with the economic and social criteria employed, the selection of species with a Type I population structure (i.e. with abundant natural regeneration) is strongly recommended.**

To aid in the selection process, different expressions of important species characteristics are summarized in Table 5. The main categories and subdivisions have been adapted from the topics discussed in Sections I and II. There are admittedly a variety of different combinations and intermediate stages of the three possibilities listed. Some species may use both **biotic** and **abiotic** dispersal, different populations of the same species may exhibit a Type I size-class distribution in some habitats and a Type III in others, and some individuals within a single population may fruit annually while others are unpredictable in their phenology. These shortcomings notwithstanding, the information shown in Table 5 provides an ecological framework for

Biotic implies an active role by animals; **abiotic** means either wind or water.

comparing different forest resources which have been pre-selected using economic and social criteria.

Table 5. Overall management potential of different non-timber forest resources based on their botanical characteristics, life strategy, productivity, and population structure. See Section I for further information on categories.

	....Potential for Sustainable Management....		
	Low	Medium	High
Resource Group	Bark, stem tissue, roots	Some resins, fruits and seeds	Latex, fruits and leaves
Yield/plant	Low	Medium	High
Species Characteristics:			
Flowers	Few, large	Intermediate	Small, many
Fruits	Few, large	Intermediate	Small, many
Seed germination	Low viability	Intermediate	High viability
Sprouting capability	None	Low	High
Population Structure:			
Size-class distribution	Type III curve	Type II curve	Type I curve
Tree density/hectare	0-5 adults	5-10 adults	10+ adults
Spatial distribution	Scattered	Clumped	Homogeneous
Regeneration Guild	Early Pioneer	Late Secondary	Primary
Flower/Fruit Phenology	Unpredictable	Supra-annual	Annual
Reproductive Biology:			
Pollination	Biotic, with specialized vector	Biotic, with generalist vector	Abiotic
Pollinator Abundance	Rare; bats, hummingbirds	Intermediate; beetles, moths	Common; small insects
Seed Dispersal	Biotic, with specialized vector	Biotic, with generalist vector	Abiotic
Disperser Abundance	Rare; large birds, primates	Intermediate; small mammals	Common; bats, small birds

The easiest way to use the table as a selection tool is to assign a numerical value to each category. All parameters with low, medium, or high management potential, for example, could be recorded as 0, 1, or 2, respectively. Summing the total score for each species provides a rough "sustainability potential" index that can be used to compare and rank different species. All other factors being roughly equal (i.e. economic and social considerations), the species with the highest sustainability index should be selected.

To give an example of how this works, let's assume for the moment that we want to appraise the management potential of two hypothetical species. The **first species**, a small woody climber, produces bark from which a beautiful yellow dye is obtained. The species occasionally re-sprouts after harvesting. Its flowers are small, sweetly scented, produced at unpredictable intervals, and pollinated by small insects. The fruits are eaten and the seeds subsequently dispersed by birds. The species depends on canopy gaps for successful

The **first species** is patterned after *Fibraurea tinctoria*, a common dye-producing plant in Southeast Asia. The roots and stems of this liana are also used medicinally to treat dysentery and eye diseases.

The **second species** is based on *Brosimum alicastrum* (see Figure 2). In addition to its edible fruits, the seeds of this species are exceptionally rich in protein, the leaves provide a palatable forage, and several parts of the tree are used medicinally.

establishment. Natural populations exhibit a Type III size-class distribution and occur at densities of 3-5 individuals per hectare. The **second species** is a large, primary forest tree. It produces abundant quantities of fruit every year and sprouts copiously after cutting. The flowers are small and pollinated by wind. The seeds are dispersed by bats, birds, and a number of small ground-foraging mammals. The species occurs naturally in high-density populations of from 10 to 20 adult trees per hectare; the structure of these populations conforms to a Type I size-class distribution. Nothing is known about the seed germination or spatial distribution of either species.

To derive the sustainability index, the ecological data for each species are grouped into categories and then scored using a 0-2 point system and the management potential rankings shown in Table 5. The first species receives high management potential scores because of its flower and fruit characteristics (2 points each) and abundance of pollinators and dispersers (2 points each), and medium scores because of its low sprouting capability (1 point), biotic, generalist pollination and dispersal (1 point each), and late secondary regeneration guild (1 point). Low management potential scores are assigned to the species because of its resource group, yield per plant, Type III size-class distribution, low population density, and unpredictable phenology (0 points). Summing all of the points yields an index value of 12 for the first species.

The second species receives high management potential scores in every category except fruit characteristics and seed dispersal and exhibits a significantly higher sustainability index (26 points). There is little question that this species has the higher potential for being managed on a sustained-yield basis.

FOREST INVENTORY

Density and size-class structure data are the most fundamental pieces of information required for management. Just as foresters need to know how many cubic meters of mahogany (*Swietenia spp.*) occur in a particular forest, the management of non-timber resources also relies on estimates of the distribution and abundance of different species. These estimates can only be obtained through a quantitative forest inventory. Inventories also provide the baseline data necessary to monitor the impact of harvesting. Without some knowledge of initial density and size-class structure, the population could slowly go extinct with each successive harvest and never be noticed.

Forest inventories are time-consuming, somewhat costly, and extremely tedious to conduct. It is a good idea, therefore, to do a little planning before initiating this fieldwork. In particular, several questions concerning the resources that have been selected for exploitation (or that are already being exploited) need to be addressed:

1. Where exactly does the species/resource of interest occur in greatest abundance? Try to map its distribution as precisely as possible using references to physical or cultural features (e.g. mountains, rivers, villages,

etc.), established political boundaries (e.g. which sub-district or province) or geographic coordinates (e.g. from **Global Positioning System** readings).

2. Is the species limited to a certain forest type, or is it more or less evenly distributed throughout the region?

3. Is the resource of interest produced by only one species or several species? What is the exact taxonomic identity of these plants?

4. In what manner, for how long, and by whom has the resource been exploited? Are some collecting areas more heavily exploited than others? Has the resource being planted, selectively favored, or otherwise managed by local communities?

5. Are there any good maps, aerial photos or satellite images of the region?

6. Has the region ever been inventoried before, and if so, for what type of resource (e.g. timber surveys, botanical exploration, mining or geochemical reconnaissance)?

Global Positioning System (GPS) devices receive signals from a special network of satellites and use these readings to calculate the precise geographic coordinates of a given location. This simple, portable, and relatively inexpensive technology has numerous applications in forestry and resource management.

Cartographic information is essential for planning and implementing a forest inventory. Especially useful are large-scale maps (scale from 1:10,000 to 1:100,000), soil or geologic survey maps, standard aerial photographs (scale from 1:6,000 to 1:12,000; preferably as overlapping stereopairs), and multi-spectral satellite images. Sketch maps drawn by experienced collectors can also be very helpful.

Questions 1 to 3 attempt to define the location and identity of the species. The latter part of this can be more difficult than it sounds. Given the high diversity and limited botanical exploration of tropical forests, many important fruit trees, rattans, and medicinal plants have yet to be identified. A specimen collected recently in Peruvian Amazonia of one of the most commonly used trees for house construction turned out to be a species new to science. **Without a scientific name, it is very difficult to find the information that may be available about a plant.** A whole literature can be overlooked by failing to realize that the rambai trees (see Table 4) in the forest are really *Baccaurea motleyana*.

Question 4 assesses the resource's history of exploitation. The structure of populations which have been exploited commercially for hundreds of years is usually very different from those which have been subjected to only periodic, subsistence use. If no type of management activity has been conducted, it is very likely that the exploited species occurs at a lower density in the forest. Extensive planting, on the other hand, may have notably increased the local abundance of the resource.

Questions 5 and 6 provide some idea about how difficult or expensive the inventory will be to conduct. Doing inventory work in a region with no maps requires quite a bit more planning than that conducted in more familiar terrain. Needless to say, if a general forest inventory or timber survey has already been conducted in the region—and the resource of interest is a tree—every attempt should be made to get a copy of the results.

As much information as possible should be compiled for each of these six questions. Potentially useful sources include both published and unpublished "gray" literature (e.g. local government documents, internal reports, memoranda, maps, etc.) about the region and species of interest. A review of plant specimens at the nearest **herbarium** can provide information on the distribution, habitat, and flowering and fruiting phenology of different species. Informal interviews with local collectors are always extremely enlightening. Local export statistics, although notoriously unreliable and covering only a small percentage of the useful flora found in tropical forests, can sometimes provide a good historical overview of the pattern and intensity of resource use.

A **herbarium** is basically a botanical museum containing dried specimens of different plant species. These specimens show the leaves, flowers and/or fruits of the plant, its scientific name, and the date and locality of collection. Supplemental information on local uses, nomenclature, or the ecology of the plant are also frequently included. Careful comparison with these specimens can be used to identify a species.

A list of useful references on forest inventory are included at the end of this section.

Armed with this preliminary information, the next step is to actually design and conduct the inventory. **It is strongly recommended that a professional forester or inventory specialist be involved at this stage**. Although the mechanics of designing such an inventory are beyond the scope of this primer, a few general comments about the nature of the data that need to be collected are warranted:

- The inventory should provide a reasonably precise estimate of the total number of harvestable trees per hectare (i.e. the resource density) in different forest types. For fruit and oil seed species, this means the total number of adult trees. For latex-producing species, medicinal plants and rattans, some juvenile trees may also need to be included.

- The inventory should provide data on the current population structure or size-class distribution of adult trees. Collecting these data requires that the diameter (DBH) of all stems be measured. Height measurements can be substituted in the case of herbaceous plants, small understory palms or woody shrubs.

- The inventory should provide a preliminary assessment of the regeneration status of the species. Does the species appear to be maintaining itself in the forest? Are there a sufficient number of small trees to replace the inevitable death of adult trees? To begin answering these questions, smaller, non-productive individuals must also be counted and measured in the inventory.

- How small should the smallest individuals be that are included in the inventory? This depends on the size of the species and its abundance in the forest. The lower size limit for rattan or a stemless palm will be different from that required for a large canopy tree. For tree species that occur at a relatively low density in the forest, a minimum diameter limit of 10 cm DBH is recommended; more abundant species will probably require a slightly higher diameter cut-off. A smaller minimum diameter increases the amount of information obtained from the inventory, but it also increases the time and expense of fieldwork because of the greater number of stems that have to be counted.

The results from the inventory should be separated into different forest types prior to analysis. The data from each habitat are then compiled into size-class histograms showing the number of individuals in different diameter or height classes (see Figures 3 and 4). For most large canopy trees, grouping the data into 10 cm diameter classes will produce a reasonable depiction of population structure. A 5 cm diameter class interval may be warranted for understory trees; the use of 50 cm height classes is frequently appropriate for shrubs and small palms. As a general rule, the histograms should contain from 8 to 12 size classes. Dividing the overall range in size of the data (i.e. the diameter or height of the largest individual minus that of the smallest one) by 10 provides a quick estimate of an appropriate size-class interval.

The inventory lays the foundation on which a program of sustainable forest use can be developed. We now know how many trees we have to work with, where they are located, and whether they are regenerating or not. Based on the visual analysis of the size-class histograms, we also now have an extremely important point of reference against which to assess the ecological impact of forest exploitation.

YIELD STUDIES

Given an understanding of the density and size-class distribution of a forest species, the next question that needs to be addressed is "How much of the desired resource do natural populations of the species produce?" Suppose 250 kilograms of seed are harvested from a mixed dipterocarp forest. Is this level of harvest sustainable? Well, that depends. How many seeds does the population produce? Is this only 10% of the total population seed production, or were 95% of all seeds removed? It makes a difference. Just as foresters (theoretically) use growth data to avoid cutting timber faster than it is produced in the forest, the sustained-yield management of non-timber resources also requires information about the productive capacity of the species being exploited. This information is obtained through yield studies.

The basic objective here is to obtain a reasonable estimate of the total quantity of resource produced by a species in different habitats or forest types. Given that larger plants are invariably more productive than smaller plants, of particular interest is the relationship between productivity and plant size. A simple yield study designed to collect these data can be conducted in three steps:

1. As it is rarely feasible, or even warranted, to measure the yield from all of the individuals in a population, a representative sample of plants of differing size is first selected from each forest type. Selection should be limited to healthy, undamaged trees; if possible, a minimum of three individuals per size class should be chosen from each habitat. The sample plants should be permanently labeled with paint to facilitate their re-location in the field. In addition to their use in the yield studies, these individuals will later form part of the monitoring system used to assess the impact of harvesting.

2. The productivity of each sample plant is then carefully measured. The exact methodology employed to make these measurements will necessarily vary with the type of resource. Counting fruits is different from counting leaves or measuring stem growth (e.g. for rattan), and latex which drips slowly into a cup is different from crystallized resin or "damar" which has

to be chipped off the trunk. Probably the easiest way to obtain meaningful production data is to enlist the help of local collectors and train them how to weigh, count, or measure the quantity of resource actually collected from each tree during harvest season. For plant exudates and many vegetative structures, this procedure provides a sufficiently precise estimate of size-specific productivity. In the case of fruits and seeds, these harvest data must be supplemented with visual or, even better, quantitative estimates of the amount of marketable material that was left unharvested.

3. Finally, the data collected from each sample tree are plotted to construct a simple scatterplot or *yield curve* for each forest type showing the relationship between plant size and yield. An example of this type of graph is presented in Figure 7, which shows the size-specific rate of fruit production for ***Myrciaria dubia***. In this species, there is an exponential increase in fruit production with increasing diameter, the largest individuals producing over 3,300 fruits in some years. Yield curves like this are important because they can be used to predict the quantity of resource produced by any size plant—regardless of whether a plant of that exact diameter or height was actually measured in the yield studies. The values can be read straight off the graph.

Myrciaria dubia is a small shrub commonly found along the banks of rivers and ox-bow lakes in western Amazonia. Its fruits contain one of the highest concentrations of vitamin C (2,000-2,990 mg ascorbic acid/100 g of fruit) of any species known to science. There is a considerable local demand for the fruit which is used to prepare juices, ice creams and liqueurs.

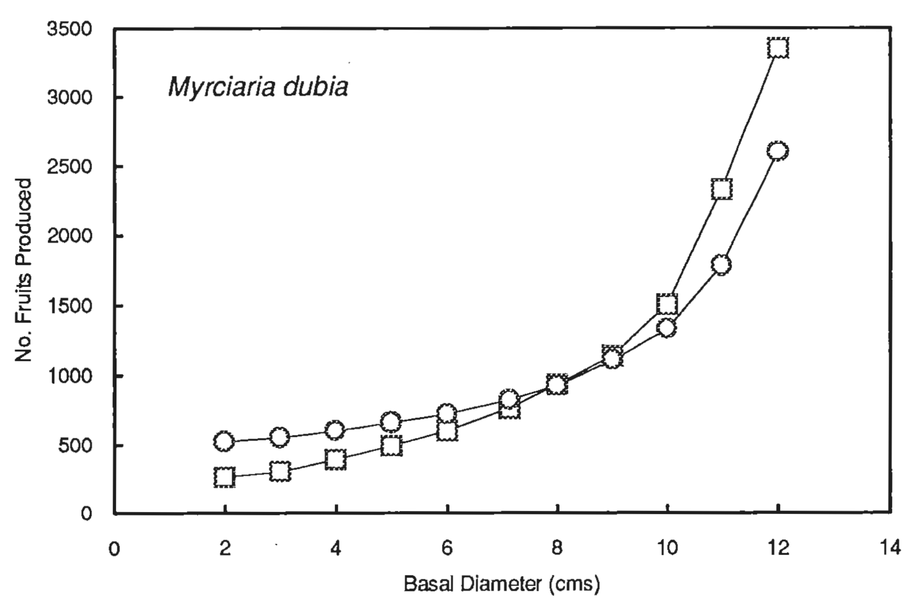

Figure 7. Annual fruit production as related to tree size for *Myrciaria dubia* plants growing in the lowlands of Peruvian Amazonia. Two years of fruit production data are shown.

An additional point of interest in Figure 7 is the variation in fruit production exhibited by *M. dubia* from year to year. This type of behavior is almost standard practice with tropical plants, and applies to the production of latex, resins, leaves, and bark as well as to that of fruits and seeds. Temperature, rainfall, sunlight, soil nutrients, pollination, competition, and a multitude of other ecological factors are not constant from one year to the next—and the plants reflect this. To account for this variability, **yield studies should be repeated every few years using the same group of sample plants.** This task can be greatly simplified by having trained local people collect the data as part of their routine harvest activities.

The results from the inventory provide information about how many productive trees of each size class occur in different forest types. The yield studies will tell us how much of the desired resource each one of these trees produces. Combining these two data sets will generate satisfactory estimates of: (1) how much the entire forest can produce, (2) what size plants are responsible for the largest percentage of this production, and (3) which forest types provide the highest yields.

These estimates are of incalculable practical value. Specific production areas can now be delineated in different forest types, access routes and collection centers can be established, and the costs and benefits of different harvest scenarios can be evaluated in detail. At this point, the resource in question is no longer simply being extracted from the forest—it is now being managed.

REGENERATION SURVEYS

The baseline data collected in the forest inventory and yield studies provide an estimate of the *total* harvestable yield from the forest. From the discussions presented in Sections I and II, however, it is clear that not all of this material can be harvested from the forest for very long. What we really want to know is the *sustainable* harvest yield from the forest. How much of this resource can we harvest year after year without damaging the long-term stability of the plant populations being exploited? Answering this question requires information about the ecological impact of differing harvesting levels.

The first signal that a plant population is being subjected to an overly intensive level of harvest is usually manifested in the size-class distribution of that population. **For most species and resources, the effects of over-exploitation are most clearly visible in the seedling and small sapling stages**. Harvesting may kill a large number of adult trees (e.g. rattan, gharu, or palm hearts), may lower individual tree vigor to the point that flower and fruit production is affected (e.g. leaf or bark harvest, or the tapping of plant exudates), or may remove an excessive number of seeds from the forest. From a population standpoint, the net result of these activities is the same—all reduce the rate at which new seedlings are established in the population. This impact can be detected, and hopefully avoided, by periodically monitoring the density of seedlings and saplings in the populations being exploited.

The basic procedure used to conduct these regeneration surveys is as follows:

Given the abundance and scattered distribution of the individuals to be measured, the **regeneration plots** used in tropical forestry are usually of small size (e.g. 25 to 100 square meters) and of either a circular or square configuration.

1. A network of permanent **regeneration plots** is first established throughout the forest. The exact number of plots that are used will depend on the current abundance of seedlings and saplings in different forest types. High-density populations will require a smaller number of plots; scattered low-density populations will require a more intensive sample. Each plot

should be permanently marked and its exact location mapped or described in detail to facilitate re-location. The services of an experienced forester or ecologist would be extremely helpful in laying out this plot network.

2. Within each plot, the total number of seedling and saplings of the desired species less than or equal to 10 cm DBH (or whatever the minimum diameter limit used in the original forest inventory) are counted and recorded. For ease of data collection, these plants can simply be tallied into height classes and it is not necessary to actually measure each individual. The use of four 50 centimeter height classes (e.g. 0–50 cm, 50–100 cm, 100–150 cm and 150–200 cm) and one 1–10 cm DBH diameter class is appropriate for most tree species. A larger class interval (e.g. 100 cm) may be necessary for tree populations exhibiting a reduced number of seedlings and saplings; smaller classes will be required for understory trees and shrubs (e.g. note 2.0 cm basal diameter classes used for *M. dubia* in Figure 7).

3. The plot results are grouped by forest type and averaged. These summary data are then added to the size-class histograms constructed from the inventory results to provide a complete picture of population structure from seedlings to large adult trees. An example of a composite histogram containing height classes for seedlings and saplings and diameter classes for juveniles and adult trees is shown in Figure 8. The data were collected in West Kalimantan from a natural population of ***Shorea atrinervosa***. The transition between height and diameter classes was defined based on the observation that most *S. atrinervosa* saplings start to obtain a diameter (DBH) of 1.0 cm at heights slightly greater than 200 cm.

Shorea atrinervosa is a widely distributed canopy tree in northern Borneo and Sumatra. It is a common component of mixed dipterocarp forest and can obtain high densities in selected habitats. The seeds produced by the tree, a type of illipe nut, contain an edible oil.

4. The regeneration plots are periodically re-inventoried to monitor fluctuations in the number of seedlings and saplings recruited into each population. An interval of every five years is probably sufficient for most species. The occasional observations of collectors who may have passed through the plots during harvesting are also useful for monitoring the smaller size classes.

The final size-structure histograms produced using the regeneration survey data (e.g. Figure 8) are important management tools. In essence, the seedling and sapling densities shown for each populations are a demographic "yardstick" with which to measure the actual long-term impact of harvesting. To use a medical analogy, these data are the vital signs by which to assess the health or infirmity of the population.

HARVEST ASSESSMENTS

Harvest assessments are an additional type of monitoring activity used to gauge the ecological impact of resource harvest. These are primarily visual appraisals of the behavior and condition of adult trees that are conducted concurrently with harvest activities. In many cases, these quick assessments can detect a problem with reproduction or growth before it becomes serious enough to actually reduce the rate of seedling recruitment.

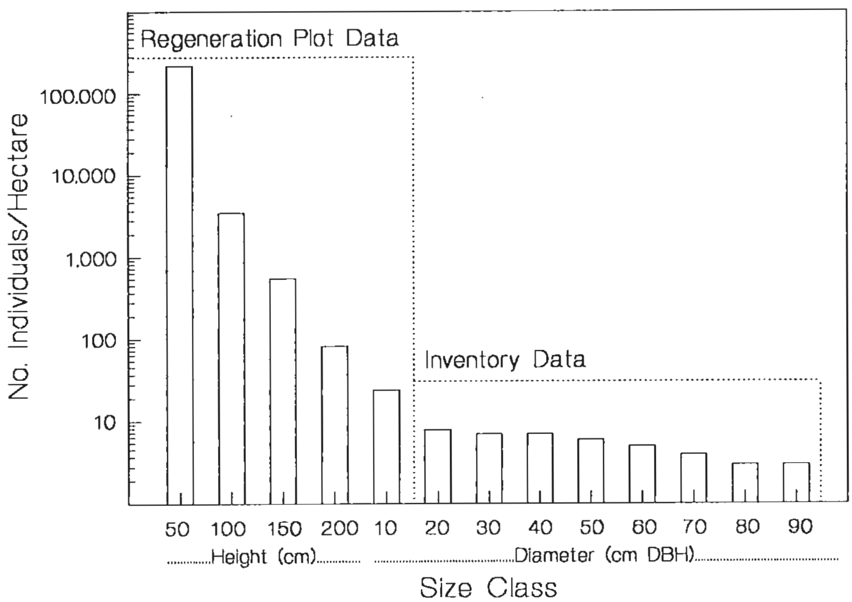

Figure 8. Size-class histogram for *Shorea atrinervosa* population illustrating the use of both height and diameter classes. Data from regeneration plots have been grouped into four 50 cm height classes and one 1.0 - 10.0 cm diameter (DBH) class. Inventory results are divided into eight 10 cm (DBH) diameter classes. Numbers shown along x-axis represent the upper size limit of each class. Note compressed, logarithmic scaling of y-axis due to the large range in values (e.g. from 3 to 250,000).

The sample plants selected and marked for the yield studies are perfect subjects for these observations. They represent a range of different size classes and they are stratified by forest type. During the regular harvest period, each of these individuals should be carefully inspected and observations recorded on several different aspects of the plant and its immediate environment:

- Does the overall vigor of the plant appear to be good? Are there yellow leaves or obvious wounds caused by harvesting? Is there any evidence of insect pests or fungal pathogens?

- If inspections are made during the period of flowering and fruiting, pay special attention to the number of **fallen flowers** and immature fruits under the crown of the tree. A simple visual estimate of few, moderate, or excessive is sufficient in most cases. Collect a sample of seeds (e.g. 20–50) and review each one for the presence of insect predators. Record the percentage that are predated.

- Are the seedlings in the vicinity being trampled or otherwise damaged by collectors?

In most cases, these **fallen flowers** will be aborted or unpollinated reproductive structures. A drastic increase in the quantity of fallen flowers encountered beneath a tree could indicate a lack of pollinators or resource limitations.

In addition to these basic observations, the results from the periodic yield studies should also be used to monitor the health of adult trees. Careful comparison of the data collected from each tree over several measurement periods will, in many cases, be sufficient to distinguish between normal variability and an actual reduction in size-specific productivity.

HARVEST ADJUSTMENTS

The monitoring operations are used to appraise the sustainability of current harvest levels (see Figure 6). **The seedling and sapling densities recorded in the original regeneration survey represent the *threshold values* by which sustainability is measured.** As long as densities remain above this threshold value—and no major problems are detected in the harvest assessments—there is a high probability that the current level of exploitation can be sustained. If, however, seedling and sapling densities are found to drop below this value, immediate steps should be taken to reduce the intensity of harvest. The effectiveness of this harvest reduction will be verified during the next regeneration survey. Further reductions in harvest levels may be warranted if seedling and sapling densities fail to stabilize, or drop even lower, during the five-year period.

The ***threshold values*** for seedlings and saplings are a benchmark for describing the ecological conditions in the forest at time 0 when monitoring activities were first initiated. They do not necessarily represent the optimal levels of regeneration for that plant population.

Specific problems encountered during the harvest assessments (e.g. loss of vigor, increased seed predation, or drop in productivity) should result in similar harvest adjustments. If the problem is limited to only one or two individuals, the harvest of these trees should be completely suspended until subsequent assessments indicate that the situation has improved. Physical impacts such as trampling or wounding may require that changes in the pattern, as well as the intensity, of harvesting be implemented.

The general mechanics of this adjustment process are shown graphically in Figure 9. The left side of the figure depicts the initial structure of the population at TIME 0, immediately following the first inventory of the regeneration plots. The right side shows the structure of the population five years later at TIME 1. The threshold values for seedlings and saplings are shown as dotted, horizontal lines. The first four size classes shown in each histogram represent 50 cm height classes, the remainder are 10 cm DBH classes.

The uppermost histogram, Figure 9A, illustrates the incipient stages of resource over-exploitation. By TIME 1, seedling and sapling densities have dropped well below their threshold values. Harvest levels in this population should, as a result, be immediately decreased before the reduction in numbers exhibited by the smaller size classes is passed on to the intermediate and large size classes.

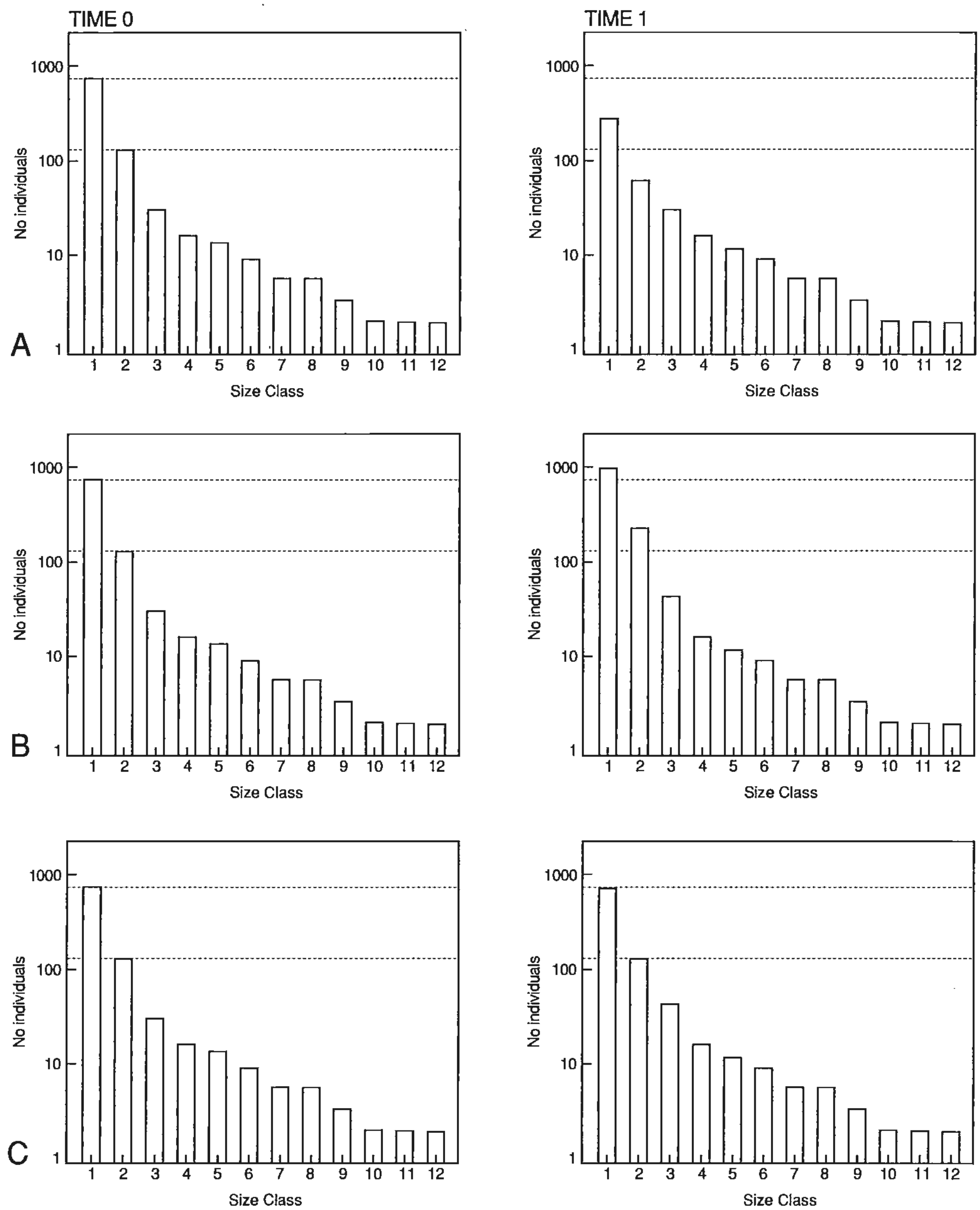

Figure 9. Diagrammatic effect of harvest intensity on the size-class structure of a plant population to illustrate the basic strategy behind periodic harvest adjustments. TIME 0 represents size-class distribution immediately following inventory of regeneration plots; TIME 1 shows population structure 5 years later after annual harvesting. A. Incipient stages of over-exploitation with decrease in seedling (size class 1) and sapling (size class 2) numbers below threshold values (shown as dotted, horizontal lines). B. Under-exploitation of resource. C. Sustained-yield harvesting.

Figure 9B, on the other hand, depicts a hypothetical example of under-exploitation. The population in question has actually increased its level of seedling establishment in response to harvesting, a behavior that suggests that additional quantities of resource could be safely harvested from the forest. That exploitation might, in fact, enhance regeneration is not an entirely unrealistic scenario. Seed collections could reduce the competition and mortality rate among seedlings, or limit food supplies to the point that many frugivores and seed predators were driven from the site. The reduction in canopy cover caused by the harvest of leaves or stems might also improve light conditions in the understory for seedling establishment. Whatever the ultimate cause may be, an increase in seedling and sapling densities over a five-year period is a good indication that the population can withstand a greater intensity of exploitation.

Finally, the histogram shown in Figure 9C illustrates a steady-state or sustainable harvest level. The existing intensity of resource extraction has little effect on the number of seedlings and saplings recruited into the population, and, unless conditions change drastically, this level of exploitation should be able to be maintained almost indefinitely. **From an ecological perspective, this situation represents a verifiable example of sustainable resource exploitation.**

In actual practice, achieving a sustainable yield in this manner will probably involve a considerable number of harvest adjustments. There is frequently a lag time in a population's response to disturbance, and after several cycles of apparently stable results from the regeneration surveys, the population may exhibit a drastic fluctuation in seedling and sapling densities. The important thing is that these fluctuations do not go unnoticed. By gradually lowering, or even raising in some cases, the intensity of resource extraction, the level of seedling establishment should eventually approximate the threshold value established for the population.

A key variable in all of this is control over the actual intensity or level of exploitation. How do you go about reducing the level of harvest a certain percentage? Two different procedures can be used to make these adjustments:

1. The **first method** regulates the number or size of the plants being exploited. For example, if a 10% reduction in resource extraction is desired, the baseline data from the inventory and yield studies can be used to determine the exact number of trees from each size class required to achieve this objective. These trees should be marked with bright paint or flagging and left unharvested to regenerate. A different set of "seed" trees can be chosen every two to three years to ensure a more even distribution of regeneration throughout the site.

To illustrate the **first method**, let's say we start with a productivity or harvest yield of 100,000 fruits per hectare. A 10% reduction in this is equal to 10,000 fruits. How many trees need to be taken out of production to save 10,000 fruits? This result can be calculated from the yield curves for the species. In the case of *Myrciaria dubia* (Figure 6), the answer is three 12 cm diameter trees, twenty 6 cm diameter trees, or a variety of other tree size-tree number combinations.

2. The second method limits the total area from which the resources are extracted. Using this procedure, the management area is divided into ten parcels or *production units*, each parcel containing more or less the same number of adult trees. Harvesting only nine of these parcels would produce roughly a 10% reduction in harvest level. The parcels should be rotated so that a different one is left unharvested each year.

For populations that have never been exploited before, a good first approximation is to extract no more than 80% of the total harvestable yield during the first collection cycle. Harvest levels can later be increased or decreased as necessary based on the results from the first regeneration survey.

A NOTE ABOUT REMEDIAL TREATMENT

The six steps outlined in this section provide a simple and effective method for achieving a sustainable harvest of non-timber forest products. The hallmark of this inherently *passive* form of management is that the intensity of human intervention is adjusted to account for the ecological dynamics of the plant populations being exploited—instead of the other way around. In some situations, however, a more intensive or *active* form of resource management may be warranted. If, for example, seedling densities continue to drop in spite of drastic harvest reductions, or productivity declines, or trees start to die, some form of remedial treatment should be initiated as soon as possible. A few potential courses of action are listed below:

- Enrichment planting is a relatively easy method for enhancing the seedling abundance of a valuable species. Dayak communities in West Kalimantan use enrichment planting to maintain commercial densities of durian, rattan, and illipe nut in their managed forests. The açai stands managed by the forest farmers in eastern Amazonia are similarly enriched by planting mango and cacao seedlings. In both cases, the practice has proven quite successful. An additional advantage of enrichment planting is that the planting stock can be specifically selected from the most desirable individuals in the population (e.g. the most high-yielding, the most vigorous, or those with the most tasty fruit), with the result that the overall genetic composition of the population is gradually improved over time.

- Selective weeding can be used to increase the survival and growth of young plants or to stimulate the productivity of adult trees. Also known as "cleaning" or "underbrushing", this operation decreases the competition at ground level by removing the seedlings and saplings of undesirable species. Light levels in the understory may also be increased somewhat following treatment. Selective weeding is most commonly applied around the base of especially high-value or productive trees prior to harvest season to facilitate the collection of fruits or seeds.

- Cutting and removing woody vines from the crowns of adult trees can frequently increase their productivity. This practice can also have a positive effect on seedling establishment by opening up the canopy a little and allowing more sunlight into the understory.

Depending on the nature and severity of the management problem, these operations can be applied either singly or in combination. **Regeneration surveys and yield studies should be conducted annually for several years following any type of treatment to closely monitor changes in population**

structure and/or yield. A pre-treatment schedule of monitoring activities can be resumed as soon as the population exhibits a return to normal, baseline conditions.

LITERATURE

Several basic texts on forest inventory techniques are available to interested readers:

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5. Loetsch, F. and K.E. Haller. 1973. *Forest Inventory*. Vols. I and II. BLV Verlagsgesellschaft, Munich.

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CONCLUSIONS

There are basically three major conclusions to be drawn from this book. The first concerns the ecology of tropical forest plants. Natural populations of most species occur at low densities in the forest, most require the services of animals to pollinate their flowers and disperse their seeds, and most have a very hard time getting their seedlings established in the understory. Plant populations with these characteristics exist in a very delicate balance with their environment.

The second conclusion of importance relates to the ecological impact of harvesting non-timber resources from these plant populations. Although the exploitation of some plant parts (e.g. fruits, seeds and latexes) is less damaging than others (e.g. bark, stems, or roots), almost any form of resource harvest produces an impact on the structure and function of tropical plant populations. If nothing is done to mitigate these impacts, continued harvesting will deplete the resource. This process is accelerated by destructive harvesting.

The final conclusion is a challenge. There are ways to exploit the non-timber resources produced by tropical plant populations with a minimum of ecological damage. Doing so, however, requires management. Baseline data about the size-class structure and yield characteristics of the population must be collected, regeneration surveys must be conducted, harvest levels must be periodically adjusted, and, in some cases, remedial treatments such as enrichment planting or weeding must be initiated. Although quite a bit more involved than simply picking up fruit or tapping rubber trees, these management procedures will produce a sustainable form of resource utilization.

There are convincing ecological reasons to implement the management strategies outlined in this book. If practiced on a sustainable basis, the exploitation of non-timber forest products provides a unique way to use species-rich primary forest for profit and still conserve most of the biological diversity and ecosystem functions (e.g. protect soil fertility, prevent erosion, control run-off, regulate climate) of the forest. No other form of land-use practiced in the tropics has the potential to do this.

ABOUT THE AUTHOR

Charles Peters studied forestry at the University of Arkansas and received his Masters and Ph.D. in plant ecology from the Yale School of Forestry and Environmental Studies. He has been investigating the ecology, use, and management of tropical forest resources for more than 15 years. His fieldwork has taken him to two of the largest and least explored tropical regions in the world, lowland Amazonia and the island of Borneo, as well as to the managed forests of Mayan Mexico. He is the author of numerous scholarly papers and articles. He currently works for the West Kalimantan Program of the New York Botanical Garden's Institute for Economic Botany, and lives in West Kalimantan, Indonesia.

ACKNOWLEDGMENTS

The author would like to thank all the people who have read and commented on the draft versions of this manual, especially Molly Kux, Kathy Saterson, Elaine Joyol, Dan Nepstad, and Francis Putz.

Thanks are due also to the Biodiversity Support Program's wonderful Asia/Pacific Program staff—Janis Alcorn, Stephen Kelleher, and Richard Richina.

Thanks also to all the staff members at WWF-US who cheerfully gave of their time and talents to help turn computer files into reality: Kathy Dale, Joy Patterson, and Pam Holmes in Computer Services, Laura Bennett, and Pedro Lopez-Valencia.

And a special word of thanks to Margaret Bjerklie, whose patience and talent made this little manual so pleasant to look at.

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